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Australian Centre for
International Agricultural Research

Adoption of ACIAR project outputs

2014

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ACIAR
Research that works for developing countries and Australia
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The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. 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.

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ACIAR ADOPTION STUDIES

ACIAR seeks to ensure that the outputs of the research it funds are adopted by farmers, policymakers, quarantine officers and other beneficiaries. As part of its efforts to monitor the outputs and outcomes of its projects, ACIAR commissions project leaders and participants to revisit projects 3–4 years after completion, and report back to ACIAR on the medium-term outcomes of the work. This series reports the results of these studies. Numbers in this series are distributed internationally to selected individuals and scientific institutions, and are also available from ACIAR's website at <aciar.gov.au>.

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Cover: (left) Hill tribe minority farmers using wicker baskets to carry the local plum variety to the market in Bac Ha, Vietnam (Photo: B. Nissen); (top right) A proud farmer with his wheat (Var WH-147) crop near the village of Salamatpur, India. (Photo: N. Menzies); (bottom right) Peanuts are sold in small quantities at roadside markets in Papua New Guinea (Photo: M. Hughes).

Foreword

As part of its ongoing evaluation process, the Australian Centre for International Agricultural Research (ACIAR) periodically revisits a sample of past projects some time after their completion and critically appraises their outcomes. ACIAR commissions specialists to assess large projects 3 or 4 years after they are completed to determine the level of uptake of the project outputs and gauge the extent of the projects' legacies. The specialists study the outputs under three broad categories: the emergence of new technologies or practical approaches to tackle problems; the gaining of new knowledge that would lead to better understanding of scientific and socioeconomic aspects of agriculture; and the introduction of new structures to assist policymakers with decisions about the welfare of farmers and other stakeholders.

These retrospective studies have provided valuable insights that have helped in making decisions about further involvement in certain areas of research, and have provided accounts of lessons learned that aid planning and developing new projects. Many have yielded success stories that further confirm the value of ongoing investment in agricultural research as a means of development assistance.

This report is the 11th in our series of adoption studies. It examines seven projects completed around 2009–10. The scope of the projects indicates the broad sweep of ACIAR's brush. The countries involved—China, India, Pakistan, Papua New Guinea and Vietnam—all have long histories of successful collaboration in ACIAR projects. The projects covered food and crops, conservation agriculture and livestock.

It is gratifying to note that new technologies or practical approaches were the major outputs for most of these projects. They are bringing benefit at the farm level while underpinning the programs of research project managers, scientists and breeders. Some of the standout gains include new varieties of plum, peach and nectarine tailored to specific conditions, and improved pest and disease control methods in temperate fruit. In a world where food security has become an ongoing and growing issue, it is satisfying to report progress in lifting yields of peanut with superior varieties in Papua New Guinea and improved wheat harvests in India (with spin-off benefits for Australian farmers) through better integrated management of animal manure and inorganic fertiliser. Our longstanding research to improve the productivity of meat sheep in India has made significant progress that should lead to optimal productivity from specific genotypes. Finally, the adoption of raised bed technologies suited to the particular conditions of Pakistan and China has contributed benefits such as greater water use efficiency and better soil health, with consequent improvements in farmers' livelihoods.

The authors have provided a valuable summary of factors influencing the adoption and impact of key outputs from the projects. They remind us that challenges are ever present and provide valuable lessons for consideration in our future research investments.

Nick Austin
Chief Executive Officer, ACIAR

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ACP	Asiatic citrus psyllid
BAIF	Bharatiya Agro Industries Foundation (India)
FAVRI	Fruit and Vegetable Research Institute (Vietnam)
FRB	fresh raised bed
HLB	huanglongbing disease
IISS	Indian Institute of Soil Science
IPDM	integrated pest and disease management
NARI	Nimbkar Agricultural Research Institute (India)
PNG	Papua New Guinea
PRB	permanent raised bed
R&D	research and development
SAPRB	National Project to Stimulate the Adoption of PRB Farming (Pakistan)

Overview

AMIR JILANI, DAVID PEARCE AND ANDREW ALFORD

Introduction

This report summarises the adoption results for seven Australian Centre for International Agricultural Research (ACIAR) projects completed in 2009–10. The projects involved:

- five individual partner countries—China, India (two projects), Pakistan, Papua New Guinea (PNG) and Vietnam (two projects)
- six food- and crop-related projects—wheat (two projects), temperate fruits, peanuts, maize, soybean and citrus
- one conservation agriculture project designed to improve crop water use efficiency for farmers in China
- one livestock project aiming to improve sheep-meat production and rural incomes in India.

The outputs from the projects were as diverse as the countries and research areas they covered. Most projects developed new technologies (often new varieties of a crop), while some developed practical approaches designed for use by farmers (crop growers), breeders, project staff, managers or researchers.

Some projects also developed new scientific knowledge that will aid future research and management decisions. This included a better understanding of key pest and disease problems in temperate fruits, and enhanced knowledge about the susceptibility of citrus species and varieties to serious diseases. Five of the projects also developed knowledge for policy and policymakers, ranging from input into laws, regulations and institutional structures dealing with land aggregation to a seed multiplication and supply strategy.

All of the projects involved extensive capacity building in partner countries and institutions, ranging from formal university-based training to a variety of on-the-job training activities for technical staff, research scientists and farmers. Most projects improved the institutional capacity of collaborating organisations to undertake new research or continue existing research more effectively. Others also involved the establishment or enhancement of research facilities and infrastructure.

The seven adoption studies indicate medium to high levels of adoption of the project results, although in some cases adoption by final users was limited. In each case, the adoption results provide some useful lessons and observations.

What was discovered—project outputs

ACIAR's adoption studies classify outputs into three broad categories:

- **new technologies or practical approaches** dealing with particular problems or issues, and designed to be applied ultimately at the farm, processing or marketing level, or in some cases at the breeder level
- **new scientific knowledge or basic understanding** (pure or basic science) of the phenomena or social institutions that affect agriculture, designed as inputs into further research processes, ultimately to help in the future development of practical approaches for smallholders, processors, wholesalers and retailers
- **knowledge, models and frameworks for policymakers** or broad-level decision-makers, which are not necessarily for use at the farm level but will influence the contextual environment in which farmers, processors, wholesalers and retailers must operate.

Given the diversity of ACIAR-funded research, there is considerable overlap between these categories, and many projects contribute to more than one of them. Table 1 summarises the the outputs for the seven projects covered in this report.

New technologies or practical approaches were the major outputs of most of the projects. They were targeted at both the farm level and more broadly at research project managers, scientists and breeders.

New technologies and approaches at the farm level included:

- new varieties of plum, peach and nectarine
- improved pest and disease control methods in temperate fruit
- mechanisation adapted to farmers' needs
- the use of satellite imagery technology
- the identification and selection of improved sheep genotypes and management strategies to optimise ovine productivity
- permanent raised bed technology compatible with field sizes to prevent waterlogging and salinisation, improve crop production and reduce the amount of water used for irrigation
- high-yielding peanut varieties
- fertiliser management strategies to improve wheat yields.

New scientific knowledge was an important output from three projects. It included better understanding of the major pests and diseases affecting temperate fruits in Vietnam, and enhanced knowledge about the susceptibility of citrus species and varieties and citrus relatives to serious diseases in Indonesia, Vietnam and Australia.

Five projects also developed **knowledge or models relevant to policymakers**. This included new knowledge about fresh raised beds, irrigation and residue management and input into laws, regulations and institutional structures affecting land aggregation in China. A new seed multiplication and supply strategy in PNG is also relevant to policymakers. In addition, one project provided recommendations for the generation and dissemination of improved sheep genotypes to enhance sheep production in India.

Table 1. Summary of project outputs

New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
Improving postharvest quality of temperate fruits in Vietnam and Australia		
30,000 trees of new varieties of plum, peach and nectarine multiplied at government nurseries and released to farmers New orchard-management techniques Improved pest and disease control methods New harvest indices allowing fruit to be harvested with greatly improved colour and sweetness New postharvest technologies (such as postharvest dips) Improved cool chain practices Improved supply and value chains New dried fruit products Improved technology transfer, including farmer manuals on production, pests, diseases, and integrated pest and disease management	Identification of major pests and diseases	

continued …

Table 1. (continued)

New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
Promotion of conservation agriculture using permanent raised beds in irrigated cropping in the Hexi Corridor, Gansu, China		
Promotion of conservation agriculture production systems that require lower inputs and improve water use efficiency, maintain soil health and improve farmers' livelihoods Adaptation of existing crops to new farming practices, including zero-till farming systems Mechanisation adapted to farmers' needs Appropriate management of crop residues and competing off-farm demands		Policy advisory papers, seminars and workshops on fresh raised beds, irrigation and residue management Input into laws, regulations and institutional structures dealing with land aggregation, the disposal of farm residue and machinery acquisition processes Conservation agriculture cartoon book made available in seven languages to facilitate adoption
Productivity and market enhancement for peanut in Papua New Guinea and Australia		
High-yielding peanut varieties, including four early-maturing (110 days) and six medium-maturing (130 days) varieties for lowlands, and five early- and four medium-maturing varieties for highlands Best management practice Satellite imagery technology Market scoping study to assess potential and feasibility of new markets and products for peanuts	Monitoring of aflatoxin, a major food safety problem in peanuts and some other crops	Seed multiplication and supply strategy
Improved productivity, profitability and sustainability of sheep production in Maharashtra, India, through genetically enhanced prolificacy, growth and parasite resistance		
Improved diagnostic test (PCR-RFLP DNA test) for detection of the Booroola fecundity gene (*FecB*), which has the potential to enhance prolificacy and productivity Improved sheep genotypes carrying the *FecB* gene.		Policy recommendations, including wider introgression of the *FecB* gene into Indian breeds of sheep Recommendations for the generation and dissemination of improved sheep genotypes

continued …

Table 1. (continued)

New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
Management strategies to optimise the productivity of genotypes carrying the *FecB* gene		
Refinement and adoption of permanent raised bed technology for the irrigated maize–wheat cropping system		
Permanent raised bed machinery matched to Pakistani field sizes and farm finances Soil management through the use of a bedformer/renovator machine to improve soil condition and irrigation efficiency Demonstration and subsequent understanding of the comparative productivity and irrigation efficiency of wide and narrow beds Improved irrigation efficiency through irrigation scheduling		Simulation modelling tool that can be used in setting research priorities and managing research funding Simulation modelling of irrigation timing and amount
Integrated manure nutrient management in soybean/wheat cropping systems on Vertisols in Madhya Pradesh and Queensland		
Two fertiliser management strategies—integrated nutrient management and balanced fertilisation Broad bed and furrow cultivation as an agronomic strategy to overcome some of the adverse effects of waterlogging Improved understanding of the causes of nutrient loss from compost pits and potential strategies for reducing losses, including bunding of pits Use of rhizobium inoculation of soybean encouraged during the project to increase yields or reduce fertiliser demand		

continued ...

Table 1. (continued)

New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
Huanglongbing management for Indonesia, Vietnam and Australia		
Indirect recommendation for the use of mineral oils through collaborating institutions after studies in Indonesia and Vietnam confirmed that mineral oils, pesticides (including systemic insecticides) and natural enemies may reduce the incidence of Asiatic citrus psyllid *Diaphorina citri* and slow the spread of huanglongbing in orchards	Postgraduate studies, initially in Indonesia and then in Australia, to determine the identity of orange jasmine and show that the correct specific name is *Murraya exotica*, resolving two centuries of uncertainty and controversy Enhanced knowledge of the susceptibility of citrus species and varieties and citrus relatives to huanglongbing, the most serious disease of citrus, through studies in the Mekong Delta	Incursion management plan developed for the Australian citrus and nursery industries for incursions of the pathogens that cause huanglongbing or the vectors of the pathogens, including Asiatic citrus psyllid

Capacity development

Most of the projects reported here had explicit objectives to improve the capacity for research and development in partner countries, and all had substantial capacity-building outcomes. Table 2 summarises the capacity built and used in the projects.

Capacity development included training in basic experimental and research skills and farming practices, delivered in formal settings and through less formal on-the-job training and mentoring. Some projects involved training to obtain higher academic qualifications, including PhDs and Masters degrees.

A number of projects included the provision or enhancement of research infrastructure, varying from infrastructure and machinery for commercial seed production of peanut varieties in PNG to infrastructure (including laboratories and animal handling facilities) for sheep-related research in India.

In most cases, the research capacity and research infrastructure continue to be used. The collaboration developed between organisations remains in place, and staff skills and expertise developed through training continue to be used. However, there are some exceptions. For example, the capacity to use satellite imagery technology developed in collaborating organisations in PNG could not be sustained beyond the project, either because the trained personnel changed employers or because the business priorities of the collaborating agencies changed. Similarly, extension officers are not using the knowledge and skills they gained from the irrigated maize–wheat cropping system project in Pakistan. This is partly because of a lack of enquiries from farmers, but also because the extension workers are not proactive in pursuing similar programs and outcomes.

Table 2. Research capacity built by the projects and continued use

Partner-country/ies research capacity built	Research infrastructure	Capacity used
Improving postharvest quality of temperate fruits in Vietnam and Australia		
Farmers and extension officers were trained in fruit management in subtropical environments. In particular, two farmers and one extension officer received training during an Australian study tour on how technologies and practices used by Australian stonefruit producers could be adapted and applied to Vietnamese farms. The project improved the institutional capability of the National Institute of Plant Protection and Fruit and Vegetable Research Institute (FAVRI) for identifying and controlling major pests and diseases of temperate fruits. Thirty government extension workers and local village extension workers attended a stonefruit extension workshop covering all aspects of peach and plum production. The project improved the institutional capability of FAVRI and the extension centres (Bac Ha Research and Extension Centres, Lao Cai Variety Research Centre, Moc Chau Research Station) for mapping supply chains of temperate fruit and identifying limitations and potential improvements in the chain.		Some extension workers trained during the project continue to share their knowledge with farmers in their district or commune. The research and extension agents have also established good links with researchers and research agencies in Australia. Other regional extension officers have moved on and no longer work in this area. The project orchard blocks at Bac Ha Research Station and Moc Chau Research Station continue to provide an excellent training resource, not only for the project but also for the many groups of extension workers and farmers who visit.
Promotion of conservation agriculture using permanent raised beds in irrigated cropping in the Hexi Corridor, Gansu, China		
The conservation agriculture skills, knowledge and expertise of researchers, extension agents, farmers and manufacturers were enhanced. Research sites gave five researchers, five Masters students and one PhD candidate a good platform for their research. Project fields were used to promote conservation agriculture and train researchers from various institutions. An agricultural machinery textbook was re-edited to include a specialist chapter on forms of tillage. Project participants produced eight conference papers and eight journal articles (at least four more are in preparation).		Gansu Agricultural Mechanisation Bureau staff regularly use the capacity, knowledge and innovation introduced through Australian visits, domestic workshops, train-the-trainer courses and farmer field schools. They apply the lessons learned in the project in a wide range of situations, including new government extension programs in conservation tillage and water saving. Researchers from China Agriculture University's College of Resources and Environmental Sciences use the project fields to train postgraduate students in conservation agriculture.

continued ...

Table 2. (continued)

Partner-country/ies research capacity built	Research infrastructure	Capacity used
Productivity and market enhancement for peanut in Papua New Guinea and Australia		
The project set up capacity to analyse aflatoxin in peanuts at the National Agriculture Research Institute and Ramu Agri-Industries Ltd. Collaborating scientists trained in peanut agronomy demonstrated an increase in crop yields in all on-farm trials. Collaborating scientists developed skills in satellite imagery technology, including image ordering, processing and validating (GPS operation), for yield prediction and weed and disease monitoring. The Queensland Department of Agriculture, Fisheries and Forestry developed the capacity to apply imagery technology in a range of areas in the peanut industry, including yield prediction, maturity prediction, cost analysis, disease monitoring and regional yield forecasting.	Infrastructure for commercial seed production of peanut varieties was established at Ramu Agri-Industries by importing a peanut planter and thresher from Australia. Company staff were trained to operate the machinery.	The peanut research experience gained by Ramu Sugar (part of Ramu Agri-Industries) and the National Agriculture Research Institute collaborators has enabled them to assist Solomon Islands. As part of the ACIAR Livelihood Program (April 2009 to June 2010), they designed a peanut seed supply scheme and provided training on best management practices in peanut production to 171 research and extension officers and farmers in Solomon Islands. Information generated by the project on aflatoxin contamination of peanuts in roadside markets continues to be used by researchers. The aflatoxin research experience gained by the research institute chemistry laboratory staff has enabled them to strengthen collaboration with the School of Medicine and Health Sciences at the University of PNG to assess the prevalence of aflatoxin contamination in peanuts and peanut foods. The capacity in satellite imagery technology developed at the collaborating agencies could not be sustained beyond the project because the trained personnel changed employers or or because of changes in the agencies' business priorities. In Australia, satellite imagery and the processing protocols developed in the project have been used for estimating the total yield of a broadacre peanut crop via pod yield and to accurately identify disease, irrigation inefficiencies and inherent spatial variability resulting from constraints on production. The technology has also spread into other cropping and horticulture industries.

continued ...

