ADOPTION OF ACIAR PROJECT OUTPUTS

STUDIES OF PROJECTS COMPLETED IN 2001–2002

Editors: Viv McWaters and Jeff Davis

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Australian Government
Australian Centre for International Agricultural Research

The Australian Centre for International Agricultural Research (ACIAR) operates as part of Australia's international development cooperation program, with a mission to achieve more productive and sustainable agricultural systems for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

ACIAR seeks to ensure that the outputs of its funded research are adopted by farmers, policy makers, quarantine officers and other beneficiaries.

As part of its efforts to monitor the outputs and outcomes of its projects, ACIAR has commissioned project leaders and participants to revisit projects three to four years after completion, and report back to ACIAR on the medium-term outcomes of the work. This series reports the results of these studies.

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Foreword

The Australian Centre for International Agricultural Research (ACIAR) has a funding base of about A$50 million and invests in agricultural research projects that contribute to poverty alleviation.

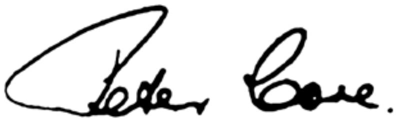
ACIAR's work and its projects are part of the Australian Government's commitment to international development in general, and to more productive and sustainable agricultural systems, in developing countries and Australia, in particular.

One of the challenges facing ACIAR and its partner scientists is to ensure that projects leave a legacy—that they continue to benefit the partner countries and communities well after the project itself is completed. It is not good enough for projects to be delivering benefits only while donor funds are provided. Successful projects impart knowledge and skills and leave in place technology that is sustainable in the long term under local conditions.

Project impact evaluation has always been an important part of ACIAR's accountability process and means of improving project selection and management. These adoption studies have been undertaken for three years now and are proving to be an important dimension of this process. They are undertaken three to four years after the project is completed to assess the level of uptake and the legacy of the project. They provide valuable insights into the uptake of project results, and the impact on local communities.

Adoption studies also help ACIAR determine its research priorities and improve its capacity to select projects that will be scientifically successful and have a lasting benefit.

I particularly want to thank the Australian project participants who undertook the task of revisiting partner countries to gather and collate data and write the adoption statements that form the basis of this publication. I also want to thank the many project participants in our partner countries who hosted visits, helped with data gathering, and provided useful insights on the ongoing impact and effectiveness of these projects. My sincere thanks to each of you for your support.



Peter Core
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Viv McWaters

Introduction

ACIAR continues to monitor and assess the impact of its funded projects by enabling Australian project leaders to assess the effectiveness of large projects three years after their completion. This time frame is considered adequate, in most cases, to provide some evidence of adoption. This assessment process analyses the degree of uptake of the project's results, and also examines those factors that affect the uptake and why, and whether the project has made any difference to the social, economic and environmental wellbeing of the local community.

During 2005–06, ACIAR completed adoption studies for eight of its projects. This report summarises the findings and, importantly, identifies the lessons learnt. This valuable information is used by ACIAR to help guide future investment in ACIAR projects.

Broad project categories and adoption levels: a qualitative assessment

The eight projects covered in this report are divided into three broad categories according to the type of project. They are:

1. New technology, practical approaches
2. Scientific knowledge or understanding (pure or basic science)
3. Knowledge, models and frameworks to aid policy- and decision-making.

While it is recognised that many projects will contribute to all of these outcomes, it is considered helpful to assess the impact of the projects according to their primary purpose.

The classification of each of the projects and the ranking of the level or extent of uptake by key users of the results is presented in Table 1.

Key users are defined as the people who will be directly using the research findings that result from the research project activities to change some aspect of the way they operate. They can be divided into two broad groups: initial users (e.g. government agencies responsible for providing advice to landholders, extension officers, scientists who will use the results for further research etc.) and final users (e.g. smallholders, suppliers, policy makers). Of the three projects that focused on new technologies/practical approaches, only one was able to demonstrate some uptake by final users (Nf). However all three projects demonstrated uptake by initial users. All of the Category 2 projects demonstrated varying degrees of uptake of their results by initial users, as well as some uptake by final users. Due to the nature of these projects (scientific research) additional resourcing and/or the ongoing involvement of local scientists and extension staff is needed for the full impact of the research to be realised. This may take longer than three years after the completion of the project. There were no Category 3 projects in this study.

Table 1. Type of projects and uptake of project results since projects finished

Project categorised by type	Level of uptake*
1. New technology, practical approaches	
Manufacture of low-cost wood-cement composites in the Philippines using plantation-grown Australian species.	N
Improved orchard productivity and water-use efficiency using modern irrigation and tree-management techniques in Northern China	N
Evaluation of East Asian citrus germplasm as scions and rootstocks	Nf
2. Scientific knowledge/understanding (pure science)	
The importance of mangroves to prawn fisheries, particularly banana prawns	Nf
Management of legume nitrogen-fixation for rainfed cereal production in Pakistan, Nepal, Vietnam and Australia; Sustainable grain legume–cereal production systems through management of nitrogen-fixation	Nf
Agrochemical pollution of water resources under tropical intensive agricultural systems	NF
Nutrient and irrigation management for sustainable rice–wheat cropping systems in Bangladesh and Australia	Nf
Managing the rumen ecosystem to improve utilisation of thornless acacias	N
3. Knowledge, models and frameworks to aid policy- and decision-making	
None in this study	

* Level of uptake is summarised as high, medium or low using the following criteria:
NF: Demonstrated and considerable use of the results by the initial and final users
Nf: Demonstrated and considerable use of the results by the initial user but only minimal uptake by the final user
N: Some use of the results by the initial users but no uptake by the final users
O: No uptake by either initial or final users

A slightly different reporting framework was used this year, enabling a clearer differentiation in the impact statements between (initial and final) users and beneficiaries. Users (initial and final) are the specific audience or stakeholder that the project is targeting to bring about a change in the way they operate. While there might be many users of the project's findings, those targeted for change are usually a very distinct group. However some projects still had difficulty differentiating between next and final users, and beneficiaries, citing everybody from researchers to the broader community as all of the above. A clear differentiation between the various stakeholders in a project, and understanding of the specific changes in behaviour that the project is trying to influence, is critical to a meaningful adoption study.

Factors affecting uptake: lessons learnt

It is expected that projects designed to research and develop new technologies and practical approaches (Category 1) will have a high level of take-up, either within the life of the project or shortly thereafter. Those projects that are more pure scientific research (Category 2) may in turn contribute to the scientific understanding required to develop practical approaches. Thus, they may not even target final users, and may have difficulty demonstrating any level of take-up beyond the specific next users that the research is aimed at. It is surprising, therefore, that more uptake was evident in Category 2 (scientific knowledge/understanding projects). This is probably due to the specific nature of these projects and the fact that they were mainly targeted at other researchers who would use the findings for further research and development. Local capacity is also important for the further development of these projects. Predictably, most of these Category 2 projects were unable to identify much, if any, impact on final users.

According to the adoption studies, there are a number of factors that contribute to, or inhibit, uptake. These are summarised in Table 2 and discussed in more detail below.

Factors contributing to uptake

Face-to-face contact

There is no doubt about the benefits of exchange visits and collaboration, especially for in-country scientists who can benefit from exposure to a wide range of scientific and technical personnel in Australian universities and institutes. In addition, these scientists are often exposed to new techniques and equipment that are unavailable in their own countries.

The project that explored agrochemical pollution of water resources under tropical intensive agriculture spanned three countries—Thailand, Malaysia and Australia—with very high interaction between scientists of those countries. This has helped create a very well-trained group of scientists experienced in soil physics, pesticides analysis, water quality, microbiology, geomorphology and the various aspects of surface and groundwater modelling.

Table 2. Summary of factors that have affected uptake of results

New technology, practical approaches	
Factors contributing to uptake	Factors inhibiting uptake
• Usefulness and extent of the knowledge generated • Personal contact between the project team scientists and the in-country personnel • Targeted training of in-country scientists • Geography: smallholders close to demonstration sites/research facilities were more likely to take up the findings	• Comparative higher costs for the new approach and no government subsidies • Difficulty in differentiating between products, i.e. they look the same • Secondary factors such as endemic diseases that negate the benefits of the research • Illiteracy of farmers • Lack of resources • Not feasible to develop demonstration sites • No effective extension delivery to farmers • Lack of community development expertise in the Australian project team • No follow-up training provided to farmers on how to use, manage and maintain new infrastructure • Language barriers—need for someone who speaks the local dialect • Depressed economic conditions, inflation and currency instability • Complex and changing regulations that inhibit investment • Competition from conventional products
Scientific knowledge/understanding (pure science)	
Factors contributing to uptake	Factors inhibiting uptake
• Tailored training • Exchange visits and collaboration • Mechanisation that enables further advantageous changes • Widespread availability of new product • Direct contact between researchers and farmers (now common in Australia; not so common in Asia)	• Lack of time and resources (e.g. limited or no access to computers) to learn new approaches • Lack of local support • No scaling-up/adoption program as part of the overall project • Unresolved issues of cause and extent of secondary effects, e.g. toxicity • Inability to capitalise on geography and provide field days for local farmers • Confusion between the ACIAR project and another similar project delivered by a different country NGO • Limited discussions with collaborating researchers at the start of the project • Mismatch between the project's objectives and the government's objectives • Lack of developing-country experience by Australian project leaders

The project exploring legume nitrogen-fixation in Pakistan identified great interest in the project and its results from farmers in the areas close to the experimental sites. While it is now common in Australia for scientists to interact directly with farmers, this is still somewhat unusual in developing countries and provides an untapped potential for enhancing uptake, especially where farmers are illiterate and unlikely to have any capacity to use written materials.

Applicability of the knowledge

Much of the knowledge generated, while useful, has not been taken up so far due to external factors. However, an unintended outcome has been the interest in new approaches by industry and government policy makers who can influence the behaviour of farmers through policies and regulation. For example, the manufacture of low-cost wood-cement composites in the Philippines for low-cost housing has had little uptake, but the research itself is extremely useful and practical, demonstrating the usefulness of wood-cement composites, and has led to further research and interest from local manufacturers. The potential is enormous.

Similarly, in China citrus is the most important fruit crop in southern China and among the top two to three crops in output value. In some countries, citrus accounts for 50% of agricultural GDP and is a major source of local government revenues. The introduction of improved scion cultivars and rootstocks can increase options available to farmers and the opportunities for expansion of citrus into new areas.

Training

Targeted training of scientists, extension officers and users has been a consistent theme in the success of adoption. Where training has been provided to in-country scientists, they are more able to continue the project when it is formally over. In addition, farmers who receive practical, hands-on training are more likely to use the new technologies.

Facilitated adoption

The availability of new products is a key contributor to the successful uptake. For example, the release of BARI Mung 5 and Mung 6 in Bangladesh has contributed to the uptake of the rice–wheat–mungbean rotation that enables better nutrient and irrigation management. In addition, a number of shorter-duration rice varieties were released, and most farmers use small tractors (three-wheel) for cultivation. As a result of mechanisation, soil preparation for rice transplanting and wheat sowing is faster, leading to earlier wheat harvest and sowing of mungbean. Earlier sowing of mungbean reduces the risk of damage from pre-monsoon rains.

Factors inhibiting uptake

Benefits negated by other on-farm factors

When the cost of a new technology is greater than the current cost, and there is no clear incentive to change, smallholders are reluctant to adopt new practices, even when it can be proven that it will benefit them in the long run. This was the experience in China where a significant barrier to adoption was the higher cost of virus-free citrus trees (at least twice the cost of standard trees). Uptake was highest in government-sponsored schemes where tree subsidies were available for the virus-free stock.

Similarly, in Vietnam, farmers were reluctant to plant disease-free citrus trees because of perceptions of how well they could control the endemic disease called greening. Apart from planting disease-free trees, good cultural practices are needed to keep trees disease-free for as long as possible by maintaining low-vector populations and removing infected trees as they appear. If farmers are not confident in their ability to control greening, the higher cost of trees is difficult to justify.

Language barriers

Language barriers appear to be particularly challenging for projects with a focus on a new technology or practical approaches. The most common language barriers are related to illiterate farmers or the need for information in local languages, and underlines the importance of an extension component for these projects that tackles communication of the results to farmers in a culturally appropriate manner.

Inadequate in-country extension capability

This barrier is closely linked with language issues discussed above. It remains difficult for Australian researchers to promote their findings to local farmers when they have little or no access to extension staff who speak the local dialect. And having access to such a person only partly resolves this issue. Much of the science and results don't translate readily into other languages. Therefore scientists and researchers would need to work closely with local translators to make sure that the messages being delivered are accurate and consistent with their research findings.

The project focusing on orchard productivity and water-use efficiency in northern China experienced difficulties with follow-up extension support to farmers after new irrigation hardware was installed. In fact, researchers reported that there was no capacity, intention or resources to provide such support.

Another difficulty experienced mainly by projects that were focused more on scientific knowledge and understanding was the expectation that there would be a scaling-up or adoption component to the project that would be delivered by in-country extension officers. While this is a reasonable expectation, where there is limited capacity for this to be done, there needs to be some alternative approaches explored to ensure some follow-up. This was particularly evident in Bangladesh where no effective extension delivery to farmers of results from the rice–wheat cropping project was exacerbated by a lack of local expertise and resources to learn how to use, and hence communicate, the models.

Resource issues

While resource issues are a common theme in many of the barriers to adoption, it is worth noting that this is not simply a funding issue. It includes such issues as a lack of time and resources to learn new approaches; limited or no access to needed equipment, e.g. computers or laboratory equipment; and a lack of local support.

External economic and policy factors

Sometimes external factors completely outside the control of the researchers—and hardly able to be predicted—can limit uptake, or even negate the results achieved during the project.

For example, in Pakistan where crop rotation with legumes would significantly increase income and long-term viability, especially on poor soils, the demand for continuous cropping was fuelled by the population growth during the project years (1994–2001) of 24 million. This means there is a greater number of people to feed and an increased population pressure on land itself. This places even greater demands for production from land that is inherently unsuitable for cropping and/or is prone to soil erosion.

The low-cost wood-wool project in the Philippines also faced problems associated with depressed economic conditions, inflation and currency instability that affected the commercialisation and uptake of the new technologies developed. In addition, complex and changing regulations regarding harvesting of forest timber affected the supply of the raw product.

In Malaysia, the project to explore the importance of mangroves to prawn fisheries identified that a major barrier to uptake was a mismatch between what the project was trying to achieve (sustainable prawn fisheries) and government objectives of increasing fishery production.

Inadequate community-development expertise

Doing research in a developing country, and with scientists from that country, requires specific skills and knowledge that may not always be available in Australian project teams. This was the experience of the project to explore the importance of mangroves to prawn fisheries. While the project itself generated good results, the uptake has been limited by a lack of developing-country experience in the project team, probably exacerbated by only short visits by Australian scientists.

In northern China the improved orchard and water-use efficiency project experienced another difficulty. Without community-development expertise on the team, they weren't aware that the community simply does not say 'no' in public. So while the project expected community support for their work, there was in fact little or no intention to provide such support. This highlighted the need for a Chinese-speaking community specialist.

Communication issues

This barrier to uptake is different to language in that it is more about the process of communicating with collaborators and partners to ensure ultimate success of the project (which is measured by uptake). Many of the barriers to uptake discussed above can be traced to some communication issues, e.g. different expectations regarding follow-up and extension.

In addition, the project on the importance of mangroves to prawn fisheries in Malaysia suffered because of confusion between this and a similar Japanese project, and limited discussions at the beginning of the project with collaborating scientists.

Communication and dissemination activities

Table 3 summarises the approaches used for communication and dissemination to initial and final users—and to collaborators and other interested parties—by projects in each of the categories.

There is still little innovation in communication and dissemination activities, and a continued reliance on extension staff, both in-country and in Australia, to take on this responsibility.

While there is an admirable, and extensive, dissemination of research results to the scientific community through the usual sources of journal articles, workshops, seminars, publications and conferences, some further thought should be given to appropriate communication and dissemination activities to the final users of the research.

There is still little or no evaluation of the effectiveness of these communication and dissemination activities—reach (the number of presentations, articles, publications, people attending) is evident, but there has been no assessment of the impact of these activities or how effective the approaches have been in not only delivering the messages, but making sure they are heard, understood and acted upon.

