# PIGEONPEA IMPROVEMENT

## ACIAR Projects 8201 and 8567

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*July 1998*

ACIAR is concerned that the products of its research are adopted by farmers, policy-makers, quarantine officials and others whom its research is designed to help.

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# Contents

# 1. Introduction

This study was commissioned by the Australian Centre for International Agricultural Research (ACIAR) to evaluate the economic impact of two projects (8201 and 8567) for which ACIAR provided support from 1982–89. These projects were aimed at the improvement of the grain yield potential of pigeonpea (*Cajanus cajan)* using modern plant breeding, along with associated physiological, agronomic, processing and socioeconomic research. The commissioned organisation in Australia was the University of Queensland. The partners were:

## Fiji

Ministry of Primary Industries
Native Land Development Corporation

## Indonesia

Central Research Institute for Food Crops
Agency for Agricultural Research and Development

## India

Indian Council for Agricultural Research
International Crops Research Institute for the Semi-Arid Tropics

## Thailand

Field Crops Research Institute, Department of Agriculture
Kasetsart University
Prince of Songkla University
Chiang Mai University

The initial project was the first formal ACIAR collaborative research project. It aimed to (i) develop widely adapted short-season pigeonpea (SSPP) to replace the traditional longer-season cultivars and (ii) to design management strategies which allowed their full grain yield potential to be realised and demonstrated. Prior to the ACIAR projects the University of Queensland team was targeting their research on these technology options primarily for Australia. The ACIAR projects broadened the scientific and geographic scope of the work to the above four developing countries.

The primary focus of this evaluation is on India, where around 90 per cent of the world's pigeonpeas are grown and where adoption of the SSPP technology options has been both significant and partially documented. There has been limited impact in the other three developing countries and Australia. Brennan and Bantilan (1998) have recently analysed the economic impact of research undertaken by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) on SSPP on Australia and concluded that it is also very limited. Neither of the two ACIAR projects which are the subject of the present evaluation were included in the review of 71 ACIAR projects by Auld (1990) nor the recent assessment by Mauldon (1998).

The time and resources for the economic evaluation were very limited so resort had to be made to a mail survey of key collaborators in th projects, secondary data sources, along with various assumptions and estimates. The sources and bases of these are detailed in the report.

## 2. Background

Pigeonpea (*Cajanus cajan)* represents about 5 per cent of the total world production of pulses. In recent years this has meant around 3 million tonnes have been produced annually. More than 90% of this has been in India. The balance is in Africa (6%), the rest of Asia (2%) and the Caribbean (2%).[1]

The area and production of pigeonpea in India have been growing by more than 2% per year since 1970 but yields have been stagnant at around 700 kg/ha. Production in other countries of Asia has been growing at more than 3% per year, driven largely by yield growth. In Africa, area has been growing at about 1% per year which along with yield growth of 0.6% has led to production growth of some 1.6% annually.

In India, until recently, pigeonpea has been regarded as a subsistence crop, grown in rainfed semi-arid tropical regions in association with other cereal, fibre and oilseed crops. It was often a minor component of these intercrop systems and farmers did not apply purchased inputs or improved management to the crop. However there are growing indications (Mueller et al. 1990) that farmers are sowing larger areas with improved cultivars of

[1] Most of the statistics here are from Ryan (1995).

pigeonpea which, as a sole crop, are receiving more inputs. In this way pigeonpea is changing from subsistence to a commercial crop. It is suspected that the research supported by the partners in the two projects being evaluated here has been instrumental in bringing about this change.

In India, pigeonpea is consumed as dhal, which is derived from dehulling after overnight soaking in water and drying. The resultant split peas are cooked with spices into a soup, which is used as a high protein complement to cereals like rice. With the exception of the Caribbean, pigeonpea is eaten the same way in other countries, although sometimes also as a green vegetable. In the Caribbean, a major part of production is exported as a canned vegetable to North America. However world trade in the crop is very thin, representing less than 1% of production, although in recent years India has been increasing its imports, mainly from Eastern Africa.

Real prices of pigeonpea in India have been rising by more than 1% a year, indicating strong demand growth, but not necessarily much in excess of supply growth. This has not been the case with the other major pulse crop in India, chickpea, where supply growth has been stagnant in the face of substantial demand growth, leading to growing imports. Competing crops (in production) to pigeonpea like sorghum, millet, maize, cotton and groundnut either had weaker price trends than pigeonpea or failed to achieve significant breakthroughs in yield.

The traditional varieties of pigeonpeas grown by farmers in India and elsewhere prior to the initiation of research by the University of Queensland (UQ) in the early 1970s, were photoperiod sensitive medium- to long-season types. The latter were sown early in the monsoon in July–August and matured ready for harvest between 180 and 300 days later, well after the shorter season cereal crops they were often intercropped with were harvested. The traditional indeterminate pigeonpeas often had several harvests over a number of months as a result of flowering flushes after insect damage to pods occurred. Indeed it is the resilience of these traditional cultivars that offered one of their primary advantages in these risky semi-arid tropical environments, although this came at the expense of a low yield potential.

The traditional cultivars are able to perform well in low fertility situations and where moisture stress is a recurring problem. The perennial habit of traditional cultivars also ensures that there is a substantial amount of fuelwood produced from the stalks. As fuelwood is an increasingly scarce commodity in these drought prone environments, its value to farmers and families is rivalling that of the grain.

# 3. Genesis of the ACIAR Projects[2]

The team at UQ who were commissioned to undertake the ACIAR pigeonpea improvement project commencing in 1982 had begun work on the crop in the early 1970s. They were exploring its potential as a new crop for Australian farming systems, using genetic material acquired from the Indian national program. The particular focus of the UQ program was on short-season pigeonpea (SSPP) which was photoperiod insensitive and matured in 90–120 days. Experimental yields of up to 8 tonnes/ha were reported at that time. The plant type was dwarf with a determinate habit. Pods set towards the top of the plant, which meant mechanical harvesting and spraying could be used. This was an important consideration for the commercial farming systems of Australia, contrary to the subsistence nature of the mixed cropping systems where the traditional cultivars were grown in India.

During the 1970s the UQ team developed informal relationships with the Indian program, which was formalized later in the second ACIAR project. From the late-1970s the work on SSPP at UQ, ICRISAT and in the Indian national program intensified. Indeed an indication of the potential that was seen in this new approach to pigeonpea improvement was the fact that a number of donors supported the research, including ICRISAT from 1978–82, prior to the commencement of the ACIAR projects. The UQ program also received support from the Indo–Australian Science and Technology Agreement and the Australian Special Research Grants Scheme. These facilitated staffing, exchange visits and germplasm exchange.

By 1982 ICRISAT had a SSPP program which represented 10%–15% of their total research on the crop. The ACIAR project hence followed more than 10 years of research endeavour by both UQ and ICRISAT, both of which followed research by India. Therefore it is difficult to separately attribute whatever impacts have arisen from SSPP research to the four major actors: ACIAR, ICRISAT, UQ and the Indian Council of Agricultural Research (ICAR).

The research effort prior to the ACIAR project had established the potential of SSPP as a new crop for Australia, by acquiring knowledge of

[2] More details can be found in Byth and Wallis (1988) and in Appendix I.

the growth and phenological development of a range of genetic materials, and the forging of close links between UQ, ICRISAT and ICAR.

## 4. Objectives of the Projects

Project 8201, which began in 1982, had the following objectives:

1. To establish collaborative research programs with scientists in Fiji, Indonesia, Thailand and India to examine the potential for pigeonpea in those countries by testing the production systems and germplasm developed in Australia; and to improve the research capacity of the co-operators in partner countries in the areas of design, experimentation and evaluation of the introduced breeding material.

2. To identify and release genotypes with superior performance and adaptation.

3. To undertake genetic studies to investigate the nature of the variation with respect to agronomic characters and their genetic control.

4. To develop improved breeding and selection procedures for SSPP.

5. To develop and test specific genotypes for frost tolerance and to commence studies of inheritance of this trait.

6. To investigate the extent of genotype ( environment (G ( E) interaction in the pigeonpea breeding material and to determine the effects of environment on genotype performance.

7. To investigate constraints to growth and development, yield accumulation and the importance of various yield components in a range of environments using elite genotypes.

The project was reviewed in September 1985 by a team commissioned by ACIAR. It was led by the then Director of ACIAR, Professor J.R. McWilliam, and comprised Dr G.J. Persley (the ACIAR Coordinator responsible for the project), Professor Ivan Buddenhagen (Leader of the Food Legume Program, University of California, Davis, USA) and Mr Ian Wood (Senior Principal Research Scientist, CSIRO Division of Tropical Crops and Pastures)(see McWilliam et al. 1985).

The review was quite positive about the progress made in the project and recommended adding India as a partner in a new three-year phase. They also recommended the establishment of local selection programs in partner countries to evaluate early generation material rather than fixed lines developed in Australia, in order to identify lines suitable for local ecosystems and the limits to production. In this process a wider range of germplasm was to be employed than was the case in Project 8201, along with genetic analysis of G ( E data, to devise more efficient selection procedures. Attention to marketing and utilization of pigeonpeas was seen as a need in the new project, especially in Australia, Thailand and Indonesia. The development of a pigeonpea growth model was suggested as a means of identifying constraints to productivity and to enable zones of adaptation of SSPP to be identified. The review team saw plant protection as a major constraint to an expansion of the area of SSPP.

From the outset the project was primarily intended to develop intermediate products and enhance human capital in partner countries. To quote from McWilliam et al. (1985, p. 5):

> "The stimulation of creativity in scientific research should be a major thrust of any new project. One of the long-term benefits of the project should be the research experience gained by the young scientists from Australia, South-East Asia and the South Pacific who have participated in this applied crop improvement program. The long term goal of ACIAR projects cannot be to solve all the production problems of a crop but to steer local scientists to creative research by which they can solve particular problems as they arise."

As far as possible in this impact assessment, cognisance will be taken of the fact that this project was so predicated.

Taking into account the comments and recommendations of the Review Report of Project No. 8201, a second project was developed and approved by ACIAR. Project No. 8567 formally commenced in December 1985 and concluded in November 1988. The objectives of this project were as follows:

►►►► 1. To study the scientific bases of high yield potential of SSPP in favorable environments.

►►►► 2. To study the adaptation of pigeonpea to environments characterised by stress of various kinds, and the mechanisms underlying that adaptation.

►►►► 3. To evaluate production systems for SSPP including:

- (sole and ratoon cropping, intercropping and rotations;
- (pest build-up in particular cropping systems; and

- (detailed studies of specific limits to productivity in such systems.

4. Exchange germplasm, visits and information among all collaborators within each country.

In April 1988 Project No. 8567 was reviewed as a part of ACIAR's review of its Food Legume and Oilseeds Program. The members of the review panel were Dr G. Hawtin (Chairman; Associate Director [Crop and Animal Production Systems] International Development Research Centre [IDRC] Canada), Dr Aran Patanothai (Department of Plant Science, Khon Kaen University, Thailand), Dr D.R. Laing (Deputy Director General, CIAT, Colombia), and Dr D.E. Byth (Reader in Agriculture, University of Queensland)(see Hawtin et al. 1988). Dr Byth was not involved in the critical review of the pigeonpea project as he was the joint Chief Leader. The review was informed by a detailed submission prepared by Byth and Wallis (1988). This document, along with McWilliam et al. (1985) and Appendix I to this report by Byth, provide the basis of the compilation contained in the next section.

# 5. Achievements of the Projects

There were many scientific findings and achievements of the two projects that were supported by ACIAR. Indeed the proponents maintained that these provided the primary raison d'être for the project. Among these are the following:

- The likelihood that the stem canker disease complex *Xanthomonas* and *Botryosphaeria* were the causal agents of flower and pod shedding in Fiji (detailed etiological studies were suggested to confirm this). The project had begun to screen germplasm for resistance to the stem canker complex.
- The identification of germplasm able to withstand aluminium toxicity in Fiji— these were being evaluated in Sumatra at the end of the project.
- The potential for pigeonpea to replace soybeans in the preparation of tempeh in Indonesia was established; this had the potential to reduce soybean imports.
- Demonstration that pigeonpea could be used in poultry feedstuffs, but that its economics were yet to be confirmed.