Table 2. (continued)

Partner-country/ies research capacity built	Research infrastructure	Capacity used
Improved productivity, profitability and sustainability of sheep production in Maharashtra, India, through genetically enhanced prolificacy, growth and parasite resistance		
Two PhD scholars were trained during the project, in animal breeding and molecular genetics. The project enhanced the skills and capacity of almost all staff at the Nimbkar Agricultural Research Institute (NARI), including in sheep reproductive technology, parasitology techniques and extension methods.	Infrastructure for sheep-related research (laboratories, yards, animal handling facilities etc.) was enhanced at NARI.	Scholars trained in the project have progressed to successful scientific careers. One continues to work on the development of improved *FecB*-carrying sheep at NARI and on dissemination throughout India. The other holds senior advisory positions and continues to advocate for more effective sheep and goat breeding programs in India. NARI staff continue to use their skills, including as trainers and consultants and in their interactions with local shepherds. One staff member at NARI has adapted and improved the methodology for the DNA test for the *FecB* mutation and performs the test routinely with high accuracy. At NARI, the knowledge, skills and infrastructure developed under the project continue to be used for purposes consistent with the aims of the project.
Refinement and adoption of permanent raised bed technology for the irrigated maize–wheat cropping system		
An estimated 26 researchers, 60 extension staff, 20 research and development managers, 7 manufacturers and 200 farmers were trained in permanent raised bed (PRB) farming and technology. The project developed Water Resources Institute researchers' capacity in soil management and irrigation practices.		Water Resources Institute researchers continue to use their awareness and knowledge to develop new research projects to adapt PRB farming technology to a wider range of crop types and agroecological zones in Pakistan. Extension officers are not using the knowledge and skills they gained from the project, partly because of a lack of enquiries from farmers and because they are more reactive than proactive in pursuing programs and outcomes. Research managers continue to direct and facilitate research into ways of refining PRB technology for a wider range of crops in a wider range of agroecological zones while encouraging collaboration with farmers.

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Table 2. (continued)

Partner-country/ies research capacity built	Research infrastructure	Capacity used
Integrated manure nutrient management in soybean/wheat cropping systems on Vertisols in Madhya Pradesh and Queensland		
The project induced cultural change in partner research institutes, including the Indian Institute of Soil Science (IISS) and the Bharatiya Agro Industries Foundation (BAIF). This included a better understanding of how to work with farming communities and with other external research providers. Individual researchers' knowledge and personal capabilities benefited from cultural exchanges and trips between India and Australia. Capacity built by the project has provided IISS with new crop-modelling capabilities. The project introduced a mother–baby trial concept, in which mother trials were followed in subsequent seasons by smaller, unreplicated trials by farmers to validate initial results for the most promising treatments. Three hundred farmers were directly involved in the baby trials program.		Cultural change fostered by the project is allowing IISS to engage with external research providers and deliver its soil science and agronomy expertise into a wider range of areas in agriculture. BAIF is now regularly involved in the provision of crop nutrition advice and also tailors its advice to the needs and capacities of individual farmers. It is unclear whether individual researchers continue to use the capabilities developed as a result of the project. BAIF has used the established baby trial areas for farmer field day activities, exposing many more farmers to the fertiliser regimes developed in the project.
Huanglongbing management for Indonesia, Vietnam and Australia		
Research capacity in Indonesia, Vietnam and Australia was enhanced through collaboration in field and laboratory studies, meetings and discussions, and through the supervision of seven postgraduate students in Indonesia and one postgraduate student from Vietnam at the University of Western Sydney (UWS). A workshop in Yogyakarta in 2004 developed the capacity of Indonesian, Vietnamese and Chinese scientists to use field microscopes for diagnosing huanglongbing (HLB). Meetings, workshops and field days in Indonesia built the capacity of Indonesian Ministry of Agriculture staff, Universitas Gadjah Mada researchers and students, extension officers from Java, Kalimantan, Sulawesi and Bali, and farmers in Central Java.		Two graduates are now university lecturers; one is actively involved in research and extension related to Asiatic citrus phyllid and HLB. Strong links continue between institutions involved in the project, including UWS and Universitas Gadjah Mada. Capacity gained through increased knowledge about the taxonomic status of citrus species and varieties is being used for biosecurity and incursion management. It will continue to influence research and policies related to dealing with the threats posed by HLB.

continued …

Table 2. (continued)

Partner-country/ies research capacity built	Research infrastructure	Capacity used
Australia's capacity to combat incursions of HLB and its vectors was strengthened by the production of an HLB incursion management plan for the Australian citrus and nursery industries. Seven seminars and workshops based on a comprehensive review and analysis of literature on the disease and vectors of the pathogens also built Australian capacity.		

Uptake of the R&D outputs—progress along adoption pathways

Most of the projects had a number of different objectives and outputs. Summarising the often complex adoption outcomes for a range of projects is inevitably a difficult task and involves an element of judgement. For the summary in Table 3, a four-level classification scheme has been used (as in previous adoption reports).

In this classification scheme, the lowest level of adoption is *0*, or no uptake of the results by either initial or final users of the outputs of the project. Five projects had no adoption of some of the project outputs (although there was medium to high adoption of other project outputs). In the temperate fruits project in Vietnam, for example, there was no adoption of improved cool chain practices by next or final users. In the irrigated maize–wheat cropping system project in Pakistan, there was similarly no evidence of adoption of simulation modelling by policymakers and researchers.

The next level of adoption is *N*, in which there has been some uptake by initial users but not by final or ultimate users of the research. Three projects had some outputs in this category (although other outputs had lower or higher levels of adoption): the conservation agriculture project in China, the peanut productivity and market enhancement project in PNG and the citrus disease management project in Indonesia, Vietnam and Australia.

The next level of adoption is *Nf*, in which there has been uptake by initial users and some uptake by ultimate users. All seven projects had at least some outputs in this category. For example, in the refinement and adoption of permanent raised bed (PRB) technology project in Pakistan, the supply of downsized Australian PRB machinery stimulated immediate adoption by farmers in the early stages of the project. However, in recent years, there has been extensive dis-adoption (abandonment) of PRB in favour of narrow fresh beds. This has been driven mainly by design, reliability and cost problems related to PRB machinery.

The highest level of adoption, *NF* (use by initial and final users), was achieved in at least some of the components of four of the projects. For example, after the conservation agriculture project in China, conservation agriculture has been included in the national government's Five-Year Plan as a water saving strategy to be implemented and promoted. Similarly, after the integrated manure nutrient management project in India, the management approach developed in the project was widely adopted by farmers. This has been partly due to the increased rate of fertiliser nutrient application associated with the management approach, which has been driving significant wheat yield increases.

Table 3. Current levels of adoption of key project outputs

New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Improving postharvest quality of temperate fruits in Vietnam and Australia		
Nf—There has been slow adoption of new varieties of fruit. Current users include research stations and selected farmers. *Nf*—Some techniques, such as pruning, have been well adopted by farmers (40%); others, such as fruit thinning, have been poorly adopted (<5%). *Nf*—Most farmers are using fungicides and pesticides when there are major problems. There is currently no adoption of integrated pest and disease management or fruit-fly bait sprays. *Nf*—There has been modest adoption of new harvest indices by farmers (16%). *Nf*—Adoption of new postharvest technologies such as postharvest dips has been limited to project farmers. *O*—There has been no adoption of improved cool chain practices. *Nf*—10% of farmers have adopted new improved packaging that was introduced during the project to reduce impact damage and improve fruit quality after transport. *Nf*—Adoption of new dried fruit products by processors and farmers has been limited (4%). *Nf*—There has been good uptake by extension agents of farmer manuals on production, pests and diseases, and integrated pest and disease management, and limited uptake by farmers. The current users of these manuals are mostly research and extension officers and project farmers.	*NF*—Excellent publications on the identification of key pests and diseases are being used by research and extension officers. The knowledge is also being shared with farmers.	

continued ...

Table 3. (continued)

New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Promotion of conservation agriculture using permanent raised beds in irrigated cropping in the Hexi Corridor, Gansu, China		
O—Conservation agriculture production systems have not been adopted by farmers, as the demonstrated efficiency and production gains were not significant. *N*—There is some use of zero-till farming systems, mainly by the Gansu Agricultural Mechanisation Bureau (GAMB) through demonstration sites. However, the non-adoption of conservation agriculture production systems by farmers has meant that existing crops have not been adapted to permanent raised bed (PRB) farming. *N*—Fresh raised bed seeders and strip till seeders are being used by some government controlled and semigovernment organisations. However, there has been no adoption of mechanisation technologies, including zero-till conservation agriculture equipment, by farmers. *N*—There has been minimal adoption of crop residue management by farmers, but considerable use by corporate and demonstration farming operations.		*NF*—Conservation agriculture has been included in the national government's Five-Year Plan as a water saving strategy to be implemented and promoted. *NF*—GAMB continues to hold meetings, demonstrations, displays and farmer field schools, mainly for conservation tillage, PRB and conservation agriculture. The theory presented at these activities comes from fresh raised bed, irrigation and residue management knowledge gained during the project. *Nf*—Ex-collaborators of the project have had considerable input into the machinery acquisition processes associated with the National Conservation Tillage Long Term Project.

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Table 3. (continued)

New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Productivity and market enhancement for peanut in Papua New Guinea and Australia		
N—Adoption of high-yielding peanut varieties by growers has been low, particularly because the varieties are not suitable for fresh markets. There is also no buying point for new varieties. There is some use by researchers. *Nf*—Elements of best management practice (row spacing and seeding density) are being adopted by some growers, while problems with the cost or availability of chemicals and local beliefs about the use of soil amendments (such as lime) are limiting adoption overall. *N*—Although there was some use of satellite imagery technology by researchers, the capacity was lost when trained staff in collaborating agencies changed employers or moved to different roles. *O*—Changes in industry priorities, particularly in private agencies such as Ramu Sugar and Trukai Industries, have had a negative impact on the exploration of new markets for peanut products.	*N*—The survey of aflatoxin contamination in peanuts led to an improved understanding of the effects of planting time on aflatoxin. However, the loss of trained human resources and the lack of national policy to pursue the implementation of food safety regulation have limited further adoption of this output.	*N*—Change in industry priorities at Ramu Sugar and Trukai agencies has affected the seed supply strategy, limiting adoption in private and public agencies. There is some use by researchers in developing varieties suitable for local markets.
Improved productivity, profitability and sustainability of sheep production in Maharashtra, India, through genetically enhanced prolificacy, growth and parasite resistance		
Nf—There has been some use of the PCR-RFLP DNA test for detection of the *FecB* fecundity gene at the National Agriculture Research Institute (NARI) and the Central Sheep and Wool Research Institute, but wider adoption by end users has been limited because they perceive it as too expensive. *NF*—Adoption of improved sheep genotypes carrying the *FecB* gene has been high. There are clear signs of ongoing and increasing dissemination, including to neighbouring Karnataka. *Nf*—There is evidence that extension messages on improved animal nutrition are being implemented by some farmers. This has not been uniform, and other management strategies to optimise the productivity of improved sheep genotypes carrying the *FecB* gene have not been widely adopted by farmers.		*Nf*—Government policies and research activities supporting the generation and dissemination of improved sheep genotypes have been mixed. In Maharashtra, new projects do not have a particular emphasis on *FecB*. This may change in the light of recent awareness of the project findings at NARI. However, the Karnataka state government is launching a major project to introduce *FecB* into the Bellary and Deccani sheep breeds.

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Table 3. (continued)

New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Refinement and adoption of permanent raised bed technology for the irrigated maize–wheat cropping system		
Nf—The supply of downsized Australian PRB machinery stimulated immediate adoption by 39 tenant farmers in the early stages of the project. In the past 3 years, there has been extensive dis-adoption (abandonment) of PRBs in favour of narrow fresh beds, driven by problems with the design, reliability and cost of PRB machinery. *Nf*—Researchers and research managers have used information on managing soil with the bedformer/renovator machine to investigate the implications for improved irrigation practices and irrigation efficiency. This information was of lesser interest to farmers and machinery manufacturers. *NF*—The comparable productivity of wide and narrow beds is now fully accepted as conventional wisdom among all levels of users, but most importantly by farmers in Pakistan. *O*—There is no evidence of adoption of irrigation scheduling as a means of achieving greater irrigation efficiency in Pakistan.		*O*—There is no evidence of simulation modelling being used to maximise lateral infiltration and minimise capillary rise in a quantitative or qualitative way by next users. *O*—Simulation modelling of irrigation timing and amount is only just emerging from modelling being finalised from Pakistan data unanalysed at the end of the project. There is no sign of use of this output by final users, but the output is very recent.
Integrated manure nutrient management in soybean/wheat cropping systems on Vertisols in Madhya Pradesh and Queensland		
NF—The integrated nutrient management approach developed in the project has been widely adopted. A key aspect of this is the increased rate of fertiliser nutrient application, which has been driving wheat yield increases. *Nf*—In areas with poor drainage, the broad bed and furrow technique gave farmers a simple and inexpensive means of temporarily achieving good soybean crop establishment and increased yields. However, wider adoption will be constrained because rice cultivation has now been introduced in the monsoon season, replacing soybean cultivation in wetter areas. *O*—While the project demonstrated that much nutrient loss from compost pits was the result of leaching or run-off and highlighted strategies for reducing that loss, there has been no evidence of adoption of changed practices. *NF*—Farmers have widely understood the need for effective nodulation of the soybean crop, which ultimately increases yields or reduces fertiliser demand. They now have a better understanding of this benefit and routinely use the inoculum supplied with the soybean seed that they buy.		

continued ...

Table 3. (continued)

New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Huanglongbing management for Indonesia, Vietnam and Australia		
N—Mineral oils are being used alone or as adjuvants in sprays for suppressing the incidence of Asiatic citrus phyllid, some other pests and some fungal foliar diseases of citrus in Vietnam, but the extent of use has not been quantified. Adoption of mineral oils in management programs for Asiatic citrus phyllid and huanglongbing was hampered in Indonesia because no products were initially registered. Later, one product that became registered was deemed unsuitable for use.	*Nf*—*Murraya exotica* has been adopted as the valid specific name of orange jasmine by the United States Agricultural Research Service's Germplasm Resources Information Network. It is gradually being adopted in lieu of *Murraya paniculata* by Unites States and Brazilian authors of papers published in scientific journals.	*Nf*—The huanglongbing incursion management plan has been used for extension, research and policy development and will remain a useful document for several years. However, it requires comprehensive revision to incorporate new knowledge and lessons from successful post-incursion management responses in the Americas.

Note: Level of uptake is summarised as high, medium, low or none using the following abbreviations:

NF Demonstrated and considerable use of results by the initial and final users

Nf Demonstrated and considerable use of results by the initial users but only minimal uptake by the final users

N Some use of results by the initial users but no uptake by the final users

O No uptake by either initial or final users.

Factors contributing to the adoption of project outputs

Many factors always underlie particular adoption outcomes. They can be summarised as follows:

- Knowledge
  - Do the final or ultimate users *know* about the project outputs?
  - Is there *continuity* of staff in organisations associated with adoption, leading to the ongoing transfer of knowledge?
  - Are the outputs *complex* in comparison with the capacity of users to absorb them? (Do users have a sufficient knowledge base to support adoption?)
- Incentives
  - Do users have sufficient *incentives* to adopt the outputs?
  - Does adoption of the outputs increase *risk or uncertainty* for the users, thus reducing incentives to adopt?
  - Is adoption either *compulsory* or indirectly *prohibited*? (Are there extreme forms of incentives or barriers?)

- Barriers
  - Do potential users face *capital or infrastructure constraints*, limiting their ability to fund the adoption of the outputs?
  - Do potential users of the outputs face *cultural or social constraints* on adoption?