Impacts and lessons learnt

Impacts describe the legacy of a project. At ACIAR, an impact is defined as a *change* that has occurred at the community and/or scientific level, and in research capacity.

A community impact should be interpreted as an impact beyond the scientific sphere. It refers to any *change* in social, economic, or environmental conditions due to the uptake of project results by individuals or groups (including government) as a result of the project. A capacity-building impact is a *change* in the knowledge and skills of researchers (particularly those in the partner country) that has occurred through their participation in the project and its training elements. Capacity also refers to equipment (hardware and software), buildings and infrastructure provided through the project that enable researchers to continue research outside the scope of the project. A scientific impact is a *change* in scientific practices that has occurred outside the project because of the findings of the project.

Community impacts

Where relevant and possible, the difference the project made at the community level is described in the adoption studies. A summary of the information contained in the adoption studies about community impacts is given in Table 4. In general, evidence of community impacts is limited. Projects in Category 1 (new technology, practical approaches) are more likely to be able to demonstrate community impacts due to the nature of the projects and the direct applicability of the outcomes to farmers. All projects were able to identify *potential* community impacts.

Table 3. Summary of approaches used for communication and dissemination

Approaches used for communication and dissemination	1	2
Project coordination activities • Annual project meetings • Project review meetings • Coordination workshop		✓
Information published (print or electronically) and targeted at project stakeholders • Booklets for farmers • Publications • Brochures in local language	✓	✓
Hands-on training • Field-based training workshops for farmers • Formal training workshops • On-the-job training • Video training • Training manuals	✓	✓
Demonstrations • On-farm demonstrations • Field days	✓	✓
Information targeted at a broader scientific/technical audience • Scientific conferences • Papers, reports and presentations • Publications in the scientific literature	✓	✓
Informal approaches • Personal networks and direct contacts • Exchange visits • Visiting scientists program • Visits to field sites	✓	✓
Mass media • Interviews • Newspapers and publications		✓
Tertiary study • Undergraduate and post-graduate studies including PhDs	✓	✓
Technical presentations • Industry forum • Technical workshops • Technical presentations • Seminars	✓	✓
Other • Establishment of a national centre	✓	

1. New technology, practical approaches
2. Scientific knowledge or understanding (pure or basic science)

Table 4. Summary of impacts: what difference the projects have made to the social, economic or environmental wellbeing of a community

Project	Social, economic and/or environmental impacts
New technology, practical approaches	
Manufacture of low-cost wood-cement composites in the Philippines using plantation-grown Australian species	There is a lot of interest in this technology and the community impacts could be enormous: providing employment and low-cost housing, as well as emergency housing. A marketing and commercialisation strategy for an emergency shelter is being developed.
Improved orchard productivity and water-use efficiency using modern irrigation and tree-management techniques in northern China	This project needs more support and analysis at the village level. While there is great potential, especially for the water-use efficiencies demonstrated in the project, uptake has been limited with little local support, resources or will to further develop and implement the project achievements.
Evaluation of East Asian citrus germplasm as scions and rootstocks	In China there has been an increase in planting of virus-free trees and an acceptance of a new variety that extends the harvest period, and hence returns to the farmers. In Vietnam, there has been less acceptance of the virus-free stock due to the endemic greening disease and farmers' perception that they don't have the skills or capacity to control that disease in their orchards.
Scientific knowledge/understanding (pure science)	
The importance of mangroves to prawn fisheries	This project has had few community impacts so far, however the potential is high, especially in relation to increasing awareness and understanding of the importance of mangroves for prawn fisheries. The monitoring data have the potential to provide further monitoring of the status of coastal species.
Management of legume nitrogen-fixation for rainfed cereal production; Sustainable grain legume–cereal production systems through management of nitrogen-fixation	There is little evidence of community impact. However there is some local uptake around the research sites, providing those farmers with the capacity to improve their practices. There is unlikely to be much impact without investment in a targeted extension and adoption program.
Agrochemical pollution of water resources under tropical intensive agricultural systems	Thailand: Fewer pesticides are being used and alternatives trialled, and there is increasing interest in 'hygienic vegetables'. There are also changes being developed at a policy level. Malaysia: Rain-shelter cultivation has been proven to be more sustainable than open farming, and is now being promoted in Cameron Highlands. The pesticide endosulfan is now banned near water bodies. Australia: Government authorities have taken the results on board to develop sustainable groundwater use.
Nutrient and irrigation management for sustainable rice–wheat cropping systems in Bangladesh and Australia	This project has led to the adoption of mungbean in the rice–wheat rotation and adoption is expected to increase rapidly over the next few years. There have also been changes in fertiliser recommendations, and further research and development of integrated nutrient management.

Table 4. <continued>

Project	Social, economic and/or environmental impacts
Managing the rumen ecosystem to improve utilisation of thornless acacias	While this project did not specifically deliver community benefits there has been related work undertaken in other research institutions that appears to have these impacts. The increased nutrition of livestock due to supplementation with forage high in protein leads to better-quality dairy products and meat. The employment of alley cropping with species such as *Acacia angustissima* has resulted in increased crop production, thus providing more incentive to use these multipurpose trees. Farmers also report using these trees for other applications, including fuelwood, light construction, poles, fencing, and tomato stakes.

These adoption studies have provided a great deal of useful information, particularly about the factors that contribute to or inhibit uptake. However there is still some reluctance to recognise that scientific research projects have a responsibility for the ultimate usefulness of their results for the community.

These adoption studies have highlighted some useful lessons:

- The need to link projects so that application is not presented to farmers and the community in isolation. This was particularly true of the project exploring new citrus varieties in China and Vietnam. In Vietnam the impact has been limited due to farmers believing they don't have the capacity to control the endemic greening disease. There could be much greater uptake if this project was combined with another that dealt with the greening disease.
- Projects could be enhanced if more work was done up front, with in-country scientists and extension staff, to determine appropriate levels and types of communication. Some projects could also be enhanced by incorporating more participatory communication activities throughout the life of the project, rather than just at the end of the project.
- Local community support could be enhanced at the front end of the project as well, and requires someone to be able to explain the project in the local dialect. This requires scientists to work closely with a translator to make sure the messages aren't 'lost in translation'.

Capacity building and scientific impacts

Products and activities, such as scientific papers, publications, seminars, training courses, workshops and conference presentations continue to be described as indicators of capacity building and scientific impacts. As suggested previously, it may be unreliable to attribute scientific impact to the number of these only, as publication alone is not a good indicator of scientific impact. However, there is no doubt that the increased scientific knowledge gained by being involved in the project and publishing the results contributes to partner-country scientists having a better understanding of their field and therefore able to make more informed scientific decisions.

As evidenced in other adoption studies, ACIAR projects contribute significantly to increasing the scientific capacity of the partner-country scientists involved directly with the project. In some cases, where adoption is limited due to factors outside of the control of the project, the capacity-building and scientific impacts can be the most significant legacies.

Trained, expert local staff continue to apply their new knowledge and skills in their ongoing work. This has multiple benefits for partner-country scientists, such as:

- more likely to be promoted to lead further research
- being awarded PhD candidatures and places for other post-graduate study
- ability to secure more funding, and be involved in ongoing research
- improved laboratory equipment and processes that are used in subsequent projects
- improved and enhanced, formal and informal, scientific networks and contacts
- new knowledge and skills transferred more broadly as scientists and others move to new positions/organisations/regions
- a better understanding of the need to consult and work with local communities
- generating local interest and knowledge when a new approach is taken to research
- prizes, rewards and recognition.

Without exception, all the adoption studies identified the capacity-building and scientific impacts as significant.

Evaluation of East Asian citrus germplasm as scions and rootstocks (CS1/1996/076)

Ken Bevington

Collaborating organisations	New South Wales Department of Primary Industries, and CSIRO Plant Industry, Australia; Citrus Research Institute (CRI) of Chinese Academy of Agricultural Sciences (CAAS), Beibei, China; Research Institute of Fruits and Vegetables, Hanoi, and Southern Fruit Research Institute, Mytho, Vietnam
Project leaders	Mrs Patricia Barkley (July 1997 to October 1999); Dr Ken Bevington (October 1999 to June 2002)
Related projects	CS1/1987/002
Principal researchers	Mrs Patricia Barkley, Dr Ken Bevington, Dr Nerida Donovan (NSW Department of Primary Industries); Dr Stephen Sykes (CSIRO Plant industry); Dr Chen Zhusheng, Dr Zhao Xueyuan, Dr Jiang Yuanhui, Dr Zhou Changyong (CRI); Dr Vu Manh Hai, Dr Do Dinh Ca, Mrs Nguyen Thi Kim Son (Research Institute of Fruits and Vegetables, Hanoi); Dr Nguyen Minh Chau, Dr Le Thi Thu Hong, Nguyen Thi Thanh Mai, Nguyen Thanh Nhan (Southern Fruit Research Institute, Mytho)
Duration of project	1 July 1997 to 30 June 2000, extension 1 July 2000 to 30 June 2002
Total ACIAR funding	$847,174

Project objectives	The principal objectives of the project were to collect and exchange citrus rootstock and scion germplasm of economic significance to each country; cooperate in the characterisation and evaluation of rootstock germplasm including assessment of tolerance to pathogenic and edaphic stresses, and assessment of horticultural potential; assess, improve and maintain the health status of citrus scion germplasm; and establish virus-free source trees of important new citrus scion cultivars in each country.
Location of project activities	China, Vietnam and Australia

Overview

An ACIAR-funded project on the evaluation of East Asian citrus germplasm as scions and root-stocks (CS1/1996/076) was undertaken by the New South Wales Department of Primary Industries in collaboration with CSIRO Plant Industry in Australia; the Citrus Research Institute (CRI), Beibei of the Chinese Academy of Agricultural Sciences (CAAS); and the Research Institute of Fruit and Vegetables (RIFAV), Hanoi and the Southern Fruit Research Institute (SOFRI), Mytho in Vietnam. The project enhanced the research capabilities of the collaborating institutes in screening rootstock and scion germplasm, progressed the development of high health-status planting material and gave further impetus to the development of citrus-improvement programs in each country.

The project followed on from an earlier ACIAR-funded project on citrus rootstock improvement conducted at the CRI in China (PN/1987/002).

Project achievements

The project successfully fostered the exchange of citrus rootstock and scion germplasm between Australia, China and Vietnam for the benefit of citrus-improvement programs in each country and promoted the further collection and conservation of native germplasm in China and Vietnam.

The subsequent screening of accessions for disease tolerance, salt tolerance, graft incompatibility and horticultural performance identified important sources of variation in key attributes relevant to current rootstock and scion-improvement programs.

The training of Chinese and Vietnamese scientists in molecular diagnostic techniques, and the provision of funds for equipment and propagation facilities, significantly enhanced the capacity of project collaborators to undertake indexing for virus and virus-like diseases and to generate virus-free mother trees for budwood multiplication.

Photo: K. Bevington.

Citrus germplasm evaluation trials at the Citrus Research Institute, Beibei, China.

As a result of the project, CRI scientists became highly skilled in the use of semi-nested PCR to detect citrus tatter leaf virus (CTLV), PCR to detect Huanglongbing (HLB) and citrus canker, and in the use of DTBIA, RT-PCR and RLFP to detect and characterise citrus tristeza virus (CTV) strains. At SOFRI, improved techniques were developed for detecting HLB and CTV, and improved micro-grafting procedures developed for cleaning up infected material.

Virus-free progenies of local clonal selections of key cultivars were obtained by heat treatment and shoot-tip grafting at the CRI and SOFRI. Mother trees were subsequently housed in insect-proof screenhouses for the distribution of clean budwood for commercial propagation or international exchange.

An ACIAR John Allwright Fellowship was awarded to Dr Zhou Changyong from China who completed his PhD under the guidance of project scientists at the Elizabeth Macarthur Agricultural Institute (EMAI) in Australia and the University of Sydney. Dr Zhou's research was concerned with the mechanism of mild strain cross protection against CTV. Successfully dealing with CTV is a critical aspect of citrus-improvement programs in Australia and Asia.

The results of Dr Zhou's research led to the development of an improved micro-extraction technique for total nucleic acid used to detect citrus viruses and to changes in the distribution of pre-immunised budwood from the Auscitrus budwood scheme.

The difference the project has made

The major impact of the project has been the impetus given to the further development of citrus-rootstock and scion-improvement programs at the collaborating research institutes.

In Vietnam, RIFAV and SOFRI researchers have used screening methods developed in Australia to screen local and introduced rootstocks for *Phytophthora* tolerance, salinity tolerance and graft incompatibility, with work on salinity tolerance and graft incompatibility continuing after completion of the project. Promising rootstock/scion combinations have progressed to the stage of field testing for assessment of horticultural performance.

The comprehensive training of CRI and SOFRI scientists in molecular diagnostic techniques served as a foundation for the build-up of improved pathogen-indexing capabilities at the institutes. Of particular relevance in China has been the setting up of the National Citrus Virus Exclusion Center (NCVEC) within the CRI. The NCVEC was established by the Ministry of Agriculture to increase the efficiency of virus indexing and virus exclusion and to promote the planting of virus-free trees and was established at the CRI on the basis of work being carried out by the virus diseases research group. Associated with development of the NCVEC has been substantial investment in new laboratory facilities, greenhouses and budwood multiplication blocks, which have greatly enhanced the capacity of the CRI to generate virus-free propagation material.

From 2002 to 2005, 788 candidate mother trees of 36 local citrus cultivars were indexed by RT-PCR and semi-nested PCR at the CRI. Twenty-three trees were found infected with CTLV and 21 trees infected with citrus exocortis viroid. Budwood of trees indexed free of viruses was subsequently used by six regional nurseries to propagate five million trees. The trees were mostly distributed to new citrus orchards in Chongqing with some going to orchards in other areas.

At SOFRI, the laboratory for detection of Huanglongbing or greening disease is now very well equipped and is being used to test samples from farmers' nurseries to identify infected trees that may otherwise be used for propagation of trees. Greening disease is endemic throughout the citrus-growing regions in Vietnam and has devastated the industry. Key control strategies for greening are the widespread planting of disease-free trees, rigorous control of vector populations through orchard management, and the removal of infected trees.

Since completion of the project SOFRI has continued to produce 40,000–50,000 certified disease-free nursery trees a year for distribution to farmers. These trees are in very high demand with farmers having to order trees 4–6 months in advance. SOFRI is also very actively involved in promoting a certified nursery scheme and is lobbying provincial governments to regulate nursery standards.

RIFAV has also been active in arranging disease indexing of trees on behalf of farmers and has been assisting producers with the selection of elite native citrus clones, in particular local pummelo selections. Following indexing, mother trees are being maintained in a screenhouse to be used as a source of budwood for commercial propagation.

Through the fostering of further germplasm collection and establishment of trees in national repositories the project also made a major contribution to ensuring the conservation of unique native germplasm, which is under continuous threat in China and Vietnam from ongoing development activities and endemic diseases. In China, project resources helped restore the National Citrus Germplasm Repository at the CRI. Collecting trips undertaken throughout southern China resulted in 124 accessions (old local varieties and sub-wild types) being added to the repository. The CRI has been designated the primary citrus germplasm repository site in China.

In Vietnam, 40 native varieties were collected throughout the northern citrus growing regions. The material is being maintained in an insect-proof screenhouse at RIFAV and gradually being evaluated for use as rootstocks and scions for large-scale commercial production. Horticulturally superior clones of 60 pummelos, 17 mandrins, 14 oranges and 12 limes were identified on farmer properties in south Vietnam. These clones are being considered for national release after the health status of the trees has been assured and have the potential to considerably improve orchard productivity and farmer returns.

The marketing period for citrus in China has traditionally been quite short and a key goal of current citrus-improvement programs is to extend the marketing season by selecting improved later and earlier-maturing varieties. Among the scion cultivars introduced to China, Lane Late navel and Ellendale tangor (a late maturing mandarin hybrid) have shown good adaptation to the subtropical growing areas of China. Lane Late navel was extensively propagated and 100,000 trees planted in south China.

At SOFRI, further work has also been carried out on evaluating the field performance of mandarin and orange cultivars introduced from Australia. A key result from this work has been the excellent performance of the Leng navel in Lamdong province with high yields of good-quality fruit. It is now planned to multiply this cultivar for wider testing in other areas.