- ►►►► Initial demonstration of the high seed yield potential of SSPP in a range of environments.
- ►►►► Contribution to the release of at least four SSPP cultivars in three countries; 'Quantum' ('QPL 42'), 'Quest' ('QPL 702'?) and 'Hunt' in Australia, 'Mega' ('Hunt') in Indonesia, and 'QPL 511' in Fiji.
- ►►►► Identification of a genic male sterile line which has been utilized in the development of pigeonpea hybrids by ICRISAT and ICAR.
- ►►►► Identification of frost tolerant lines.
- ►►►► Development of an understanding of inheritance of traits, and design of efficient methods of recombination and selection for use in breeding programs.
- ►►►► Development of a pigeonpea growth model based upon PNUTGRO (a model developed for groundnuts) and performance of considerable G ( E analysis exploring environmental adaptation.
- ►►►► Undertaking of physiological studies of crop growth and development, photothermal responses in phenology, water stress tolerance and reproductive biology.
- ►►►► Evaluation of the potential of SSPP in a range of farming systems.
- ►►►► Demonstration that a holistic approach to crop improvement of pigeonpea had major benefits if focussed on priority constraints and cross-disciplinary integration instead of reductionist, disciplinary research.
- ►►►► Publications arising from the projects facilitated the spillover of knowledge-based outcomes arising from the project. There were 24 such publications.
- ►►►► Long- and short-term training of collaborators from the National Agricultural Research Service (NARS) and ICRISAT under the auspices of the project ensured that there would be a cadre of scientists to carry forward the research agenda beyond the life of the ACIAR projects.

The review panel in 1988 stated that the progress made in the projects over the six years in the above and other areas was highly satisfactory and laid a firm basis for on-going activities. They felt, however, that progress had been slow in India compared to the four other countries. This was attributed to delays in negotiating an umbrella memorandum of understanding between ACIAR and the ICAR, and the devastation of the 1987 trials in India by *Phytophthora* disease.

To quote from Hawtin et al. (1988, pp.76–78):

> The research has clearly demonstrated the potential applicability of adapted, short-season pigeonpea to a wide range of environments and cropping systems. Although further research is needed, particularly on resistance to diseases, tolerance of acid soils and insect management, these problems should not prove intractable and can mostly be handled by the national research programs, either alone or in collaboration with ICRISAT or other ACIAR projects where appropriate.
>
> The project has been able to demonstrate possible marketing and utilization options for pigeonpea in Indonesia and Thailand. Limited further research is justified in this area. However the application of the results of the research will depend, to a large extent, on the willingness of local food and feed manufacturers to include pigeonpea in their products, and thus provide a market for local production. Beyond the initial contacts with manufacturers and government agencies, which have already been made or are planned for the near future, there appears to be little more the ACIAR project can do in this regard.
>
> The project has made a significant contribution to developing the national capacity to conduct research on pigeonpea in all the countries involved. Fiji, in particular, has benefited in this respect, where there was little previous experience or expertise on early season pigeonpea prior to ACIAR's involvement. It is noted that this contact was initially fostered by ICRISAT prior to ACIAR support. As reported to the Review Team by the Indian visitors, India, which has by far the strongest national program, recognizes the value of the contacts with ACIAR through the long and short-term visits and the equipment provided for conduct of the collaborative research at Kanpur.
>
> The Review Team commends the project on its efforts in training, particularly the long-term visits to Australia, the postgraduate training funded through an Australian International Development Assistance Bureau (AIDAB, now AusAID)/ACIAR Fellowship, and the training courses on pest management in Indonesia and Thailand.
>
> Largely as a direct result of contact with UQ staff, ICRISAT's own pigeonpea program has now shifted its major emphasis to short-season, photo-insensitive types. The project has also played a leading role in developing international links in South-East Asia, links that are now beginning to be more fully exploited by ICRISAT, especially through the Asian Grain Legumes Network (AGLN). ICRISAT has expressed its aim to further strengthen its relationships in the region in future, and this should help ensure that the work that has been initiated under the ACIAR project is capitalized upon. AIDAB/Consultative Group on International Agricultural Research (CGIAR)/ACIAR Special Purpose funds have been used very effectively in the links with ICRISAT; for example, in the socioeconomic study in Thailand, the utilization studies in Indonesia and the pest management courses."

# 6. Establishing Impact

To establish and verify the impact of the two projects a list of key collaborators was compiled. This is contained in Appendix II. A series of 15 questions was posed to the collaborators, which related to the presumed achievements of the projects, as described in the previous section of this report. The questions are included in Appendix III. A copy of Dr Byth's overview of the project which was prepared at ACIAR's request in 1998 (Appendix I) was included with the questions sent to collaborators.

It appears that all of those who responded to the questions felt the projects had a pivotal role in demonstrating the yield potential of SSPP. This was especially the case at ICRISAT. To quote from Dr Don Faris, Leader of the Pigeonpea Breeding Program at ICRISAT in the 1980s:

> "It was a very exciting time. I am convinced that the contact with UQ scientists had a huge impact on the ICRISAT pigeonpea program. The material that they identified formed an important part of the short duration (SD) program at ICRISAT. The SSPP programme has become the major component of ICRISAT's present program. Without the ACIAR input I am convinced that this would not be the situation. The advocacy provided to (sic) Don and Eoin and the funds for research and training have resulted in the importance this crop now has."

In his view the project also had an influence on national programs. It

> "...sensitised the scientists in Asia to consider SD pigeonpeas in alternate ways and encouraged them to include SD pigeonpeas in their cropping systems trials."

The project certainly stimulated ICRISAT's involvement in Indonesia and Thailand; less so in Fiji. The ACIAR review and planning meetings also provided a model for the modus operandi of the AGLN which began in 1986. This followed the initiation of ICRISAT's Asian Grain Legume Program in 1983 with the support of the ACIAR project. Dr Faris was the first Coordinator of the AGLN.

By conceptualizing and demonstrating the greatly increased yield potential of SSPP using a high density planting system with improved management, the ACIAR project succeeded in stimulating the ICAR and ICRISAT programs which then led to widespread adoption of SSPP in India (K.B. Saxena, pers. comm.).

## 6.1 Broadening Adaptation

The current adoption of SSPP is expected to gain impetus in coming years and to continue to lead to expansion of pigeonpea into non-traditional growing areas. This is important because of the development and acceptance of the basic concept in the UQ/ACIAR project of developing SSPP cultivars with wide adaptation. Indeed the photo-insensitive lines identified at UQ were used as donors in developing materials which can now be grown over a much wider zone of adaptation and at higher elevations in new areas (K.B. Saxena, pers. comm.). Because of their early flowering they also escape drought and avoid the major diseases of the medium and late season pigeonpeas, namely wilt and sterility mosaic. However SSPP seems to be susceptible to *Phytophthora* blight.

The extent of adaptation has now increased to 45 degrees North (N) and South (S), whereas with traditional cultivars it was restricted to 30 degrees N and S (C.L.L. Gowda, pers. comm.). This explains a major part of the 43% increase in the area of pigeonpea growth in the world in the 33 years from 1961–63 to 1994–96 (Table 1). Most of the increase occurred from the late 1970s, at which time the SSPP cultivars began to be released in numbers in India.

Table 1. Average annual harvested area of pigeonpea in major world regions, 1961–63 to 1994–96 ('000 ha).

| Region | 1961–63 | 1971–73 | 1981–83 | 1994–96 |
|---|---|---|---|---|
| Latin America/Caribbean | 38 | 44 | 45 | 45 |
| Eastern/South Eastern Asia | 65 | 67 | 63 | 233 |
| Africa | 171 | 232 | 234 | 270 |
| India | 2 454 | 2 475 | 2 924 | 4 000 (3360)[a] |
| World | 2 733 | 2 836 | 3 296 | 4 592 (3908)[a] |

[a]The figures in parentheses refer to totals using Indian statistics for 1994, rather than the FAO data, which seems an overestimate for 1994–96. In other years the Indian statistics were close to those from FAO

*Source: Food and Agriculture Organization of the United Nations(FAO) data available on Internet.*

Some of the increase in the area planted with pigeonpeas is also explained by the favourable pulse/cereal price relatives which have maintained in India in the last 20 years. To illustrate, the ratio of pigeonpea/coarse grain minimum support prices rose 54% from 1.79 in 1978–80 to 2.61 in 1994–96. The ratio of pigeonpea/rice prices rose by 18% over the same period (M. Asokan, ICRISAT, pers. comm., using Government of India studies). The combination of a favourable relative price regime and the availability of SSPP cultivars apparently led to the expansion in area and production.

SSPP cultivars have now been released as far afield as in Minnesota and Georgia in the United States. In Tifton, Georgia, experimental plots at 34 degrees N had a yield potential of 5.0 tonnes per hectare. At Hisar (29 degrees N) the yield potential was 4.0 t/ha, while at Hyderabad (17 degrees N) it was 2.9 t/ha (Chauhan et al. 1996). These yields compare with the current average of 0.7 t/ hawith traditional cultivars in India.

According to L. Singh (1996), cultivar 'T21' was the first SSPP identified for double cropping in irrigated wheat systems of Uttar Pradesh as early as 1961. Subsequently it was identified for the whole country in 1973. Then followed 'UPAS' 120, 'Prabhat' and 'Pant A3' in the mid-1970s. In the 1980s there were many more releases (L. Singh 1996).

The 'T21' group of cultivars mature in 140 days at Hisar in Haryana in the northern Indian wheat belt, and 125 days at Hyderabad in Andhra Pradesh in southern India. These are referred to as the short-duration B group (SD-B). The cultivars 'UPAS 120', 'ICPL 151' and 'ICPL 87' are included in the SD-A group which are a little earlier than 'T21', maturing in 130 days at Hisar and 115 days in Hyderabad. The extra-short-duration group (ESD) consists of varieties like 'Prabhat' and 'Pant A3', which mature in 115 days at Hisar and 110 days at Hyderabad.

## 6.2 Adoption Patterns

There seems to be widespread adoption of the SD cultivars but, according to Asthana et al. (1996, pp. 7–9) ESD cultivars are yet to find favour with farmers: "despite 12 years of research, no ESD variety could be identified for release." Research based on new breeding materials is still required to enhance yield potential, and resistance to insects, *Phytophthora*, sterility mosaic, waterlogging and drought. Although SSPP can escape wilt by maturing before the disease kills the plant, the close spacing required for SSPP to fully realize its yield potential means an increased susceptibility to *Phytophthora* (C. Johansen, pers. comm.).

A hybrid pigeonpea, 'PPH4', was released in the Punjab in 1994. It matures in 140–145 days (Sekhon et al. 1996) and yields 15–30% more than the next best SD varieties. This followed upon the earlier release of 'ICPH8', the world's first pigeonpea hybrid, by ICRISAT in 1991. It yielded 30% more than 'UPAS 120' and 15% more than 'Pusa 33' and 'ICPL 87', and was recommended for Central India. Apparently neither of these hybrids was based upon the ms2 source of genetic male sterility identified by the UQ team in 1981. S.P. Singh (1996) indicates that in 1995–96, four more hybrids were in advanced testing and six determinate and 52 indeterminate early hybrids were being evaluated in coordinated trials.

In northern India, SSPP cultivars are playing a major role in the expanding pigeonpea/wheat cropping system. The quest for ESD cultivars is to ensure that wheat sowing is not delayed, as may be the case for the SD types in some years, as they are 20–30 days later than the ESD types. Legumes like pigeonpea are seen to offer the promise of a sustainable alternative to rice in the rice/wheat systems of the Indo-Gangetic Plains, which seem to be facing a yield plateau and even a decline in some districts, after years of a cereal/cereal rotation. Additionally, increasing scarcity of groundwater is casting doubts about the viability and sustainability of rice growing. This is of major concern to policy makers in South Asia and in response a Rice–Wheat Consortium for the Indo-Gangetic Plains has been established to devise a research and development (R&D) agenda to address this perplexing problem. The publication *Prospects for Growing Extra-short-duration Pigeonpea in Rotation with Winter Crops*, edited by L. Singh et al. (1996) was a contribution to that agenda.

A conservative estimate of the area sown to SSPP in India at present is about 0.4 million ha, or some 12% of the total area of pigeonpeas in the country (Table 2). It would seem the potential area could be as much as 1.3 million ha (39%), but presumably additional research would be required to go beyond this in view of the constraints identified in the publication edited by Singh et al. cited above.