Table 4 summarises some of the major factors affecting adoption for the projects reported here.

Relatively high levels of adoption of some outputs appear to have been driven by strong economic incentives, such as improved production and incomes, reduced costs and, in Pakistan, increased irrigation or other water use efficiency.

Relatively low levels of adoption of other outputs resulted from different factors, including risk aversion and hesitation to abandon traditional growing practices, staff turnover and low retention of trained personnel, including researchers and extension officers (in the Vietnam temperate fruits project), knowledge or skills constraints, and limited incentives for surplus production without secure buying points (in the PNG peanut project). In some cases, such as the conservation agriculture project in China, insufficient production and efficiency gains and therefore limited economic incentives restricted adoption.

Table 4. Factors influencing adoption and impact—summary of key findings

Factor	Key findings
Knowledge	
Do potential users know about the outputs?	*Temperate fruits in Vietnam and Australia.* Most farmers were aware of project activities and outputs, but the adoption of new temperate fruit technologies was limited because of their aversion to risk. The need for income and food security among the poorest groups in north-west Vietnam means that many are reluctant to abandon traditional growing practices and prefer to grow cash crops, such as maize and vegetables. *Conservation agriculture in the Hexi Corridor, China.* Although the adoption of conservation agriculture was extremely limited, the technology is not foreign to farmers. Most are aware of the potential benefits of conservation agriculture but have not taken any action. A host of factors, including financial constraints, cultural norms, risk aversion and knowledge or skills constraints, contributed to the low levels of adoption. *Sheep production in Maharashtra, India.* Understanding, awareness and interest in the *FecB* genotype have been spreading rapidly, driven by shepherds' active involvement in the project. However, the need for a DNA test to detect the *FecB* genotype in improved genotypes has affected the rate of adoption; informal questioning of farmers suggests that the current price of the test is too high. *Permanent raised bed technology in Pakistan.* Farmers associated with the project adopted the new technology with enthusiasm and shared their knowledge and experiences with their neighbours. However, problems with the weight and cost of PRB machinery have hampered wider adoption.

continued …

Table 4. (continued)

Factor	Key findings
	Integrated manure nutrient management in Madhya Pradesh, India. Most farmers, including those not participating in the project, became aware of the integrated nutrient management approach developed by the project and adopted it with enthusiasm because the increased rate of application demonstrated significant wheat yield improvements. Other outputs, such as the broad bed and furrow cultivation technique, were initially popular among farmers but were not widely adopted because rice cultivation was introduced in the monsoon season, replacing soybean cultivation; rice yields are much higher, and the price paid per unit of rice is much higher than that paid for soybean. *Huanglongbing management for Indonesia, Vietnam and Australia.* One of the many factors identified as restricting adoption and impact from the project was the limited knowledge of farmers about huanglongbing and Asiatic citrus phyllid and about the use of pesticides and mineral oils as a potential strategy to slow the spread of the disease within orchards.
Is there continuity of staff in organisations associated with adoption?	*Temperate fruits in Vietnam and Australia.* A low retention rate of trained personnel, including researchers and extension officers, greatly affected the adoption rate. *Peanut in PNG and Australia.* Adoption of satellite imagery technology was restricted because of loss of trained staff in collaborating agencies. Monitoring of aflatoxin in peanuts was also disrupted because trained personnel changed employers. This loss of expertise has affected the capacity built by the project in all collaborating agencies. *Sheep production in Maharashtra, India.* Research staff trained at the National Agricultural Research Institute continue to use their skills and expertise in different areas, including sheep genetics, breeding, production and extension. This enhanced capacity has led to major ongoing Indian-funded research projects at the institute for further sheep breeding work.
Are outputs complex in comparison with the capability of the users?	*Sheep production in Maharashtra, India.* While the improved sheep genotypes are designed to perform well in their local environment in the absence of management change, they are more responsive to improved management than are unimproved genotypes. However, some of the extension messages and management strategies to optimise the productivity of improved sheep genotypes carrying the *FecB* gene were too complex for farmers to implement. In particular, messages about restricting the application of additional feed to only those animals requiring it at particular phases of the production cycle were not widely understood among shepherds and their advisers.
Incentives	
Are there sufficient incentives to adopt the outputs?	*Temperate fruits in Vietnam and Australia.* The risks of growing temperate fruits, which have long periods between planting and economic returns, compared with growing cash crops such as maize or vegetables, were too great for ethnic minority farmers. Many farmers also stated that the low prices for plums were not worth the added risk. The significant costs of fertilisers and pesticides needed to produce high-quality fruit and prevent a rapid decline in tree health further limited incentives to grow temperate fruit.

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Table 4. (continued)

Factor	Key findings
	Conservation agriculture in the Hexi Corridor, China. The adoption of conservation agriculture using permanent raised beds was very limited because the efficiency and production gains demonstrated by the project were not significant enough to sway farmers. The rural community is fixated on production and perceives that yields under conservation agriculture are lower or will increase only marginally over time. However, adoption is expected to progress in the future as increasing labour constraints, ecological needs and lack of water will create a greater need for conservation agriculture, particularly in currently irrigated and high-rainfall areas. *Peanut in PNG and Australia.* Although the project demonstrated the yield and quality advantages from varietal choices and management practices, there has been no uptake of new high-yielding peanut varieties by farmers mainly because commercial avenues for those varieties under consideration at the start of the project did not eventuate. Since farmers had little incentive to produce more than they could sell at roadside markets, private-sector agencies were expected to take the lead in setting up buying points for smallholders' produce. However, changed priorities in the agencies significantly affected the development of commercial avenues for peanuts. *Sheep production in Maharashtra, India.* Increased lamb meat production per ewe or per unit of sheep feed consumed is the main technical benefit of adopting improved sheep genotypes, leading to increased income. The benefits are being realised on farms where improved genotypes have been introduced. Importantly, any gains have to be weighed against increased feed requirements and mortality rates. *Permanent raised bed technology in Pakistan.* There are sufficient incentives for farmers to adopt PRB technology and PRB farming, including increased crop production per unit area, lower input costs, lower water costs, increased crop area and substantially increased profit. There are also incentives for manufacturers and service providers to provide the technology, particularly if they overcome previous design flaws. The Australian-designed machinery used was too heavy and too expensive for small fields and farms in Pakistan. If the machinery is improved, adoption is expected to expand immediately and rapidly throughout Pakistan. *Integrated manure nutrient management in Madhya Pradesh, India.* A key factor driving the adoption of the integrated nutrient management approach developed in the project was the increased rate of fertiliser nutrient application, which is associated with higher yields. There is also a strong economic incentive for farmers to adopt higher application rates because the use of mineral fertilisers is financially attractive at current fertiliser and wheat prices. *Huanglongbing management in Indonesia, Vietnam and Australia.* Adoption was hampered by the incurable nature of huanglongbing, its rapid and devastating impacts, and the impact of other diseases that affect the longevity of citrus trees. In addition, there are no effective and sustainable strategies, natural or otherwise, to effectively limit the rapid spread of Asiatic citrus phyllid. These factors limit the incentives to adopt research outputs.

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Table 4. (continued)

Factor	Key findings
Does adoption increase risk or uncertainty?	*Temperate fruits in Vietnam and Australia.* A key factor limiting adoption was that many of the project's ethnic minority farmers are extremely poor and therefore strongly averse to changes that could threaten their income security. Many found that adopting temperate fruit technologies would increase their exposure to risk and delay their economic returns. *Conversation agriculture in the Hexi Corridor, China.* Adoption was limited because of the risks that farmers and extension agents associated with conservation agriculture, including reduced production and yields in the short term. There is considerable risk aversion in the rural community, exacerbated by financial, cultural and knowledge constraints.
Is adoption compulsory or effectively prohibited?	This did not appear to be a major factor in these projects.
Barriers	
Do potential users face capital or infrastructure constraints?	*Temperate fruits in Vietnam and Australia.* Lack of investment capital and income among farmers limits their ability to introduce new technologies and is probably the biggest factor limiting the adoption of new temperate fruit technologies. *Conservation agriculture in the Hexi Corridor, China.* Lack of strong technical support and capital investment to implement conservation measures is limiting adoption, and subsidies and incentives are generally geared to crop production and not conservation measures. Following the project, there was no government support for the technology and specialised planting equipment was neither developed nor promoted. *Permanent raised bed technology in Pakistan.* The Australian-designed PRB machinery was found to be too expensive and too heavy for small fields and farms in Pakistan. The capital investment required and design problems in the PRB technology were major barriers to adoption. *Huanglongbing management in Indonesia, Vietnam and Australia.* Effective, widespread adoption by farmers of practical knowledge stemming from the project and other sources requires significantly higher investment in capacity building than occurs now. This is a major and possibly insurmountable challenge, given the incurable nature of the disease, the limited resources available for technology transfer and extension, the high cost and limited availability of pathogen-free planting material, the large number of small farms, the wide absence of area-wide management programs, and limited funding and support to maintain capacity and collaboration within and between participating countries.
Are there cultural or social barriers to adoption?	*Conservation agriculture in the Hexi Corridor, China.* Farmers and extension agents were reluctant to depart from conventional cultural practices because of their high risk aversion and lack of skills. The rural community and the government are fixated on production and perceive that yields under conservation agriculture are lower or will increase only marginally over time. Interwoven in these perceptions were farmers' largely restrictive short-term views. Cultural norms therefore contributed to the lack of adoption of conservation agriculture.

Lessons

The results from the adoption studies reported here provide a number of lessons for ACIAR-funded projects.

Identify the most limiting constraints

In the temperate fruits project in Vietnam and Australia, a major lesson was the need to identify the most limiting constraints affecting adoption. ACIAR projects on temperate fruits appear to focus on either production or supply-chain issues. While mapping the supply chain and identifying better marketing systems are important, that alone will not deliver the economic performance needed unless a high-quality product leaves the farm gate. The best approach for future industry development and for selecting R&D priorities would be to identify and tackle the most limiting constraints based on analyses of the whole system (production, supply chain and marketing). Future ACIAR projects on temperate fruits should develop an adoption strategy that targets those constraints before the projects are initiated.

Strengthen value chains and support integrated programs

The study on the conservation agriculture project in China emphasises the need to strengthen value chains and integrate the biophysical, socioeconomic and marketing aspects of future projects. Engagement with the private sector, public–private partnerships and long-term postings of foreign experts are essential, particularly in countries such China, where cultural norms are especially strong in rural areas. CGIAR centres around the world that have embraced program-scale concepts or flagship strategies and the implementation of innovation platforms, such as the International Maize and Wheat Improvement Centre (CIMMYT), appear to be the way forward. The lack of emphasis on integrated programs that focus on the cropping system, value chains, manufactures of inputs, socioeconomics and pathways of change has probably contributed to the slow pace of adoption of agroecological farming in China.

Understand the role and importance of the private sector

In the peanut project in PNG and Australia, the research demonstrated the yield and quality advantages from adopting high-yielding peanut varieties and appropriate management practices. However, there was no uptake by farmers because the commercial avenues for the new varieties failed to eventuate. Since farmers in PNG had little incentive to produce more than they could sell at conventional roadside markets, industry players were expected to take the lead in setting up buying points for smallholders' produce. However, a shift in the direction and business priorities of collaborating agencies meant that new market opportunities for farmers could not be realised. Without private-sector agencies willing to develop new market avenues for peanuts and peanut products and promote profitable peanut production for smallholders, the impact of future projects will be limited. Greater private-sector engagement is therefore important for understanding market forces, research priorities, current constraints and future opportunities.

In the PRB technology project in Pakistan, a key factor limiting recent adoption was the heavy weight, large size and high cost of the machinery. While Pakistani farmers adopted downsized Australian PRB machinery with enthusiasm, versions of the Australian-designed machinery that were manufactured in Pakistan had design and cost problems and were not as widely adopted. The adoption study notes that machinery design could best be refined by forming a partnership directly with the private sector. In this way, future adoption is contingent on investment to achieve the necessary construction, design and cost improvements. If those improvements were to be achieved with the help of the private sector, the adoption of PRB farming by farmers would expand immediately and rapidly throughout the country.

Involve local partners and agencies

In the sheep production project in Maharashtra, India, much of the success was attributed to the involvement of the Nimbkar Agricultural Research Institute. However, it would have been beneficial to work also with agencies that work with other sheep production systems and breeds. This would have accelerated adoption by targeting multiple breeds rather than just one.

Anticipate unexpected changes

During the peanut project in PNG and Australia, participating private agencies decided to move away from the key focus of the project, which was on providing commercial avenues for higher yielding peanut varieties and setting up buying points for smallholders' produce. Because growers had little incentive to produce more than they could sell at roadside markets, the withdrawal of the private companies was a major factor affecting the adoption of project outputs, including high-yielding peanut varieties. Policy measures to deal with such situations should be built into project contracts. Identifying potential future partners during the project design stage could also help to accommodate and respond to unexpected changes.

Implement effective extension

In the huanglongbing management project in Indonesia, Vietnam and Australia, extension was limited because of inadequate resources and limits on funding and support for maintaining collaboration and capacity within and between the participating countries, and more broadly in Asia and Australasia. This contributed to the lack of adoption of the practical knowledge, techniques and strategies introduced by the project. Although the disease is incurable, effective extension is still needed to prevent new incursions and to ameliorate impacts in areas where it is present. The lesson is that extension strategies should often be embedded in project planning.

Foster collaboration and partnerships

In the integrated manure nutrient management project in India, a major lesson was the importance of nurturing collaborative partnerships between local organisations, such as research institutes and non-government organisations. The research and extension collaboration between the Indian Institute of Soil Science (IISS) and the Bharatiya Agro Industries Foundation (BAIF) clearly contributed to the success of the project by delivering adoptable outputs and disseminating knowledge of them. BAIF's participation in the research helped the IISS scientists to work closely with farmers and provided the necessary outreach to set up a large 'baby trial' program. The collaboration also gave BAIF social scientists a far clearer understanding of the underlying biophysical constraints on production. As a result of the strong relationship developed during this project, BAIF is now able extend the expertise and breadth of advice and support that it provides to farmers.

Consider long time frames for adoption

In China, increasing labour constraints, ecological needs and lack of water will necessitate the adoption of conservation agriculture in the future, despite current low levels of adoption. In the 5 or 6 years after the conservation agriculture project, after further and research and demonstration, adoption is expected to progress in irrigated and high-rainfall areas. However, adoption can be expected take much longer in low-rainfall areas because farmers in those areas follow strong cultural norms and because the use of plant residues for feed and fuel is prevalent. It is important to appreciate the long time frames needed for adoption, which often extend for several years after a project is completed.

Improving postharvest quality of temperate fruits in Vietnam and Australia (AGB/2002/086)

ALAN GEORGE

Project number	AGB/2002/086
Project title	Improving postharvest quality of temperate fruits in Vietnam and Australia
Collaborating institutions	Australia: Queensland Department of Agriculture, Fisheries and Forestry Vietnam: Fruit and Vegetable Research Institute; Plant Protection Research Institute
Project leaders	Australia: Dr Shane Hetherington, NSW Department of Primary Industries, 2004–2007; Dr Suzie Newman, NSW Department of Primary Industries, 2008–2009 Vietnam: Dr Dang Vu Thi Thanh, Fruit and Vegetable Research Institute
Project duration	1 July 2004 – 30 November 2009
Funding	$1,443,250 total (ACIAR contribution $906,070)
Countries involved	Vietnam, Australia
Commodities involved	Plum, peach, nectarine, persimmon
Related projects	CS1/1994/947, PLIA/2000/165, CP/2001/027, AGB/2006/066, AGB/2008/002,

Motivation for the project and what it aimed to achieve

Temperate fruits can be grown in the upland regions of Vietnam because those regions receive enough hours of chilling for the trees to complete their dormant phase.

Asia's demand for temperate fruit is forecast to continue to grow significantly. There is also a market in the Northern Hemisphere from March to May, when there is little or no stonefruit on the Asian market.

The most commonly grown variety of stonefruit in Vietnam is the Tam Hoa plum. The variety survives and adapts well and can set fruit even under drought conditions, but the quality of the fruit is poor compared with that of varieties recently bred in developed countries. Even with that limitation, returns per hectare from Tam Hoa plums grown with minimal inputs can be double those from maize or upland rice.