Project impacts

Community impacts

The main community impact of the project has been the increased planting of virus-free trees generated from the scion improvement programs at the CRI and SOFRI. Impact has been greatest in Three Gorges region of the Yangtze River Valley in China and in the Mekong Delta in Vietnam.

The specific contribution of the project was improvement in the capacity of the CRI and SOFRI to undertake pathogen indexing and to generate virus or disease-free mother trees for budwood multiplication. Based on the numbers of the trees produced by nurseries in Chongqing supplied with budwood from the CRI, an estimated 6,000 to 7,000 ha of new plantings were established with virus-free budwood sourced from the CRI between 2002 and 2005.

Photo: K. Bevington.

National Citrus Germplasm Repository, at the Citrus Research Institute in Beibei, China.

At SOFRI, the 40,000–50,000 trees distributed to farmers each year would be equivalent to about 100 ha of new plantings a year. If budwood supplied to other certified nurseries is taken into account then the actual impact is much greater, although no reliable data were available on the quantities of disease-free trees being produced by other nurseries. There are currently 30 certified nurseries registered in the Mekong Delta.

No economic data were available on the actual increase in farm income likely to result from planting virus-free trees. Expected benefits would be improved tree growth, higher early yields, better fruit quality and increased tree longevity, which would all impact positively on farm profitability and household income. Analysis of returns from recently established demonstration orchards of virus-free trees in Chongqing could eventually provide some hard data in China. In Vietnam, because of the devastating effects of greening disease, prolonging orchard life through planting disease-free trees would have a substantial economic impact.

Farmers who are encouraged to change from other forms of farming to citrus growing, because of better prospects with high health-status propagating material or new varieties of higher market demand, are likely to see a substantial rise in farm income. For example, in Vietnam, it was reported that the average farm income from rice growing can be as low as 7 million VN dong, whereas orange and mandarin growers can earn 80–100 million VN dong a year.

The potential for ongoing community impact is considerable and is being influenced by a number of factors:

- The high priority attached to ongoing development of the citrus industries in China and Vietnam, and government goals for industry restructuring, has created a high demand for improved varieties and high health-status propagating material.
- The virus-free nursery tree propagation program is fully endorsed by government.
- All new large-scale developments in China (especially government sponsored initiatives) only utilise virus-free trees for planting.
- Although most new developments in China tend to be centred in areas with a better supporting infrastructure, planting of citrus is still being actively encouraged in other areas with favourable climates and is seen by governments as an effective means of helping impoverished areas develop economically.
- There is a significant build-up of a modern nursery infrastructure in Chongqing and there are continuing efforts to fully establish a registered certified nursery program in Vietnam.
- The NCVEC at the CRI is responsible for improving the efficiency of production of virus-free mother trees and promoting the uptake of virus-free trees in Chongqing and other provinces.

The rate of adoption of virus-free trees outside of the major government-sponsored schemes was considered low in China. A significant barrier to adoption is the higher cost of trees, with virus-free trees at least twice the cost of standard trees. In the government-sponsored schemes, tree subsidies are often available to offset the higher cost of virus-free trees. Subsidies are typically offered when the local government wants to introduce a new variety or establish a new production area. Positive results from the recently established demonstration orchards should assist uptake. Another issue in some provinces is the lack of facilities for producing virus-free trees. A government goal is to see virus-indexed mother tree blocks established in other areas and this is part of the brief of the NCVEC.

In Vietnam, farmer perceptions of how well they can control greening is a major factor influencing uptake. Apart from planting disease-free trees, good cultural practices are needed to keep trees disease-free for as long as possible by maintaining low-vector populations and removing infected trees as they appear. If farmers are not confident in their ability to control greening, the higher cost of trees is difficult to justify. Without control of greening, orchards can be wiped out in as little as 5 years. SOFRI is very active in promoting integrated management of greening and many pamphlets have been produced at SOFRI to help farmers understand and deal with greening. Positive outcomes from the ACIAR-funded citrus greening project CP/2000/043 'Huanglongbing management for Indonesia, Vietnam and Australia' will also impact positively on outcomes from CS1/1996/076.

A direct community impact arising from the germplasm-exchange component of the project was the planting of 100,000 trees of Lane Late navel throughout the navel-growing areas in southern China. The relatively quick release of Lane Late highlights the benefits of targeted introductions to address particular production issues, in this case, the need to extend the sweet orange harvest period. The favourable performance of Leng navel in recent trials in Vietnam suggests that further benefits may arise from the germplasm-exchange component of the project.

No significant change in rootstock use has occurred as a result of the project. Any substantial change in rootstock usage by farmers will extend well beyond the end of the project. Although screening trials have identified several promising new rootstocks, longer-term field trials are necessary to evaluate suitability for different scions and growing areas. The long-term benefit will be improved returns through the provision of rootstocks more tolerant of disease and salinity problems, and compatible with preferred scion cultivars.

The project had no negative environmental impacts in any of the partner countries nor is there likely to be any negative impacts as a consequence of ongoing activities. In contrast, the successful achievement of the objectives will lead to more productive and efficient use of agricultural land by citrus farmers.

Capacity building and scientific impacts

China

There was general acknowledgment from project collaborators that the project had significantly increased the knowledge and skills of participating scientists and enhanced the capacity of the collaborating institutes to undertake work on the screening and evaluation of citrus rootstock and scion germplasm. At the CRI and SOFRI, the development of molecular diagnostic skills has had a significant capacity-building impact on these institutes creating additional opportunities for research.

In China, the project funded the training of seven young scientists at the CRI in molecular procedures for detection of citrus pathogens using equipment supplied by the project. Training was also given in molecular fingerprinting techniques for cultivar identification to be used as an adjunct to isozyme analysis. The training courses provided the trainees with a working knowledge of molecular-indexing procedures to be used as part of their research and diagnostic programs, and formed a foundation for the further development of molecular indexing capabilities at the institute.

At the time of the adoption study, Mr Tang Kezhi, Mr Huang Sen, Mr Yang Fangyun and Mr Jiang Dong were still actively involved in research at the CRI. The development of molecular diagnostic capabilities at the CRI as a result of the ACIAR-funded project is viewed as a significant milestone for the institute.

After successfully completing PhD studies in Australia, Dr Zhou Changyong was appointed Section Leader on his return to China in 2001 and Director of the CRI in 2003. Under Dr Zhou's leadership and with the significant injection of Ministry of Agriculture funding for upgrading of laboratories and other facilities, the CRI has enhanced its standing as one of the key citrus research institutes in China. The establishment of the NCVEC at the institute has had a substantial capacity-building impact.

Basic facilities within the Department of Germplasm Resources and Breeding, which has responsibility for the National Citrus Germplasm Repository, have also recently been improved, including upgrading of greenhouses and the major refurbishment of laboratories. It is now felt that the primary functions of the repository, including the conservation, evaluation, utilisation and exchange of germplasm, can be fully implemented.

In current research within the Department of Germplasm Resources and Breeding, new cultivars or budlines are being developed through the selection of bud mutations, selection of nucellar lines, hybridisation, irradiation, genetic engineering and tissue culture. Inheritance patterns, breeding methodology and the adaptability of new cultivars to different localities are also being studied.

The CRI formed an alliance with the Southwest Agricultural University in 2001 that has since been extended to include the Southwest University in Chongqing. As a result of this alliance, 40 postgraduate students were reported to be currently working at the CRI, which is having a major impact on research outputs.

Dr Zhou has also been actively involved in supervising postgraduate students. Since 2001, 27 research projects supervised by Dr Zhou with the assistance of nine other CRI scientists have been started or recently completed. Projects have included studies on the control of pummelo dwarf and sweet orange stem-pitting by mild strain cross protection. Total funding associated with the projects is RMB 15 million yuan. Twenty postgraduate students (15 MSc students and 5 PhD students) have been involved in the research. Forty-two scientific papers have been published on the work.

The strong impression gained from the adoption study is that the CRI is well positioned to continue its key role in research on citrus improvement in China.

Vietnam

In Vietnam, the project had positive impacts on the development of rootstock screening skills by Vietnamese scientists and on the establishment of molecular disease indexing capabilities at SOFRI. The project was seen at both RIFAV and SOFRI as having significantly strengthened the technical capabilities of the institutes. Since the project finished, research on identifying improved rootstocks for use with local scion cultivars has continued at both institutes.

The training undertaken by Dr Le Thi Thu Hong in Australia played a key role in the development of molecular-indexing capabilities at SOFRI. Although equipment and facilities provided from the project were somewhat limited, they were of considerable importance at the time as SOFRI became the first institute in the south to use molecular procedures for citrus-disease indexing. Research carried out by Dr Hong during the course of the project contributed to the completion of her PhD thesis in Vietnam on 'Investigation on some plant-protection technologies in citrus seedling production in the Mekong Delta'.

Since completion of the project, Dr Hong has coordinated four projects in Can Tho, Vinh Long, Dong Thap and Tien Giang provinces related to citrus planting material improvement and assisted as coordinator in other citrus-greening projects with CIRAD-FHLOR, JIRCAS and FFTC. Dr Hong's current position is Head of the Division of Research Management and International Cooperation at SOFRI.

The key role SOFRI now plays in the production of disease-free planting material in south Vietnam has had other benefits for the institute. SOFRI's credibility among the local farming community has apparently been considerably enhanced. Cooperation between SOFRI and the provincial government Service of Science and Technology and Environment is also leading to more citrus research opportunities.

At SOFRI, the project directly contributed to the successful completion of postgraduate research by Ms Thanh Phong and Ms Thanh Mai. Ms Phong was awarded an MSc from the University of Can Tho for research on the micro-propagation of citrus rootstocks and Ms Mai an MSc for research on screening citrus rootstocks for salinity tolerance.

Research facilities at SOFRI have improved considerably since the project finished and the impression gained during the adoption study was that the institute is well set up to continue research on citrus rootstock and scion improvement. The disease-indexing laboratory in particular is now well equipped and staffed, and is proposed to be officially registered by the government as the 'Laboratory for virus disease detection in fruit trees in the south'. The South Eastern Fruit Research Center is also now directly affiliated with SOFRI. The centre is located on 436 ha in Baria-Vungtau province and will no doubt further expand opportunities for SOFRI.

RIFAV was not visited during the adoption study but was represented by Dr Do Dinh Ca during the visit to SOFRI. Ongoing research at RIFAV since the project finished on identifying compatible rootstocks for use with local scion cultivars, and the further selection of elite clones and maintenance of disease-free mother trees for budwood multiplication purposes, is evidence of a strong commitment to building on project outputs.

Nutrient and irrigation management for sustainable rice–wheat cropping systems in Bangladesh and Australia (LWR2/1994/032)

Liz Humphreys

Collaborating organisations	CSIRO Land and Water, Australia; CIMMYT, Bangladesh, and Bangladesh Agricultural Research Institute (BARI), Bangladesh
Project leaders	Prof David Connor
Related projects	LWR2/1992/010, LWR2/1994/048
Principal researchers	Dr E. Humphreys (CSIRO Land and Water); Dr G.M. Panaullah (CIMMYT, Bangladesh); Dr M.A. Quayyum (BARI)
Duration of project	1 July 1996 to 30 June 1999, extension 1 July 2000 to 31 December 2001
Total ACIAR funding	$864,286
Project objectives	Project objectives were to quantify the water and nutrient constraints to greater productivity of irrigated rice–wheat cropping systems in Bangladesh, and recommend how these constraints can be removed or minimised through better rotations and management of soil, water and nutrient inputs; and to develop computer-based systems for the evaluation and selection of various crop-rotation and nutrient-management options that could be applied to the rice–wheat systems of Bangladesh and rice-based systems in Australia.
Location of project activities	Bangladesh and Australia

Overview

Food production must be increased in Bangladesh to meet the needs of the rapidly expanding population. Rice, the traditional basic staple, has been supplemented in the last 30 years by increasing production of wheat, about 80% of which is grown in rotation with rice, resulting in about 500,000 ha of rice–wheat production systems. 'T aman' rice is grown during the monsoon season, followed immediately by wheat during the dry, cool 'Boro' season. The land commonly remains fallow for about 3 months after wheat harvest, before planting rice again. Could a third crop, grown during the pre-monsoon season when rains are erratic and at times heavy, be economically attractive and increase production from the rice–wheat system?

As for all crops in Bangladesh, the majority of the crop residues in rice–wheat systems are removed from the field for use as fuel or fodder. At the time the ACIAR project was planned, soil fertility and organic-matter management in this intensive cereal-cultivation system were major concerns. A combination of biologically fixed nitrogen from legumes with fertiliser nitrogen had been suggested as a means of increasing the sustainability and productivity of the rice–wheat system in Bangladesh. In Australia, the major concerns were increasing water-use efficiency and controlling watertables and salinisation in rice-based cropping systems.

Therefore the ACIAR project was designed with the ultimate goal of enhancing the financial and food security of rice–wheat farmers of Bangladesh, and the environmental sustainability of Australian rice farmers. The project sought to gain a better understanding of the intensive rice–wheat irrigated systems in Bangladesh and Australia, leading to the development of improved soil, water and nutrient management.

The ACIAR project led to the adoption of mungbean in rice–wheat rotations, but only on a small scale to date. However, the project findings also stimulated further on-farm evaluation, demonstration and training activities funded by national and international groups to further promote adoption. These activities, together with the recent release of improved mungbean varieties more tolerant to rain, are likely to lead to a rapid increase in adoption in the near future. The project also demonstrated severe potassium depletion with current (and recommended) fertiliser practice, while the recommendations for phosphorus application to T aman rice appeared to be excessive. This led to further investigations outside the ACIAR project that confirmed the need to increase potassium rates for both rice and wheat, and to reduce the phosphorus rate in rice, and subsequent changes to the National Fertiliser Recommendations. Also, as a result of their experience in the ACIAR project, scientists in Bangladesh are now conducting comprehensive nutrient-balance studies for a range of cropping systems, and on the role of legumes in a range of cropping systems. The research in Australia demonstrated the benefits of growing a winter crop (wheat) shortly after rice in terms of capture and productive use of water that would be otherwise lost as runoff or deep drainage, and control of watertables. The findings were incorporated in the SWAGMAN® (Salt Water And Groundwater MANagement) Farm model which has been widely used in the rice-growing regions to identify sustainable land use in terms of control of watertables and salinity.

Photo: Palash Talukder.

Rice growing in a rice–wheat–mungbean rotation, near Nashipur, Bangladesh.

Project achievements

Field experiments were conducted for four and six years at two locations in the major wheat-growing areas in north-west Bangladesh (Nashipur and Ishurdi), and also for six years near Dhaka, a non-wheat area. The experiments determined the performance of a rice–wheat–mungbean cropping system (with and without mungbean residues retained) and nutrient extraction and inputs from all sources. The performance of these systems was evaluated for the local farmers' fertiliser practice at each site, and for the recommended (soil test based) practice. A high-nutrient-demanding rice–wheat–maize system was included for comparison with the mungbean system. Crop modelling was also used to evaluate management strategies for improving the performance of individual crops, and the system as a whole.

The research showed that growing mungbean or maize after rice–wheat is feasible and financially viable in the major rice–wheat areas of Bangladesh, but risky due to adverse impacts of pre-monsoon rains on establishment and reproductive stages, especially in more northern regions. The results also suggested that growing mungbean and retaining the residues reduced the decline in soil fertility, although this requires further investigation. Both the field and modelling studies highlighted the importance of early establishment of all crops in the sequence, and the benefits of shorter-duration rice varieties, to maximise wheat yield and increase the chance of avoiding early rain, reducing the yield of the mungbeans.

The nutrient-balance studies showed that there is severe potassium depletion in rice–wheat cropping systems, even using the recommended fertiliser doses, while the recommended phosphorus rate for transplanted rice during the monsoon (T aman) was too high.