Table 2. Current and potential regions where short-season pigeonpea (SSPP) have a niche[a].

| Region | Estimated area sown to SSPP (ha) | Proportion of total (%) | Year | Source |
|---|---|---|---|---|
| **Current** | | | | |
| Western Maharashtra, India | 150 000 | 57 | 1994 | Bantilan and Parthasarathy (1997) |
| Northern Karnataka, India | 40 000 | 14–40 | 1994 | Bantilan and Parthasarathy (1997) |
| Punjab and Haryana, India | 80 000 | ? | 1998 | K.B. Saxena (pers. comm.) |
| Northern Gujurat, India | 50 000 | ? | 1998 | K.B. Saxena (pers. comm.) |
| Uttar Pradesh, India | 70 000 | 15 | 1991 | S.P. Singh (1996) |
| Sri Lanka | 1 000 | 100 | 1997 | Niranjan (1997) |
| Total | 391 000 | | | |
| **Potential**[b] | | | | |
| Punjab, Haryana and Western U.P. India | 500 000 | ? | ? | L. Singh (1996) |
| North Indian wheat belt | 800 000 | ? | ? | Asthana et al. (1996) |
| Andhra Pradesh, India | 500 000 | ? | ? | Cheralu (1996) |
| Australia | ? | ? | ? | Byth (pers. comm.) |
| Fiji | ? | ? | ? | K.B. Saxena (pers. comm.) |
| Kenya | ? | ? | ? | K.B. Saxena (pers. comm.) |
| Nepal | ? | ? | ? | K.B. Saxena (pers. comm.) |
| Sri Lanka | 10 000 | ? | ? | Niranjan (1997) |
| Thailand | ? | ? | ? | C.L.L.Gowda (pers. comm.) |
| United States | ? | ? | ? | Chauhan et al. (1996) |

Notes: Releases of SSPP have occurred in Fiji, Kenya, Nepal, Sri Lanka, Thailand and the United States. However it is not clear what has been the extent of adoption. K.B. Saxena (pers. comm.) reports that on-farm trials in Fiji have identified two photoperiod insensitive varieties for possible release as vegetable pigeonpeas. These are Pragati (QPL 511) and ICPL 86012. Both yield significantly more than the local variety, Vikram, and were derived from the UQ/ACIAR project.
[a]? = not known, or not estimated by the author; [b]where SSPP cultivars have been released.

It seems SSPP was grown for a period in the early 1990s in north eastern Thailand by a private company for export as dhal to the Middle East. Due to floods and high production costs it is understood the operation has now closed . As in Indonesia and Sri Lanka, the problem in expanding the production of pigeonpea in Thailand has been the difficulties in processing and marketing the crop, which is not a traditional food item in local diets[3]. This has led to a “chicken and egg” problem with what remains an infant, or orphan, industry. The ACIAR project did endeavour to address these problems but it seems they remain major constraints to significant expansion of pigeonpea in these three countries.

[3] There was hope that pigeonpeas could be effectively used in animal feed rations in Thailand. The project showed it was technically possible to do so but the economics was such as to rule this out unless the relative price of alternatives substantially increased.

According to C. Johansen and C.L.L. Gowda (pers. comm.), pigeonpea has not found a place in Indonesia, even though the project successfully demonstrated that it could be used as a substitute for soybeans in tempeh. However ICRISAT is still pursuing funding for a project to capitalize on pigeonpea potential in this regard.

The impact of ICRISAT's work on pigeonpea in Australia has been described recently by Brennan and Bantilan (1998). In Appendix I, Byth describes how factors beyond the control of UQ meant the considerable early promise of the SSPP cultivars released by UQ, with the support of the ACIAR project, resulted in the commercial area declining from a peak of some 8 000 hectares in the mid-1980s, to an insignificant area currently.

## 6.3 Intermediate Outputs

The major publications emerging from the two ACIAR pigeonpea projects are contained in an ACIAR Proceedings edited by the co-leaders of the projects, Wallis and Byth (1986). This publication had a print run of 2 000 copies in February, 1987. A total of 847 copies were initially distributed to Workshop participants, authors and ACIAR's standard mailing list at the time. Of the remaining 1153 copies, subsequent individual requests have accounted for 58, with 54 still in stock at ACIAR and Bibliotech. This leaves some 1041 copies, an unknown number of which went to ICRISAT and E. Wallis for distribution.

It appears that the pigeonpea crop model which was developed by the projects using the PNUTGRO model has not been utilized to any extent, and certainly not by ICRISAT, despite suggestions by the project leaders. With the wealth of data generated by the project, and by NARS and ICRISAT, it is unfortunate that this is the situation. Indeed this seems to be a familiar refrain with crop modelling. There appears to be more attention given to differentiating crop models among modellers than in using them to address key issues in crop adaptation and management.

# 7. Measuring Impact

The only systematic study of the impact of SSPP is that by Bantilan and Parthasarathy (1997). They traced the adoption pattern of 'ICPL 87' in southern India. The following discussion and analysis draws heavily on this study.

## 7.1 Technology

Cultivar 'ICPL 87' was released in 1986 and resulted from pedigree selection from the cross 'ICPL 73032' ('T21' ( 'JA 277') made in 1973. Hence the original cross could not have been directly influenced by the UQ/ACIAR projects or its genetic materials, although its evolution and testing undoubtedly was. C. Johansen (pers. comm.) indicates that 'Quantum' ('QPL 42'), which was released by the UQ/ACIAR project, was in fact a sister line with the same parents as 'ICPL 87'. 'ICPL 87' was originally targeted for northern India but it was also introduced into eastern Maharashtra. It did not flourish in these regions, but from 1990 it began to find a niche in western Maharashtra as a result of intensive extension efforts and subsidies in sugarcane areas in sequence with wheat and chickpeas, and in drought-prone districts.

## 7.2 Adoption and Research Lags

Initially adopters replaced other pigeonpea cultivars with 'ICPL 87' (85% of them) but then increased the area of pigeonpeas by replacing sorghum and millet (21%) or by bringing fallow land into cultivation (65%). From 1990–94 the area of pigeonpea expanded substantially in western Maharashtra as a consequence of increasing adoption of 'ICPL 87'.

Some 46% of adopters sowed a post-rainy season crop after 'ICPL 87', compared to 9% of non-adopters. Hence it seems clear that the shorter growing season of 'ICPL 87' was reflected in a greatly enhanced capacity to increase cropping intensity, which is a major benefit in a land-scarce environment. Compared to the longer duration pigeonpea cultivars which it replaced, 'ICPL 87' had a 93% yield advantage. With the added costs of growing 'ICPL 87', this translated into a reduction of rupees (R) 1 296 in the cost of production per tonne (12%). As a result, net income per hectare was 30% higher than 'BDN 2', the medium duration cultivar it largely replaced.

The UQ/ACIAR project had, as its major benefit, the spillover of scientific knowledge and intermediate scientific products such as sources of genetic male sterility and photoperiod insensitivity, rather than final genetic products which were widely adopted by farmers. It is hence appropriate to view the impact of the UQ/ACIAR projects in terms of a reduction in the research and adoption lags of collaborators. That is, in the absence of the UQ/ACIAR projects, the release and adoption of SSPP cultivars would have been delayed. It seems reasonable to assume that the delay would have been between one and five years. Hence the investment of A$1.447 million from 1982–89 in the ACIAR project, on top of the A$2.1 million spent by UQ from 1969–81, gained between one and five years in the earlier generation of socioeconomic benefits from the adoption of SSPP by Indian farmers.

As best as can be estimated, meaningful adoption of SSPP began to occur in India in the early 1980s. In Table 3, a profile of likely adoption patterns in India was constructed based upon what is known from the work of Bantilan and Parthasarathy (1997) and others noted in Table 2. The discounted present value of the benefit streams net of the total ICAR, ICRISAT, UQ and ACIAR research costs was estimated, using the adoption pattern of Table 3. This was the base case. Then the adoption patterns were delayed one, three and five years, and instead of the total research costs, only the ICRISAT and ICAR costs for their SSPP programs were used. The difference in the net benefit streams between the base case and the other three simulations were the estimated range of contributions of the UQ/ACIAR projects, from which a marginal internal rate of return could be estimated.

Table 3. Estimated areas sown to short-season pigeonpea (SSPP) in India ('000 ha).

| Year | South India | North India | Total |
|---|---|---|---|
| 1983 | 0 | 0 | 0 |
| 1984 | 0 | 10 | 10 |
| 1985 | 0 | 20 | 20 |
| 1986 | 0 | 30 | 30 |
| 1987 | 5 | 40 | 45 |
| 1988 | 10 | 50 | 60 |
| 1989 | 40 | 70 | 110 |
| 1990 | 100 | 85 | 185 |
| 1991 | 110 | 100 | 210 |
| 1992 | 130 | 110 | 240 |
| 1993 | 150 | 130 | 280 |
| 1994 | 190 | 150 | 340 |
| 1995 | 230 | 180 | 410 |
| 1996 | 270 | 210 | 480 |
| 1997 | 320 | 230 | 550 |
| 1998 | 370 | 250 | 620 |

Source: Profiles of adoption built up from the information in Table 2. These are based on the author's best estimates of the time rate of adoption over the periods. Beyond 1998 to the year 2007 when the analysis will end, it is assumed the investments up to 1998 as shown in Table 5 will have generated the innovation pipeline to support adoption of SSPP to the extent of 1.3 million ha.

## 7.3 Cost Savings

As the Bantilan and Parthasarathy (1997) study on ICPL 87 is the only one available which allows an estimate of the yield and cost-saving effects of SSPP, these were used as one basis of the assessment of the economic impact of the ACIAR projects.

The estimate of A$ 48 per tonne[4] as the cost-saving effect of the adoption of 'ICPL 87' compared to the longer duration varieties it replaced is a somewhat conservative estimate, as it ignores the benefit to subsequent crops from the residual nitrogen left by the pigeonpea as a result of natural nitrogen fixation. Ryan (1995) and Bantilan and Parthasarathy (1997) have reviewed studies of this which show that the nitrogen benefits are much greater with the medium- and long-duration types than with SSPP. However, as Bantilan and Parthasarathy indicate, it seems two-thirds of adopters of 'ICPL 87' have sown it in erstwhile fallows and 21% have replaced cereal crops like sorghum and millet with it. The literature shows

[4] This is calculated using the Bantilan and Parthasarathy (1997) cost-saving of rupees R 1,296 per tonne and converting this to $A at the ACIAR required exchange rate of R 26.919.

that SSPP contributes 5–40 kg of nitrogen per hectare to non-leguminous crops grown in sequence with them. This implies the nitrogen cost savings per hectare for sequential crops could be between A$2–17 per ha. This compares with savings in the costs of fertilizers and manure in SSPP-cereal systems compared to cereal-cereal systems that farmers in one village in Maharashtra reported to Bantilan and Parthasarathy (1997) as R 1 340 per ha (A$49.8).

As indicated, to the extent that SSPP replaces medium- and long-duration pigeonpea cultivars, there would be a reduction in the nitrogen contribution to subsequent non-leguminous crops. However, as Bantilan and Parthasarathy report above, it is likely in these instances that the introduction of the SSPP cultivars meant that a second post-rainy season crop was possible, whereas this was not the case with the pigeonpea cultivars they replaced. Hence it would not seem to bias the assessment to attribute the additional nitrogen contribution from SSPP as a benefit for the current purposes. The issue is how estimates can be made of the relative areas involved in (i) substitution of SSPP for medium- and long-duration pigeonpea cultivars, versus (ii) sowing of SSPP on erstwhile fallows and/or substituting for non-leguminous crops in the system with resulting nitrogen benefits, so that an estimate can be formulated of the aggregate benefits.

As mentioned above, another benefit of SSPP is that it often makes use of fallow land that, by definition, has a low opportunity cost in the rainy season, without jeopardizing the sowing of a post-rainy season crop. Hence this is an additional cost saving that is not already captured by the above two estimates. Intuitively, it translates into a much larger unit cost-saving effect than is the case with crop and/or varietal substitution, as there are large areas of fallow land yet to be regularly cultivated, and the availability of SSPP cultivars allows them to be harnessed for production purposes, often for the first time.

## 7.4 Welfare Effects

Figure 1 illustrates the welfare effects. The shift in the supply curve from cost-saving effects of varietal and/or crop substitution is shown as a move from $S^s_0$ to $S^s_1$ in Figure 1(a). The ‘$k_s$’ factor involved is estimated above as approximately A$48 per tonne. In addition, the elasticity-increasing effect of enabling fallows to be more effectively utilised is represented by a shift in the supply curve in the “fallow” region from $S^f_0$ to $S^f_1$.

The increased economic surplus from the substitution effects is measured as the area **A** in Figure 1(a). The added surplus from the fallow effect is measured as the area **B** in Figure 1(b). Before the advent of SSPP the implicit cost of growing pigeonpea, as depicted by $S^f_{0,}$ was greater than the market price, $P_{o,}$ and this explains why there was none grown on the fallows. After the advent of SSPP it is shown as having a lower cost of production than $P_o$, to the extent of '$k_f$'. The combined effects lower the market price from $P_o$ to $P_1$. The total increase in economic surplus is then the area **C** in Figure 1 (c), which is the sum of **A** and **B**.