Many new, high-quality varieties of stonefruit that are better adapted to low-chill climates have been introduced to Vietnam in recent years as part of a previous ACIAR project (CP/2001/027, *Adaption of low-chill temperate fruits to Australia, Thailand, Lao PDR and Vietnam*). Higher levels of technical knowledge and inputs are needed to grow the introduced varieties compared with those needed to grow Tam Hoa plums and other cash crops, such as maize and rice. Farmers introducing the new varieties need to adopt multiple technologies and methods to succeed.

After slow rates of adoption of new technologies and new varieties in previous ACIAR projects, ACIAR and Vietnam's Ministry of Agricultural and Rural Development decided to initiate a new temperate fruit project with greater emphasis on reducing supply-chain losses. The first phase of the project reported here (August 2004 – December 2007) took a systems approach to improving productivity and quality. The second phase (January 2008 – November 2009) focused on the transfer of technological innovations developed during the earlier phase. The overall objective of the project was to develop a sustainable temperate fruit industry for Vietnam.

Outputs—what the research project produced

This project produced technical and capacity outputs.

Technical

The project demonstrated that high-quality stonefruit can be grown and marketed in Vietnam. Some of the key technical outputs are presented below.

The forerunner ACIAR project introduced 25 new varieties of plum, peach and nectarine from Australian nurseries. During the project reported here, at least 30,000 and perhaps as many as 200,000 trees of the new varieties were multiplied at government nurseries and released to farmers on an ad hoc basis. Those released consisted of early-season low-chill and medium-chill varieties in the public domain. The project demonstrated that they have a low chilling requirement and that they are well adapted to the major production regions of Vietnam. In on-farm demonstration orchards, they produced fruit of very high quality.

Long-term on-farm demonstrations were established in seven orchards in Bac Ha, Sa Pa and Moc Chau, enabling farmers to judge management techniques and fostering farmer-to-farmer learning. Later in the project, two model orchards were established in Bac Ha to show how the techniques could be applied to introduced low-chill varieties. Techniques demonstrated at all sites included the use of fertilisers, insecticides and fungicides, integrated pest and disease management (IPDM) practices, the use of fruit-fly bait sprays, mulching, structural pruning of trees and thinning of fruit. The project showed that farm profitability could be increased by up to 170% with modest improvements in production techniques.

The project identified the major diseases affecting stonefruit. Many cause severe defoliation, greatly limiting productivity and causing early tree death. The project demonstrated that a combination of fruit-fly bait sprays, pheromone traps and applications of insecticides could be used to control fruit fly. Dipping fruit in fungicides after harvest decreased postharvest disease by 25–50%. An IPDM program using locally available pesticides was developed to control the major pests and diseases, and a user-friendly IPDM manual was developed to help farmers identify them. The manual has been widely disseminated to farmers.

In Vietnam, peaches and plums tend to be harvested early to avoid fruit-fly infestation and to enable the fruit to withstand the rigours of the supply chain. For Tam Hoa plums, delaying harvest by 7–9 days improved the fruit's weight and sugar concentration by about 20% without reducing storage life.

In Vietnam, plums are normally harvested and transported to market without cooling and can reach core temperatures approaching 32 °C. Cool storage was highly beneficial: 99% of Tam Hoa plums were saleable after 21 days in storage.

Extension training workshop in Bac Ha, one of the main production regions for temperate fruit, conducted by ACIAR project leader Dr Suzie Newman and Mr Bob Nissen (Photo: B. Nissen)

Poor packaging and poor road transport can compress and bruise stonefruit. Cardboard boxes that hold 30 kg of fruit are currently used by collectors to transport fruit, with unacceptable losses. Project trials using 10 kg boxes with shredded paper reduced physical damage to the fruit.

The project mapped plum supply chains from Bac Ha to Hanoi to determine where the major losses were occurring and where interventions were warranted. Quality out-turn was poor: 31% of fruit was physically damaged in some way, 24% was bruised and 11% was diseased. An improved value chain for high-quality Tam Hoa plums was established by connecting premium producers and collectors in Moc Chau with Hanoi's boutique fruit retailers.

During its second phase, the project developed new dried products to ameliorate the problems associated with the long-distance transport of highly perishable fresh fruit. Two dryers (solar and coal-fired) were built and piloted in Bac Ha, and the quality, nutritional content and storage potential of the end-product were evaluated. In addition, a small market acceptance study was undertaken in Lao Cai.

The main focus of the second phase of the project was on culturally appropriate and effective technology transfer. Three extension manuals were produced on production, IPDM and postharvest management. Simple pictorial manuals in Vietnamese and Hmong were also produced.

Excellent training resources were developed and have been piloted and evaluated in the major production region of Bac Ha, but further upscaling is needed to foster greater adoption.

Capacity

The project greatly improved:

- extension officers' and farmers' knowledge of how to manage temperate fruits in subtropical environments
- the ability of the major research institutes—the National Institute of Plant Protection and the Fruit and Vegetable Research Institute (FAVRI)—to identify and control major pests and diseases of temperate fruits
- the ability of FAVRI and the extension centres at Bac Ha, Lao Cai and Moc Chau to map supply chains for temperate fruit and to identify limitations and potential improvements.

Adoption—how the project outputs are being used

To date, imported varieties have not been widely distributed to ethnic minority farmers and make up less than 2% of all stonefruit plantings. This may due to the higher management needs of those varieties but also to government regulations (the planting of new varieties requires government approval).

Some preharvest techniques demonstrated in the project have been widely adopted by farmers, particularly the fertilising and structural pruning of trees, presumably because of the large number of on-farm demonstrations of pruning by research and extension officers.

There has been little or no adoption of the practice of fruit thinning. The farmers are reluctant to thin fruit because they see the practice as causing an economic loss, even though larger fruit receive higher prices and the time involved in picking and packing is significantly lower.

About 10% of farmers are mulching and irrigating their trees. Mulching conserves soil moisture for trees and can significantly benefit tree health. Hoses are the main means of watering trees as very few farms have modern irrigation systems, which are too expensive for ethnic minority farmers.

The project clearly demonstrated that fruit-fly baits can effectively control fruit fly, but this technology has not been adopted by farmers. Without baits, the fruit must be picked before it is fully mature, greatly reducing its quality.

Surveyed farmers indicated that they use pesticides or fungicides only when there is an obvious emergency. Preventive sprays of fungicides to control leaf diseases such as leaf curl, shot hole and rust are not used; consequently, the introduced varieties, which are very susceptible to such diseases, quickly decline in health and eventually die.

There has been less adoption of postharvest technologies compared with preharvest technologies because many are too expensive for individual farmers (for example, coolrooms and refrigerated transport) and some (such as the use of ethylene inhibitors) require greater knowledge.

There has been some adoption of the practices of harvesting fruit at the correct stage of maturity and of drying plums. Fruit shipped in the new 10 kg packs was less subject to bruising and breakdown, and there has been some adoption of the new packs.

Despite the mapping of the supply chain and the identification of areas of concern, there has been little or no change to the chain, in which farmers supply fruit to collectors who deliver it to the major markets. However, regional extension officers' knowledge of supply-chain management has been greatly improved.

There has been little adoption of cool storage on farm or refrigerated transport, although the lychee industry is now starting to use this technology. Farmers saw these practices as too expensive.

The research and extension capacity of the agencies involved in the project were greatly increased. However, with the exception of farmers directly involved with the project, there has been only a small capacity improvement among farmers in the wider community, even though the project clearly demonstrated that high yields of quality stonefruit can be produced in Vietnam.

Impact—the difference the project has made or is expected to make

The main beneficiaries of the project will be minority farmers, their families and their communities in north-west Vietnam. Those directly involved with the project have gained the greatest benefits. Most of these people live in extreme poverty on annual per capita incomes of about $500. Farmers currently produce poor-quality temperate fruit, which sells for very low prices through traditional marketing channels.

While the project used very effective participatory action learning and extension tools (hands-on training in farmers' orchards, user-friendly manuals and workshops) and clearly demonstrated that high yields of excellent fruit could be produced, the adoption of new technologies has been very slow.

The low rate of adoption has been due mainly to the low incomes of the minority farmers, who lack the capital to implement new technologies and are unable to take risks. The extreme poverty of the minorities leaves the farmers vulnerable to food and income shocks, against which they have little capacity to insure. In these circumstances, even large future returns might not seem attractive. Most farmers cannot afford the irrigation systems, fertilisers and pesticides needed to produce high-quality fruit and keep trees healthy.

In addition, higher levels of technical knowledge and inputs are necessary to grow the introduced varieties of stonefruit successfully, compared with requirements for other fruit crops and subsistence crops such as rice. Critical orchard-management practices, such as fruit thinning, pruning and the application of fungicides, must be done at the right time during the phenological cycle to achieve satisfactory yield and fruit quality and maintain tree health in the long term. Thus, as well as planting new varieties, the farmer must also adopt multiple technologies as a complete package if the operation is to be successful. This contrasts with efforts to improve the production of many dryland agricultural crops, in which each component of a package can be adopted independently of the others.

New strategies are needed to increase the rate of adoption. To help farmers change from their traditional growing practices, it may be necessary to provide greater government or aid-agency financial support and incentives to do so. An alternative would be to encourage the entry of private companies that have the capital to set up productive orchards.

Hill tribe minority farmers using wicker baskets to carry the local plum variety to the market in Bac Ha (Photo: B. Nissen)

Promotion of conservation agriculture using permanent raised beds in irrigated cropping in the Hexi Corridor, Gansu, China (LWR/2002/094)

ALLEN D. MCHUGH

Project number	LWR/2002/094
Project title	Promotion of conservation agriculture using permanent raised beds in irrigated cropping in the Hexi Corridor, Gansu, China
Collaborating institutions	China Agricultural University Gansu Academy of Agricultural Sciences Gansu Agricultural Mechanisation Bureau
Project leaders	Dr Allen McHugh, CIMMYT–China, Ningxia Academy of Agriculture and Forestry Sciences, Yinchuan, China Dr Li Hongwen Dr Ma Zhongming
Project duration	1 July 2005 – 31 December 2009
Funding	$1,504,938 total (ACIAR contribution $707,000)
Countries involved	China, Australia
Commodities involved	Various
Related projects	SMCN/1996/143, SMCN/1992/09

Motivation for the project and what it aimed to achieve

The Hexi Corridor in Gansu province in China is a narrow strip of land bounded by the Qianlian Mountains to the south-west and a number deserts to the north-east. Reduced and unreliable snowmelt water and the overextraction of groundwater have led to the widespread lowering of watertables and a diminished agroecological system.

This project proposed to save irrigation water at the field level through the implementation of conservation agriculture, essentially incorporating zero-till permanent raised beds (PRBs) and furrow irrigation. The project used comparative research and on-farm demonstration sites to develop elements of conservation agriculture to address agronomic issues such as a lack of low-powered zero-till planters, competing uses of plant residues, infield residue management and irrigation water management. Fresh raised beds (FRBs) using intensive tillage and conventional farming (inversion tillage) were compared with the conservation agriculture practices of PRB and zero-till controlled-traffic farming.

This project arose out of an approach by Dr Tony Fischer to the Gansu Academy of Agricultural Sciences, CIMMYT-China and long-time CIMMYT collaborator Mr Yuan Hanmin (Ningxia province). After meetings involving the China Agricultural University, the Australian Centre for International Agricultural Research (ACIAR) and others, Dr Christian Roth and the proponents refined the proposal. Contact was established with Gansu Agricultural Mechanisation Bureau through the China Agricultural University.

Outputs—what the research project produced

This project produced technical and capacity outputs.

Technical

There has been no adoption of conservation agriculture by farmers following the project, as there was no government support for the technology and specialised planting equipment was not developed or promoted. FRB farming, which existed before the project, continues to expand in popularity, along with conservation tillage (reduced tillage and strip till), even though the project demonstrated that FRB farming was not as effective as PRB or zero-till controlled-traffic farming in increasing production and reducing inputs. Because a conservation agriculture production system has not been adopted, crops have not been adapted to PRB farming. To date, there is no commercially available zero-till conservation agriculture equipment for small landholders' low-horsepower tractors. However, there are successful third-generation FRB seeders and a complete range of strip and rotary tiller seeders.

Before the project, farmers' residue management strategies included the removal of most above-ground biomass, the burning of the remainder and incorporation by soil inversion, rotary tillage or both. In the Hexi Corridor, standing stubble 5–20 cm high is currently left in the field. However, the residue is still burned and rotary tiller (full-width and strip tiller) seeders are used to incorporate it at planting (conservation tillage).

Therefore, only soil inversion has been removed from the tillage practices. In general, weed control remains a significant problem and is one of the main factors constraining the adoption of conservation agriculture and zero-till farming.

Capacity

Outputs since the end of the ACIAR project include a wide range of experiments and publications directly related to the project or the sites that were established in 2004. They include carbon sequestration, soil physical responses, impacts on soil microbiology, salinity management, soil water and irrigation management, residue retention, the adaptation of various lines to PRB, weed control with residue, and greenhouse gas emissions.

Specialist subjects within the conservation tillage program, such as PRB, were electives before 2009; now they are compulsory. Masters and PhD students must take the Advanced Technology in Agricultural Mechanisation course, of which conservation agriculture is a significant part. Institutes within the Gansu Academy of Agricultural Sciences for water saving, seed and fertiliser, and soil have significant R&D programs that cover a wide range of activities under the banner of conservation agriculture. The extension collaborators regularly use capacity, knowledge and innovations gained from Australian visits, domestic workshops, train-the-trainer courses and farmer field schools.

A number of publications since the end of the project arose directly or indirectly from the research, including a conservation agriculture cartoon book in seven languages; an agricultural machinery textbook, with a specialist chapter on forms of tillage; eight journal articles; and eight conference papers, including one on salinity research in conservation agriculture presented at the 2013 CIMMYT international conservation agriculture forum in Ningxia province.

Local government demonstration farm with an appropriate level of wheat residue near Shandan county, Gansu province (Photo: A.D. 'Jack' McHugh)

New conservation agriculture demonstrations are being established in six provinces, including one in Heilongjiang province specifically dedicated to controlled-traffic farming. The Long-Term National Conservation Tillage Demonstration Project, which is targeting 600 counties over the next 10 years, includes descriptions of conservation agriculture implementation. Ex-members of the ACIAR project drafted the implementation plan for these and other conservation tillage farming practices for all the provinces involved.

Adoption—how the project outputs are being used

This project tested soil and water conservation measures in a conservation agriculture framework of production-enhancing practices. Different definitions of 'conservation agriculture' in China complicate external assessments of adoption across the region, while a commonly used reductionist notion of adoption as the uptake of minimum tillage (usually termed 'conservation tillage') casts doubts on the validity of published figures for the adoption of conservation agriculture. Nevertheless, the promotion of conservation tillage is causing considerable positive change to cropping in the Hexi Corridor, and that change can be linked to this ACIAR project.

Knowledge, skills and infrastructure built during the project have allowed collaborators to continue research in the same thematic areas. The project built research capacity by gaining additional funding, developing and supporting staff, broadening their publication and proposal-writing skills, and using the research outputs for effective extension among collaborators and government institutions. The project collaborators continue to influence the Ministry of Agriculture's policies on mechanisation and conservation farming practices through the Department of Agricultural Mechanisation. The national Five-year Development Plan and the Long-Term National Conservation Tillage Demonstration Project include conservation agriculture technology, and were largely influenced by ex-members of the ACIAR project. They state clearly that they have applied the capacities and knowledge gained through the project to many aspects of their research, extension and lobbying activities.

In general, FRB and the retention of some residues have been promoted through demonstration farms, farming cooperatives, farmer field schools and the extension activities of the three collaborators. However, this awareness has been confined to demonstration sites, farming cooperatives and local and provincial government initiatives, largely because the efficiencies and production gains demonstrated by the project were not significant enough to sway the farming community. Although government support, extension activites and funding for conservation agriculture remain limited, priorities have been radically expanded in recent times to include saving water, reviews of water allocations, subsidies for conservation tillage equipment, farmer factories (companies), and joint government support for the aggregation of farmland. Informants agreed that the drivers for change are gradually shifting towards environmental issues, sustainability and food supply stability. They conclude that conservation agriculture is the future but that conservation tillage is the popular agricultural development at this time.

FRB farming existed before the project and continues to expand in area and popularity, along with conservation tillage (reduced tillage). For this component of conservation agriculture, there is considerable use by next users but not yet by final users.

There has been some adaptation of existing crops to new farming practices. Some practices, such as intercropping maize and canola, may have linkages back to the project. There is some use of zero-till farming systems by the initial and next users, and isolated changes towards higher value cash crops.