In Australia, the impact of growing wheat after rice on components of the water balance was evaluated in field experiments and using the SWAGMAN® Destiny crop model, with co-funding from the Cooperative Research Centre for Sustainable Rice Production. The research showed that in the absence of irrigation, the soil profile remained wet where fallow was practised after rice harvest, whereas there was considerable drying in areas planted to wheat. The drying created capacity in the soil profile to capture and use winter rainfall, and resulted in net discharge from the groundwater of about 1 ML/ha, in comparison with zero discharge in the fallow. In the absence of irrigation, yields were always higher with earlier-sown than late-sown wheat. Irrigation water productivity for early-sown wheat was also much higher than for late wheat due to much higher irrigation water requirement to raise yields of late wheat to achieve comparable yields.

The difference the project has made

The area under rice–wheat–mungbean has increased from about 3,000 ha around the time the ACIAR project started to about 20,000–30,000 ha in 2005 (about 1–2% of the target area). Adoption has been much greater in the lower-rainfall area of central west Bangladesh. Most of the farmers retain and incorporate the mungbean residues after harvest.

The project findings also stimulated further interest in the role of mungbean and other legumes in rice–wheat and other rotations. A new replicated experiment was initiated at Ishurdi in 2002 on integrated nitrogen management for rice–wheat–mungbean, and is currently up to the fourth wheat crop. The results of the ACIAR project also helped to stimulate further interest and research in the role of legumes and legume residue retention in a range of other cropping systems, including rice-mungbean-rice, which is now a recommended practice in southern Bangladesh.

The farmers who have adopted mungbean into the rice–wheat rotation have benefited from increased profitability, while the nutrition of Bangladeshis is slowly improving through increased production and consumption of grain legumes.

The project findings also stimulated further research on potassium and phosphorus requirements and responses in rice, leading to changes in the recommended rates for rice and wheat. The potassium (K) recommendation was increased from 33 to 50 kg K/ha for each crop, while the phosphorus (P) recommendation for T aman rice was reduced from 20 to 0 kg P/ha. These changes have been included in the Bangladesh Agricultural Research Council 'Fertilizer recommendation guide', which is widely distributed to extension centres throughout Bangladesh, together with seminars and training programs for extension staff and farmers.

The experience of the ACIAR project also led to comprehensive nutrient-balance studies being undertaken for a range of other cropping systems for the first time in Bangladesh.

In Australia, the results of the research influenced the development of soil water model processes and water accounting in SWAGMAN® Farm, a farm-scale model developed by CSIRO to help farmers and irrigation area managers identify profitable but sustainable cropping mixes in terms of controlling watertables and avoiding root-zone salinisation. The model has been extensively used in both the Coleambally Irrigation Area and Murray Irrigation Districts. Growing crops after rice is now seen as a major way to control watertable levels by the irrigation companies responsible for the implementation and monitoring of Land and Water Management Plans. Farmers recognise the value of the residual soil water after rice for growing a winter crop with little or no irrigation. Coleambally Irrigation Cooperative Ltd now has a policy that sets the rice-area limit each year at 25% of the rice-suitable land. Growers can increase the rice area if they balance that with growing wheat after rice (2 ha of wheat after rice for every additional hectare of rice above the 25% limit).

Project impacts

The potential area for adoption of mungbean in the rice–wheat rotation is probably about 200,000 ha, and it is likely that adoption will increase rapidly over the next few years for several reasons. First, the Bangladesh Agricultural Research Institute has recently released two new varieties of mungbean that are less adversely affected by early rains and disease (BARI Mung 5 and 6), while Bangladesh Agricultural University has released a third improved variety (BU Mung 5). BARI Mung 6 has the additional advantages of shorter duration and height, and synchronous flowering (80–90%), which means only one picking is required instead of two. One picking is a major benefit because less labour is needed, even in a country as densely populated as Bangladesh. Second, soil tillage has become highly mechanised in Bangladesh thanks to the advent of two and three-wheel tractors. This results in faster turnaround between crops, and the opportunity for earlier planting of all crops in the rotation including mungbean, reducing the risk of adverse pre-monsoon rain events during the mungbean crop. Third, there are currently several BARI projects underway, funded by a range of international donors and nationally, to train farmers in rice–wheat–mungbean cropping systems, and to evaluate and demonstrate the systems in farmers' fields. Finally, the findings of the ACIAR project stimulated further research on integrated nutrient management for rice–wheat–mungbean, and also helped stimulate interest in including legumes in a range of other cropping systems, including rice–mungbean–rice, which is now also a recommended practice.

The ACIAR project also led to changes in the fertiliser recommendations for rice–wheat systems, and for T aman and Boro rice. This has potential impacts throughout Bangladesh, where cropping intensity is now 2.2 crops a year on average over the entire lands of Bangladesh, with rice growing accounting for 80% of this (about 25 million tonnes of rice per year). This means more than three crops a year in some locations, because in others it may only be one crop a year.

The ACIAR project also had a significant impact on the capacity of the Bangladeshi researchers to contribute to improved nutrient management and productivity of cropping systems. In particular, the scientists' understanding of and interest in nutrient-balance studies was increased, leading to

Photo: Palash Talukder.

Mungbean growing in a rice–wheat–mungbean rotation, near Nashipur, Bangladesh.

further investigations for a range of crops and cropping systems. The Bangladeshi scientists also benefited from the opportunity to gain experience and training in the use of computers, and in preparing results and papers for publication in the international scientific literature. Several of the Bangladeshi scientists also spent time at the University of Melbourne, providing the opportunity to develop their knowledge and experience by interacting with many scientists from a range of disciplines. Through the ACIAR project, many basic items of equipment, which researchers from the developed world probably take for granted, were provided to BARI and BRRI, such as fridges, shakers, digestion equipment, pH meter, photocopiers and computers. The PC provided to BRRI was the first modern computer in the Department of Soils. All this equipment is still in use, and vital to the conduct of many research projects.

In Australia, the proportion of the rice area in the Murrumbidgee Irrigation Area sown to winter crops shortly after rice harvest increased from about 40% of the rice area around the time the project started to about 60% in 2000 and 2001, and to 80% in 2002, 2003 and 2004. The increase coincided with excellent weather for establishing wheat after rice from 1998 to 2000, followed by the onset of a long drought, eclipsing any potential influence of the ACIAR/Rice CRC research findings.

Improved orchard productivity and water-use efficiency using modern irrigation and tree-management techniques in northern China (LWR1/1994/047)

Peter Jerie

Collaborating organisations	China Agriculture University, Beijing (CAU), and Beijing Horticulture Research Institute (BHRI), China; Department of Primary Industries, Institute of Sustainable Irrigated Agriculture (ISIA), Tatura, Victoria, Australia
Project Leaders	Dr Ian Goodwin, Dr Peter Jerie (ISIA); Professor Zeng Dechao (CAU)
Related Projects	Projects SWL/1985/078 and SWL/1990/048
Principal researchers	Professor Zeng Dechao, Dr Lei Tingwu, Dr Huang Xingfa, Dr Li Guangyong, Mr Wang Wei, Professor Kang Shaozhong (CAU); Mr Wang Xiaowei (BHRI); Dr Ian Goodwin, Dr Anne-Maree Boland, Dr Christian Maul, Dr Peter Jerie (ISIA)
Duration of project	1 January 1996 to 31 December 2000, extension 1 July 2001 to 31 December 2001
Total ACIAR funding	$997,390
Project objectives	Objectives were to develop techniques for efficient irrigation and Regulated Deficit Irrigation scheduling for orchards in Beijing; to adapt the techniques to environments in northern China; to strengthen the capacity to conduct field-based research in deficit irrigation and orchard management.
Location of project activities	Beijing, China and Tatura, Australia

Overview

The ACIAR project established methods for improving water-use efficiency in orchards in northern China. The research has been widely used by others and has contributed towards a rapidly increasing interest into research and applications of deficit irrigation methods in a broad range of crops.

At the start of the project orchardists used the traditional excessive amount of water, both irrigating too often and too deeply. Water resources were over used with falling aquifer levels. The research led to correct timing and quantity of irrigation in the deep soil and summer rainfall environment. Results also showed that Regulated Deficit Irrigation (RDI) scheduling reduced actual tree water consumption while maintaining yield. In an average season the scheduled water requirement was less than half of normal usage. RDI also reduced excessive shoot growth leading to improved leaf canopies and potentially to improved fruit quality. Applying these results could significantly increase orchard productivity.

Since the start of the project the Beijing Horticulture Research Institute (BHRI) has developed simple methods to help farmers conserve water by omitting unnecessary irrigations and by flood-irrigating alternate rows. Currently about half the orchard area of 15,000 ha in the Beijing municipality is using some form of this method. Lower pumping cost is the main benefit for farmers. Reduced irrigation levels coincide with RDI requirements but precise RDI scheduling is not readily applied in this way. Other research groups have gone on to apply alternate-row irrigation in annual crops.

In the final demonstration phase of the project (1995–2001) micro-irrigation and soil-moisture-based monitoring were established in four locations on areas of 3–40 ha to bring together the benefits of water saving, RDI scheduling and canopy management. Three sites were selected in drier climates where water was scarcer and more expensive than in Beijing. The demonstrations each involved numerous smallholders who had planted their orchards in a solid block. Although Water Bureau staff collaborating in the demonstration and farmers were provided with training, the demonstrations did not operate successfully except for one that ran for 6 years and then stopped. The reasons for the lack of success varied but in general land tenure and community issues made it difficult for farmers to use the irrigation systems and scheduling. Some lessons were identified that would help to improve future demonstrations of this type.

Project achievements

At the time of the first project water-use efficiency (WUE) in orchards in northern China was low with yields and fruit quality well below half the accepted values in Australia. The investigation showed that orchards in the Beijing area were irrigated too often and typically with an excessive depth of water so that more than half of the applied volume drained below the root zone. Irrigation-scheduling techniques were not used or widely known. The scarcity of water resources in many

Photo: P. Jerie.

Extending micro-irrigation in a large-scale orchard in Beijing for which Wang Xiaowei (standing behind the two orchard managers) has been providing management advice for 10 years.

parts of northern China and the falling groundwater level in the North China Plain had been well documented. Government policy sets out to conserve underground and surface-water resources by publicising the problem in various ways. Farmers are encouraged to use water-saving technology. Typically engineering interventions such as sprinkler irrigation and piped water supply for flood irrigation water were funded. There was very little research or training on orchard management as opposed to engineering solutions to the water-resource problem.

The results in China showed how the RDI scheduling techniques developed at ISIA in Tatura should be applied to different varieties in Beijing given deep soil and a relatively short dry season. Once irrigation scheduling had been refined similar tree responses to RDI that had been documented in Tatura were also found in Beijing. Apart from the water saving, excessive vegetative growth was reduced allowing better light penetration through the canopy. Yield and fruit size were unchanged and WUE was increased. Soil-moisture-based monitoring was used to predict the time and quantity of irrigation either for standard scheduling or for RDI. The results of monitoring were initially used to reduce the number and depth of traditional irrigations so that the water applied approximated to the water requirement of a fully irrigated orchard. Depending on the season this represented a water saving of 50% of traditional irrigation. RDI scheduling reduced this by a further 20–30%. One year in four the experimental Beijing orchard did not require any irrigation at all.

The practical application of basic irrigation scheduling has been extended by the activities of BHRI staff in the Beijing area in the last 10 years. They report that water-saving techniques have been adopted on about half the orchard area of 15,000 ha. Farmers omit one or two out of the three traditional spring irrigations and generally flood-irrigating every second row. Water use is reduced by 1,500–2,500 m3/ha. Large corporate or community farms under central management adopted the changes more quickly than smallholder communities. However the more advanced techniques that become possible with RDI scheduling to improve control of shoot growth and fruit quality have generally not been adopted at this stage. This may change as the market demand for high-quality fruit becomes increasingly competitive.

Project research and particularly published scientific results have helped to stimulate a major interest in deficit irrigation in China over the last 10–15 years. In the early 1990s very little such research was carried out but since then investigations into the use of deficit scheduling for annual crops have expanded rapidly. Project publications have been widely quoted and the two major national research grant committees of the Ministry of Science and Technology, which supports agricultural R&D, have included reference to the RDI concept in the guidelines to applicants.

The difference the project has made

In orchard communities in Beijing where managers or farmers have adopted the initial stage of project results, pumping costs for irrigation water have been reduced by 40–60%. Labour and fertiliser costs would have been reduced by a small margin. Water saving by correcting excessive irrigation does not directly relate to an environmental benefit in the Beijing situation because a high proportion of the excessive volume becomes recharge for the aquifer. However, as the drainage flow through the cycle of excessive irrigation and aquifer recharge is reduced, one environmental benefit is that less nitrate pollution is carried into the aquifer.

BHRI staff have taken the opportunity and extended project results on irrigation and tree management through consultancies to large farms and via agencies to smallholders in the Beijing municipality. Starting with the opportunity presented by the project results they have put in place an approach to extension that had not previously existed. The number of large-scale orchards in Beijing is increasing with many installing micro-irrigation. The training program has the potential to improve water management in these developments.

In the last 10 years project results and RDI principles have been used and quoted in many research projects on deficit irrigation in China. The commencement of the project in 1988 and its early publications contributed to the current research emphasis on deficit irrigation and RDI techniques. The China Agriculture University (CAU) project team continues research and student training in RDI and has applied the principles in a range of annual crops. Other research groups concentrating on annual crops have used alternate furrow irrigation to reduce water use in deficit or RDI stages of crop development. This method is used widely in at least three counties with substantial water saving, lower costs and claims of increased yield in some instances.

The experience of trying to implement demonstrations with micro-irrigation and scheduling methods in smallholder communities showed that community attitudes and land tenure are critical to the chance of success. The demonstrations were generally not adopted by communities even though the technology was well suited to their water-scarce environment. The Chang Ping demonstration in Beijing was initially successful and showed the circumstances in which the technology could be used effectively. Micro-irrigation and scheduling worked well for 6 years under the leadership of the head farm manager. The system halved water use and saved labour. Financial details were not available but were said to be good and the village extended the orchard and redeveloped some blocks to more valuable varieties. The land belonged to individual households but was centrally managed. In 2005 land-tenure regulations changed and all households reclaimed their own land for independent farming. The irrigation system and the accumulated experience were lost during the change. Most farmers decided to return to independent flood irrigation.

Project impacts

Community impacts

The full impact of water saving and improved productivity has not been realised in smallholder communities because of lack of adoption of micro-irrigation, scheduling and RDI. Adoption of these methods would reduce the need for heavy labour making orchard work more acceptable for women farmers. To a lesser extent some reduction in heavy work occurs when the number of flood irrigations is reduced and only alternate rows or furrows are irrigated. The same changes in work requirement occur on large farms where micro-irrigation is used and women commonly do most of the work.

Adopting any significant change to irrigation practice and water-allocation rosters is a challenge to community organisation. A very simple change like omitting spring irrigations is readily accommodated even if only a few farmers want to trial the method. With more complicated changes either all farmers have to agree to use the new method, or adopters are allowed to schedule irrigation as needed. Such agreements are difficult to bring about because out-of-phase irrigations are often perceived as a threat by non-adopting irrigators. For example, micro-irrigation and RDI scheduling reduces the amount of water taken by participants but they require more frequent access to the water resource. Communities need support to develop the capacity that would enable them to organise and monitor these activities and to ensure security of installations.

Farmers or communities who have simply reduced irrigation frequency or amount of water applied will save the corresponding pumping cost. That is about RMB 1,000/ha in Beijing conditions and represents a relatively small increase in returns. The potential benefit from combining better irrigation with improved canopy and fruit management is much greater. This may become demonstrated and adopted on larger farms with extension and training from BHRI.

In drier and more water-limited environments a much greater potential economic return is possible from water saving and RDI scheduling. A correspondingly higher community interest had been expected. However in that type of environment other factors become more important and households progressively stopped cooperating with the demonstrations. Problems stemmed from conflict between intercropping and fruit production, domestic and irrigation water supply and falling apple prices in a relatively high production-cost environment.

Capacity building and scientific impacts

Project collaborators developed a detailed knowledge of RDI principles and applications. They also experienced a methodical approach to field-based research in irrigation and tree management, which at that time was not an active area of interest in China. The experience has strengthened their ability to identify effective approaches and be more analytical in evaluating results and opportunities. Methods included collection and use of data on meteorology, tree-root distribution in deep soils, soil water-holding capacity and nutrient leaching.