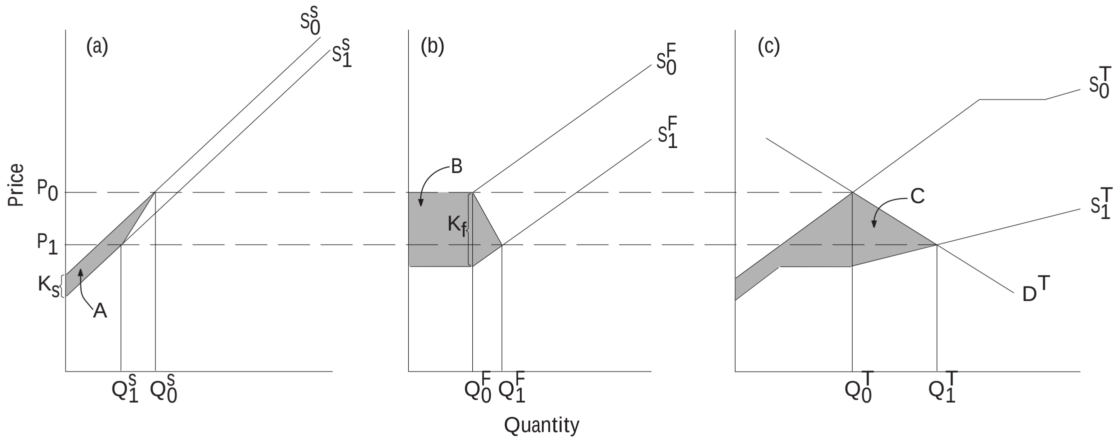
To estimate **A**, **B** and **C** requires an estimate of '$k_f$'. While an estimate of '$k_s$' was obtained from Bantilan and Parthasarathy (1997), there is no a priori reason to assume that '$k_f$' is the same. Indeed it is likely that '$k_f$' is larger than '$k_s$' as shown in Figure 1, because of the low opportunity cost of fallow land compared to land already growing pigeonpea or other crops. Hence, to be conservative, it is assumed that '$k_f$' and '$k_s$' are equal.

In Figure 1(a), the quantity $Q^s_0$ is the current production of pigeonpea at pre-research yields, estimated to come from regions where SSPP substitute for longer duration cultivars and/or non-leguminous crops. This assumes 60% of current production. In Figure 1(b), $Q^f_0$ is the current production of pigeonpea in fallow areas, using before-research yields. Of course, as there is no existing pigeonpea production from fallows where SSPP finds a place, the assumption is made that at the original price $P_o$, production of SSPP in fallows (at the margin) would be represented by the inflection point on the fallow supply curve $S^f_0$, represented by the intersection of $Q^f_0$ and $P_o$. This is estimated as 40% of the pigeonpea area.

In estimating **A**, **B** and **C** the following parameters from Bantilan and Parthasarathy (1997) were used, in addition to the adoption and research lags specified above:

| | |
|---|---|
| Elasticity of supply | 0.51 |
| Elasticity of demand | –0.76 |
| Price per tonne ($P_o$) | A$528 |
| Cost saving per tonne ($k_s$) | A$48 |

Figure 1. Disaggregating the (a) substitution, (b) fallow and (c) combined effects of short-season pigeonpea technology in India on pigeonpea supply response and estimating welfare gains (see text for details).




In addition to including an estimate of **A**, **B** and **C,** the value of the nitrogen contribution from SSPP to succeeding non-leguminous crops was assessed to be at the mid-range of the experimental figures cited previously, namely 20 kg per hectare of the area of SSPP adoption in northern India. This is estimated at about 40% of the total SSPP area (Table 3). It is assumed that this is the area of fallow and/or cereal crops which have been replaced by SSPP in the rotations. During the period 1986–95, nitrogen provided by urea was priced at between A$0.43–A$0.83 per kilogram, net of taxes and subsidies. Taking the lower end of this range and assuming that each kilogram of nitrogen generated a benefit:cost ratio of 2:1 in terms of crop yield response[5], an estimate is derived for the benefits of nitrogen-saving of A$0.86 per kilogram of nitrogen, or A$17.20 per hectare of non-leguminous crops. By 1998 this is estimated to be worth A$4.3 million per year to Indian farmers, rising to A$8.9 million by 2007 (Table 4).

5 Given the risks of fertiliser application, it is reasonable to assume a marginal benefit:cost ratio of 2 applies. Many studies show that this is what current levels of use of fertilizer by farmers imply, given the crop-fertiliser response functions that have been estimated.

Table 4. Estimated benefits from nitrogen contribution to succeeding non-leguminous crops in northern India.

| Year | Area benefitting[a] ('000 ha) | Benefits to farmers[b] |
|---|---|---|
| 1984 | 10 | 172 |
| 1985 | 20 | 344 |
| 1986 | 30 | 516 |
| 1987 | 40 | 688 |
| 1988 | 50 | 860 |
| 1989 | 70 | 1 204 |
| 1990 | 85 | 1 462 |
| 1991 | 100 | 1 720 |
| 1992 | 110 | 1 892 |
| 1993 | 130 | 2 236 |
| 1994 | 150 | 2 580 |
| 1995 | 180 | 3 096 |
| 1996 | 210 | 3 612 |
| 1997 | 230 | 3 956 |
| 1998 | 250 | 4 300 |
| Ø | Ø | Ø |
| Ø | Ø | Ø |
| 2007 | 520[c] | 8944 |

[a]See Table 3.
[b]Based upon a net benefit per ha of A$17.20 (see text).
[c]The benefits continue beyond 1998 to 2007 when the analysis will end.

# 8. Benefit–cost Analysis

The framework described in the previous section was subjected to empirical analysis using the ACIAR economic evaluation computer model as described by Lubulwa and McMeniman (1997). The "substitution" and "fallow" effects were estimated using economic surplus measures in a two region model. The additional benefits of the nitrogen contribution from SSPP in the 'fallow' region were added to the two surplus measures to derive total gross benefits. The analysis was run from 1978 to 2007, the thirty year period that ACIAR specifies in its model. [6]

[6] Table 5 shows that UQ expenditures on SSPP began in 1969 and ICAR in 1973. These cost streams were compounded to 1978 at a discount rate of 0.05% so that the analysis would not truncate the benefit streams arbitrarily.

## 8.1 Simulations

Four simulations were conducted:

- **Baseline**—using the parameters in the preceding text and tables; the adoption ceiling was set at 38.7% in 2007 (1.30 million ha of the 3.36 million ha sown to pigeonpea in 1994–96 [Table 1]); the costs of all four institutions were included in the benefit–cost analysis;
- **Scenario 1**—the adoption lag was increased one year from the baseline case (to 1985) before the gross benefit stream commenced; the adoption ceiling was reduced to 37% in 2007; the annual costs of UQ and the ACIAR projects were deducted from the total cost stream; this is the most conservative estimate of the gains from the UQ/ACIAR SSPP projects;
- **Scenario 2**—the adoption lag was increased three years from the base-line case (to 1987) before the gross benefit stream commenced; the adoption ceiling was reduced to 33.5% in 2007; the annual costs of the UQ SSPP program and the ACIAR projects were deducted from the total cost stream; this is the most likely estimate of the gains from the UQ/ACIAR projects;
- **Scenario 3**—the adoption lag was increased five years from the baseline case (to 1989) before the gross benefit stream commenced; the adoption ceiling was reduced to 30% in 2007; the annual costs of the UQ SSPP program and the ACIAR projects were deducted from the total cost stream; this is the most optimistic of the three estimates of the gains from the UQ/ACIAR projects.

It seems reasonable to expect, as the ACIAR projects were conducted over a eight year period and the UQ program went for 13 years prior to that (Table 5),that this led to at least a three year gain in terms of reduced research and adoption lags from the investments made by the partners, ICAR and ICRISAT. Hence scenario 2 is classified as the most likely one.

Table 5. Estimated costs of the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), University of Queensland (UQ) and Australian Centre for International Agricultural Research (ACIAR) short-season pigeonpea (SSPP) programs (A$'000 nominal).

| Year | Total ICRISAT Pigeonpea Program[a] | Share to SSPP Program[b] (%) | ICRISAT SSPP Program | ACIAR SSPP Project[c] | UQ SSPP Program[d] | ICAR SSPP Program[e] | Total SSPP Program |
|---|---|---|---|---|---|---|---|
| 1969 | | | | | 70 | | 70 |
| 1970 | | | | | 70 | | 70 |
| 1971 | | | | | 70 | | 70 |
| 1972 | | | | | 70 | | 70 |
| 1973 | | | | | 70 | 10 | 80 |
| 1974 | | | | | 150 | 20 | 170 |
| 1975 | | | | | 150 | 30 | 180 |
| 1976 | | | | | 150 | 40 | 190 |
| 1977 | | | | | 150 | 40 | 190 |
| 1978 | 2636 | 1 | 2 | | 150 | 44 | 196 |
| 1979 | 1509 | 4 | 60 | | 250 | 44 | 354 |
| 1980 | 1943 | 7 | 136 | | 250 | 44 | 430 |
| 1981 | 2124 | 10 | 212 | | 250 | 44 | 506 |
| 1982 | 2719 | 15 | 401 | 177 | 250 | 44 | 872 |
| 1983 | 2317 | 20 | 462 | 108 | | 44 | 614 |
| 1984 | 2337 | 30 | 701 | 220 | | 44 | 965 |
| 1985 | 2682 | 40 | 1073 | 91 | | 44 | 1208 |
| 1986 | 3570 | 50 | 1785 | 171 | | 50 | 2006 |
| 1987 | 4042 | 50 | 2021 | 268 | | 55 | 2344 |
| 1988 | 3908 | 50 | 1954 | 270 | | 60 | 2284 |
| 1989 | 4598 | 50 | 2299 | 142 | | 70 | 2511 |
| 1990 | 4011 | 50 | 2006 | | | 75 | 2081 |
| 1991 | 4011 | 60 | 2407 | | | 80 | 2487 |
| 1992 | 4138 | 70 | 2897 | | | 85 | 2982 |
| 1993 | 4649 | 70 | 3254 | | | 90 | 3344 |
| 1994 | 3169 | 80 | 2535 | | | 95 | 2630 |
| 1995 | 2979 | 80 | 2383 | | | 100 | 2483 |

[a]Converted from A$ at the ACIAR recommended rate of A$1.00 = US$0.7845.
[b]Source: D.E. Byth and C. Johanson (pers. comm.).
[c]Source: ACIAR.
[d]Source: D.E. Byth (pers. comm). From 1983 the UQ investment is embedded in the ACIAR figure.
[e]Source: K.B. Saxena and C. Johansen (pers. comm.).

While it would be desirable to separate the contributions of UQ from those of ACIAR in generating the benefit stream from reduced research and adoption lags, it is not possible to do so. As the UQ effort started much earlier than the ACIAR support and adoption of SSPP began to occur in the midst of the ACIAR project (1984), there is a case to be made that UQ was the primary contributor. However, as Dr D. Faris (pers. comm.) attests, it was the interactions during the eighties under the ACIAR project which had a wholesale influence on ICRISAT and the NARS. This no doubt influenced the benefit stream in later years. Two ways of distinguishing the two contributions would be (i) to use either the relative number of years both institutions funded SSPP research or (ii) the relative size of the financial contributions. The former suggests a 64:36 split between UQ:ACIAR and the latter a 59:41 split. However these are somewhat arbitrary and no attempt is made in the analysis to apportion benefits separately to ACIAR or UQ.

## 8.2 Research Costs

Bantilan and Parthasarathy (1997) did not proceed to estimate the rate of return on the research investments involved in developing ‘ICPL 87’. They only estimated adoption, yield, sustainability and cost saving implications. However an attempt is made to do this, with their collaboration, using additional data and analyses. They have compiled a time series of the costs of the entire ICRISAT pigeonpea program from 1973 to 1995. It is estimated that after commencing in 1978, by 1982 ICRISAT devoted 10–15% of its pigeonpea program resources to the development of SSPP. This rose to 50% in 1986 (the year that ‘ICPL 87’ was released) and is currently estimated to represent about 80% of the ICRISAT pigeonpea program.

On this basis, Table 5 has been constructed to show the estimated cost series for ICRISAT’s SSPP program. It also contains the costs of the ACIAR projects from 1982–89, that of the UQ prior to the ACIAR project (1969–82) and of ICAR (1973–95), as well as the total costs of the SSPP efforts of all four institutions over the whole period 1969–95. The latter reached an annual peak of A$3.34 million in 1993. ICRISAT’s investment was by far the most significant, rising from 54% of the total SSPP investment in 1981–83 to 97% in 1991–93.

## 8.3 Investment Returns

It seems clear that the investments made by all four research institutions on SSPP over the period examined have been wise economic decisions. For a total expenditure of A$27.8 million in 1996 dollars discounted to 1978 at 5%, the net present value (NPV) in 1978 was A$191 million when projecting the benefit stream to the year 2007 (Table 6).[7] This represents an internal rate of return (IRR) of more than 27.4%. Even if one assumes the adoption lags were five years longer than actually occurred, the IRR is still an attractive 24.2%.