To date, there is no commercially available zero-till conservation agriculture equipment for landholders' low-horsepower tractors. However, there are successful third-generation FRB seeders and a complete range of strip tillers. For this output there is considerable use by next users, but not yet by final users outside the demonstration and training farms.

In the Hexi Corridor, stubble 5–20 cm high is left in the field and the remainder is removed for feed and fuel. There is considerable demonstrated adoption of appropriate management of crop residues by next users in corporate and demonstration farming operations, but minimal adoption by final users.

Without appropriate herbicide application equipment and skills, herbicide resistance and the persistence of weeds are limiting the adoption of conservation agriculture.

Theories about water saving in furrow irrigation have been broadly used to promote FRB, which has been widely adopted. Zero-till machinery in various forms has also been taken up, but many small and medium-size machines include strip tillers of varying widths and thus disturb too much soil. This falls outside the guidelines for conservation agriculture farming practice.

In the 3 years to 2012, FRB farming expanded to 325,000 ha in the Hexi Corridor, but this includes the use of plastic mulch (80,000 ha). The area of conservation tillage is also set to expand on the implementation of the Long-Term National Conservation Tillage Demonstration Project to 640,000 ha in 32 counties (five counties have started implementation). Only some elements of the ACIAR project outputs contributed to this adoption.

The lack of adoption of other outputs can be attributed largely to inadequate conservation agriculture machinery, inability to manage in-field crop residue, competing uses of residue, widespread monocropping and cultural norms. Wider adoption can be expected because of increasing labour constraints, agroecological needs and the scarcity of water, but not for some years.

Impact—the difference the project has made or is expected to make

The adoption of water saving technologies, such as FRB and stubble retention, has the potential for saving a considerable volume of irrigation water, but it is difficult to quantify the volume or transfer it back through the irrigation system. This is partly due to the management of the water supply, which is based on a set volume and a fixed cyclic delivery model. In addition, farmers pay equally at the village level whether or not they save water. Rapid development as part of the National Inland Development Project is raising water demand and affecting irrigation water delivery volumes and timings. Competing uses for the water include dust suppression, extensive tree plantings and irrigation for existing trees in drier areas and along roadsides. In-field burning of residues has been reduced in some places, but evidence of burning is still quite apparent in the countryside.

The built environment and economy are improving rapidly in Gansu and adjacent provinces, and there has been a rapid rise of entrepreneurial and cooperative farming enterprises. Some enterprises are adopting conservation tillage, zero-till and conservation agriculture farming practices to overcome conventional farming inefficiencies, but probably not for agroecological or sustainability reasons. The resulting land aggregation offers opportunities for many farmers to seek off-farm work, but has left women to provide the workforce in the farming communities.

Conservation tillage machines (strip tiller seeders) are widespread and very popular with farmers and service providers, who have consequently taken an incremental approach to conservation farming and so not taken full advantage of the benefits of conservation agriculture. At the same time, the promotion of conservation tillage has supressed the development of Chinese-made zero-till planters. This is probably the most significant factor limiting the magnitude of benefits from this project. Nevertheless, conservation tillage has put agricultural sustainability and food security on an improving trajectory.

However, the idea that farming can and should supply ecosystem services is a concept that is far from the minds of farmers and the general agricultural community in northern China. The entire agricultural community and the value chain are focused solely on production. Although an economic approach towards adoption is gaining some traction, and water saving is extremely topical, the supply of ecosystem services from soils and the agricultural landscape is still not well understood. Farmers' high risk aversion, general lack of skills and unwillingness to depart from conventional cultural practices are also significant factors affecting adoption.

After a rain and wind storm, a barley crop in a conventional tillage field (left) showed considerable lodging, while a conservation agriculture field (right) did not suffer any damage. (Photo: A.D. 'Jack' McHugh)

Productivity and marketing enhancement for peanut in Papua New Guinea and Australia (SMCN/2004/041)

RAO C.N. RACHAPUTI AND MICHAEL HUGHES

Project number	SMCN/2004/041
Project title	Productivity and marketing enhancement for peanut in Papua New Guinea and Australia.
Collaborating institutions	Australia: Queensland Department of Agriculture, Fisheries and Forestry Papua New Guinea: Ramu Agri-Industries Ltd, National Agricultural Research Institute, Trukai Industries
Project leaders	Rao C.N. Rachaputi, A. Ramakrishna, Lastus Kuniata, Geoff Fahey
Project duration	1 January 2006 – 20 June 2009
Funding	$844,422
Countries involved	Papua New Guinea, Australia
Commodities involved	Peanuts
Related projects	ASEM 2001/55

Motivation for the project and what it aimed to achieve

Peanut production was an important commercial industry in Papua New Guinea (PNG) during the 1960s and 1970s, but commercial-scale production subsequently declined rapidly to less than 1,000 t/year due to the collapse of the peanut processing industry. It was believed that aflatoxin would be a major problem in peanuts, and this food safety issue might have contributed to the collapse of the PNG peanut industry.

While yields of 2 t/ha were harvested from trial plots in 1987, there was little information on yields harvested from farmers' fields. A precursor project (ASEM 2001/55, *Improving yield and economic viability of peanut production in PNG and Australia*) implemented from 2002 to 2005 documented the critical role of peanuts in PNG farming systems and established the peanut as one of the five most popular income-generating crops in the country. That project also evaluated high-yielding peanut germplasm lines introduced from the International Crops Research Institute for the Semi-Arid Tropics into PNG and identified varieties with better yield and seed quality than local varieties. However, there was a need for farmer-participatory adaptive trials to disseminate new varieties, along with cost-effective agronomic packages to improve peanut yield and quality in smallholders' fields.

In Australia, one of the major constraints on improving yield and profitability of broadacre peanut crops is spatial variability in yield and quality. Aflatoxin contamination is also a major constraint in dryland peanut crops (aflatoxin causes quality deterioration and spoilage, has carcinogenic effects in humans, affects livestock health and can lead to the loss of export markets).

Earlier work at the Queensland Department of Primary Industries and Fisheries (now the Department of Agriculture, Fisheries and Forestry) indicated that near-infrared reflectance data captured from aerial and satellite platforms could be used to identify and monitor spatial variability (for disease, crop growth, crop maturity and aflatoxin risk) in peanut crops and implement novel in-season management and harvesting strategies. The collaborating agencies in PNG and Australia were keen to work together and promote best management practices, including the satellite imagery technology, in their focus regions.

Bonny Wera discussing peanut agronomy with farmers. (Photo: M. Hughes)

There was also a need to explore new avenues to enhance the marketability of peanuts and peanut products in collaboration with private-sector agencies engaged in developing the peanut industry in PNG and Australia. The PNG growers hoped that the participation of Ramu Sugar (part of Ramu Agri-industries Ltd) and Trukai Industries Ltd farms in the project would lead to the establishment of processing plants and commercial buying points for peanuts.

Given the importance of peanuts as a food crop, the aflatoxin problem and the economic viability of the industry, the PNG and Australian governments supported further research to improve the productivity and profitability of the industry.

The main aim of this project was to expedite the spread of the varieties and management technologies among smallholders to establish sustainable and profitable peanut production systems and to explore new avenues to enhance the marketability of peanuts and peanut products in PNG and Australia.

Outputs—what the research project produced

Technical

On-farm trials demonstrated yield increases of up to 100% from improved practices in the project's three focus regions. Planting time, plant spacing, row configuration, disease protection and harvest management (using timing and windrows to prevent crop losses) were the key factors contributing to the yield response.

The yield responses of the new varieties have not been consistent, but some growers and processors consider that the new varieties' kernel quality is better suited for processing (into peanut butter and roasted peanuts) compared with local cultivars, which are preferred for fresh food markets.

The results from the varietal and management practice trials and technical expertise from Queensland research teams were used to publish *Growing peanuts in Papua New Guinea: a best management practice manual*.

The validation and application of the APSIM peanut crop model for PNG production environments resulted in a better understanding of the importance of the time of planting for yield and aflatoxin risk, and also the value of daily weather data.

The project demonstrated the value of satellite imagery technology in monitoring the spatial variability and yield of peanut crops in PNG and Australia. The project outputs have led to adoption of the technology by the Peanut Company of Australia and Trukai Industries and Ramu Agri-Industries in PNG, all three of which are now buying their own imagery.

A strategic survey of peanut samples drawn from popular roadside markets revealed significant regional differences in aflatoxin contamination. While the samples from the Eastern Highlands showed little aflatoxin, those from the upper and lower Markham regions showed significant (up to 40%) contamination. Crops planted after February in the Markham region had higher levels of aflatoxin contamination because of end-of season droughts. This finding has led to a better understanding of the effects of planting time on aflatoxin.

Two market scoping studies implemented in the project have provided an insight into the state of markets for peanuts and peanut products in PNG and Australia, and particularly into the global market for peanut oil. The studies suggested a potential for domestic and export sales of raw peanut kernel and oil for PNG and exports of high-oleic peanut oil for Australia. Those findings are expected to stimulate commercial players to further explore new market opportunities.

Capacity

The project established a capacity for commercial peanut seed production at Ramu Agri-Industries by importing a peanut planter and thresher from Australia and by training the company's staff to operate the machinery at a commercial scale.

The project established a capacity to analyse aflatoxin in peanuts in National Agriculture Research Institute and Ramu Agri-Industries laboratories. These facilities are expected to play a key role in the future, as the economic impact of aflatoxin contamination could become significant in PNG.

The collaborating scientists acquired agronomic knowledge about the new varieties and practices, allowing on-farm trials to realise higher yields of up to 4 t/ha.

They also developed skills in satellite imagery technology, including image ordering, processing and ground truthing for yield prediction, weed and disease monitoring, and using handheld GPS units to digitise the boundaries of targeted paddocks for processing.

In Australia, the project built capacity to develop and apply the imagery technology in yield prediction, maturity prediction, cost analysis, disease monitoring, temporal analysis and regional yield forecasting.

Peanuts are sold in small quantities as fresh or roasted pods or kernels in the roadside markets. (Photo: M. Hughes)

Adoption—how the project outputs are being used

As a result of peanut R&D trials conducted in this project, the National Agriculture Research Institute has released four early-maturing (~110 days) and six medium-maturing (~130 days) varieties for lowlands (the lower and upper Markham regions) and five early-maturing and four medium-maturing varieties for highlands (Eastern Highlands province). However, there has been little uptake of the varieties by farmers, mainly because of the unavailability of seed and a lack of market support.

Peanut agronomic knowledge and the best practice manual have empowered collaborators at Ramu Agri-Industries to develop a new project grant proposal on smallholder commercial production and marketing of peanuts in PNG.

The research experience gained by Ramu Sugar and National Agriculture Research Institute collaborators has enabled them to design a training program to help Solomon Islands improve its peanut production as part of the ACIAR Livelihood Program.

Researchers are using the information generated by the project on aflatoxin contamination of peanuts in roadside markets. The research experience gained by the institute's chemistry laboratory staff has enabled them to strengthen collaboration with the School of Medicine and Health Sciences at the University of PNG to assess the prevalence of aflatoxin contamination in peanuts and peanut products.

Farmers have changed from planting peanuts randomly to planting them in rows. (Photo: M. Hughes)

The capacity in satellite imagery technology developed at the three collaborating agencies could not be sustained beyond the project, either because the trained personnel moved into more lucrative jobs in private companies or because of changes in the agencies' business priorities.

In Australia, the imagery and processing protocols developed in the project have been used for estimating the total yield of a broadacre peanut crop from pod yield and to accurately identify disease, irrigation inefficiencies and spatial variability resulting from constraints on production.

Impact—the difference the project has made or is expected to make

Farming communities in the upper Markham, lower Markham, Kainantu and Aiyura regions have been the beneficiaries of this project. The main element of best management practice adopted by the farmers was row planting, which reduces the time required for weeding (usually done by women) by up to 50%.

Changes in business priorities and staff movements have affected the satellite imagery technology capacity put in place by the project at the collaborating agencies. The imagery processing skills that were built are not being used in peanut production, but are expected to be used for other crops, such as rice, sugarcane and oil palm and for other agricultural data collection, biosecurity monitoring and natural disaster monitoring.

The quantification of aflatoxin contamination in fresh peanuts sold in roadside markets has established a clear link between agricultural practices and effects on human health. Further action by the government to develop aflatoxin monitoring and management strategies is needed. The significance of aflatoxin as a food safety problem for consumers is grossly underestimated by all sectors of the peanut value chain.

The R&D experience gained in the peanut project by scientists from Ramu Sugar and the National Agriculture Research Institute has brought them recognition as regional experts. The ACIAR Livelihood Program has invited them to design a peanut seed supply scheme and provide training in peanut production to extension officers and farmers in Solomon Islands.

Growing peanuts in Papua New Guinea: a best management practice manual has gained popularity in Cambodia, Timor-Leste and Tonga, as well as among farmers and educators in PNG, and has been used as the basis of a training course and a reference guide in Solomon Islands. Students at universities in PNG are also using the manual in their study. A former student commented that there were not enough copies of it in the library, so it was often in high demand.

In Australia, the satellite imagery technology developed for peanuts has now been extended into other cropping and horticultural industries. Since 2009, more than nine projects have been implemented to maximise profitability in the cotton, grain, pastoral and horticultural industries by using satellite imagery.

Improved productivity, profitability and sustainability of sheep production in Maharashtra, India, through genetically enhanced prolificacy, growth and parasite resistance (AH/2002/038)

STEPHEN WALKDEN-BROWN AND CHANDA NIMBKAR

Project number	AH/2002/038
Project name	Improved productivity, profitability and sustainability of sheep production in Maharashtra, India, through genetically enhanced prolificacy, growth and parasite resistance
Collaborating institutions	Australia: University of New England, Armidale, New South Wales India: Nimbkar Agricultural Research Institute, Phaltan, Maharashtra (NARI); National Chemical Laboratory, Pune, Maharashtra
Project leaders	Dr Stephen W Walkden-Brown, University of New England Dr Chanda Nimbkar, NARI Dr Vidya Gupta, National Chemical Laboratory
Duration of project	1 January 2003 – 31 December 2008
Funding	ACIAR $557,635; partners (in-kind) $1,082,129
Countries involved	India, Australia
Commodities involved	Sheep meat
Related projects	AS1/1994/022, AS1/1997/027

Motivation for the project and what it aimed to achieve

The overall aim of this project was to improve sheep-meat production and rural incomes in the Indian state of Maharashtra. Low prolificacy of Indian sheep breeds had been identified by Indian agencies as a major barrier to productivity in Indian sheep in general. A highly prolific but very small sheep breed, the Garole, had been identified in West Bengal, and it was hoped to use the prolificacy of the breed to increase the productivity of Deccani sheep, which are by far the dominant sheep breed in India, making up about 31% of the country's 61.5 million sheep. A preceding ACIAR project in Maharashtra (AS1/1994/022, *Prolific, worm-resistant meat sheep for Maharashtra, India*) established that the prolificacy of Garole sheep was due to the Booroola fecundity mutation (*FecB*), established a molecular test for the mutation in India, found that the Garole breed also exhibited considerable resistance to gastrointestinal worm infestation and found that the introgression of the *FecB* gene into Deccani sheep as part of a breed improvement program was feasible.

The specific goals of project reported here were therefore to:

- develop and multiply promising sheep genotypes at the Nimbkar Agricultural Research Institute (NARI)
- test the sheep genotypes' performance in local shepherds' flocks and develop appropriate management technologies
- investigate the regulation of expression of the *FecB* fecundity gene in Indian and Australian breeds of sheep
- develop extension and genetic models for the dissemination of proven genotypes within and beyond the local project area.

Pioneers of improved prolificacy in Indian sheep (left to right): Mr Chavan (farm manager, NARI); Mr Bonbehari Nimbkar (founder of NARI and initiator of forerunner ACIAR project; collaborating shepherd Mr Dattatray Sopan Pisal and Mrs Pisal; Dr Chanda Nimbkar (Director, Animal Husbandry Division, NARI); and Dr Pradip Ghalsasi (Associate Director, Animal Husbandry Division, NARI) (Photo: S. Walkden-Brown)

Outputs—what the research project produced

This project achieved its objectives and produced technical and capacity outputs.

Technical

The project resulted in the development of a new strain of Deccani sheep, the NARI Suwarna, that carries the *FecB* gene. The strain was selected for growth, reproductive performance, mothering ability and the appearance preferred by shepherds in the Phaltan and adjoining areas of south-western Maharashtra. A composite breed of Bannur and Awassi sheep was also developed and selected for similar traits, apart from appearance.