The project had a major effect on BHRI staff working on orchard management and adaptive field research and extension. The work of Mr Lu Renqiang, formerly Director of BHRI, greatly assisted project objectives in the Beijing area by developing and extending practical applications from project results. His work has enhanced the extension role of BHRI. When interviewed he acknowledged that project activities and results had led their program on orchard irrigation and management. Both he and Mr Wang continue this direction of work through consultancies or by work through the Forest Bureau and local governments.

A CAU/CAS (Chinese Academy of Sciences) research group now being led by Dr Lei Tingwu is conducting research at theoretical and applied levels into irrigation and related topics. The work has also resulted in a strong capacity to obtain grants within the Chinese system. CAU, with both Dr Lei and Dr Kang in the institution, would be the foremost organisation in China for research on deficit irrigation and crop responses. The expertise covers annual as well as perennial plants and there is a wide experience of soil and environmental conditions. Dr Kang continues research on deficit irrigation and Partial Rootzone Drying in annual crops.

Through the project experience the Chinese and Australian researchers have developed a much better understanding of the need to consult and work with communities over an extended period in order to assist adoption of a socially and technically complex change. The knowledge and skills needed to carry out community consultation was not available in the Water Bureau with which we worked and could not be developed by the research team from this limited experience. A specialist community-development and facilitation input should be considered essential for the type of demonstration work.

Scientific papers produced by the project became a part of the rapidly developing literature on deficit irrigation and RDI in the early 1990s. The ACIAR project was the first to engage in work on RDI in China and over the last 12 years undoubtedly helped to stimulate the broad interest and current capacity in deficit irrigation. The inclusion of RDI in the national research guidelines is evidence of that impact.

Project collaborators have a better understanding of the potential contribution of RDI and related concepts to achieving a sustainable level of water use while maintaining food security. This is not widely accepted in China where improved water-use efficiency is still largely considered in hardware terms that serve to reduce water loss from canal seepage and over-irrigation. However in groundwater irrigated regions like the North China Plain, where water passing the root zone rejoins the aquifer, the water resource can only be protected by reducing the area of irrigation or reducing evapo-transpiration per unit area by using RDI and related techniques. Production can be maintained while net water extraction is reduced.

Importance of mangroves to prawn fisheries (FIS/1992/018)

Neil Loneragan

Collaborating organisations	CSIRO Marine Research, and Griffith University (GU), Australia; Fisheries Research Institute of Malaysia (FRIM), and University Sains Malaysia (USM)
Project leaders	Ms Choo Poh Sze (FRIM); Dr Neil Loneragan (CSIRO)
Related projects	FIS/1994/012
Principal researchers	Ms Choo Poh Sze (FRIM); Professors Gong Wooi Khoon and Ong Jin Eong (USM); Dr Neil Loneragan (CSIRO); Dr Stuart Bunn (GU)
Duration of project	1 July 1999 to 30 June 2000, extension 1 July 2000 to 31 October 2001
Total ACIAR funding	$531,368
Project objectives	The primary objective of the project was to provide management with better information about the importance of mangroves to the production of commercially important penaeid prawns and the coastal habitats that support these fisheries in Malaysia and Australia. The three initial objectives of the project were to examine the impact of mangrove loss on the environment and productivity of the Sungai Merbok estuary of Kedah, Malaysia; to examine the impact of mangrove loss on juvenile prawns in the Sungai Merbok estuary of Kedah, Malaysia; to assess the commercial fishery for banana prawns in different states of Malaysia in relation to fishing practices, environmental factors and changes in the extent of mangroves.

	A fourth objective was added as the project progressed. This was to establish a Geographic Information System to link information in changes in mangrove habitat with that on prawn production, and to enhance the communication of results to managers and scientists.
Location of project activities	Malaysia

Overview

This project aimed to promote better management-orientated research on the commercially important prawn resources on the west coast of Peninsular Malaysia, and increase our understanding of the effects of mangrove removal on mangrove systems and prawn production. The project developed new approaches for collecting information on the status of complex coastal fisheries and established a Geographic Information System (GIS) and database to link data on the environment and coastal fisheries. It also developed a GIS system for the mangroves within one estuarine system over a 30-year period to display and communicate the types of changes in these systems to researchers, managers, planners and the community.

Photo: Mick Haywood, CSIRO Marine and Atmospheric Research.

Aerial view of the Sungai Bujang, a tributary of the Merbok estuary in Kedah, western Peninsular Malaysia. Note the bund wall that has been erected around the mangroves, with the land outside of this having been reclaimed and used for rice cultivation.

Some of these new approaches have been incorporated in developing and implementing research on environmental impacts, shark fisheries and fishery indicator species by researchers at the Fisheries Research Institute of Malaysia (FRIM). Knowledge and information from this project has also increased the understanding of prawn fishery dynamics in Australia and their productivity in relationship to other systems.

Project achievements

The importance of different states in western Peninsular Malaysia for mangrove and prawn production was identified. This highlighted the importance of the state of Perak to the production of prawn fisheries and the area of mangroves in Malaysia (accounting for at least 40% of both). It is significant that Perak has the largest area of mangrove forest reserve in western Peninsular Malaysia that has been managed on a sustainable cropping basis for over 100 years. States where the area of mangroves has declined greatly over the last 20 years were also identified. These results, and those on evaluating the population dynamics of juvenile prawns in a Malaysian system, were published as co-authored papers in international journals between CSIRO and the Malaysian Fisheries Research Institute. They have also been presented at international workshops and conferences.

Photo: Mick Haywood, CSIRO Marine and Atmospheric Research.

Aerial view of the Sungai Dedap, a tributary of the Merbok estuary in Kedah, western Peninsular Malaysia, showing extensive areas of aquaculture ponds, which have been established in what was the mangrove zone.

Research in one estuarine system has identified the need to maintain at least the fringe area of mangroves to maintain the mangrove sediments and habitat for juvenile prawns. In areas of total mangrove removal, soft sediments disappeared and no juvenile banana prawns were found. The project also examined the effects of mangrove removal on the fauna in the sediments of the mangroves and found that total mangrove removal led to much lower numbers of species and a reduction in the abundance of species. This aspect of the research resulted in the completion of a Masters thesis by a Malaysian student.

A GIS was established for the bathymetry and distribution of mangroves along the west coast of Peninsular Malaysia. It was used to evaluate the long term changes in mangroves and the importance of mangroves and shallow waters to prawn production. The GIS can also be applied to planning further research at FRIM on other coastal fisheries e.g. in the stratification of the sampling design for fishery-independent surveys. The GIS established for the long-term changes of mangroves in the Merbok estuary proved to be an effective way to communicate with fishery and environmental managers.

Understanding of the nutrient dynamics of river systems with different areas of mangroves (and mangrove removal) has been increased through this project and resulted in the completion of two PhDs at the University of Malaysia. The nutrient status and primary productivity of the control and impacted system did not differ. However, it appears as though the amount of heterotrophy (i.e. respiration or secondary production) increases in the more impacted system.

This research in Malaysia has provided information for managers in Australia on the potential impacts to fisheries, particularly the Northern Prawn Fishery, from mangrove loss at a much greater scale than has been witnessed so far in Australia. Related work in Australia on the red-legged banana prawns in the Joseph Bonaparte Gulf (Fisheries Research and Development Corporation 1997/105) increased understanding on the linkages between coastal habitats and offshore fishery production. In this case, the nursery habitats supplying the fishery are located up to 200 km from the fishery. The research in this project also contributed to understanding and insights gained for a major review of mangrove fishery linkages published in 2005, as part of the completed research by an Australian PhD student.

The difference the project has made

The project has provided new approaches, methods and training for evaluating data on habitat and fisheries. These methods continue to be applied by the participants, particularly those in the FRI, to new research on understanding environmental impacts and evaluating fisheries. These approaches have been provided as the Government of Malaysia is moving from policies of encouraging the harvesting of natural resources to appreciating the need for conservation to sustain fisheries production.

In Malaysia, the project led to the completion of one Masters thesis and contributed to the training of two completed PhDs, all by women. Since then all three women have obtained academic positions with the University Sains Malaysia (see below). The findings in this project also contributed to the knowledge and understanding gained by two PhD students in Australia.

Project impacts

Community impacts

Community impacts will be indirect and difficult to observe in the short term. Community impacts in the longer term are likely to be better-directed research and improved policies for planning and management in fisheries and coastal environments as the project collected important information on the status of mangroves and prawn fisheries, the spatial change of mangroves in one area and methods for monitoring fisheries. Part of the monitoring approach has been used to develop approaches to monitor the status of other coastal species. It also developed approaches that can be applied to enhance understanding in other areas. Further impacts could be facilitated in the community by increasing awareness of the links between coastal habitats and fisheries through mechanisms that are most appropriate for the Malaysian people, e.g. meetings of fishing cooperatives, and brief information notes for the public.

Photo: Rob Kenyon, CSIRO Marine and Atmospheric Research.

The banana prawn *Penaeus merguiensis*, a species whose juveniles have a strong dependency on mangrove-lined mud banks and one of the most valuable species of prawn caught in western Peninsula Malaysia and the South-East Asian region.

Capacity building and scientific impacts

This project has had most impact on the researchers involved in the project. The researchers at FRI have gained knowledge to make greater contributions to the focus of fisheries research in Malaysia. One researcher developed approaches for sampling landings information on prawns that are being considered for monitoring other coastal species of fish and crustaceans. The experience he gained in publishing scientific findings in international journals was also recognised by FRI, who invited him to become editor of the Malaysian Fisheries Journal and awarded him the researcher of the year in 2005. He is leading major projects on assessing fisheries in Malaysia and approaches to monitor indicator species of fisheries production. Another researcher at FRI gained experience through the project in sampling methods and approaches, data analysis and presenting the results of research in both the written and spoken format. This has provided him with the background to take more senior roles at FRI since the project completed, including leading elements of projects on environmental impact assessment and evaluating the status of sharks.

Several students at the University Sains Malaysia (USM) gained training during the project and have since secured university positions in Malaysia. Ms Rohasliney Hashim completed a Masters of Science, on the fauna of the Merbok mangroves. Since then she completed a PhD at Mississippi State University and is now lecturing at the Institute of Health Science, USM, Kelantan. The project also contributed to the training of Ms Foong and Ms Khairun, who completed their PhDs on nutrient dynamics of the Merbok estuary at USM and are now lecturing in the School of Biological Sciences at USM.

The results from this project also contributed to the training and development of one PhD student in Australia who has since graduated. The findings from her studies have been published in the international literature and presented at international scientific meetings. Since completing her PhD, she has completed postdoctoral research at the Iceland Institute of Natural History and is currently an Inshore Fisheries Advisory Officer at the Scottish Natural Heritage.

The publications from the project have highlighted that sustained prawn production is maintained in areas where sustainable mangrove harvesting is practised. They also highlighted the importance of maintaining some fringe of mangroves as an environment necessary for the juvenile stages of prawns and hence prawn fishery production. Research in this project contributed to a major scientific review of mangrove fisheries linkages published in Oceanography and Marine Biology: An Annual Review, the highest-ranking journal in the area of coastal ecology. This review synthesises the existing knowledge and highlights areas for further research in the field.

Managing the rumen ecosystem to improve utilisation of thornless acacias (AS1/1998/010)

Chris McSweeney

Collaborating organisations	CSIRO Livestock Industries Australia, University of Adelaide (UA), University of Queensland (UQ), University of Western Australia (UWA), Australia; University of Zimbabwe (UZ), Zimbabwe; Balai Penelitian Ternak (BPT), Indonesia; Bogor Agricultural University (IPB), Indonesia
Project leaders	Dr Pascal Osuji; Dr G.J. McCrabb
Related projects	AS1/1993/018, AS1/1995/111 and AS1/1997/058
Principal researchers	Dr Chris McSweeney (CSIRO); Dr J Brooker (UA); Dr Linda Blackall (UQ); Dr Phil Vercoe (UWA); Dr Simba Sibanda, (UZ); Dr Budi Tangendjaja (BPT); Dr Komang Wiryawan (IPB)
Duration of project	1 January 1998 to 31 December 2001, extension 1 January 2002 to 30 June 2002
Total ACIAR funding	$841,360
Project objectives	Objectives were to characterise the nutritional attributes and genotype of thornless acacias (Acacia angustissima, A. vilosa, A. boliviana) and to identify the toxin(s) in thornless acacias; to characterise the mechanism of their detoxification by rumen micro-organisms from indigenous African ruminants; to prevent toxicity from thornless acacias by modifying the rumen ecosystem; to develop and strengthen the ongoing capacity to undertake rumen ecology research at the International Livestock Research Institute.
Location of project activities	Africa and Indonesia

Overview

This ACIAR-funded project to assess the use of thornless acacias (*Acacia angustissima, A. villosa, A. boliviana*) as a protein supplement in regions of Africa, Indonesia and Australia, was carried out by the International Livestock Research Institute (ILRI) in collaboration with CSIRO and a number of other universities and institutions. The lack of high-quality fodder in these areas often causes inadequate livestock nutrition and therefore below-optimum production, thus posing a major obstacle for farmers. Also, soil quality declines as farmers try and increase productivity to meet the demand caused by population growth. Thornless acacias could provide an alternative to commercial protein supplements and improve livestock nutrition.

These species of acacia were found to be very adaptive to infertile soil conditions and an appropriate option as fodder trees in Africa, Asia and northern parts of Australia. *Acacia angustissima* in particular was found to tolerate drought, have a high leaf yield, excellent growth throughout the year, and excessive seed production. Using *A. angustissima* as a protein supplement would be highly beneficial as it would enable farmers to reduce costs and increase their ability to farm sustainably and profitably.

The project also assessed potential toxicity of these acacia species and identified a number of compounds that could be responsible for the anti-nutritive effects observed in feed trials of *A. angustissima*. The cause of the anti-nutritive effect was found to be complex and the exact mechanism of toxicity was not ascertained.

Project achievements

The project made considerable progress toward understanding the phytochemistry of *A. angustissima*. A number of non-protein amino acids, tannins and flavanol glycosides present in the leaves of *A. angustissima* were identified. This also led to development of analytical procedures to identify toxins from plant material.

Through the project, knowledge of the metabolism of non-protein amino acids was gained. The toxicology of the non-protein amino acids ADAB and DABA in rats, sheep, chickens, and rabbits was investigated. A collection of cultures tolerant to *A. angustissima* and its various compounds was achieved, and several novel micro-organisms of interest were studied further. This provides a useful knowledge base for future research into alternative sources of forage. Research into these areas has continued due to the considerable amount of progress achieved from this project.

The difference the project has made

This project promoted awareness of supplementing livestock diets with fodder trees high in protein. Farmers in Africa and Indonesia struggle with providing their livestock with adequate nutrition, due to poor soil quality and harsh environment. Leguminous multipurpose trees, such as the thornless acacias used in this study, have many desirable agronomic attributes including a high protein content in their leaves and offer an alternative to costly commercial protein supplements. These trees also fix nitrogen, a highly desirable quality, as they can be planted in fallows or amongst crops to increase soil fertility.

The project did not aim to nor did it contribute directly to the uptake of the species. However there has been adoption of the plant by farmers due to related research in other institutions. The degree to which *A. angustissima* has been adopted has varied from country to country, with research still ongoing in these countries. Some farmers in Zimbabwe are supplementing the diets of livestock with a number of species of multipurpose trees and are reporting many beneficial outcomes. In other projects, farmers have been trained to collect seed and propagate new trees, which provide them with further means of self-sufficiency. Some farmers have also reported profiting from selling seedlings of these trees to neighbouring farmers. Farmers supplementing with various multi-purpose trees have reported that the milk quality has improved, commenting that it is creamier and tastier.

Acacia angustissima has been introduced as an agroforestry intervention in Tabora Central and Njombe in Tanzania. In addition it is being implemented as fodder banks (for feed and/or shelter) to improve milk production by smallholder dairy farmers in both Tanzania and Zimbabwe. In Zimbabwe it, along with other forage species *Leucaena* and *Calliandra*, are being promoted by the National Agricultural Research System (NARS) and adopted by farmers. In Malawi *A. angustissima* seeds have been distributed for trial by farmers, and in Kenya *A. angustissima* is being used in a research project and there have been reports of some use by farmers.