Table 6. Benefit—cost analysis of short-season pigeonpea research investments by four institutions[a].

| Case | Using realised and projected benefits to 2007 | | | | Using realised benefits to 1997 only | | | |
|---|---|---|---|---|---|---|---|---|
| | Discounted gross benefits (A$m) | Discounted costs (A$m) | Net present value (A$m) | Internal rate of return (%) | Discounted gross benefits (A$m) | Discounted costs (A$m) | Net present value (A$m) | Internal rate of return (%) |
| Baseline Adoption 1984 | 219 | 28 | 191 | 27.4 | 103 | 28 | 75 | 25.4 |
| Scenario 1 Adoption lagged 2 yrs | 201 | 20 | 181 | 37.0 | 89 | 20 | 69 | 35.7 |
| Scenario 2 Adoption lagged 3 yrs | 170 | 20 | 150 | 28.9 | 65 | 20 | 45 | 25.2 |
| Scenario 3 Adoption lagged 5 yrs | 145 | 20 | 125 | 24.2 | 47 | 20 | 27 | 17.9 |

[a]ACIAR, the Indian Council of Agricultural Research (ICAR), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the University of Queensland (UQ). Benefits and costs are expressed in 1996 Australian dollars using the non-farm gross domestic product (GDP) deflator for all years but 1978–90, when the Consumer Price Index (CPI) was used (ABARE, 1997). All figures were then discounted to 1978 using a 5% discount rate as specified by ACIAR.

If the benefit stream were truncated to include only those realised to 1997, the NPV in the baseline case reduces to A$75 million with an IRR of 25.4%, which is still quite healthy (Table 6). In the most pessimistic scenario, these fall to A$27 million and 17.9%, respectively.

[7]The ACIAR model only allows a 30 year horizon for the benefit–cost analysis. As the cost stream was commenced in 1978 (using compounded costs incurred prior to that) this meant that benefits beyond 2007 could not be included. This lends further conservatism to the estimates. ACIAR also requires all financial analyses to be expressed in 1996 Australian dollars using the Australian non-farm gross domestic product (GDP) deflator. This was used in all years except 1978–80 when the Consumer Price Index (CPI) was used. In addition ACIAR specifies that a 5% discount rate be used for all compounding and discounting.

The annual incremental benefits that are attributed to the strategic UQ/ACIAR investments in Table 5 are shown in Table 7. These are expressed in nominal dollars before applying inflation factors or discounting. Scenario 2 shows that the year after the ACIAR projects concluded in 1989, the incremental nominal net benefits to ACIAR and UQ had reached more than A$5.2 million annually.

Table 7. Measuring the incremental nominal benefits from University of Queensland (UQ)/ACIAR short-season pigeonpea projects (A$'000).

| | Nominal Gross Benefits[a] | | | | Incremental Nominal Net Benefits Attributable to UQ and ACIAR[b] | | |
|---|---|---|---|---|---|---|---|
| Year | Baseline | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 1 | Scenario 2 | Scenario 3 |
| 1978 | | | | | –1322 | –1322 | –1322 |
| 1979 | | | | | –250 | –250 | –250 |
| 1980 | | | | | –250 | –250 | –250 |
| 1981 | | | | | –250 | –250 | –250 |
| 1982 | | | | | –427 | –427 | –427 |
| 1983 | | | | | –108 | –108 | –108 |
| 1984 | 485 | | | | 265 | 265 | 265 |
| 1985 | 2 481 | 485 | | | 1 904 | 2 390 | 2 390 |
| 1986 | 4 477 | 2 574 | | | 1 732 | 4 306 | 4 306 |
| 1987 | 6 475 | 4 665 | 485 | | 1 543 | 5 722 | 6 207 |
| 1988 | 8 474 | 6 756 | 2 825 | | 1 448 | 5 379 | 8 204 |
| 1989 | 10 646 | 8 849 | 5 167 | 485 | 1 655 | 5 338 | 10 019 |
| 1990 | 12 734 | 11 115 | 7 510 | 3243 | 1 618 | 5 224 | 9 490 |
| 1991 | 14 822 | 13 297 | 9 855 | 6 003 | 1 525 | 4 967 | 8 819 |
| 1992 | 16 826 | 15 480 | 12 373 | 8 766 | 1 346 | 4 453 | 8 060 |
| 1993 | 19 003 | 17 578 | 14 807 | 11 531 | 1 425 | 4 195 | 7 471 |
| 1994 | 21 181 | 19 849 | 17 243 | 14 471 | 1 331 | 3 938 | 6 710 |
| 1995 | 23 532 | 22 122 | 19 595 | 17 326 | 1 410 | 3 937 | 6 206 |
| 1996 | 25 884 | 24 568 | 22 120 | 20 184 | 1 316 | 3 765 | 5 700 |
| 1997 | 28 066 | 27 015 | 24 647 | 22 959 | 1 050 | 3 419 | 5 107 |
| 1998 | 30 249 | 29 292 | 27 347 | 25 908 | 957 | 2 902 | 4 341 |
| 1999 | 32 604 | 31 570 | 30 049 | 28 859 | 1035 | 2 555 | 3 745 |
| 2000 | 34 965 | 34 021 | 32 581 | 31 985 | 940 | 2 381 | 2 977 |
| 2001 | 37 320 | 36 474 | 35 114 | 35 113 | 846 | 2 205 | 2 207 |
| 2002 | 39 679 | 38 928 | 37 822 | 35 457 | 752 | 1 858 | 4 223 |
| 2003 | 42 040 | 41 383 | 40 530 | 35 801 | 657 | 1 510 | 6 239 |
| 2004 | 44 402 | 43 839 | 41 046 | 36 317 | 563 | 3 355 | 8 085 |
| 2005 | 46 765 | 46 297 | 41 562 | 36 833 | 468 | 5 202 | 9 932 |
| 2006 | 49 129 | 46 813 | 42 078 | 37 349 | 2 316 | 7 051 | 11 780 |
| 2007 | 49 645 | 47 329 | 42 594 | 37 865 | 2 316 | 7 051 | 11 780 |

[a]Attributable to all four institutions.
[b]Calculated by subtracting each scenario's gross benefits from baseline gross benefits and subtracting UQ and ACIAR costs.

The discounted costs in 1978 of the research by ACIAR and UQ in 1996 dollars amounted to a total of A$7.4 million from 1969–1989 (Table 5). The most likely scenario (2) indicates that for this investment the discounted gross benefits were A$48.1 million if, in addition to those realised up until 1997, we project forward to 2007 as well (Table 8). This implies a NPV of A$40.7 million and an IRR of 48.9%. The minimum IRR is estimated to be 31.6% and the optimistic one 53.2%.

Table 8. Benefit–cost analysis of short-season pigeonpea research investments by ACIAR and the University of Queensland (UQ)[a].

| Case | Using realised and projected benefits to 2007 | | | | Using realised benefits to 1997 only | | | |
|---|---|---|---|---|---|---|---|---|
| | Discounted gross benefits | Discounted costs | Net present value | Internal rate of return (%) | Discounted gross benefits | Discounted costs | Net present value | Internal rate of return (%) |
| Scenario 1 Adoption lagged 2 yrs | 17.6 | 7.4 | 10–.2 | 31.6 | 14.4 | 7.4 | 7.0 | 13.4 |
| Scenario 2 Adoption lagged 3 yrs | 48.1 | 7.4 | 40.7 | 48.9 | 38.1 | 7.4 | 30.7 | 25.6 |
| Scenario 3 Adoption lagged 5 yrs | 73.9 | 7.4 | 66.5 | 53.2 | 55.9 | 7.4 | 48.5 | 29.5 |

[a]Benefits and costs are expressed in 1996 Australian dollars using the non-farm gross domestic product deflator for all years but 1978–80, when the Consumer Price Index was used (ABARE 1997). All dollar ($) figures are discounted to 1978 using a 5% discount rate as specified by ACIAR.

If the benefit streams are truncated to end in 1997 instead of 2007, the most likely NPV is reduced by 25% to A$30.7 million. The IRR falls to 25.6%, which is still attractive. The range in IRR in this truncated analysis is from 13.4% to 29.5%.

As the whole exercise has been undertaken using conservative values, it seems clear from Table 8 that the ACIAR and UQ investments in SSPP have resulted in very attractive returns to India. Indian producers of pigeonpea have been the major beneficiaries of this investment, as the share of producers' surplus in the total economic surplus is more than 95 per cent. Non-Indian producers of pigeonpea have also been losers, although non-Indian consumers would have benefited. As the orphan Australian pigeonpea industry declined to insignificance after an initial adoption of SSPP, it seems it has subsequently been a casualty.

# Conclusion

It seems that only in India is it possible to say that there have been significant economic benefits from the investments made by ACIAR in SSPP. There was little evidence of sustainable economic impact in the four other countries where research activities took place, namely Australia, Fiji, Indonesia and Thailand.

The combined investment by ACIAR, ICAR, ICRISAT and UQ in SSPP in India has been a wise economic investment for all four institutions, generating overall IRRs between 24 and 37%, with the most likely value being 27%. More than 40% of these benefits have been already realised. The balance are projected to occur over the next ten years.

The strategic research investment on SSPP made by ACIAR and UQ has hastened the flow of benefits to India from the endeavours of the other two institutions. This has generated IRRs of between 31% and 53% on the ACIAR/UQ investments, with the most likely figure being 49%. More than three-quarters of these benefits were estimated to have been already realised, with the balance to accrue over the next ten years.

Pigeonpea producers in India have been the primary beneficiaries from the development and spread of SSPP in India, rather than Indian consumers, who reaped only around 5% of the benefits. Australia and other non-Indian producers have been the losers. Non-Indian consumers have also gained.

As pigeonpeas have traditionally been grown in the more marginal environments in India, where the poorest of the poor reside, it is likely that the large new income streams generated by SSPP have primarily benefited the lowest socioeconomic spectrum. The extra production of fuelwood byproducts from pigeonpea stalks as a result of the expanded pigeonpea production would also have a special value for poor rural women and children, who are primarily responsible for collecting fuelwood. Additional employment for women in harvesting, threshing and processing would also result from the increased pigeonpea harvests, as they are heavily involved in these tasks in India. Time did not allow these aspects to be studied in detail; they deserve more attention.

The stimulation of research on SSPP provided by the UQ/ACIAR collaboration is continuing today, even though work on SSPP by the two institutions ended ten years ago. Efforts are now being made in South Asia to develop extra-short-duration pigeonpea for the rice–wheat systems of the Indo-Gangetic Plains. These cultivars will mature 10–20 days earlier than the SSPP cultivars that emerged from earlier research and possibly lead to further expansion of pigeonpea cultivation in that region. Should this occur, there will be considerable benefits in terms of the stainability of agricultural production in what is the food basket of South Asia.

In addition, the greatly increased zone of adaptation that the SSPP cultivars have achieved, means that the crop can be expected to find new niches in future. Constraints related to processing, utilization and marketing seem to be the primary determinants of the speed with which the crop will expand into these new production environments. Plant protection also will require increased attention.

Some of those contacted about the SSPP projects regretted the fact that there was not more opportunity to develop scientific synergies among the collaborators both during, and especially after the end of the Australian support in 1989. The implication was that both the genetic material developed during the projects and intermediate outputs like the pigeonpea crop model based on PNUTGRO, were not effectively disseminated and institutionalised. Hence potential future impacts might have been foregone. This reminds us that one of the consequences of a project mode of funding such as used by ACIAR, and indeed most R&D agencies, is once that funding ceases project leaders and staff have no obligation or incentive to maintain contact with partners. Whilst this is understandable in this era of competitive funding, there is a danger that it can be at the expense of the attainment of temporal spillovers and sustained impacts.

Indeed it was very difficult for this impact assessment to be made ten years after the cessation of the UQ/ACIAR support for SSPP research, because there had been essentially no continuity of effort in the programs. Staff had moved on in all the institutions involved and only one had conducted adoption studies. An outside consultant has difficulty assembling the required data in a matter of weeks and without the time and resources to gather primary data. This raises questions about the appropriate responsibility for the conduct of impact studies of ACIAR projects in the future. Perhaps ACIAR should review whether commissioned organizations should be required to assume more responsibility for this aspect. ACIAR could use external consultants to help verify and evaluate these studies to lend the appropriate degree of quality control and credibility, rather than be expected to originate the impact studies.

The ACIAR economic evaluation model used to undertake the assessment was extremely helpful. The development of user-friendly computer routines is to be commended. Indeed the framework offers an excellent opportunity for ACIAR to ensure consistency in the impact assessments it commissions or conducts. It also provides a capability to explicitly link ex ante impact assessments in the project approval processes with subsequent ex post evaluations, which is to be encouraged.