These sheep were developed to improve meat productivity under normal farming conditions, but to also be more responsive to improved nutrition and management than the existing non-fecund sheep. Research in India and Australia revealed that one copy of the mutation confers unequivocal ewe-productivity advantages over non-carriers. In Deccani sheep, the available data suggested that two copies also conferred advantages over non-carriers; in the Australian merino sheep, two copies were shown to confer unequivocal disadvantages over non-carriers. Studies in both countries confirmed that the effect of the mutation on the ewe's ovulation rate was additive, as previously postulated, but that this did not translate into additive effects on litter size.

NARI Suwana, improved Deccani ewes selected for improved performance and carrying the *FecB* fecundity gene (Photo: S. Walkden-Brown)

Testing of improved genotypes in the flocks of 26 collaborating shepherds demonstrated improved performance under traditional shepherding conditions. One copy of *FecB* led to an increase in ovulation rate from 1.0 to 2.0 eggs, and an increase in live litter size at birth from 1.0 to 1.4 in smallholders' flocks. More recent data showed the average litter size of 244 heterozygous ewes in nine shepherds' flocks to be 1.52 (Nimbkar et al. 2013). The increased litter size was found to be manageable under the existing production system. The gross margin of improved genotype ewes carrying the *FecB* mutation was found to be 37–50% higher than for non-carrier ewes.

To aid the dissemination of the improved genotypes, the project develped technical and extension information on husbandry, nutrition and animal health. The information increased the benefits associated with the genotypes.

The project also resulted in the establishment at NARI of improved breeding technologies based on objective measurement and best linear unbiased predictions of breeding value, and effective artificial breeding programs using semen collection and artificial insemination. These technologies continue to be used at NARI.

Capacity

The project built significant capacity. Two PhD scholars were trained during the project, including project leader Dr Chanda Nimbkar, and the research capacity at NARI and to a lesser extent the National Chemical Laboratory was enhanced significantly. By the end of the project, NARI had:

- staff highly trained and skilled in sheep genetics, breeding, production and extension
- enhanced infrastructure for sheep-related research
- 525 sheep of improved genotype carrying the *FecB* gene.

The project developed and published clear recommendations on the desirability of the future introgression of improved genotypes carrying the *FecB* mutation into Indian sheep breeds and on the best methods for achieving it. The major technical and policy outcomes of the project are set out in Walkden-Brown et al. (2009).

Adoption—how the project outputs are being used

The capacity developed at NARI during the project is still being used for purposes consistent with the original aims of the project. NARI has been able to obtain Indian Government research funding to continue the work initiated by this and the previous ACIAR project. An important finding of the post-project research has been that Deccani crossbred ewes that are homozygous *FecB* carriers do not exhibit the marked disadvantages of homozygous *FecB* carrier ewes reported in Australian merinos. This has also been shown for Malpura crossbred ewes at the Central Sheep and Wool Research Institute in Rajasthan. The diagnostic test to detect the *FecB* fecundity mutation has been optimised and implemented at NARI, extending its range beyond major government laboratories. The *FecB* mutation has also been detected in two more breeds of Indian sheep, the Kendrapada from Orissa and the Nilagiri from Tamil Nadu.

The findings and recommendations of this project appear to have had wide-ranging influence. Indian Government policy has supported the development and dissemination of improved sheep genotypes carrying the *FecB* fecundity gene, and nationally funded projects to promote them are being implemented in Tamil Nadu and Karnataka. Smaller breeding initiatives funded privately and at local government level have occurred in many parts of India. At the Central Sheep and Wool Research Institute, the *FecB* evaluation project has expanded and changed in line with the findings and recommendations of the ACIAR project; it now uses an altered breeding plan and plans the involvement of farmers in evaluating improved genotypes. India now has two major centres of *FecB* research and dissemination: the institute in the north and NARI in the central south. A new centre is emerging in the south at the Tamil Nadu Veterinary and Animal Sciences University. Between these centres, introgression into the main meat sheep breeds of India can be achieved. Current introgression programs involve the Deccani, Malpura, Madgyal, Patanwadi, Mercheri, Madras Red and Nilagiri breeds.

The exact scale of introgression to date is difficult to assess, as the *FecB* mutation is detectable only by DNA test. The most tangible measure of introgression is the number of *FecB* carrier animals sold by NARI since the completion of the ACIAR project. Between 2009 and 2012, NARI sold 436 breeding animals carrying the *FecB* mutation (128 rams and 308 ewes) in 49 separate sales to customers in six states in India. Most have gone to Karnataka, Maharashtra and Andhra Pradesh. Sales and interest are increasing with time. There is also an emerging trade in *FecB* carrier animals between shepherds. Because *FecB* carrier animals have been introduced into shepherds' farms since 2003, considerable natural spread of *FecB* carrier animals can be expected to have occurred. The efficient introgression of the gene and the development of a trade in animals based on its presence requires a relatively cheap test to show whether animals are carrying zero, one or two copies of the mutation. The current test is available at around R400, which is a low enough price for it to be widely used in introgression projects but not low enough for shepherds to use the test to know the *FecB* status of their animals. In the longer term, making an affordable test available to farmers will be an important plank in ongoing introgression.

While the improved genotypes are designed to perform well in their local environment, they are more responsive to improved management than unimproved genotypes. On farm visits there was evidence of the implementation of extension messages on improved nutrition using concentrates or high-quality cut fodders such as lucerne, on providing additional milk to twin lambs and on adequate parasite control. However, implementation was not uniform. More complex messages about restricting the application of additional feed to only those animals requiring it at particular phases of the production cycle (ewes bearing or rearing multiple lambs or young growing lambs) were not being widely advocated or adopted by farmers.

Adoption can be expected to progress steadily. The rate of adoption will be influenced by government policy and funding to support genotyping and performance recording. However, there is clear evidence of a growing commercial opportunity for the generation and sale of improved genotypes carrying the *FecB* mutation.

Indian Government project funding ended at NARI in 2012, but the breeding program continues, underpinned by sales of breeding stock. Sufficient improved sheep have now been disseminated, demand for twin-bearing ewes is well enough established and the price of sheep is high enough to support the dissemination of improved genotypes between shepherds and within the wider commercial sector. However, the need for a DNA test to determine *FecB* status remains a significant barrier to efficient introgression, as do the lack of a nationally coordinated introgression project and the lack of available advanced animal breeding technologies, such as artificial insemination, embryo transfer, and juvenile in-vitro fertilisation and embryo transfer, which would speed up introgression.

Impact—the difference the project has made or is expected to make

The major project output is more productive meat sheep genotypes, and the main end users are sheep farmers in India. While the pace of introgression has been modest, there is clear evidence of improved productivity on farms that have adopted these genotypes, in line with the predicted benefits made at the conclusion of the project. The magnitude of the economic impact is also modest. Gains in litter size need to be weighed against increased feed requirements and mortality rates (Swan 2013). Nimbkar et al. (2009) estimated that the gross margin per twin-bearing ewe in smallholder flocks was 30% higher than that of single-bearing ewes. The technical efficiency of production is increased by having greater lamb meat production per ewe or per unit of sheep feed consumed, leading to increased income per ewe or per unit of sheep feed. The economic impact on an individual farm is gradual as the overall gene frequency of *FecB* and other beneficial genes increases. In this sense, the uptake of this technology results in 'evolutionary' rather than 'revolutionary' change for the end user.

The benefits of improved genotypes with higher fecundity are more likely to be observed in settled than transhumant or migratory pastoral systems because the management of twin lambs in a single location is easier. These genotypes will therefore help to increase the proportion of sheep production from settled farms or systems that use shorter migrations, leading to incremental improvements in school education and other benefits. They should also spur the development of large, intensive commercial production systems, as they benefit more than traditional breeds from high levels of management.

Shepherd family and Dr Nimbkar with triplet-bearing Mercheri cross ewe, bred from *FecB*-carrying rams from NARI, Mallasamudram block, Nammakkal district, Tamil Nadu (Photo: Y. Langenberg)

The project's impacts are cumulative and unlikely to be reversed rapidly. Unlike other outputs, which may be adopted and quickly discarded, the changes to sheep genotype that this project has brought about are difficult to reverse. This is particularly so because the presence of a fecundity gene is not identifiable phenotypically in male sheep, and phenotypic markers are seen only in females of reproductive age. If the fecundity gene is beneficial, as the project research indicated, it will spread naturally through natural and artificial selection. If it is less beneficial than predicted, its frequency will gradually decline by the same processes.

There are few expected negative impacts. In times of dire drought or economic hardship, ewes with multiple lambs and lambs born as multiples will be disproportionately affected. In the field, it appears that the solution to this problem is the sale of surplus lambs, even at a very young age. The environmental impact is likely to be positive because improved genotypes are more efficient converters of scarce feed resources into meat.

The project has also had a significant impact on the scientific and sheep advisory sectors. The proceedings of the project's final workshop remain the single most important current source of information about the *FecB* gene and its application in sheep-breeding programs. A measure of the success of the project is that the UN Food and Agriculture Organization has selected the introgression of the *FecB* into Indian sheep breeds, led by NARI, as one of only seven case studies on the successful application of new agricultural technologies in the field (Ruane et al. 2013).

NARI Suwarna, improved Deccani rams homozygous for the *FecB* gene. (Photo: Mr Chavan)

The impacts of the project have been slowed by the comparative slowness of the introgression of new genotypes and because the desired genotype is identifiable only with a DNA test. This is very different from traditional breed improvement work based on identifiable phenotypes and requires major changes in thinking and methods. In some areas, there remains significant resistance to twin-bearing ewes among shepherds, but those areas are rather limited.

Because the *FecB* gene is 'invisible', it is also more difficult to assess impacts accurately. Inferences drawn from sales of animals from known sources will become less accurate with time as improved genotypes reproduce and disseminate naturally or through informal systems. If impacts are to be assessed again in the future, a survey of *FecB* gene frequency in some of the main target areas should be considered for funding.

Overall, the project's national impact on sheep-rearing communities in India to date has been small, but is increasing. In the original project target community of Dhangar shepherds in the Phaltan district of Maharahstra, progress has been good, given the poor education status and tradition-bound nature of the community and the absence of any previous systematic genetic improvement programs for Deccani sheep.

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Refinement and adoption of permanent raised bed technology for the irrigated maize–wheat cropping system (LWR/2002/034)

GREG HAMILTON, ZAHID HUSSAIN, GHANI AKBAR AND MUHAMMAD IRFAN

Project number	LWR 2002-034
Project title	Refinement and adoption of permanent raised bed technology for the irrigated maize–wheat cropping system,
Collaborating institutions	Australia: Western Australian Department of Agriculture and Food; University of Southern Queensland; University of South Australia; New South Wales Department of Primary Industries; Ausplow Pty Ltd Pakistan: Pakistan Agricultural Research Council; Federal Ministry for Food and Agriculture; University of Faisalabad
Project leaders	Greg Hamilton, Western Australian Department of Agriculture and Food Dr Zahid Hussain, Federal Ministry for Food and Agriculture, Pakistan
Project duration	1 January 2004 – 31 March 2010
Funding	$848,352 (including three variations)
Countries involved	Australia, Pakistan
Commodities involved	Wheat, maize, plus other field crops (rice, cotton)
Related projects	LWR2/1998/131; LWR/2005/059; Ghani Akbar, John Allwright Fellowship

Motivation for the project and what it aimed to achieve

This project followed an earlier project (LWR2/1998/131, *Permanent raised beds to improve productivity and control salinity in Pakistan*) that introduced permanent raised beds (PRBs) with no-tillage crop establishment to the Pakistan farming community. The earlier project aimed to introduce technology to prevent the waterlogging and salinisation of irrigated land. Despite the machinery used being too large, too heavy and too expensive for the small fields and farms, the project was successful.

That success created an opportunity to improve the productivity and irrigation efficiency of virtually all of Pakistan's irrigated crops.

This project reported here became the vehicle to refine the introduced technology, adapt it to the socioeconomic circumstances of Pakistan's farming community and demonstrate that the benefits of PRB farming would apply across different soil types and cropping systems in different agroecological zones.

Opportunities to expand the impact of ACIAR's investment in PRB technology grew over the term of the project as a result of the Japan Bank and World Bank providing funds to raise Pakistan's irrigation productivity and the Federal Government of Pakistan investing in a project to stimulate the adoption of PRB farming throughout the nation.

The project was varied three times over its life.

Initially, in 2004, it had as its objectives to:

- better quantify the soil improvement that occurs under a new form of the soil management—deep blade-loosening (or renovation) of PRBs—and no-tillage crop establishment, and the impact such management has on the irrigation efficiency and productivity of wide and narrow beds
- foster adoption of the technology by providing the Pakistani research team and two cluster groups of farmers with their own PRB machinery and training
- foster the local manufacture of PRB machinery.

The project was first varied in 2005 in order to:

- accommodate the late provision of downsized Australian-made PRB machinery into a field research program with a scientifically sound duration, allowing for at least one more cropping season
- provide technical support and assistance to use grants obtained by the Pakistan project director, Dr Zahid Hussain, from the Japan Bank and World Bank to demonstrate and adapt the technology to the farming systems in Punjab province.

The Punjab activities were aimed at replicating the PRB results from Mardan in Khyber Pakhtunkhwa province and stimulating a larger number of Pakistan machinery manufacturers to produce PRB machinery of an adequate quality.

A second variation was initiated in 2007 as an outcome of the project's final review report. The objectives of this extension were to:

- assist Pakistani manufacturers to develop a seed-delivery mechanism on the PRB no-tillage seeders that would allow them to seed both field and row crops
- certify Pakistani manufacturers as capable of making good-quality, reliable PRB machinery
- introduce an irrigation scheduling regime to the experiments to further increase irrigation efficiency
- develop a training course curriculum for Pakistani extension staff and other interested personnel.

In 2009, a third variation was made after a request from the Pakistan Government to support the implementation of its National Project to Stimulate the Adoption of PRB Farming (SAPRB). Its objectives were to:

- disseminate all the findings on PRB from Mardan
- facilitate the adaptation of PRB to other soils, climates and farming systems in Pakistan
- identify new researchable issues that would lead to the ongoing improvement and adaptation of PRB technology and machinery for Pakistan's farming areas.

Farmers inspect machinery at a project field day (Photo: G. Hamilton)

Outputs—what the project produced

This project produced technical and capacity outputs.

Technical

None of the technical outputs from this project and its predecessor was known of or experienced before this work was done in Pakistan.

The technical outputs of the two projects, and research by a John Allwright Fellow Ghani Akbar, fulfilled the expectation developed at the outset: that the technology would be adaptable to and equally beneficial for all major cropping systems throughout Pakistan. The benefits of the application of PRB technology that were established and refined at the field research site near Mardan were replicated even by first-time adopters throughout the Khyber Pakhtunkhwa, Punjab and Sindh provinces.

The demonstrated benefits were an increase in crop production of 15–30%, a decrease in irrigation water use of 30–50%, a decrease in input costs, and an increase in profitability of at least 25%. In addition, the sustainability aspects of the technology were established: soil structure improves; waterlogging is prevented; water penetration into beds is adequate initially and improves with time; and salinisation from capillary rise or from accumulation in the bed centre is minimal to non-existent.

Presentation at a field day in September 2006 (Photo: G. Hamilton)

In addition, the machinery necessary to apply PRB farming was conceptually proven. However, it requires further refinement and good-quality construction and competitive pricing within Pakistan.

The projects produced biophysical modelling outputs for the farming practices needed to minimise capillary rise (and salinisation), assure lateral penetration of water into the centre of wide beds, and base irrigation scheduling on water balance to further reduce irrigation water use.

Capacity

The main capacities built by this project were:

- a heightened awareness of the need to improve irrigation productivity and efficiency across all of Pakistan's irrigated cropping systems
- knowledge of which practices to use to capture the required improvements
- knowledge of how to go about achieving changes in farming practice.

This increased capacity has been passed on to researchers and research and extension managers (as a by-product) and to extension staff and machinery manufacturers (as a primary objective). Its use was evident during the adoption study. Pakistan Agricultural Research Council management had adopted PRB as a research priority, and National Agricultural Research Centre researchers were formulating research projects for both irrigated and dryland farming in Pakistan. Also, Agritec Industries in Multan expressed a desire for designs of simpler, cheaper and more versatile PRB machinery, which it was unprepared to finance from its own resources.