In Zambia in 2002 a survey of over 100 farmers was conducted to rate 11 agroforestry trees. *Acacia angustissima* rated highly according to its use as fuel wood, light construction material, poles, fodder, and the ability to improve soil fertility. The farmers went on to plant species that rated highly, however they were limited by seed availability in some cases. A programme to generate seed orchards in eastern Zambia was established in 2003–2004. This illustrates the willingness of farmers to use agroforestry trees as fodder.

In Indonesia where these species of acacia are currently grown, research has continued in several laboratories and *A. angustissima* and *A. villosa* are still being pursued as a forage tree. Scientists in the West Timor and East Java areas will carry on studies of *A. villosa* with an outlook to transfer knowledge to farmers of the region. With continued research into the application of the thornless acacias as a protein supplement, and its potential for other applications for smallholder farmers it is possible that the rate of adoption may increase in the future.

Project impacts

This project advanced the awareness of supplements with multipurpose trees in Africa and Indonesia. Research into alternative feed sources and supplements has been encouraged by the findings and work carried out on the thornless acacias in this project. Research into *A. angustissima* and its use as a fodder tree for farmers has continued in several institutions since this project was completed. The information gained into the phytochemistry of *A. angustissima* can be used to help assess other species with the potential for fodder supplementation.

While this project did not specifically deliver community benefits, there has been related work undertaken in other research institutions that appears to have these impacts. The increased nutrition of livestock due to supplementation with forage high in protein leads to better-quality dairy products and meat. The employment of alley cropping with species such as *A. angustissima* has resulted in increased crop production, thus providing more incentive to use these multipurpose trees. Farmers also report using these trees for other applications, including fuel wood, light construction, poles, fencing, and tomato stakes.

Agrochemical pollution of water resources under tropical intensive agricultural systems (LWR1/1994/054)

Ramsis Salama

Collaborating organisations	CSIRO Land and Water, Perth, Australia; Malaysia Agricultural Research and Development Institute (MARDI), Malaysia; Prince of Songkla University (PSU), Hat Yai, Thailand
Project leaders	Dr Ramsis Salama (CSIRO Land and Water); Dr Apinan Kamnalrut, Dr Wichien Chatupote (PSU); Dr Aminuddin bin Yusoff (MARDI)
Related projects	None
Principal researchers	Dr Ramsis Salama, Dr Rai Kookana (CSIRO Land and Water); Dr Amainuddin bin Yousef, Dr Cheah Uan Boh, Mr Wan Abdullha Yusoff, Dr Mohamed Ghulam (MARDI); Associate Professor Apinan Kamnalrut, Dr Wichien Chatupote, Dr Nipa Panapitukul (PSU)
Duration of project	1 January 1996 to 31 December 1999, extension 1 July 2000 to 30 June 2002
Total ACIAR funding	$1,075,109
Project objectives	The project objectives were to conduct field and laboratory experiments to understand the mechanisms and principles of contaminations of groundwater by nitrate and selected pesticides; to conduct field experiments to quantify water and pollutant fluxes in relation to system parameters (hydrologic, soil physical/chemical, management) on a range of selected agrosystems of significance; to adapt and evaluate application of model(s) to assess risks of groundwater pollution through selected agrochemicals; to devise management practices to minimise agrochemical pollution.

Location of project activities	Australia (Gnangara Mound, Western Australia), Malaysia (Cameron Highlands), Thailand (Rathaphum Catchment, Songkhla Lake Basin)

Overview

This project was conducted in three countries: Thailand (Rathaphum Catchment), Malaysia (Cameron Highland) and Australia (Gnangara Mound). It was formulated to understand the principles of agrochemical pollution to surface and groundwater resources under different water regimes and different management scenarios. The study included the evaluation of the resource, assessment of pollution risk potential and the possible management scenarios to reduce the risk. The project objectives were primarily geared to increasing understanding of water and solute transport mechanisms in the catchments, and evaluating the contribution of agriculture to pollution. Pre-project training included laboratory analyses and field techniques, pollution assessments at different spatial scales, adaptation and evaluation of risk-assessment models, quantifying pollutant transport parameters, and technology and information transfer.

In a follow-up two-year extension of the project, adoption strategies and project findings application were carried out mainly in Thailand with some follow-up activities in Malaysia and Australia.

The three catchments studied were diverse in temporal and spatial scale, as well as in the processes and activities leading to water pollution. The Rataphum catchment in Thailand is characterised by a gradation of topography, seasonal water tables that are close to the surface for much of the year, and agricultural activity ranging from vegetable production to fruit and rubber plantations. Agriculture and human and animal waste have a more direct impact on local water quality at the Thai site since lateral water flow is relatively slow. The Malaysian team conducted their research on a number of nested catchments in the Cameron Highlands. Here, processes were dominated and controlled by steep topography and high rainfall, rapid surface runoff and shallow subsurface flow causing severe erosion and sediment transport.

The Australian site, the Gnangara groundwater mound from which Perth obtains a large proportion of its water supply, is subject to low rainfall, negligible runoff, deep water tables and slowly changing, low-intensity agriculture.

Project achievements

Thailand

In Thailand the farming-system studies in the Rataphum catchment included detailed monitoring of the types and amounts of pesticides used by farmers in three different farming systems. These systems are geomorphologically controlled; fruits in the upper slopes, rubber in the midslopes, and vegetables in the flat and low-lying areas near Songkhla Lake. The results showed that pollution risk from chemicals is highest in the low-lying vegetable areas where the groundwater is near to the surface. The results also showed that most of the shallow groundwater in the catchment is bacteriologically contaminated and not suitable for drinking except after boiling. An integrated crop management (ICM) system was introduced and tested as a possible alternative management practice to reduce agrochemical pollution risk in the vegetable-growing area. The selected ICM systems included several crop choices, irrigation systems (sprinklers, drip irrigation, fertigation), plastic cover, lime solution for protection from fungus disease and alternative cropping patterns. The experiments were conducted both in farmers' fields and at the Faculty of Natural Resources, Prince of Songkla University (PSU), which was used for demonstration.

Evaluation of the degree of farmer acceptance was also conducted after the experiment. It was found that covering the soil bed with plastic sheets and using pipe irrigation underneath was the most promising practice and highly acceptable to farmers. The locally made bio-extract fertilisers gave the same level of vegetable yield but products were of lower quality and less attractive when compared with chemical fertiliser products. In terms of buffer zones, grasses such as lemon and Ruzy grass (*Brachiaria ruziziensis*) were more effective than Hamata stylo (*Stylosanthes hamata*) in reducing sediment load and nutrient leaching to surface-water sources due to faster growth and ground-cover development. Locally prepared biological extracts were also used for the control of pesticides, but farmers preferred to use more potent chemical concoctions.

Malaysia

A comparative study of erosion and pollution levels from tea, vegetable and flower-farming in Malaysia showed that the traditional tea plantations are best suited for the steep slopes of the Cameron Highlands, with flowers and vegetables grown under shelter coming second best, while open-area cultivation is detrimental because of the amount of sediments washed into surface water streams and dams. Erosion caused by farming on steep slopes and the subsequent rapid water flow causes massive silting problems for power-generating dams. Water quality is also affected by many different activities, including road and building construction and urban activities.

Australia

In Gnangara Mound, Australia, there was no direct threat of pollution from applied fertilisers and pesticides, but the work showed that the groundwater resources are over-exploited and that the native vegetation and wetlands are being endangered due to the falling groundwater levels.

The difference the project has made

Thailand

Recommendations on the most favourable practices for minimising agrochemical contamination to groundwater were made once pollution sources to groundwater in low-lying vegetable areas and risk areas in commercial sites of Rathaphum Catchment were identified using field trials, soil classification, geomorphology and remote sensing. The relationship between geomorphology, soils and pollution paths were also established. Detailed and complete local and regional nutrient and pesticide mass balances were conducted in the three different farming systems. Prediction of risk to agricultural systems was determined using simulation models and was also used as a decision support tool for researchers and growers.

The project results were incorporated into the National Agricultural Policy for promotion of organic farming and food safety. The project recommendations were also implemented by local extension officers. The project area local authority has prohibited leasing areas with high risk of chemical pollution for commercial vegetable production, and vegetable growing near schools was restricted.

The project enhanced awareness of safe use of the agrochemicals in the area. The vegetable growers in the village community organised watchdog groups to monitor the risk of misuse of chemicals through body mapping and blood-sampling tests.

Exploration of alternative management practices was carried out in conjunction with the farmers, and increasing extension activities, at the local level between farmers, at the scientific community and the relevant government agencies personnel, were enhanced.

Public and government awareness of the importance of pollution, and the information and skill resources that currently exist to aid its control, was increased.

Malaysia

The findings of the project have clearly illustrated the status of water resources and pollution at the farm, subcatchment and catchment levels. Large amounts of the applied nutrients and pesticides were removed from the farms. However, due to dilution effects, the pollution at the catchment level was within the tolerable limits.

The research project has successfully generated important information on the status of water resource pollution in the Cameron Highlands area. This is regarded as a milestone work in Malaysia in terms of quantifying the extent of water pollution due to intensive agricultural activities. It can be used as a benchmark in assessing water pollution due to agricultural activities. The information gathered has been disseminated among scientists, and to some extent to other clientele groups. Apart from generating awareness on the water pollution, the information gathered enables follow up action to be taken by relevant agencies.

Several government departments working in Cameron Highlands were made aware of the severe problems of erosion of sediments, loss of nutrients and migration of pesticides with water and sediments. Tenaga Nasional Berhad (TNB), the national power company that was suffering badly from the silting-up of its power-generation dams, was very interested in the work conducted by MARDI in the experimental areas. TNB Research Branch took over the operation of the four research stations established by the ACIAR project—MARDI Vegetable Site, Kartigesu Vegetable Farm (Sungai Palas), Sungai Palas Tea Plantation, and Haji Li Vegetable Farm—and is continually running them to date. They are conducting more research to provide data to make further representations to the government to influence current policy on land use.

Australia

Land use influences the amount of water recharging the Gnangara Mound, which provides about 50% of Perth's domestic water supplies. Water levels have been declining due to increasing water use by the maturing pine plantations, market gardens, and abstraction by the Water Corporation, and decreasing recharge due to decreasing rainfall. Removing the pine plantations was an effective solution to partly recovering falling water levels in the Gnangara mound. The project provided information and new methods and techniques for assessing pollution risks and a sound basis for planners to modify existing land use, develop new land uses and advise farming communities about better farming practices, which are compatible with the protection of water quality and sustainable agricultural production.

The project results on aquifer sustainability led to several other research projects and the development of new ideas for groundwater allocation plans. The most important outcome of the project is that the sustainable criteria for the shallow aquifer have been redefined as the additional amount of captured recharge, or reduced discharge, and not based on the initial pre-development rates of recharge and discharge.

Several methods and techniques for up-scaling of modelling results were developed and were used in other projects in Australia and overseas. The hydrogeomorphic classification, developed in Perth, formed the basis for integrating and classifying land types in a way that is useful for predicting pollution hazards, and was used successfully in the three countries.

Project impacts

Community impacts

Thailand

Extension activities to reduce the use of pesticides and nutrients, and to avoid drinking contaminated shallow well-water, were carried out in several forms including field demonstrations, training courses, study tours, workshops and seminars. About 500 farmers from Songkhla and Nakon Sri Thammarat participated in six training courses on the safe use of pesticides, integrated pest management and appropriated cropping patterns for vegetable production. After the training courses, farmers took part in the hygienic vegetable production project in close collaboration with the World Vision Foundation and ACIAR-organised project. Handbooks and user guides of pesticides were published and distributed to interested farmers and concerned officers. The project constructed a low-cost leak-free chemical storage room for pesticides and roof-water collection system for drinking water, and supplied small tanks to 10 farmers in the vegetable-growing area for practical use and demonstration purposes. Several posters on how to minimise agrochemical pollution in vegetable production and avoid drinking shallow well-water without boiling have been distributed and posted in the villages.

Department of Health provided funding for training and transfer of Integrated Pest Management (IPM) on chemical use for the farmers, which included:

- increasing the use of organic/biological insecticides and hydroponic vegetable production
- recommendation package of friendly chemicals for vegetable production for extension officers
- alternative agronomic practices for reducing contamination risk, reducing fertilisers and water use:
  - plastic covers and drip irrigation to reduce water use and evaporation
  - use of bioinsecticide and biofertilisers
  - creation of buffer zone to retain nutrients and sediments and protect surface-water sources
  - recommend type and season for planting vegetables and best-farming practices.

Malaysia

The project has resulted in providing additional baseline information for the Pesticides Board of Malaysia to initiate regulatory action for the restricted use of endosulfan, which is now banned for use in the vicinity of water bodies.

Results obtained in this project show that the soil erosion under rain shelters is far less than those under open farming. This indicated that rain-shelter cultivation is indeed sustainable and is a promising agricultural practice in the steep highlands, and needs to be adopted at a wider scale.

The responsible authorities have already promoted the use of rain shelters in Cameron Highlands, which produce high crop yields and reduce erosion and pollution.

Australia

The scientific results from this project were presented at several seminars for the stakeholders and farmers to discuss the acceptable management practices that can be applied to guarantee sustainable use of the groundwater without endangering the natural vegetation and wetlands.

Capacity building and scientific impacts

Interaction between the three countries has been high. Training sessions, reciprocal visits to sites, and workshops have been features of this project. There were high degree of personal interaction and friendship between the participants, which indicates good cooperation. The list of published journal, conference and workshop papers is impressive. One PhD and one MSc resulted from the work at MARDI, as well as several Masters degrees at PSU.

Several training workshops were held in Malaysia and Thailand; this was followed by two workshops in Thailand, which resulted in two published proceedings (Salama and Kookana 2001; Salama and Kookana 2005).

International cooperation between PSU scientists, MARDI and CSIRO in international workshops created a well-trained group of scientists experienced in soil physics, pesticide analysis, water quality, microbiology, geomorphology and the various aspects of modelling, including surface and groundwater solute modelling and risk analysis. Due to the well-established relations with other ACIAR and CSIRO projects, several team members attended workshops and seminars in Thailand, India, China, Malaysia and Australia.

Thailand

The PSU team established linkages with many government and non-government organisations:

- World Vision Foundation, in developing practical techniques for producing hygienic vegetables
- National Center for Biological Control, Department of Agriculture Extension in developing appropriate Integrated Pest Management (IPM) systems for the vegetable farmers
- Office of Research and Development, Region 8, Department of Agriculture in collaboration work on the soil and water analyses for mineral and nutrient contamination
- Rubber Research Institute in providing information and consultation on agrochemical pollution risk assessment in rubber-production areas
- Department of Public Health in establishing a health-monitoring system for the vegetable-grower a community and public awareness campaign
- PSU interfaculty collaboration for the upcoming research and development program in improvement of drinking water quality for the rural community (the four faculties that agreed to collaborate are Faculties of Natural Resources, Science, Engineering, and Nursing).

In addition four Thai scientists gained experience and technical proficiency in their specific areas by receiving training in Australia to improve their professional standard, teaching capacity, data analysis, interpretation and modelling. They also acquired expertise and training in Geographic Information Systems (GIS), chemical, physical and biological analysis techniques, and modelling. The four scientists were promoted on their activities in the project, publications and development of new projects.

In 2005, four MSc students were preparing their research on natural extracts, neem oil, and biological extracts on control of pesticides.

Malaysia

The project was instrumental in developing approaches to evaluate erosion processes and estimate nutrient loss in the highlands, which facilitated the design of control measures.

The project has introduced advanced field instrumentation and modelling techniques. Predictive models for environmental management and as a research tool have been taken up. The research methodology adopted has enhanced the capability of local scientists to pursue research in the field of pollution due to erosion and leaching of agrochemicals.

Two position papers were prepared and presented to the concerned government departments and published in scientific journals (Aminuddin et al. 2001; Aminuddin et al. 2005). The project has culminated in a PhD and an MSc thesis.

Australia

Several methods and techniques for up-scaling of modelling results were developed for use in projects in Australia, Thailand and Malaysia and were also used in another ACIAR project in China. New methods and techniques for assessing pollution risks based on hydrogeomorphological classification of catchments were also initiated. Innovative definitions and methods of estimating aquifer sustainability received wide attention from researchers and planners and led to the creation of several other research projects.