In refining the economic evaluation model, ACIAR might consider incorporating exchange rate variations into the data bases that are used. Domestic inflation rates are used but only single valued exchange rates. This can imply biases of an unknown magnitude. Perhaps Purchasing Power Parity indices could be incorporated in the future. Another suggestion is to allow more flexibility in the time horizon used in the model. At present it is limited to 30 years. While this is reasonable when discounting the future, it limits the analysis when compounding past costs is an important consideration, as was the case in the present exercise.

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I am grateful to Ma Cynthia Bantilan and her colleagues at ICRISAT for providing data to allow the economic assessment to be attempted for India. Thanks are also due to those listed in Appendix II who responded to the questions that were posed about the achievements and impact of the two ACIAR projects. Don Byth and Eoin Wallis, the co-leaders of the projects, were very helpful in providing necessary background information and insights. Jeff Davis assisted with the elaboration of the economic model which was used to measure the socioeconomic impact and Godfrey Lubulwa assisted in applying the model using the empirical data gathered in the exercise. Maureen Kenning, Susan McMeniman and Ken Menz of ACIAR provided valuable support to enable the project to be completed.

All are absolved of any sins of omission and/or commission.

## References

ABARE (Australian Bureau of Agricultural and Resource Economics) 1997. Australian Commodity Statistics, Canberra.

Auld, B.A. 1990. A report on independent reviews of ACIAR projects 1982–1990. Canberra, ACIAR.

Asthana, A.N., Ali, M. and Dubey, S.D. 1996. Extra-short-duration pigeonpea in India: research in the All India Coordinated Pulses Improvement Project. In: Singh, L., Chauhan, Y.S., Johansen, C., and Singh, S.P., ed., Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT workshop and monitoring tour, 16–18 Oct 1995, New Delhi, India. IARI and ICRISAT, 6–10.

Bantilan, M.C.S. and Parthasarathy, D. 1997. Efficiency and sustainability gains from adoption of short-duration pigeonpea in nonlegume-based cropping systems. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Brennan, J.P. and Bantilan, M.C.S. 1998. Impact of ICRISAT research on Australian agriculture. NSW Agriculture and ICRISAT.

Byth, D.E.B. and Wallis, E.S. 1988. Pigeonpea improvement project no: 8567. Submission to Review Panel. ACIAR/University of Queensland Pigeonpea Improvement Program.

Chauhan, Y.S., Johansen, C. and Singh, L. 1996. Enhancing adaptation of extra-short-duration pigeonpea by improving plant type. In: Singh, L., Chauhan, Y.S., Johansen, C. and Singh, S.P., ed., 1996. Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT workshop and monitoring tour, 16–18 Oct 1995, New Delhi, India. IARI and ICRISAT, 62–68.

Cheralu, C. 1996. Prospects for short-duration pigeonpea in Andhra Pradesh. In: Singh, L., Chauhan, Y.S., Johansen, C. and Singh, S.P., ed., 1996. Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT workshop and monitoring tour, 16–18 Oct 1995, New Delhi, India. IARI and ICRISAT, 34–37.

Hawtin, G., Patanothai, A., Laing, D.R., Byth, D.E. and Wallis, E.S. 1988. Review of ACIAR’s food legume and oilseed program. Canberrra, ACIAR.

Lubulwa, G. and McMeniman, S. 1997. The Economic Evaluation Unit model for project level economic evaluations: a users manual. ACIAR, Canberra (Draft).

Mauldon, R.G. 1997. An assessment of the success and impact of ACIAR projects. Economic Evaluation Unit, Working Paper No. 29, Canberra, ACIAR.

McWilliam, J.R., Persley, G.J., Beddenhagen, I. and Wood, I. 1985. ACIAR Project 8201: pigeonpea improvement review report. ACIAR, Canberra.

Mueller, R.A.E., Parthasarathy Rao, P. and Subba Rao, K.V. 1990. Pigeonpea: markets and outlook.In: Nene, Y.L., Hall, S.D. and Sheila, V.K. ed., The pigeonpea. Wallingford, U.K., CAB International, 457–479.

Niranjan, F.F. 1997. Ex-post evaluation of research and development activities of pigeonpea in Sri Lanka. A study undertaken for the Asian Development Bank–Sri Lanka–ICRISAT Pigeonpea Intercropping and Diversification Project (TA 1742 SRI), Colombo, Sri Lanka.

Ryan, J.G. 1995. A global perspective on pigeonpea and chickpea sustainable production systems: present status and future potential. In: Sinha, S.K. and Paroda, R.S., ed., Production of pulse crops in Asia and the Pacific region. Bangkok, Food and Agriculture Organisation , Regional Office for Asia and the Pacific (RAPA) Publication No. 1995/8, 225–248.

Sekhon, H.S., Sidhu, P.S. and Phul, P.S. 1996. Use of extra-short-duration pigeonpea in rotation with winter crops in Punjab In: Singh, L., Chauhan, Y.S., Johansen, C. and Singh, S.P., ed., Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT workshop and monitoring tour, 16–18 Oct 1995, New Delhi, India. IARI and ICRISAT, 17–22.

Singh, L. 1996. The development of and adoption prospects for extra-short-duration pigeonpea. In: Singh, L., Chauhan, Y.S., Johansen, C. and Singh, S.P., ed., 1996. Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT workshop and monitoring tour, 16–18 Oct 1995, New Delhi, India. IARI and ICRISAT, 1–5.

Singh, L., Chauhan, Y.S., Johansen, C. and Singh, S.P., ed., 1996. Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT workshop and monitoring tour, 16–18 Oct 1995, New Delhi, India. IARI and ICRISAT.

Singh, S. P. 1996. Prospects for varietal improvement in extra-short-duration pigeonpea. In: Singh, L., Chauhan, Y.S., Johansen, C. and Singh, S.P., ed., 1996. Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT workshop and monitoring tour, 16–18 Oct 1995, New Delhi, India. IARI and ICRISAT, 86–95.

Wallis, E.S., and Byth, D.E. (ed.) 1986. Food legume improvement for Asian farming systmes. ACIAR Proceedings No. 18.

# A1 Appendix I

## A1.1 Overview of pigeonpea research funded by ACIAR

*D. E. Byth (March 1998)*

As ACIAR staff were advised by me verbally, full details of the ACIAR-funded research project on pigeonpea are available in the reports of the project to ACIAR and in the report of the Review of the Food Legume and Oilseeds Program of ACIAR which was conducted in 1988 by the Team led by Dr G. Hawtin. Nevertheless, as requested, a brief overview of that research is presented here, together with an analysis of achievements and impact.

## A1.2 Context of the research—a background

Pigeonpea research commenced at UQ under the leadership of Dr P. Whiteman, around 1970. The primary focus of this work was directed to achievement of effective grazing animal utilisation, particularly as a source of stand-over feed reserves for cattle in northern Australia. This involved introduction, quarantine and agronomic evaluation of a relatively large number of pigeonpea accessions from a range of sources internationally (note; this was pre-ICRISAT).

This initial phase of research was funded mainly by support during 1969 to 1973 from the Colombo Plan, together with funds from UQ. The outcome of this work was a substantially improved understanding of growth and development, and of dry matter accumulation, of these materials which were long or medium duration. It was found that the crop was only weakly perennial under grazing/heavy defoliation, and thus not particularly attractive for this purpose. However, a number of lines were identified to produce high yields of pods and dry seed, which suggested that there may be some potential for the crop in arable agriculture in Australia.

The major problems of long crop duration, perenniality and excessive biomass for mechanisation of seed harvest were the primary topics of investigation in the next phase of the work, which was supported by Australian Rural Credits Development Fund, together with inputs of funds and resources by UQ. A detailed understanding of the phenological responses of medium duration genetic materials to sowing date and photoperiod was developed. Agronomic packages were developed using sowing date ( row spacing/plant density interactions to optimise crop canopy performance, with effective mechanisation possible in tropical and subtropical Australia using late sown crops in narrow rows and high plant density. This was a major breakthrough, although it did place sensitive phases of crop development at the time of low temperature and generally low moisture availability which did constrain the practicality of this proposed cropping system for most of northern Australia.

The chance identification of a single off-type plant which flowered in about 60 days after sowing (DAS) in a longer duration accession triggered the next phase of study. Initial studies of the self-pollinated progeny of this plant demonstrated that it was uniformly short duration, with associated short stature, maturing in around 120–140 DAS. Preliminary experimentation with this line, and with other short duration (SD) lines identified subsequently, clearly demonstrated the potential for high yields of dry pigeonpea seed harvestable within 120–149 DAS depending on sowing date, and with a canopy structure which was able to be mechanised for harvest.

The prospect for effective establishment of a new form of SD pigeonpea crop, both in Australia and globally, was potentially revolutionary in its impact. It was at this time (1976) that an Australian team (three UQ staff plus a representative of the Queensland Grain Growers Association) visited India as the first exchange visit under the India–Australian Science and Technology Agreement. Visits were made to a number of major sites of the Indian National Pulse Crop Improvement Program. In addition, the team visited ICRISAT in Hyderabad, for similar discussions on the further development of SD pigeonpea. During these visits, it was clear that individual scientists in India had observed early flowering/short duration pigeonpea plants in the past, but that they were considered to have limited agronomic potential and an inherently low yield of poor quality seed. There was no serious work in progress on SD pigeonpea at any site visited. However, the results of the Australian work stimulated much interest, particularly in the ICRISAT program.

ICRISAT subsequently provided substantial funding for the staffing and operation of the program at UC from 1978 to 1982. During this phase, there was substantial introduction of additional accessions of pigeonpea germplasm into Australia. Detailed agronomic study of the SD lines developed in Australia, and others identified by ICRISAT, were continued, both in Australia and at ICRISAT. There was substantial exchange visits between ICRISAT and Australia, including two long duration secondments of ICRISAT staff to UC, one of which was supported by the Australian Commonwealth Special Research Grant scheme. The outcomes included clear confirmation of the very high yield potential of SD pigeonpea under favourable conditions for growth and development, the relative insensitivity of phenology of SD materials to sowing date (photoperiod and temperature), and the initiation of a significant program of genetic and breeding studies on SD pigeonpea at UQ. There was exchange of these materials with ICRISAT, which by 1982 had initiated an in-house program of SD research which encompassed perhaps 10–15% of its total pigeonpea program. During this period, there were on-going contracts between UQ staff and the Indian National pulse improvement program, with regular exchange visits and exchange of genetic materials.

In summary, prior to the establishment of the ACIAR–UQ project (CS 2/82/01) in 1983, the UQ program had undertaken substantial research over 10–12 years into the potential of pigeonpea as a new crop for Australian industry; had detailed knowledge of growth and phenological development of a wide range of pigeonpea genetic materials; had identified SD materials which offered the potential for a new dimension of pigeonpea culture as a SD component of farming systems globally; and had formed a close partnership with ICRISAT in the agronomic study and breeding/genetic study of SD pigeonpea. An outcome of this work was the initiation of a significant shift of the ICRISAT pigeonpea improvement program to provide a greater focus on non-traditional SD materials and production systems.

## A1.3 The ACIAR—UQ project

There were two phases to this project. According to the papers provided by ACIAR, Phase I (CS 2/82/01) started 1/2/83 and terminated 31/1/86 and Phase II (CS 2/85/67) extended from 2/12/85 to 31/12/88, although I suspect these need to be checked for accuracy. No further extension was sought by the UQ. In fact, UQ personnel were terminating the program on pigeonpea improvement at that time, because they were of the view that UQ had completed the contribution that was appropriate for it, and that other institutions were positioned more effectively to continue the necessary work.

The project was initially approved to involve collaboration with Fiji (Ministry of Agriculture, Fisheries and Forests), Thailand (Department of Agriculture), and Indonesia (Agency for Agricultural Research and Development), with close interaction with ICRISAT. Collaboration with India was proposed under Phase I, but was only able to be extended to the

All India Coordinated Pulse Improvement Project during the last two years of Phase II after the appropriate umbrella agreement had been signed.

Phase I of the project was designed primarily to develop breeding lines and cultivars and appropriate production systems, with emphasis on SD pigeonpea. A key objective was to study the physiological basis of yield accumulation in SD pigeonpea in a range of production environments, including the study of genotype ( environment (G ( E) interactions. Development and selection of improved SD phenotypes was emphasised, and genetic studies of cold tolerance, floral biology, male sterility and phenology were targeted in addition to quantitative genetic analysis of SD populations. Extensive agronomic studies in, and exchange of genetic materials with, collaborators in other countries was undertaken, including substantial exchange visits. Utilisation studies were also a component of Phase I.