The base of this increased capacity is an awareness of the requirement that soil management practices must change for soil conditions and productivity to improve, and knowledge of what must be done and why it must be done to capture the benefits. There is now an appreciation of the necessity for researchers and extension staff to possess the knowledge, skills and tools of farmers and to be able to demonstrate convincingly to them in their own fields a capacity to apply the new practices competently and economically. They also understand the basic design principles that must be built into machinery for it to deliver the desired improvements in soil condition.

Adoption—how the project outputs are being used

Pakistan researchers and research managers at the Pakistan Agricultural Research Council's National Agricultural Research Centre are using the awareness and knowledge of soil management practices that improve the productivity of and water and air movement in soil to develop research projects to better adapt PRB technology to a wider range of crops and agroecological zones in Pakistan. This includes projects for rainfed areas to prevent waterlogging and harvest excess rainfall. They are also involving Farm Machinery Institute expertise to improve the Australian-designed PRB machinery and the Plant Industries Institute to provide assistance in research and extension on the cost-effectiveness of chemical weed control, which is urgently needed throughout Pakistan. To further facilitate these initiatives, they are seeking the assistance of overseas expertise and funding bodies.

Pakistan extension officers are not using their improved capacity because their management is essentially reactive and they are not receiving requests for assistance to adopt PRB farming practices. This is entirely due to the Pakistan agencies being unable to fund or unwilling to second staff to promote and demonstrate PRB technology.

Machinery manufacturers are no longer receiving orders for or making Australian designed or Pakistan-modified PRB machines. However, despite this hiatus in production and sales, all remain very interested in manufacturing and promoting sales for PRB machinery that is lighter, better-designed and easier to operate and can make or renovate seedbeds in a one-pass operation.

Over the course of this project, more farmers adopted PRB farming or had PRB demonstrations on their farms than the resources of the SAPRB and ACIAR were able to support. Because of this inability to provide assistance, and difficulties with operating the Australian-designed machinery satisfactorily, there has been a large amount of dis-adoption (abandonment). However, all of the farmers who adopted PRB technology remain committed to bed farming. They use freshly constructed beds for each successive crop, for which they have adequate but poorly manufactured Pakistani machinery. This allows them to continue to use cultivation (ineffectively) for weed control. Despite the dis-adoption of strict PRB farming, all the farmers interviewed, plus many of their neighbouring farmers, want to adopt PRB farming, and would do so immediately if reliable, simple, composite and cheap machines were available.

Wide raised bed renovation (Photo: G. Hamilton)

Since the Australian PRB machinery was introduced in 2004, 39 farmers (final users) in the area around the Mardan research site have used the machinery. From 2007 to 2009, two sets of the machinery were lent to six Pakistani manufacturers (intermediate users) to copy; by 2013, 67 sets of PRB machines had been manufactured, 57 of which were sold to farmers (final users). SAPRB staff (intermediate users) used some of the machines to establish 30 monitored PRB demonstrations on farmers' land and government research stations in the Khyber Pakhtunkhwa, Punjab, Sindh and Balochistan provinces.

However, over the past 3 years there has been much dis-adoption, and only about five sets of the Australian-designed machinery remained in use in 2014. The dis-adoption has occurred because there has been no follow-on project to properly design better, cheaper PRB machines and to run well-targeted PRB promotions and demonstrations.

Future adoption will depend on improvements in the design, construction, operation and cost of PRB machinery. What is needed is a lighter, simpler, versatile machine that is easily converted from row cropping to field crop planting and is able to form or renovate beds and seedbeds in a one-pass operation. Furthermore, the machine must be relatively cheap. If these requirements were met, there would be an immediate and dramatic increase in the adoption of PRB farming throughout Pakistan.

Researchers and extension staff (intermediate users) have used information on soil management and improvement and irrigation efficiency to advise other professionals (intermediate users) and farmers (final users) of the value to be gained from PRB farming. Researchers and research managers are using this information to develop new research projects to better adapt PRB technology to a wider range of cropping systems and agroecological zones in Pakistan. While available PRB machinery remains limited in its operational capabilities, difficult to operate and expensive, farmers cannot adopt the practice of renovating beds by blade loosening, which is essential for improving soil conditions, lateral infiltration and productivity.

Because future use of this knowledge is tied to the availability of machinery that can loosen beds and retain the roots of previous crops, there will be no widespread adoption until such machinery becomes available.

The comparable productivity of wide and narrow beds is now fully accepted by all levels of users, but most importantly by farmers (final users). Narrow beds are now the default irrigation practice for bed farmers, who are now a very large majority among irrigation farmers in Pakistan. This transformation is the result of narrow bed machinery, also financed by the SAPRB, being cheaper and involving traditional cultivation practices. There is therefore no need for farmers to learn, understand and apply conservation agriculture practices. The use of fresh beds will continue to increase based solely on the increase in productivity that their use delivers.

Knowledge of the lack of water efficiency of narrow beds is being used by research and extension managers (intermediate users) to formulate research projects and to justify work on refining the PRB machinery and reducing its cost.

Future PRB farming using wide beds will be entirely dependent on the availability of machinery with the attributes outlined above. Irrigation efficiency will remain poor until the machinery challenges are met and good machinery is widely available at an affordable price.

The project demonstrated improved irrigation efficiency through irrigation scheduling. This output was used in a workshop for irrigation officers (intermediate users) from Pakistan in February 2014.

Future use of this knowledge and technology is likely to take time. Technical challenges will be overcome first to deliver substantial, easily achieved improvements in irrigation efficiency. On a larger scale, because better scheduling of irrigation water supplies would be a government responsibility, its implementation would be political and therefore much more difficult to achieve.

There is no evidence that the project's biophysical modelling of the soil conditions needed to minimise capillary rise and salinisation or to maximise lateral infiltration is being used by research managers (intermediate users) or researchers (final users) in a quantitative way to set research priorities and monitor research success. Failure to use modelling in this way reflects the organisations' and researchers' approach to research. The potential value of using modelling to determine the best approach to research was demonstrated in the way this project was focused and undertaken. It was not pursued as a specific project objective.

Future use of this type of modelling will probably be semi-quantitative at best because of the difficulty in inputting soil properties that are truly representative of the soils being studied.

Similarly, there is no evidence of the water-balance irrigation scheduling modelling being used, but knowledge of this output has not yet been disseminated. It will be used in workshops to challenge participants to identify ways that it could be used to change water supply policies and implement new ones.

Future use will, at best, be as background justification for policies aimed at improving the timing and amount of water supplied to farmers.

Impact—the difference the project has made or is expected to make

Local communities have benefited from the changes wrought by the introduction of PRB technology. The benefits have been increased communication and shared involvement among farmers who have adopted or demonstrated the PRB technology and their neighbours. This has also included greater involvement by extension and research staff with local communities. In return, those officers have found local communities showing a greater appreciation of their knowledge and skills.

When used in sponsored demonstrations or farmers' trial adoptions, this technology has delivered substantial benefits to machinery manufacturers, service providers, farmers, agricultural chemical suppliers and the provincial and national governments. The benefits have been greater resource (soil and water) conservation, lower input costs and increased productivity and profitability. The magnitude of the benefits has been greatest for individual farmers, and less for machinery manufacturers, service providers and agricultural chemical suppliers. Unsustained adoption has been almost entirely the result of machinery inadequacies.

There have been and will be no adverse environmental impacts from adoption; there will be substantial environmental benefits.

The only negative impact may be the loss of farm labouring jobs as cropping necessarily becomes more mechanised. Some of those jobs might transfer to manufacturers and service providers.

Integrated manure nutrient management in soybean/wheat cropping systems on Vertisols in Madhya Pradesh and Queensland (LWR/2002/032)

NEAL MENZIES AND K. SAMMI REDDY

Project number	LWR/2002/032
Project title	Integrated manure nutrient management in soybean/wheat cropping systems on Vertisols in Madhya Pradesh and Queensland
Collaborating institutions	Australia: University of Queensland; Queensland Department of Natural Resources and Mines; CSIRO India: Indian Institute of Soil Science, Bharatiya Agro Industries Foundation
Project leaders	Neal Menzies, K. Sammi Reddy
Project duration	1 July 2004 – 30 June 2010
Funding	$998,595 (plus $60,000 extension)
Countries involved	Australia, India
Commodities involved	Wheat, soybean
Related projects	LWR2/1998/136, SMCN/1999/003

Motivation for the project and what it aimed to achieve

A simple nutrient mass balance calculation for nitrogen (N) and phosphorus (P) indicated that the wheat/soybean cropping system used widely in Madhya Pradesh could be exporting more nutrient than was being supplied by fertiliser and through N fixation by the legume crop. A desktop study revealed that, during the late 1990s, the agricultural fields of Madhya Pradesh had a net negative nutrient balance totalling 0.9 Mt of N, P and potassium (K) per year for a crop area of 15.2 Mha. The nutrient deficit was steadily increasing and was predicted to reach 1.8 Mt by 2020 if current trends continued.

One variable in the mass balance calculation was the effectiveness of nutrient recycling through the production of farmyard manure, as no particular effort was made to ensure nutrient retention within the manure and the nutrient value of the manure was unknown. Nevertheless, it was clear that part of the nutrient deficit could be met through the more efficient use of animal manure, so this research project was developed to evaluate the nutrient status and nutrient balance of the soybean/wheat farming system and to develop nutrient management strategies appropriate to the farming system and farming community.

A related research problem existed in Australia, where feedlot manure was being applied to agricultural fields at rates that provided a total N application rate exceeding the requirement of the following crop, but the rate of mineralisation of N from that application was not known.

A project team consisting of researchers from the University of Queensland, the Indian Institute of Soil Science (IISS) and the Queensland Department of Natural Resources and Mines was assembled. The team had the appropriate discipline coverage of soil science, microbiology, plant nutrition and agronomy. The Bharatiya Agro Industries Foundation was also asked to join the project team to ensure good community input and because of the foundation's capacity to extend the outcomes of the research.

A proud farmer with his wheat (Var WH-147) crop near the village of Salamatpur. This crop was produced using the balanced fertilization regime and provided the farmer with an increased yield, and considerably increased profit. (Photo: N. Menzies)

Outputs—what the project produced

This project produced technical and capacity outputs.

Technical

The most important technical outputs were two fertiliser management strategies developed in collaboration with the farmers and evaluated by almost 300 farmers in their own on-farm trials. The first strategy, 'integrated nutrient management', combined farmyard manure with inorganic fertiliser. The project demonstrated that substantial benefits could be gained from a smaller farmyard manure application of 5 t/ha than from the traditional 20 t/ha application, permitting farmers to treat a larger area with manure each year.

However, even at the reduced 5 t/ha application there was not enough farmyard manure for application to all of the cropped area. Hence there was a need for the second management strategy; an inorganic fertiliser regime called 'balanced fertilisation'.

Both fertilisation strategies increased yield and profitability.

The project also acted as a catalyst for the adoption of improved farming practices, such as the use of new varieties and increased use of inoculation in legume crops.

Capacity

The project provided IISS with sophisticated crop modelling capabilities through PhD training of one of their staff, supported by a John Allwright Fellowship. It also introduced the use of the 'mother–baby' trial concept, in which trials conducted by researchers (mother trials) are followed in subsequent seasons by smaller, unreplicated trials conducted by farmers (baby trials) to test the initial results obtained for the most promising treatments.

The two fertiliser strategies were evaluated by 100 farmers in the first year of baby trials and by a further 200 in a subsequent year. The trials validated the initial results, clearly delineated the conditions under which the treatments were applicable, and achieved an initial and reasonably substantial extension of the fertiliser strategies.

Adoption—how the project outputs are being used

The integrated nutrient management approach developed in the project has been widely adopted. A key aspect is the increased rate of fertiliser nutrient application, especially where there is little or no farmyard manure available. Increased fertiliser application has been a key factor driving increased wheat yields. Farmers who participated in the research project reported that wheat yield increased to 5 t/ha, from 3 t/ha, as a result of their adoption of the integrated nutrient management approach developed in the project. Greater use of mineral fertilisers is financially attractive at current fertiliser and wheat prices, so there is a strong economic incentive for farmers to adopt higher fertiliser application rates. Since the inception of this project, the fertiliser rates recommended by various groups providing advice to farmers have increased. This project, along with other efforts by research and extension organisations, resulted in a substantial and sustained increase in the use of mineral fertiliser in Madhya Pradesh (a 70% increase in N and a 90% increase in P and K from 2006 to 2010), driving higher yields.

Impact—the difference the project has made or is expected to make

The benefits of increased fertiliser use and greater crop productivity are higher income for individual farmers and greater wealth in the general farming community. The adoption study team had the impression that conditions had improved markedly in the villages where the project was initiated, and that was confirmed by the villagers, though clearly there were other factors involved.

The benefits from the project are not evenly spread across the farming community. Improved crop nutrition can result in increased yields only where poor nutrition is the main constraint on production. For example, where crops are limited by water availability, the outputs from this project will have little impact. However, while not all farmers will benefit, none will be adversely affected.

Increased fertiliser use does not come without environmental impacts. At a most fundamental level, the production and use of fertiliser, and especially of N fertiliser, has greenhouse gas impacts through CO_2 emissions during manufacture and N_2O emissions during application. At the rates of application being used, substantial leakage of nutrients to the broader environment is unlikely.

Project scientists and farmers discuss the response of wheat (variety WH-147) to the integrated nutrient management approach developed within the project at Powanala village, Vidisha district (Photo: N. Menzies)

Huanglongbing management for Indonesia, Vietnam and Australia (HORT/2000/043)

ANDREW BEATTIE

Project number	HORT/2000/043
Project title	Huanglongbing management for Indonesia, Vietnam and Australia
Collaborating institutions	Universitas Gadjah Mada, Yogyakarta, Indonesia Plant Protection Research Institute, Hanoi, Vietnam Southern Horticultural Research Institute, Tien Giang, Vietnam
Project leader	Professor Andrew Beattie, University of Western Sydney
Project duration	1 January 2003 – 31 May 2009
Funding	$939,639 (ACIAR)
Countries involved	Indonesia, Vietnam, Australia
Commodities involved	Citrus
Related projects	CS2/1993/005, CS2/1996/176

Motivation for the project and what it aimed to achieve

Huanglongbing (HLB) is the most serious disease of citrus. It is incurable. This project stemmed from two basic needs: to build capacity and develop strategies to reduce the impacts of the disease in Indonesia and Vietnam, and more widely in Asia; and to develop an incursion management plan to prepare the Australian citrus and nursery industries for incursions of the pathogens that cause HLB, the vectors of the pathogens, or both.

When the project began in January 2003, the disease was known to be caused by two putative species of phloem-limited α-Proteobacteria, '*Candidatus* Liberibacter asiaticus' ('CLas') and '*Candidatus* Liberibacter africanus'. The spread of 'CLas' and its main vector, the Asiatic citrus psyllid *Diaphorina citri* (ACP), eastward from the Indian subcontinent over the past two or more centuries progressively devastated citrus production in Asia, particularly after the 1930s. '*Candidatus* Liberibacter africanus', a less virulent pathogen, was essentially confined to Sub-Saharan Africa, where it was transmitted by the African citrus psyllid *Trioza erytreae*. Potential incursions of 'CLas', particularly in association with ACP, pose the greatest known threat to citriculture and native species of *Citrus* in Australasia. The risk of incursions into Australia recently increased with the detection of the psyllid and the disease in Papua in the 1990s and in north-western Papua New Guinea in 2002 (Davis et al. 2005).

Gaps in knowledge about the disease and its vectors, and the need for capacity building, became evident during two earlier ACIAR projects on citrus pests in China, Indonesia, Malaysia and Vietnam (CS2/1993/005, *Integrated control of citrus pests in China*; CS2/1996/176, *Integrated control of citrus pests in China and Southeast Asia*), and through literature on the botany of citrus and citrus relatives within the Rutaceae and on citrus entomology and pathology. The need for an Australian incursion management plan stemmed from the increasing closeness of ACP and 'CLas' to Australia.