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Management of legume nitrogen-fixation for rainfed cereal production (LWR2/1992/010); Sustainable grain legume–cereal production systems through management of nitrogen-fixation (LWR2/1997/062)

Graeme Schwenke and David Herridge

Collaborating organisations	NSW Agriculture (NSWDA), CSIRO Plant Industry, Agricultural Production Systems Research Unit (APSRU)/CSIRO Tropical Agriculture, Australia; Pakistan Agricultural Research Council (PARC), North West Frontier Province Agricultural University (NWFPAU), Peshawar Agricultural Research Institute (PARI), University for Arid Agriculture (UAA), National Agricultural Research Centre (NARI), Pakistan; Nepal Agricultural Research Council (NARC); Vietnam National University (VNU)
Project leaders	Dr David Herridge (NSWDA); Dr Muhammad Aslam (NARC); Dr Nguyen Xuan Hong (VNU)
Related projects	LWR2/1983/005, LWR2/1983/006, LWR2/1987/003, LWR2/1988/000, LWR2/1988/029, LWR2/1991/002, LWR2/1992/016, LWR2/1994/048, CS1/1996/049, LWR2/1995/710, LWR2/1995/712, LWR2/1998/027
Principal researchers	David Herridge, Graeme Schwenke, Warwick Felton, Harry Marcellos, Jill Turpin (NSW Agriculture); Mark Peoples, Graham Turner (CSIRO); Michael Robertson (APSRU/CSIRO); Zahir Shah (NWFPAU); Sabir Shah, Dil Fayaz Khan (PARI); Safdar Ali (UAA); Muhammad Aslam (NARC); Surya Maskey, Shanti Bhattarai (NARI); Nguyen Xuan Hong (VNU)

Duration of project	1 January 1994 to 31 December 1996, extension 1 January 1997 to 31 December1997 1 January 1998 to 31 December 2000, extension 1 July 2000 to 31 June 2001
Total ACIAR funding	$1,260,144; $760,471
Project objectives	These projects aimed to improve, through increased use of legumes, the productivity, profitability and sustainability of cereals-dominated cropping systems in the rainfed areas of the Punjab and NWFP of Pakistan, the Hill and Terai agro-ecological zones of Nepal, the upland systems of northern Vietnam and the northern grains belt of Australia. This was to be achieved by research to enhance the benefits of legumes and legume nitrogen-fixation in cereal-production systems and putting new knowledge to work through improved management and decision-support packages.
Location of project activities	Pakistan, Nepal, Vietnam and Australia

Overview

In the early 1990s, dryland cropping in northern Pakistan, Nepal and north-eastern Australia was characterised by a dominance of winter cereals, low use of legumes and little or no nitrogen fertiliser. Consequently, cereals were often nitrogen deficient, low yielding and their efficiency of water use was poor. These two ACIAR projects aimed to improve, through increased use and better management of crop legumes, the productivity, profitability and sustainability of cereals-dominated cropping systems in barani (dryland) areas of the Punjab and North West Frontier Province (NWFP) of Pakistan, the mid-Hill and Terai agro-ecological zones of Nepal, and the northern grains belt of Australia.

Researchers combined actual legume nitrogen (N_2)-fixation measurements from field surveys and field experiments with knowledge of factors influencing N_2-fixation to devise and test improved cropping systems that would benefit farmers, soil fertility, and the environment. While these projects were primarily about new scientific knowledge and understanding, the partner researchers and their institutions benefited greatly from the introduction of new research technologies, facilities and practical approaches used in measuring and understanding legume N2-fixation in cropping systems.

Project achievements

These two projects generated new knowledge of crop legume N2-fixation in both commercial and experimental situations over a large range of country-site-years. These results were then put to use in devising, testing, costing and modelling alternate cropping systems that have both economic and environmental benefits for farmers.

Measuring crop legume N_2-fixation

Surveys of nearly 400 commercial pulse crops indicated the great potential of well-grown pulses to fix substantial quantities of nitrogen (N). Values for Pfix (the percentage of legume N derived from N2-fixation) showed no obvious effect of species and were generally high (50–80%), with the exceptions of chickpea in Australia and soybean in Pakistan that were lower (Table 1). The data on N2-fixation and N inputs were unique and greatly enhanced our understanding of the potential of pulses (and other legumes) to increase productivity and sustainability of cropping systems. An estimate for annual legume N2-fixation in Nepal of 30,000 t N/yr was derived from the farm survey data. This amounted to A$30 million in equivalent fertiliser costs.

Photo: G. Schwenke.

Dr Sabir Hussein Shah (Director of Soil & Plant Nutrition, Tarnab Agricultural Research Institute) and Dr Zahir Shah (Professor of Soil Science, North West Frontier Province Agricultural University, Peshawar) compare healthy and nitrogen-deficient wheat plots in a farming-systems trial in the Swat River Valley, north of Peshawar, Pakistan.

Table 1. Summary of nitrogen-fixation measurements in farmers' fields in Pakistan, Syria, Lebanon, Nepal and Australia

Species	Country & region	No. of fields	Pfix (%)	N_2 fixed (kg ha^{-1})
Winter legumes				
Lentil	Pakistan – NWFP	40	78	47
	Nepal – Terai	15	77	72
	Nepal – Terai	4	84	–
	Syria, Lebanon	27	72	–
Chickpea	Pakistan – Punjab	83	75	–
	Nepal – Terai	14	79	84
	Syria, Lebanon	19	60	–
	Australia – north-west NSW	21	28	22
Fababean	Australia – north-west NSW	24	52	69
	Nepal – Hills	2	85	80
Grasspea	Nepal – Hills, Terai	4	87	80
Summer legumes				
Soybean	Pakistan – Punjab	11	16	–
	Nepal – Hills	14	66	59
Mungbean	Pakistan – NWFP	40	47	28
		12	77	–
Pigeonpea	Nepal – Terai	5	75	412
Mashbean	Nepal – Hills	20	47	28
Groundnut	Nepal – Terai	16	57	153

Legume N2-fixation was also substantial in most of the crop-rotation field experiments. Values exceeded 300 kg N/ha for irrigated pigeonpea and mungbean in the NWFP, Pakistan, and for soybean in the Hills of Nepal. More commonly, values were in the range 50–150 kg N/ha. The values for the Australian experiments were similar to those for Pakistan and Nepal.

Factors influencing N_2-fixation

Our data confirmed the strong relationship between Pfix and (a) available soil nitrate-N in the soil, and (b) the plants' demand for N to satisfy biomass production. In other words, legumes will only symbiotically fix atmospheric N2 if the plant's demand for growth cannot be met by available nitrate-N in the soil. The data from surveys of farmers' fields was identical to experimental plot data in this respect and both were used to derive empirical relationships for use in decision-support packages for farmers and advisers.

Lower Pfix values for the summer-grown mung and mashbean most likely reflected nitrate-N suppression of N2-fixation. More soil nitrate is released from organic matter mineralisation during the summer growth period when soil temperatures are high and soils are going through rapid wetting/drying cycles than in winter with its low soil temperatures and more stable moisture.

Cropping systems experiments

Given a choice, farmers would prefer to grow legumes that have a positive N balance, i.e. that add more N to the soil than is taken away in grain and other products. Data from the nine rotation experiments in northern NSW indicated N balances for chickpea ranging from -67 to +61 kg/ha, with values influenced by soil nitrate, crop growth, grain yield and N harvest index. Thus, the farmer has to manage the system, particularly for soil nitrate and biomass (and grain) yield, to ensure a positive N balance. Another key outcome of the Australian experimental program was that fababean was shown to have a greater capacity for N_2-fixation than chickpea and, when soil-nitrate supply far exceeded demand, spared soil nitrate.

In the 14 crop-rotation experiments carried out in Pakistan and Nepal, crop legumes regularly increased yields of the following cereal crops by 20–100%, relative to cereal monoculture treatments. Cereals also responded to inputs of fertiliser N, particularly in the low-N soils of Pakistan. Responses there were commonly 100–200%. Increasing productivity through incorporating legumes and fertiliser N also increased soil organic fertility. For example, after 4 years of the chickpea–wheat-rotation experiments in Pakistan, soil organic matter had increased by 28–56% through inclusion of chickpea and by 35–72% through inputs of fertiliser N in the wheat monoculture. Values for increases in soil total N were 22–56% (chickpea rotation) and 66–100% (fertiliser N on cereals).

Photo: G. Schwenke.

Dr Dil-Fayaz Khan, top, (Soil Microbiologist, Tarnab Agricultural Research Institute) passing on soil-analysis techniques he learnt during PhD study in Australia to colleagues at the North West Frontier Province Agricultural University, Peshawar.

Use of the data

Economic analyses using gross margin, dominance and marginal analysis of a number of the rotation experiments revealed large benefits of legumes, particularly chickpea and fababean in Australia, and soybean and black gram in Pakistan. The legume economic benefit reflected both its high grain price and its positive impact on yields of following cereals.

Both growth and N_2-fixation models for fababean and chickpea in the Agricultural Production systems Simulation Model (APSIM) were refined as a result of the project's field experiments at Gatton in south-eastern Queensland and through verification using other data sets. APSIM-generated simulations of part of the NWFP data sets from Swat and Dir showed good agreement with observed data for wheat (-N) and mungbean, and reasonable predictions for responses of the wheat to both legumes and fertiliser N. APSIM appears to be an excellent tool for scenario analysis (e.g. fertiliser N rates, residue management) in such systems.

Field and laboratory technique development

The xylem solute method for measuring legume N_2-fixation was calibrated for cowpea, mungbean and black gram in Australian glasshouse trials thus adding them to the list of species calibrated for this method. Sampling procedures for the method were refined and simplified with the previously recommended 7–8 samplings reduced to 1–2. The ureide method for measuring legume N_2-fixation is fast and dispenses with the need for highly specialised and expensive mass-spectrometer analyses. All the project laboratories and many others trained during the project continue to use this method in related research activities.

The difference the project has made

In northern Pakistan, projects LWR2/1992/010 and LWR2/1997/062 effectively created a mini cooperative research centre for field-based research into legumes in cropping systems. Competent but under-resourced scientists from several institutions were brought together, equipped, funded and trained in new and existing techniques of field and laboratory measurements, data interpretation and communicating results. There are also now a decade of post-graduates (nearly 30) from the two local universities involved who have graduated with applied practical research experience instead of purely theoretical studies. These graduates are now in a wide range of government departments, research institutes and university teaching positions so the network of practical understanding and experience continues to grow. The core research groups continue to attract new funding grants to further their legume N_2-fixation and soil-fertility-related research and postgraduate training. Similarly, in Nepal the project led to a considerable boost in the expertise, knowledge and experience of the project scientists and their technical staff giving them skills and understanding that have been put to use in related soil's research since the project concluded.

There is no doubt that the project research contributed greatly to an increase in the cultivation of crop legumes in the areas surrounding the ACIAR field trials in the Punjab and North West Frontier provinces of northern Pakistan, and in the Hills and Terai regions of Nepal. Farmers in these areas are now more happy with the involvement of legumes in their cropping systems and understand that legumes not only increase yields of the following crops through improved soil fertility but are profitable in themselves and may be grown on marginal lands. Although it is difficult to put figures on the perceived increase in legumes grown, reports of increasing sales of legume seed seem to be backed by official statistics for the Punjab province of Pakistan, indicating a drop in the ratio of cereals to legumes grown from 9:1 to 5:1 between 1991 and 2005.

The projects' outcomes have also impacted on the farmers in a social sense—through greater experience with growing different crops, and greater knowledge of their function within the cropping system. Understanding the benefits of growing crop legumes effectively, through attention to using rhizobial inoculation and understanding the value of retaining the crop residues, gave farmers tools to better manage their limited resources of money and land. Environmentally, greater adoption and incorporation of annual crop legumes should see less reliance on chemical fertilisers that can become groundwater and surface-water pollutants when not applied in synchrony with plant demand. Greater productivity of existing arable land may relieve some of the pressure to introduce marginal land to cultivation.

However, adoption in areas not near the experimental sites was mostly low, reflecting the largely research focus of these projects. There was no formal extension program built into the ACIAR projects, instead relying on existing institutional networks for dissemination of results—a method that has not proven very effective in capitalising on this work. Since the first project began, it has become more common for researchers in Australia to extend their research results themselves through participatory farmer research, adviser-update seminars and popular media, but in Asia this trend is just beginning. During the ACIAR project, Pakistani and Nepalese researchers saw the value of on-farm trials as extension tools firsthand. They feel the best way for increased adoption is in networks of field demonstrations and small-group training rather than printed material since many farmers are illiterate and learn most effectively by personal experiences.

In Australia the aims were similar even though the background situations were not. While most farmers do now use nitrogen fertiliser on cereals, diminishing real returns mean they welcome any means of reducing reliance on fertiliser especially with ever-increasing costs. Many farmers also have increasingly negative feelings about applying increasing amounts of chemical fertilisers to their soil and prefer more 'natural' alternatives wherever possible. With continuous cereal cropping has also come significant problems of plant diseases and difficult-to-control weeds, so annual crop legumes have additional roles to play as break crops.

Research results from these projects were incorporated into the APSIM crop-simulator model and other decision-support packages that are used by farmers and advisers looking to better understand and manage their paddock nitrogen budgets. Crop legumes are now significant components of cropping systems in some areas of north-west NSW. The main impediments to farmers in other areas growing more crop legumes have been problems with diseases and adaptation to soils with increasing salinity with depth—both topics of current research in the region.

The training workshops in measurement and management of legume N_2-fixation with scientists, students and technical staff from Pakistan, Nepal, India, Vietnam, Bangladesh, Nigeria and several other countries have engendered greater understanding of legumes and their scope for improving soil and plant systems. Previous methods used were crude, imprecise and in some cases proven to be outdated science. Realistic measures of legume N2-fixation are needed to help develop and promote more sustainable cropping systems.

Project impacts

Community impacts

Detailed community impact evaluations were outside the scope of these ACIAR projects since they were research-oriented programs. Realistically, community impacts would be low on average across the mandated farming regions. The exceptions to this are those communities in the vicinity of the field-research trials who observed firsthand that crop rotation and residue-retention treatments improve yields and profitability. These farmers are happy with growing legumes and their farm income has increased. The use of chemical N fertiliser has reduced somewhat and with this we would expect that the danger of contamination of drinking water with possible nitrate movement from fertiliser has also been reduced. Soil cover with legumes has been observed to reduce soil eroding into surface water bodies.

The overall impact may well remain minimal without further investment in a formal extension and adoption program. Several of the former ACIAR project staff did report a general impression of increased inoculant use and increased area of legume production in their regions. This is perhaps due to a gradual filtering of information from the many people updated with the projects results, including agricultural college teachers and students, extension department officers, and progressive farmers. Nevertheless, all of the former Pakistani and Nepalese project staff felt that any new investment should also include the establishment of a network of field demonstration trials throughout the dryland grain-growing areas, including areas not initially targeted by the ACIAR project, e.g. the southern districts of NWFP in Pakistan, especially Bannu and Karak, which are areas suited to chickpea and pea growing.

Capacity building

Capacity building was one of the strongest features of these two projects and its clearest legacy. This is in part because the core project team engaged at the commencement of project LWR2/1992/010 were all still actively involved at the end of project LWR2/1997/062, and continue in related research to this day. All of the core staff have been promoted within and/or outside their organisations in recognition of their scientific and professional achievements during the project period. Two are now full professors at their universities. In Pakistan particularly the core team has greatly increased its national and international reputation in the scientific community with several team members winning overseas study awards. This work has led to further research grants as well as merit-based promotions of all staff involved.

Of particular note was the development of field and laboratory research facilities and expertise at the University of Arid Agriculture (UAA), Rawalpindi, and the NWFPAU, Peshawar. With supplied vehicles, field sampling and laboratory-analysis equipment, and extensive training, each was able to conduct extensive field surveys and practical research experiments in remote farmers' fields. Quality-assurance principles and practices were introduced into the laboratory operations of the three collaborating Pakistani institutes, was supported during the project, and are now part of the training given to all new students and technical staff.