The objectives for Phase II developed out of the recommendations of the Phase I review. Emphasis was continued on the scientific understanding of the high yield potential of SD pigeonpea under favourable conditions; mechanisms of adaptation to stress environments; evaluation of ratoon, inter-crop and rotation systems; and exchange of genetic materials. Increased attention was given to marketing and utilisation, pest/disease constraints, and crop modelling, among other areas.

During both Phases I and II, there was very extensive exchange visit activity, both between Australian and collaborating countries, and among the collaborating institutions in the different countries. ICRISAT was closely associated with the program, as a research partner. This multi-institutional collaboration had a major impact on human resource development as well as initiating the development of a process of regional collaboration in pigeonpea improvement. This was a key area of contribution which will be discussed again later in this paper.

It is not appropriate here to attempt a review of the actual research undertaken in each of the collaborating countries. Rather, a listing will be attempted of some of the significant achievements and outcomes of the work during the period of the ACIAR-supported project. This will provide a basis for a subsequent economic analysis of impact of the work under this project. However, it is noted that the sheer breadth of work undertaken in the project, and the fact that it targeted work in five countries, complicates the analysis of outcomes.

### *Some achievements and outcomes*

Some specific items are outlined below.

It is emphasised that two problems exist in interpreting these types of information. First, a difficulty of attribution of credit for meritorious outcomes exists where multi-organisational collaboration exists. Secondly, the attribution of credit for science-based or commercial achievements can be complicated by delays in development and by the long duration of research which often encompasses more than one phase of an on-going program involving different research partners and/or funding sources.

Both of these problems exist in this case. While UQ is the only common institutional factor and thus contributed resources to all phases, it worked in close partnership with ICRISAT virtually throughout this entire period of pigeonpea research (about 1973–1988). UQ also had had close institutional and personal relationships with the various national programs for quite extended periods. Further, the overlapping phases of work into agronomic evaluation versus physiological studies versus simulation modelling, and into line introduction/exchange versuslocal breeding, and in breeding versus genetic analysis, and so on, are difficult to distinguish.

Furthermore, the shift by ICRISAT over 15–20 years from a program initially almost completely directed toward improvement of long and medium duration pigeonpea to one which is >80% SD in focus is a strategic and significant one. Clearly, many factors have underlain and influenced this fundamental shift. However, it was obviously driven by a perception of potential benefit, and this cannot be isolated from the cascade of results initiated by the original UQ research into the off-type SD pigeonpea material.

It is against this type of complexity of interpretation and attribution that this specification of achievements/outcomes of the ACIAR-funded work is attempted.

#### ►►►► (a) Demonstration of high yield potential of SD pigeonpea

The work completed in Australia in the ACIAR-funded phases was a direct continuation of earlier phases of the research by UQ in association with ICRISAT and its Australian collaborators. Research in Indonesia, Thailand and Fiji was a direct spillover of these technologies and clearly confirmed the high seed yield potential in favourable environments. The existence of the potential for new forms of cropping systems, and for wider ranges of adaptation of the crop, conditioned by improved SD genetic materials, was demonstrated in all three countries. Cultivars were released by 1988—for example, in Australia ('Hunt', 'Quantum' and 'Quest'), in Fiji ('QPL511'), in Indonesia ('Hunt' as 'Mega').

The results in India were more ambiguous, and based on only one year of effective trial work in northern India. That limited research suggested that the yield potential of SD lines in northern India was lower than that demonstrated in Australia and elsewhere. The causes of this, and of the rapid decline in biomass and seed yield with delayed sowing, were not clearly demonstrated in these trials. It is probable that temperature was a major factor.

For Australia, commercial development of pigeonpea as a crop was made possible by SD material, and was most promising initially (8 000 ha in 1986–7). However essentially no pigeonpea is now grown commercially, largely owing to perceived problems of insect management and unreliable export markets. Limited variety trial work is now done by the Queensland Department of Primary Industries (QDPI) and the potential for development of pigeonpea as a summer-grown legume remains on hold, waiting to be exploited by industry.

### *Conclusion*

- It is impossible to separate this demonstration of high yield potential systems for SD pigeonpea from the initial discovery and early definitive work at UQ. The specific contribution of the spillover to the NARS was initiated in the ACIAR-funded work—a specific achievement.

### ▶▶▶▶ (b) Scientific knowledge of SD pigeonpea

It is clear that there was a substantive body of scientific knowledge and technologies on SD pigeonpea genetic material and production systems established prior to the commencement of the ACIAR-funded phase in 1983. Indeed, this was in part the justification for that ACIAR project. Equally, the previous phase funded in part by ICRISAT also had greatly broadened the scientific understanding of SD pigeonpea within ICRISAT, which was in the process of implementing a shift to substantial SD research, particularly in breeding. Later, ICRISAT also substantially broadened and deepened its research in SD pigeonpea into production system agronomy and physiology, and in pest management. Furthermore, there has been increasing research (breeding and non-genetic) by the Indian national program, and some ongoing work by other NARS.

For these reasons, it is very difficult to attribute credit for scientific knowledge of SD pigeonpea which is now quite comprehensive. There can be no doubt, however, that the initial scientific studies of SD pigeonpea were initiated and conducted by and at UQ; this knowledge base was substantially expanded in 1979–82 in partnership with ICRISAT, particularly in genetic improvement/breeding; that definitive physiological studies of the crop growth and development, photo-thermal responses in phenology, water stress tolerance, and reproductive biology, and the initial work on simulation crop modelling of SD pigeonpea, were initiated and conducted during the 1983–88 ACIAR-funded phase; and that the broadest study of G¥ E interaction and environmental adaptation in a number of countries also occurred during the 1983–88 phases.

*Conclusion*

- It is impossible to attribute total credit for scientific understanding to any one organisation or phase of the SD pigeonpea research.
- The ACIAR-funded phases of the work were characterised by the most definitive physiological studies of phenology, water stress tolerance, plant development and crop growth, G¥ E interaction and crop modelling. These were significant contributions.
- During these phases, the UQ program was most active in collaboration in the region (Fiji, Indonesia, Thailand; and also later in India) as well as with ICRISAT; and very significant human resource development was conducted. Details of this are in the project reports.

### ►►►► (c) Impact through adoption on-farm

It is important to recognise that at the initiation of pigeonpea research at UQ, pigeonpea was not commercially grown in Australia. It also was an insignificant traditional ‘garden plant’ for green vegetable use in parts of Thailand and Indonesia. It was cultivated commercially in a very limited scale in Fiji, largely for green pods and import substitution of dry seed, and involving traditional medium to long duration varieties. Only in India was there a substantial development of commercial production, and of a research capability in the Indian national program and in ICRISAT after 1972–3.

As indicated above, progressive commercial development in Australia culminated in about 8 000 ha in 1986–7, prior to a collapse of interest related to insect constraints and insecure export markets. Thus the net on-farm impact in Australia is zero currently.

For Indonesia, the major prospect for commercial exploitation of the demonstrated high dry seed production potential was, and remains, on the outer islands characterised by acid soil/low fertility constraints, with the product used as a partial substitute for imported soybean in tempeh manufacture. These developments were shown by the project to be technologically feasible. However no current knowledge of the extent of on-farm adoption in Indonesia is available, and this suggests it may be very limited.

For Thailand, the potential applications to low fertility acid soil areas of the north east were similar to those in Indonesia, with the need to develop markets for the dry seed as a food, feed and/or export commodity. A specific study (Wallis et al. 1988, Coarse Grains, Pulses, Roots and Tubers Centre of ESCAP, Bogor, Indonesia [CGPRT] No. 15) concluded that the use of pigeonpea in poultry nutrition in village situations deserved study. No current data is available to the writer on on-farm production and utilisation in Thailand, although it is understood that limited exports of dry seed are made to India.

In Fiji, there was a clear momentum to shift to SD cultivars and production systems, for import substitution. The extent of this shift is not known.

In India, there has been substantial adoption of SD pigeonpea varieties on-farm. This has occurred as a summer/wet season crop in north western India with harvest prior to land preparation for wheat sowings; and as a wet season crop in regions of Karnartaka, Maharastra and Andra Pradesh, both as a SD substitute for longer duration cultivars and in response to the development of new SD cultivars resistant to *Fusarium* wilt disease. This adoption has been very widespread and is continuing, and has been extensively documented by ICRISAT. Details of this work have been requested by the writer from Dr C. Bantilan of ICRISAT, but unfortunately no response has resulted. Therefore no further analysis can be attempted here.

There is evidence of increased production of pigeonpea in other countries (for example, in Myanmar, Kenya and Malawi), and these may be related in part to the adoption of SD pigeonpea genetic materials, particularly from ICRISAT. ICRISAT staff, particularly Dr Bantilan, are best placed to have access to that information.

### *Conclusion*

- Conclusive evidence of significant on-farm impact of SD pigeonpea and related production systems exists only for India. At best, adoption of SD systems in the other countries remains limited, largely related to the lower priority and importance of the crop in those countries.

- While releases of SD cultivars and lines developed within the UQ program were made, all of these materials traced directly or indirectly to genetic materials and/or parentage accessed initially from ICRISAT which holds the world collection. The extensive breeding populations of UQ were made available to collaborators in 1988, and it is not possible now to know the fate of those materials. Thus any linkage of the UQ program, and specifically in the ACIAR-funded phases of it, to on-farm impact in the various countries of collaboration is at best tenuous and probably very limited. However the entire UQ collection of genetic material was placed in the Australian Tropical Genetic Resources Centre of QDPI in Biloela, and can this be accessed freely by all interested parties.

- Nevertheless, the successful adoption of improved SD pigeonpea cultivars and production technologies cannot be separated entirely from the scientific and intellectual momentum generated by the UQ program of research. These indirect inputs should receive recognition and generate attribution of credit, although the methods for quantification of the impact may be problematic.

- As indicated, a request was made to ICRISAT for up-to-date information on impact studies, both in India and elsewhere, on SD pigeonpea. Unfortunately, no response has been received from Dr C. Bantilan who was requested to do so. In fact, there are quite extensive data available in ICRISAT on this matter, particularly for India but also for other countries, and it is strongly recommended that any follow-up economic analysis by ACIAR ensure that these data are made available by ICRISAT because they are of public interest and importance.

### ►►►► (d) Human resource development (HRD)

Throughout the full duration of the UQ program on pigeonpea improvement, there was an active commitment to, and investment in, HRD. This occurred both in Australia (via exposure of staff of UQ and collaborating institutions, training of Australian and foreign postgraduate students, and exchange visiting scientists) and in each of the collaborating countries (via training and exposure of staff of the collaborating institutions, exchange visits among collaborating countries, and exchange visits by Australian staff). In addition, there were very close interactions with ICRISAT, both in Australia and in India, and two ICRISAT scientists had long-term secondments at UQ specifically on SD pigeonpea. Details of the nature of these activities during the term of the ACIAR-funded phases are in the reports to ACIAR, and will not be repeated here.

However, the quantification of benefits arising from these interactions, training programs/exchanges will be difficult. Also the benefits were multi-directional, resulting in rapid spillover of knowledge, experiences and technologies related to SD pigeonpea. Mobility of the trained personnel also will complicate analysis, but does not necessarily detract from the impact itself. Perhaps the most important contribution in HRD was to establish acceptance of the principle of integrated holistic crop improvement research focused on priority constraints and cross-disciplinary integration, versus narrow, reductionist, disciplinary research.

The initiation of regular in-country research review and planning meetings as part of this project, particularly during the ACIAR-funded phases, was particularly creative in building awareness of the research, its potential to contribute nationally, and the potential for spillover within the region. ICRISAT was actively encouraged by UQ to participate in these project meetings, and did so. The result was increasingly effective institutionalisation of regional collaboration, which later developed into the Asian Grain Legumes Network (AGLN) and Cereal and Legumes Asian Network (CLAN) of ICRISAT. As the initial component of the subsequent ACIAR Food Legume and Oilseeds program, the pigeonpea project was highly influential in this regard this is a significant strategic achievement.

### *Conclusion*

- A major contribution in HRD was made by the SD pigeonpea program centred on UQ, particularly during the ACIAR-funded phases. The impact of this cannot be measured simply in terms of current pigeonpea research and production, because of the spillover of expertise and personnel into other pursuits.

- Introduction by the project of annual review and planning meetings in collaborating countries acted to focus the projects on priority needs and to broaden its impact. It also stimulated progressive institutionalisation of cross-organisation and cross-country collaboration within the region, and established a mechanism for closer ICRISAT involvement in the Asia–Pacific region.

### ►►►► (e) Utilisation

Apart from India and Fiji, where there were traditional patterns of pigeonpea production and utilisation, pigeonpea for dry seed production was essentially a new crop. Thus an immediate need following the demonstration of significant technical production potential, was study of potential uses and market opportunities/constraints. These were areas of very limited knowledge in which significant contributions were made, particularly during the ACIAR-funded phases of the program.