The initial project objectives sought to address these gaps and needs by:

- surveying the distributions and occurrence of psyllids and their natural enemies in Indonesia, Vietnam and Australia
- determining distributions of known and potential alternative hosts of ACP and 'CLas' in Indonesia, Vietnam and Australia
- determining the impacts of ambient temperatures at different latitudes, longitudes and altitudes in Indonesia and Vietnam on the incidence of ACP, and the spread and severity of HLB in different species and cultivars of citrus and alternative hosts
- determining impacts of feeding behaviour of adult ACP and host-plant phenology on transmission of 'CLas' in citrus and selected alternative hosts
- determining the impact of mineral and plant oil sprays on mortality, and spray deposits on feeding and oviposition behaviour, of ACP and the spread of HLB under laboratory and field conditions
- determining interactions between scion genotype, rootstock, 'CLas' genotype and ACP in Vietnam
- developing an incursion management plan for the Australian citrus and nursery industries
- conducting project workshops or seminars on HLB, citriculture and the use of horticultural and agricultural mineral oils in integrated crop management programs for citrus.

Additional project objectives, as part of the extension to the project from 1 June 2006 to 31 May 2009, were to:

- assess impacts of guava (*Psidium guajava*) interplants on the incidence of ACP and the spread of HLB in orchards in Tien Giang, Vietnam, and Central Java, Indonesia
- focus on capacity building and technology transfer in Indonesia and Vietnam.

The partners in the project were the Faculty of Agriculture of Universitas Gadjah Mada, Yogyakarta, Indonesia; the Indonesian Research Institute for Citrus and Subtropical Horticulture, Indonesian Agency for Agricultural Research and Development, Malang, Indonesia; the Plant Protection Research Institute, Chem-Tuliem, Hanoi, Vietnam; and the Southern Horticultural Research Institute (Southern Fruit Research Institute), My Tho, Tien Giang, Vietnam.

The research team in Indonesia included staff from the Indonesian Agency for Agricultural Research and Development in Yogyakarta, the Bogor Botanic Gardens (Indonesian Science Institute), Tanjungbura University in West Kalimantan, and the National Veteran University in Yogyakarta. Research and extension personnel from the Indonesian Research Institute for Citrus and Subtropical Horticulture participated in studies on the impact of guava interplants on ACP and HLB in Central Java, and in extension activities, during the second phase of the project.

The project began before the detection of 'CLas' in Brazil in 2004 and Florida in 2005, and the subsequent rapid spread of the disease and ACP (recorded in Brazil in 1940 and Florida in 1998) through the Americas and the Caribbean led to extensive investment in research on the disease and ACP in the United States and Brazil. What was a problem restricted largely to Asia when the project began is now a worldwide threat to the viability of commercial citrus production, which is a major international source of vitamin C. What was a problem for generally poor small-scale farmers in Asia is now a problem for wealthier, larger commercial producers throughout the world.

Asiatic citrus psyllid (*Diaphorina citri*) female ovipositing on immature flush growth of orange jasmine, *Murraya exotica* (Photo: G.A.C. Beattie).

Outputs—what the project produced

This project produced technical and capacity outputs.

Technical

All aspects of the project enhanced pre-existing knowledge.

Host records for the disease and its known vectors were reviewed and inaccuracies resolved. Records were summarised in the HLB incursion management plan (Beattie and Barkley 2009), which included a comprehensive literature review and analysis. The plan lists potential native Australasian rutaceous hosts of ACP and HLB.

Postgraduate studies, initially in Indonesia and then in Australia, determined the identity of orange jasmine, a favoured host of ACP, as *Murraya exotica* (not *Murraya paniculata*). This resolved more than two centuries of uncertainty and controversy. The studies also led to the discovery that a widely dispersed species of *Murraya* on the Asian mainland is possibly *Murraya elongata*, a plant described in 1875 but subsequently regarded as *Murraya paniculata*. ACP has not been recorded in that species, and the finding suggests that species of *Murraya* are not, as previously thought, the original host of the psyllid.

A review of herbarium and other records indicated the presence of 18 genera and 44 species or varieties of Aurantioideae, the citrus subfamily within the Rutaceae, in Indonesia. Distributions of some of these taxa were mapped. Orange jasmine was the preferred host of ACP among 32 known or potential host plant species and varieties evaluated as hosts of the psyllid and 'CLas' in Central Java: 'CLas' was only detected in species or varieties of *Citrus*.

Reviews indicated that there are 169 species of Rutaceae in 32 genera listed as being present in Vietnam. It was not possible to link distributions of the plants to altitude, topography, soil types and climate with any certainty. New host records for ACP were recorded on 3 of 21 species or varieties of rutaceous plants collected and propagated at the Plant Protection Research Institute in Hanoi.

Studies in the Mekong Delta enhanced knowledge about the susceptibility of citrus species and varieties and citrus relatives.

Studies in Central Java showed that populations of ACP and the incidence of HLB declined with increasing altitude as average saturation deficit values fell from 0.95 kPa at 68 m above sea level to 0.11 kPa at 1,288 m. Possible reasons for these relationships included impacts of the conditions on the development of the psyllid, the ability of psyllid nymphs to acquire and transmit the pathogen, and impacts of leaf temperatures on the pathogen. The relationships have implications for choosing locations and sites to optimise orchard longevity and productivity.

Field and pot trails in Indonesia confirmed that HLB-infected mandarin trees show mineral deficiencies, particularly zinc deficiency, and that fertiliser application may ameliorate these symptoms and improve tree health.

Studies in Indonesia and Vietnam confirmed that mineral oils, pesticides (including systemic insecticides) and natural enemies can reduce the incidence of ACP and slow the spread of HLB within orchards. However, pesticides do not prevent HLB, even when used at rates and frequencies that lead to unacceptable residues in fruit and detrimental impacts on the environment and the health of farmers and their families.

Studies in the Mekong Delta serendipitously confirmed observations by Vietnamese farmers and researchers on the reduced incidence of ACP and HLB in citrus orchards interplanted with guava. Subsequent studies in Vietnam, Indonesia, China and Florida confirmed impacts of guava on ACP.

Field and laboratory experiments in Indonesia and Vietnam indicated that mineral oils can be as or more effective than synthetic insecticides for suppressing populations of ACP and slowing the ingress of '*C*Las' into orchards. Those studies also showed that mineral oils can be used to simultaneously suppress citrus greasy spot (*Mycosphaerella citri*). No oil-induced phytotoxicity was observed in any of the studies in Indonesia and Vietnam.

Studies in Vietnam also showed that the impact of the systemic insecticide imidacloprid on ACP declined with time after application.

Universitas Gadjah Mada students, Ms Arlyna Budi Pustika (PhD) and Ms Sri Widinugraheni (MSc), demonstrating the iodine–starch test for HLB to farmers and extension personnel at Porwokerto, Central Java, Indonesia, 16 July 2008 (Photo: G.A.C. Beattie).

Capacity

The capacity of Indonesian and Vietnamese scientists and students was enhanced through studies on the host preferences of ACP; the impacts of the environment, natural enemies, mineral oils and systemic insecticides on ACP; the impacts of plant nutrition on the severity of HLB; the impacts of guava on ACP and HLB in citrus orchards; and determination of the taxonomic identity of orange jasmine. Eight postgraduate students were involved in these studies. Five students completed their studies (two MSc and two PhD students at Universitas Gadjah Mada, and one PhD student, a John Allwright Fellow, at the University of Western Sydney). Two Universitas Gadjah Mada students are completing their PhDs.

The capacity of researchers (from Indonesia, Vietnam, China and Malaysia), extension personnel and farmers was also enhanced through project meetings, workshops, reviews, field days and farmer field schools in 2004, 2006, 2007 and 2008 in Java, Indonesia, and in 2009 in Hoa Binh, Vietnam. Some of these events included demonstrations of the diagnosis of HLB based on the use of simple field microscopes to observe characteristic phloem abnormalities caused by the disease, and the use of an iodine–starch test for determining starch accumulation in leaves showing characteristic chlorosis related to phloem degeneration caused by the disease.

Post-project research and extension capacity in Asia, Australasia and the Americas was also enhanced through a Crawford Fund Master Class in Java in 2011.

The production of the HLB incursion management plan strengthened capacity in Australia to deal with incursions of the disease and its vectors. Wide distribution of the plan strengthened capacity elsewhere in Australasia and in Asia and the Americas. Capacity within Australia was also built through seminars and workshops and contributions to diagnostic protocols for liberibacters, ACP and the African citrus psyllid.

Adoption—how the project outputs are being used

Changes in farmers' practices following Universitas Gadjah Mada studies on the impact of plant nutrients on HLB-infected trees were not determined. Although the application of fertilisers may improve tree health and prolong the lives of infected trees, the cost-effectiveness may be negligible. The trees also serve as sources of inoculum for transmission by ACP to healthy trees. The use of nutrients to prolong tree health is therefore controversial and has recently received considerable media coverage in Florida.

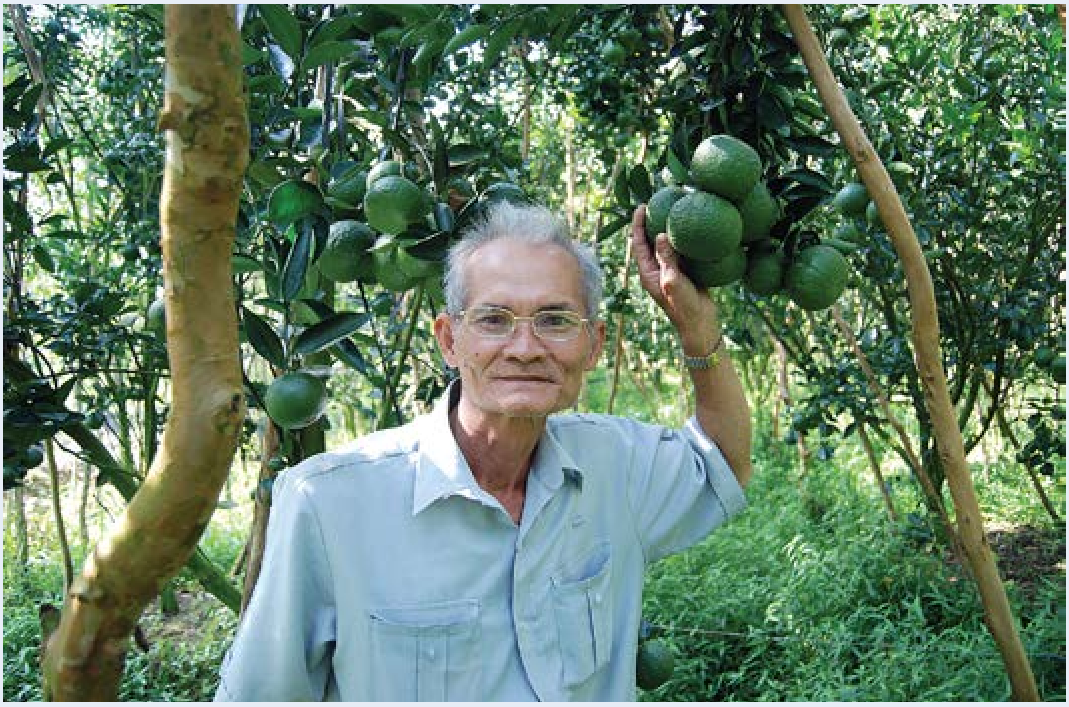
Mineral oils are being used alone or as adjuvants in sprays for ACP, some other pests and some fungal foliar diseases of citrus in Vietnam, but the extent of use has not been quantified. The knowledge of farmers needs to be improved. Interviews with farmers and research and extension officers indicated that the use of mineral oils is low and that use patterns are not as were envisaged when the project began. At this point, the effectiveness of extension activities by government agencies through traditional avenues and farmer field schools is hindered by relatively low numbers of staff compared with the estimated 4,000 field staff[1] employed nationwide by the pesticide companies to sell synthetic pesticides. A mineral oil registered for use on citrus in Indonesia from 2005 to 2012 is no longer available.

1 http://www.mekongcapital.com/en/content/giang-plant-protection

Guava interplanting is practised in Vietnam, mostly in the Mekong Delta, and information about it is readily accessible, but the extent of interplanting has not been quantified. There are concerns about its effectiveness declining 2 or more years after the planting of citrus trees within year-old guava plantings, but it nevertheless slows the ingress of ACP and HLB and boosts farm incomes in the 2–3 years after planting before citrus trees bear fruit. Guava interplanting was promoted in Indonesia after field trials were conducted as part of the project in Central Java, but the extent of adoption is not known.

Murraya exotica has been adopted as the valid specific name of orange jasmine by the Germplasm Resources Information Network, Agricultural Research Service, United States Department of Agriculture. It is gradually being adopted in lieu of *Murraya paniculata* by United States and Brazilian authors. Wider adoption will follow the formal publication of papers stemming from Nguyen Huy Chung's PhD thesis.

Since the HLB incursion management plan (Beattie and Barkley 2009) was completed in 2009, it has been used by Australian federal and state agencies and the Australian citrus and nursery industries to prepare for incursions of the HLB pathogens, ACP and the African citrus psyllid. Information from the plan has also been used to prepare an incursion management plan for the Australian nursery industry and diagnostic protocols for the HLB pathogens and their vectors. An urgent comprehensive revision of the HLB incursion management plan is needed in order to incorporate knowledge gained from substantial investments in research since HLB was detected in Brazil in 2004 and Florida in 2005 and mitigation strategies were developed from post-incursion management responses to 'CLas' and ACP in the Americas after 2004.



Mr Le Van Bay within his 'Objective 6' guava-interplanted king orange orchard at Cai Be, Tien Giang, Viet Nam, 21 January 2008 (Photo: G.A.C. Beattie).

Impact—the difference the project has made or is expected to make

The project had few direct benefits for farmers in Vietnam and Indonesia. The disease remained incurable, and extensive use of insecticides, as in the past, failed to ameliorate its impact on yields and orchard longevity.

Millions of dollars of investment in research and extension following the rapid spread of HLB in the Americas since 2004 has not led to a cure. Some plants have been identified as being 'less susceptible' to 'CLas', but genes conferring resistance have not been discovered. Most benefits in Brazil and Florida have flowed from reducing populations of ACP with coordinated applications of insecticides in area-wide management strategies over large areas. Such strategies are difficult to implement in Asia, where orchards are often smaller than 1 ha.

The project increased knowledge about mineral oils as effective and more environmentally sustainable options than insecticides, miticides and some fungicides for suppressing populations of ACP and other arthropod pests and the incidence of some foliar diseases, particularly black mildew (*Meliola citricola*) and citrus greasy spot (*Mycosphaerella citri*). However, marketing and technology transfer must be more efficient in order to match the marketing strategies of companies selling conventional pesticides.

The strategy of interplanting guava and citrus is still recommended and is used in Vietnam. However, in the Mekong Delta, second plantings on the same ground using the same techniques do not appear to be as successful as the first. The ingress of HLB is apparently more rapid on the second occasion. Observations suggest that this may be due to higher incidence of the disease in surrounding orchards and therefore higher incidence of psyllid adults harbouring 'CLas'. However, root grafting may be a contributing factor if the stumps, roots or both of infected trees are not treated with glyphosate and allowed to die before new trees are planted in previously diseased blocks.

The iodine–starch test, originally developed in Japan and promoted by the Southern Fruit Research Institute and the Food and Fertiliser Technology Center (Taiwan), is more widely used than a decade ago. However, despite its low cost and practicality for general use in lieu of polymerase chain reaction, the diagnosis of HLB-positive trees does not lead to the removal of infected trees by farmers in most instances. Moreover, the removal of infected trees has recently been shown to be of limited practical value, given the proportion of trees that are infected before foliar symptoms of the disease become apparent (Bassanezi et al. 2013).

Reviews of literature indicated that ACP and 'CLas' are from the Indian subcontinent, not China, and that species of *Citrus* and *Murraya* (*sensu stricto*) are not their original hosts. Curry leaf (*Bergera koenigii*) appears to be the original host of ACP, *Diaphorina communis* and *Cacopsylla murrayi*, but there is no evidence to indicate that curry leaf harbours 'CLas'. These insights are helping to resolve the origins of liberibacters (Nelson et al. 2013) and may contribute to means for mitigating the impact of the pathogens.

The capacity of scientists in Indonesia, Vietnam and other countries in the region was enhanced through postgraduate studies, meetings and collaboration. That additional capacity will be lost without ongoing training and collaboration and opportunities for those trained to work in positions that permit them to maintain ongoing inputs into mitigating the impact of HLB. The incursion management plan for Australia requires ongoing revision. Declining expertise in Australia needs to be stemmed.

The project also raised awareness about the potential impact of HLB on biodiversity, particularly through the loss of rare and endangered species of *Citrus* and *Citrus* relatives.

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