The experimental capacity developed by the ACIAR projects formed the basis of nearly 30 Masters and PhD programs both during and since the project period. Many of those students now work in positions that draw on their accumulated experience and expertise relating to soil fertility, crop rotations, legume N_2-fixation, rhizobial inoculation, and nutrient budgeting. Some have gone on to further studies overseas. The project also fostered collaboration between the universities and national research institutes as well as overseas research centres. Dr Shah from NWFPAU comments, 'It provided us with an opportunity to attend seven international scientific meetings, to develop linkages with various international organisations and also to publish our results in international publications.'


Photo: G. Schwenke.

Shabaz Ahmad, Imdad Mahmood and Dr Muhammad Aslam (researchers at the National Agricultural Research Centre) learning soil-nitrogen analysis during a training workshop on methods of measuring soil quality at North West Frontier Province Agricultural University, Peshawar, in 1997.

Scientific impacts

The projects' outputs have had far-reaching contributions to other agricultural research projects as evidenced by the continued research-funding grants awarded to the Pakistani and Nepalese researchers since the project ended. The techniques of measurement of field nitrogen-fixation and assessment of crop-nitrogen benefits to the soil and following crops are still in use today in new related research projects. The laboratories that were developed with the help of the ACIAR project team remain in constant use for teaching and research activities.

The project results were widely publicised and published, ranging from local-language brochures for farmers, to national and international scientific journal papers, scientific conference abstracts and posters, institute seminars, farmer and adviser updates, and newspaper publicity articles. The 1996 project review meeting held at the International Crop Research Institute for the Semi-arid Tropics (ICRISAT), Hyderabad, India, provided a major project outreach activity that brought the projects' results to date before an audience of scientists from across Asia and Africa. The proceedings were refereed and published jointly by ACIAR and ICRISAT in 1997 along with contributed papers from other delegates at the workshop.

In Australia, project research results have contributed significantly to the development of decision support packages for farmers and advisers. A compendium titled 'Nitrogen and legumes in northern Australian farming systems' draws heavily on information gathered as part of the ACIAR project activities in Australia. Annual crop legume information is also integral in an interactive spreadsheet program where users can view the impacts of varying crop choice and management on the nitrogen cycle in the soil–plant system. Extolling the benefits of crop legumes and improved stubble management on soil organic fertility has played an important role in the adoption of reduced and zero tillage by over 50% of cropping farmers in north-west NSW (higher in some areas).

Manufacture of low-cost wood-cement composites in the Philippines using plantation-grown Australian tree species (FST/1995/000)

Kate Semple

Collaborating organisations	Forest Products Research and Development Institute – Department of Science and Technology, Philippines (FPRDI-DOST), Philippines; Department of Forestry, Australian National University (ANU), and CSIRO Division of Forestry and Forest Products (DFFP), Australia
Project leaders	Dr P.D. Evans (ANU); Dr F.P. Soriano (FPRDI)
Related projects	C2003/128, FST/1992/008 and FST/1996/110
Principal researchers	Dr F.P.Soriano, Dr R.J. Cabangon, Dr D.A. Eusebio (FPRDI); Dr P.D. Evans, Ms K.E. Semple (ANU); Dr B. Coutts, Dr R. Leicester (CSIRO)
Duration of project	1 January 1997 to 31 December 1999, extension 1 January 2000 to 31 December 2001; project amendment 2002 to 2003 to cover information dissemination and standards development
Total ACIAR funding	$575,516
Project objectives	Objectives were to gain the knowledge necessary to foster the development of the wood-wool cement-board industry in the Philippines, manufacturing low-cost building panels from locally grown plantation woods. To develop wood-wool cement-board technology for a range of different building applications, including low-cost housing and pre-fabricated emergency shelters; and to establish the manufacturing and product performance standards for wood-wool cement-board products.
Location of project activities	Philippines, and Australia

Overview

This project was inspired by the acute shortage of low-cost housing in the Philippines and a need to develop a local, low-cost building-panel system suited to their tropical climate. It was a collaboration between the Australian National University Department of Forestry, the Philippines Forest Products Research and Development Institute – Department of Science and Technology (FPRDI-DOST) located at Los Baños, and CSIRO Division of Forest Products in Melbourne, and aimed to further develop the indigenous manufacture of wood-wool cement-boards (WWCBs) in the Philippines.

Imported materials and engineered composite panels familiar to building systems in Western countries are not only costly, but in many cases will not tolerate tropical climatic conditions, which makes them unsuitable for low-cost housing projects in the Philippines. WWCBs are better suited for this purpose since they contain simple and relatively cheap constituents (pulp-quality wood, Portland cement, water and small quantities of cement set accelerator), and can also be produced in small-scale, low-tech production plants, unlike conventional engineered wood composites. Cement-bonded composites also have much higher resistance to biodeterioration, including termites and decay, than solid wood and conventional composites. The use of local labour that does not require high-level skills is another significant advantage of the WWCB industry. Project FST/1995/000 was comprised of four sub-projects: Australian species selection, wood billet storage, manufacture and processing of WWCBs, and training and dissemination of information.

Photo: K. Semple.

Manufacture of reinforced wood-wool cement-boards at EARN Corp., Bay, Laguna.

Although the project has generated a wealth of knowledge on using tropical acacia and eucalypt wood for wood-cement composites, in particular WWCB, and significant advances have been made in developing WWCB technology including building design and product standardisation, the expansion of the WWCB industry in the Philippines has been adversely affected by a complex set of compounding external factors. These include depressed economic conditions, inflation and currency instability in the late 1990s, and complex and changing forest-harvesting regulations that have inhibited investment in new plantation establishment, accompanied by a recent ban on logging in 2004 in response to severe floods in previous years. There were 15 cement-bonded board plants 8 years ago; in 2005 there's just one. In this climate, the uptake of research findings from the project has been limited, although we can point to some technology transfer arising from the project and the constraints currently affecting the WWCB industry in the Philippines are seen as temporary. The foundation knowledge and experience generated from the project is expected to facilitate the future expansion in manufacture and use of WWCB building systems once economic conditions and availability of raw materials improve.

Project achievements

This project has contributed significantly to the depth of scientific knowledge and practical experience required to foster the development of a viable WWCB manufacturing industry in the Philippines. The results from early research into the compatibility of important plantation species of acacias and eucalypts with Portland showed that most eucalypt species grown in the Philippines would be suitable for wood-cement boards, making a fundamental contribution to the general lack of information about utilisation options for plantation-grown wood. Certain varieties of another important fast-growing tree species, *Acacia mangium*, are also moderately well suited for wood-cement composites and, more importantly, the research demonstrated that good-quality WWCBs can be manufactured from any *A. mangium* wood supply with an appropriate combination of billet postharvest storage, soaking of wood-wool and/or pre-treatment of wood-wool with simple inorganic compounds that neutralise the effect of heartwood on cement setting.

Product development research from the project (carried out mostly at FPRDI in the Philippines) has developed a range of medium-weight WWCBs, ranging from 450 to 900 kg/m3 in density and ranging from 8 to 50 mm in thickness that are suitable for a range of non-load-bearing applications, including walls, roofing, and flooring in housing and emergency-shelter construction. These are best manufactured in a wood/cement ratio of 60% cement to 40% wood by weight from strands measuring 3 to 5 mm in width, 0.3 mm in thickness and anywhere from 300 to 500 mm in length. Strand alignment of the surface layers has been shown to significantly improve panel stiffness and reduce the propensity for creep deformation with time under its own weight. However, since this must be done by hand it slows down productivity and adds to product cost. Such products are therefore being designed to suit specific, higher-performance applications such as flooring. While strand alignment is still in the research-and-development phase at FPRDI, the research on the optimisation of the basic board manufacturing process, including correct wood/cement ratios, billet pre-storage to reduce soaking time, and mat quality, have been transferred to and used successfully by WWCB plants, often in combination with simple mat internal reinforcement using stiffer materials.

Project research also benchmarked the quality of commercially produced WWCB products in the Philippines and evaluated the performance of surface coatings for exterior WWCB panelling. Wide variation was found in product physical properties, particularly strength and stiffness, thereby providing focus areas for product improvement through subsequent research. The simplest and most effective coatings to extend the service life of WWCB panels are fine concrete render or stucco, which significantly reduces moisture-induced thickness swell of WWCB. Elastomeric paint is another surface finish that maintains the surface character of WWCB but protects it from weathering and staining, however it is more expensive than cement render. Elasto-polymers are also now commonly mixed with cement render to give the surface finish greater flexibility and resistance to moisture.

Subsequent ACIAR-funded project activity has resulted in the development of product performance standards for WWCB along with building codes for one- and two-storey structures containing WWCB wall, floor and roofing systems. These are in the process of being formalised through the Philippines Bureau of Product Standards (Department of Trade and Industry).

The difference the project has made

This project has laid the foundation knowledge necessary for the development and growth of the WWCB industry in the Philippines to help meet the need for low-cost, locally produced building materials. It has demonstrated that low-density plantation-grown wood, which is unsuitable for applications requiring the use of solid sawn wood, can be used to manufacture WWCBs at relatively low cost and with natural durability in tropical conditions. In fact the Philippines was the first country to adapt a material that was hitherto only manufactured and used as light-weight, non-structural sound-insulating panels for interior use to a wide range of structural and non-structural applications in housing and commercial buildings. The ACIAR-sponsored project enabled them to very effectively build on this foundation to expand the range of tree species known to be suitable for cement-composite manufacture, improve product quality and develop new products.

A good example of industry uptake of research findings and ideas from the project has been through a public–private partnership (FPRDI and EARN Corp.) that has become a driving force behind much of the evolution in WWCB technology and building applications. Architect Nestor David, CEO of EARN Corp., not only owns and manages a WWCB factory in Laguna but also designs a wide range of reinforced WWCB products, building systems, houses, and housing-estate plans. His WWCB factory, located in Bay, Laguna, is a small-scale industry employing local people (12 at the time of writing), using simple, locally supplied materials (Portland cement, plantation *Gmelina* wood, rattan and bamboo strips, and hot spring water) to produce a low-cost, naturally durable and non-toxic product. Project sponsored research at FPRDI on correct billet pre-storage and soaking regime, wood/water/cement ratios, and mat forming techniques has been used to good effect at this plant. Although small scale, approximately 700 m3 of WWCB is produced generating a value of 5 to 6 million pesos annually. The factory generates little or no waste as it recycles pulverised board trimmings back into new boards, and converts its wood off-cuts into charcoal. In fact it is the only WWCB plant still in existence today and flexibly caters to a niche market by hand-making 2 x 8 ft (0.6 x 2.4 m) WWCB sheets in a range of thicknesses and densities, with or without reinforcement and surface coatings to meet specific customer requirements.

Project impacts

Community impacts

The WWCB concept has evolved in the Philippines over the past 10 years from simple slab production of highly variable quality, and little knowledge of how to design and build using the products, into a comprehensive range of specialty products for which there are now innovative wall, roof, and flooring-system designs. Architects such as Nestor David have realised the potential of WWCB and have taken the concept to a new level through innovative building systems based on WWCB. These are in the process of being patented and have already been used to design and build a number of individual 'concept' houses, and an increasing number of housing-estate projects and resort facilities. In collaboration with Dr Bob Leicester of CSIRO, extension work on the project has formulated a set of comprehensive manufacturing and product performance standards, as well as a guide to builders for constructing WWCB-based structures. The WWCB plant in Bay, Laguna, employs nearby farmers both in the plant and supplying non-timber forest products (rattan and bamboo) used in board fabrication. Indirect sources of jobs associated with the cement-board industry include the plantation establishment, tending and harvesting, transport, marketing, and labour required to fabricate new dwellings.

Photo: K. Semple.

Home built almost entirely out of wood-wool cement-boards, Quezon city, Philippines.

The existence of concept buildings and houses in use that are made almost exclusively from WWCB, as well as the extension work to promote cement bonded boards undertaken by FPRDI, demonstrates to the community that there is a design- and cost-effective building system that has been developed largely in the Philippines to suit local conditions. A good working example of this was the donation of WWCB and assembly techniques from EARN Corp. to a slum-dwellers cooperative in Metro Manila. The slum-dwellers were able to learn the correct assembly techniques and build by themselves new dwellings for three large families from WWCB in just three weeks. In time this experience will help break down commonly held beliefs that imported materials and building technologies are somehow superior to local solutions. There is an onus, however, on manufacturers, designers and builders to ensure that cement-board products are manufactured to consistent quality and performance, and installed correctly in buildings to minimise deterioration in service and loss of consumer confidence in the materials. The ACIAR-funded extension work on development of product performance standards and building codes is helping ensure that these objectives are met. There is also external interest in the Filipino WWCB concept, with a visitor from South Africa to the EARN Corp. WWCB plant and negotiations underway for a shipment of boards to South Africa for trial.

The development of the foldaway shelter for emergency-housing needs after natural disasters is a significant offshoot from the project that deserves further attention from international disaster-relief agencies. This constitutes an efficiently designed, portable shelter that has a unit production

Photo: K. Semple.

Emergency, foldout shelter prefabricated from wood-wool cement-boards, Forest Products Research and Development Institute, Los Baños, Philippines.

and installation cost of approximately US$3,000 (lower as volume of units manufactured increases). Unlike tents or other temporary shelters made from plastic or plywood, the shelters form a one-step housing solution, since after initial assembly (which takes six to eight men an hour or two to assemble using simple carpenter's tools) can be extended to form permanent dwellings. In fact the design blueprints are also particularly well suited for mass-produced low-cost housing, mobile site offices and health clinics for remote areas; and a marketing and commercialisation strategy is currently in the process of being drawn up.

Scientific impacts

At the moment the most tangible outcome from the project has been the range of scientific and technical knowledge on topics ranging from chemical interactions between wood, cement and accelerator compounds to WWCB fabrication and building systems. A total of 16 refereed papers, 11 conference papers and six books and conference proceedings have been produced from the project. A book was published by ACIAR in 2002 entitled 'Wood-cement composites in the Asia Pacific region' from a conference on wood-cement composites held in Canberra in December 2000. Proceedings from the Cement Bonded Board Industry Forum and the Wood-wool Cement Board Standards Preparation Meeting, both held in Los Baños, Philippines, in December 2002 have also been published.

Technical booklets circulated to industry and builders in the Philippines from the project include the 'Manufacturers guide on wood wool cement board' and the 'Builders guide on wood wool cement board'. Another important development is the total of 22 wood-cement-based products and building systems that have been approved for use under the Accreditation of Innovative Technologies for Housing (AITECH) scheme. The provisional WWCB product performance standards, as well as concept and design blueprints for wall systems and small structures such as the foldaway shelter, are also made available from FPRDI.

The research done during the project has received international recognition for its quality and contribution to the field. In 2005, the project director in Australia, Prof. Philip Evans, received the inaugural Commonwealth Forestry Association Medal for the Americas in recognition of his work on the project. Project research by graduate and undergraduate students has also received acclaim in the form of prizes. Dr Rico Cabangon recently received the Philippine Agricultural and Resources Research Foundation Award (Research Category) for research on development of innovative wood-cement composites for use in emergency shelters and affordable housing. Dr Kate Semple received the prestigious George Marra Award for the best paper published in 2004 in Wood and Fiber Science. Jane Lynch, an undergraduate student, won the Australian TIMBIND prize for innovative research in forest products.

Outstanding problems

The most significant remaining gap in technical knowledge of WWCB product performance required by designers and builders in the Philippines is their acoustic and thermal insulation properties. The lack of access to testing facilities has prevented the gathering of empirical data on insulation properties of locally produced WWCB products compared with its competitors, and this is hampering the further development and marketing of WWCB into the much larger area of insulating materials for commercial and industrial building applications. The other remaining problems constraining the competitiveness of WWCB against competing products such as fibro-cement sheets and plywood are quality variation and the small economy of scale of a typical WWCB plant. As market demand picks up, ways of automating the process to scale up production capacity and reduce quality variation will need to be sought.

Reports in Adoption Studies Series

Mc Waters, V. and Templeton, D. (eds) 2004. Adoption of ACIAR project outputs: studies of projects completed in 1999–2000. ACIAR: Canberra.

Mc Waters,V., Hearn, S. and Taylor, R. (eds) 2005. Adoption of ACIAR project outputs: studies of projects completed in 2000–2001. ACIAR: Canberra.

Mc Waters, V. and Davis, J. (eds) 2006. Adoption of ACIAR project outputs: studies of projects completed in 2001–2002. ACIAR: Canberra.