For Indonesia, research in both Indonesia and Australia (University of New South Wales) demonstrated effective partial substitution of pigeonpea for soybean in manufacture of the fermented product, tempeh. This was particularly significant because Indonesia was (and remains) a major importer of soybean for this purpose, and because of the superior adaptation of pigeonpea to the low fertility, acid soils of the outer islands.

For Thailand, there was significant study within the projects of human food uses for pigeonpea seed extracts (noodles, flour, etc.) with limited success. Usage as a protein feed grain component for pigs and poultry was studied in both Australia and Thailand, with very clear technical success. The economics of such substitution was questionable, and likely to change over time. The potential for direct commodity exports to India also was studied.

A detailed study of *The Potential for Pigeonpea in Thailand, Indonesia and Burma* by Wallis et al. (1988) was published by the CGPRT program.

#### *Conclusion*

- The SD pigeonpea program centred on the UQ contributed extensively to the understanding of the potential for utilisation and marketing of pigeonpea and its products as a new commodity in the South East Asia region. This included evaluation of certain processing opportunities, economic studies and demonstration of specific technologies. This work was particularly active during the ACIAR-funded phases.

- The CGPRT publication by Wallis et al. (1988) on potential for pigeonpeas remains a key reference and contribution.

- The extent to which these and other promising applications of pigeonpea for market outlets have been developed in Indonesia and Thailand is not known. Of course, adoption of technology is influenced by many factors independent of the research phase. However the nexus between local production and a market for that production is clear and unavoidable.

►►►► (f) Information exchange

This is a key area of contribution, with documentation of the research outcomes an essential activity in achieving spillover of knowledge, experiences and technologies.

The publications arising from the project are listed in reports to ACIAR, and are not repeated here.

The International Workshop on Food Legume Improvement for Asian Farming Systems was conducted in 1986, during the tenure of the ACIAR-funded phases of the SD pigeonpea project. Major input was made by Wallis and Byth, who also edited the published proceedings (ACIAR No. 18, 1987). The experiences of research into SD pigeonpea in the Asia–Pacific region were captured in the Proceedings, which constituted a timely and strategic information exchange. ACIAR was the major co-sponsor of the Workshop. Of course, this Workshop involved consideration of all food legumes, not just pigeonpea.

The regular exchange visits in all directions and the annual review and planning meetings conducted in each collaborating country by the SD pigeonpea project were a crucial point of information exchange. The research and planning meetings also constituted a significant innovation at the time in some countries, and thus contributed significantly to the HRD of national staff.

*Conclusion*

- The emphasis on documentation of the work and its outcomes in the pigeonpea project, while by no means perfect, constituted an effective and instructive information exchange process. It involved collaborators from the national programs involved.

- The high degree of emphasis of the project on generation of knowledge and intermediate technologies, rather than direct on-farm end-product impact, emphasises the importance of publication/information exchange as a core method of achieving impact by spillover of such knowledge-based outcomes.

### ►►►► (g) Specific areas of study

In-depth research was undertaken during this overall project into a number of specific areas, which resulted in significant knowledge gains with respect to SD pigeonpea, and which have contributed to the longer-term improvement of SD pigeonpea productivity, adaptation and production systems. There may not be a desire by ACIAR to seek to estimate the economic value of some or all of these achievements, so these are simply mentioned here. Additional detail can be provided if this is desired.

Some areas of special interest and achievement are:

- genic male sterility
- cytological studies, including pachytene analysis, of inter-specific crosses
- canopy water use efficiency, and innovative osmotic adjustment studies
- population improvement, and analysis of diallele crosses of pigeonpea
- floral morphology, and its relationship to out-crossing and seed purity
- simulation crop modelling of SD pigeonpea, by adaptation of the PNUTGRO model
- plant nutrition studies, particularly nitrogen nutrition and biological nitrogen fixation
- acid soil adaptation, including root penetration in heavily weathered tropical soils
- resolution of a complex syndrome constraining flower and pod set in Fiji, caused by a complex of *Xanthomonas*, *Botryosphaeria* and *Phoma spp.*, possibly confounded with high aluminium saturation.

## A1.4 Summary

By its nature, and as a result of circumstances, there were limited prospects for the UQ-based research on pigeonpea to achieve end-product impact through on-farm production. In Australia, well adapted improved SD cultivars were released but a combination of insect management constraints and export market insecurity terminated a promising growth trend in adoption of the crop. In Indonesia and Thailand, pigeonpea for dry seed production was a new crop and there was a need to identify and develop market outlets for local production before any real prospect for local exploitation of the demonstrated favourable yield potential of the SD material could be expected to occur. In India, a strong and traditional industry base was expected to respond only slowly to innovation as SD technologies became more available and understood. In fact, there has now been extensive adoption of SD technologies in both peninsular and north western India.

For these reasons, apart from in India, there was limited prospect of positive impact analysis in terms of SD on-farm adoption and production in a real time frame. The major impact of the UQ-based pigeonpea research will be seen to be in the areas of knowledge generation, intermediate technologies, human resource development and information exchange.

For all of these areas of impact analysis, the problem of attribution of credit/responsibility is a complex and serious one, owing to phased long-term research with changing collaborators and funding sources between phases, and with overlapping objectives between phases.

Thus the economic analysis of impact of the ACIAR-funded components of the SD pigeonpea project is inevitably complex, with dimensions of end-product impact in India and perhaps elsewhere; spillover impact of intermediate technologies and the associated difficulties of assessing benefit; and the inherent problem of attribution.

Regarding the end-product impact, it is regretted that a more informed and definitive analysis is not possible here because of the failure of ICRISAT to respond to the request to provide the results of their extensive impact analysis work to date. It is recommended that ACIAR, as a core donor to ICRISAT, should approach ICRISAT to achieve access to the results of the surveys and analyses by Dr C. Bantilan et al . These are quite comprehensive for India, and it is believed that they may also extend in a more limited way to other Asian countries, and to some key countries of Africa. Beyond this, it may be necessary to directly seek information on the current status of production, utilisation and varietal base from key countries. The quality and extent of information likely to result from this is, of course, problematical. This could not be attempted as part of this contract due to the tightness of the timeframe involved.

It is clear that considerable amounts of intermediate technologies and impact were generated by the UQ-based project, including during the ACIAR-funded phases. An attempt has been made to outline and define the major components of this.

# A2 Appendix II

## List of Collaborators Contacted

Dr Ma C. Bantilan, Acting Leader, Socioeconomics and Policy Program, ICRISAT Hyderabad, India

Dr T. Bottema, Coarse Grain Pulse Root and Tuber Centre, Bogor, Indonesia

Dr D. Byth, previously Co-Leader, UQ/ACIAR Pigeonpea Improvement Project

Dr J.M. Green, previously Leader, Pigeonpea Improvement Program, ICRISAT Hyderabad, India

Dr D. Faris, previously Coordinator Asian Grain Legumes Network (AGLN) and Leader, Pigeonpea Improvement Program, ICRISAT Hyderabad, India

Dr C. Johansen, Pulse Physiologist, ICRISAT Hyderabad, India

Dr Y.L. Nene, previously Leader Pulse Improvement Program and Deputy Director General, ICRISAT Hyderabad, India.

Dr C.L.L. Gowda, Coordinator Cereal and Legumes Asia Network (CLAN), ICRISAT Hyderabad, India

Dr G. Persley, previously Coordinator, Plant Sciences Program, ACIAR

Dr L. D. Swindale, previously Director General, ICRISAT

Dr E. Wallis, previously Co-Leader, UQ/ACIAR Pigeonpea Improvement Project

# A3 Appendix III

## A3.1 Questions Regarding The Short-season Pigeonpea Project

What was the impact of the six-year ACIAR supported project from 1982–88 on ICRISAT's program? It is recognised that the University of Queensland (UQ) began work on pigeonpea in the early 1970s and that ICRISAT provided financial support to the UQ from 1978–82, and hence that attribution is extremely difficult if not impossible. However there are some significant outcomes from the ACIAR project which conceivably influenced subsequent research which then led to final scientific and socioeconomic impacts. I have attempted to distill from the project reports and reviews some of the more notable of these to see if they can serve to jog your memories somewhat. Specifically:

►►►► Were there lines from the ACIAR project that were used successfully in the breeding program and led to releases subsequently adopted by farmers? If so, what was the relative contribution of the ACIAR project's lines to the releases and what is the extent of adoption and the increased yields and/or reduction in costs of production per tonne?

The project itself developed varieties 'Quantum' ('QPL42'), Quest ('QPL702'?), 'Hunt' (released as 'Mega' in Indonesia), and 'QPL511' (released in Fiji). It also identified a genic male sterile line that it is believed was and is used in the current hybrid pigeonpea program in India. Lines with frost tolerance were identified and 'Hunt' had tolerance to aluminium toxicity in trials in Fiji and Indonesia. At the end of the project in 1988 the UQ team deposited all the genetic materials arising from the project in the NARS, ICRISAT, and the Australian Tropical Genetic Resources Centre in Biloela, Queensland.

►►►► Did the project play a key role in broadening the range of adaptability of pigeonpea in cropping systems? For example, was it instrumental in helping to bring short-season pigeonpea (SSPP) into the rice–wheat systems of the Indo-Gangetic Plain? Can this be quantified in terms of adoption data?

- How important was the project in stimulating ICRISAT's involvement in countries such as Indonesia, Thailand and Fiji in the 1980s; through the project review and planning meetings in these countries for example? Is it fair to say that this was a precursor to the formation of the AGLN?

- What was the impact of long-term training of ICRISAT scientists at the University of Queensland? Did the holistic integrated approach to the improvement of SSPP, which was a feature of the project, materially affect the scientists? Can this be articulated? Did this facilitate networking in Asia?

- There was research underway at Pantanagar in India in the early 1970s on SSPP that was photo-period insensitive. Indeed it seems that the original material used by UQ and ICRISAT came from Pantanagar. It appears that the view in India in the 1970s was that SSPP did not have the yield potential that the medium and long-season material did. On the other hand, the whole premise behind the UQ/ACIAR program was the opposite, namely that SSPP had superior yield potential to the commonly grown photo-period sensitive medium and long-season types.

  Is it reasonable to attribute to the ACIAR project the successful demonstration of the yield potential of SSPP and showing how to exploit this potential? Can this be quantified?

- What was the effect of the ACIAR project's work on inheritance and the design of efficient methods of recombination and selection on the research approach and achievements of ICRISAT and the NARS?

- The ACIAR project developed a pigeonpea growth model based upon PNUTGRO and performed considerable G¥ E analysis exploring environmental adaptation. There were physiological studies of crop growth and development, photothermal responses in phenology, water stress tolerance and reproductive biology. What was the impact of these project outcomes on the work of ICRISAT?

- In 1986 project trials in India were hit by *Phytophthora* disease. Did this have an effect on the priority accorded to this disease in the context of the program on SSPP?

- What has been the interest in Indonesia in growing pigeonpeas for use in tempeh as a substitute for soybean? Demonstrating the potential for this was one outcome of the ACIAR project. Has this led to an expansion in cultivation of pigeonpeas?

- Has pigeonpea area in Thailand been increasing in the 1980s and 90s? If so, can any of this be attributable to the SSPP work of ICRISAT and

ACIAR/UQ? Has the expansion been because of use of pigeonpea as a feedstuff as the project was expecting in northern Thailand or as an export commodity? Has pigeonpea found a place in the expanding rubber cultivation systems in southern Thailand as an intercrop prior to the establishment of the rubber trees?

- Has there been adoption of the released varieties of SSPP in Fiji that arose from the project? Stem canker disease complex was found by the project to be one of the major constraints to SSPP as it caused flower and pod drop. The project found no sources of immunity but maybe later research identified resistance or tolerance?
- The development of wilt-resistant pigeonpea has been one of the major impacts of ICRISAT's research on the crop. To what extent has this been associated with the development of SSPP? Can this be quantified in ways that allow an economic assessment to be made of the joint efforts of NARS, ICRISAT and UQ/ACIAR?
- Has the development of SSPP and the knowledge of crop and environmental adaptability of pigeonpeas facilitated the introduction and/or expansion of pigeonpea cultivation in countries where the crop was previously not important? If so, can this effect be quantified in economic terms? Examples would be the current ICRISAT projects in Africa and Sri Lanka supported by the regional banks.
- What has been the impact of the various publications arising from the project? Besides the journal papers, there was the Workshop Proceedings by E.S. Wallis and D.E. Byth (ed) Food Legume Improvement for Asian Farming Systems. Proceedings of an International Workshop, Khon Kaen, Thailand, 1986. ACIAR Proceedings No. 18.
- Are there any other impacts that you can allude to and quantify if possible?

Many thanks in anticipation for your help in this important endeavour.
*Jim Ryan*