ADOPTION OF ACIAR PROJECT OUTPUTS

STUDIES OF PROJECTS COMPLETED IN

2005–06

Australian Government
Australian Centre for International Agricultural Research

ADOPTION OF ACIAR PROJECT OUTPUTS

STUDIES OF PROJECTS COMPLETED IN

2005–06

Editors: David Pearce and Deborah Templeton

2010

ACIAR
Research that works for developing countries and Australia

www.aciar.gov.au

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

ACIAR Adoption Studies

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

Communications regarding any aspects of this series should be directed to:

Program Manager
Impact Assessment
ACIAR
GPO Box 1571
Canberra ACT 2601
Australia

Phone +61 2 6217 0500
Email aciar@aciar.gov.au

Published by the Australian Centre for International Agricultural Research (ACIAR)
GPO Box 1571, Canberra ACT 2601, Australia

Telephone: +61 2 6217 0500
aciar@aciar.gov.au

ISSN 1832-1887
ISBN 978 1 921738 14 2 (print)
ISBN 978 1 921738 15 9 (online)

Pearce D. and Templeton D. (eds) 2010. Adoption of ACIAR project outputs: studies of projects completed in 2005–06. Australian Centre for International Agricultural Research: Canberra, 67 pp.

Technical editing by Biotext, Canberra
Design by Clarus Design
Printing by Elect Printing

Foreword

The Australian Centre for International Agricultural Research (ACIAR) contributes to Australia's aid program by investing in agricultural research projects that are designed to reduce poverty and promote sustainable development.

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

Formal, independent project impact assessments have always been an important part of ACIAR's accountability process and means of improving project selection and management. The adoption studies that form the body of this report are an important intermediate stage between completion of the projects and these rigorous independent impact assessment studies. The studies occur 3–4 years after each project is completed, to assess the level of uptake and the legacy of the project. They provide valuable insights into the uptake of project results and the impact on local communities, and form a basis for the impact assessments.

This is the seventh year these adoption studies have been completed. We now have an adoption study portfolio containing 65 sets of projects from which we are able to learn important lessons that can be fed back into our project development, design and implementation process.

I particularly want to thank the Australian project participants who revisited partner countries to gather and collate data and write the adoption statements that form the basis of this publication.

I also want to thank the many project participants in our partner countries who hosted visits, helped with data gathering, and provided useful insights on the ongoing impact and effectiveness of these projects. My sincere thanks to each of you for your support.

Nick Austin, Chief Executive Officer, ACIAR

Contents

Overview

David Pearce and Deborah Templeton

Introduction

This report summarises the adoption results for eight ACIAR projects completed in 2005–06. As is usually the case for ACIAR-funded research, the countries and research areas covered are diverse. The projects presented here cover:

- nine individual partner countries (the Philippines—two projects, India—one project, Bangladesh—one project, Thailand—one project, Lao PDR—one project, China—two projects, Vietnam—three projects, Papua New Guinea—one project and Indonesia—one project)
- five broad farm-level commodities (timber, rice, soybean, coconut and cereal grains)
- three projects concerned with broad resource use and quality (particularly water and soils).

The eight adoption studies indicate a generally high level of uptake of the project results, and in most cases the projects involved significant capacity building in partner countries. Most projects reported a high or medium level of adoption, although in some cases project outputs were not adopted in particular partner countries.

Of the projects presented here, six developed technologies designed for use by farmers or plantation managers—one of these also involved system-wide irrigation management techniques. One project was concerned with tissue culture and one delivered better technologies for storage (which may be off-farm).

What was discovered—project outputs

ACIAR-funded projects can be viewed as having three broad types of output:

- new technologies or practical approaches to dealing with particular problems or issues, designed to be applied at the farm or processing level
- new scientific knowledge or basic understanding (pure or basic science) of the phenomena or social institutions that affect agriculture, to be used in further research processes, ultimately to help in the future development of practical approaches at the farm or processing level
- the development of knowledge, models and frameworks to aid policymakers or broad-level decision-making, not necessarily at the farm level but in the overall environment in which farmers (and processors) must operate.

There is, of course, potential overlap between these categories, and many projects contribute to more than one of them. Table 1 summarises the nature of the outputs for the eight projects covered in this report.

New technologies or practical approaches were the major outputs for almost all of the projects. These were targeted both at the farm and the institutional level (irrigation management and storage authorities). One project (pathways for arsenic transfer) was concerned with providing information to villagers regarding the risks of arsenic exposure from contaminated food as well as with providing scientific information for researchers.

New scientific knowledge was an important output from seven of the projects, ranging from knowledge of psocid biology (relevant to grain storage in Vietnam and China) to understanding the system-wide effects of on-farm water-saving technologies (relevant to irrigation systems in China and Australia). Understanding salinity risks in new irrigation areas in Laos, and the pathways by which arsenic can be ingested by humans in Bangladesh are two other examples.

Four of the projects developed knowledge or models relevant to policymakers: particular techniques for management authorities (in soil and water management in the Philippines), knowledge of salinity hazards for irrigation planning in Laos, understanding the relationship between institutional arrangements and water use (in irrigation projects in China), and how to develop coherent strategies for the collection and conservation of coconut germplasm.

Table 1. Outputs of eight ACIAR projects completed in 2005–06

Project	New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
Soybean variety adaptation and improvement in Vietnam and Australia	New varieties of soybean more suitable for Vietnam Improved agronomic and irrigation practices relevant to Vietnam	Identification of improved breeding strategies for Vietnam and improved knowledge of the causes of limitations to yield	

Table 1. (continued)

Project	New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
Improving and maintaining the productivity of eucalypt plantations in India and Australia	Package of practices recommended for improved and sustained plantation management, including appropriate genetic material and improved silvicultural practices	Stock of knowledge on eucalypt management not available elsewhere in India	
Coconut tissue for clonal propagation and safe germplasm exchange	Development of propagation techniques for coconut: ▪ an efficient embryo culture technique ▪ a clonal propagation technique ▪ a genetic fidelity diagnostic		Development of coherent strategies for the collection and conservation of coconut germplasm from remote national and international sources
Salinity management in south-eastern Australia, north-eastern Thailand and Lao PDR	Development of catchment hydrological and socioeconomic models in Thailand	Scoping of salinity risk for new irrigation areas in Laos	Knowledge of salinity hazards for irrigation planning in Laos Recommendations for salinity management and land-use changes within project areas
Arsenic transfer in water–soil–crop environments of Bangladesh and Australia	Strategies to minimise human exposure to arsenic—in particular, advice about which vegetable crops accumulate less arsenic	Mapping of indirect pathways by which arsenic in groundwater can be ingested by humans—particularly through build-up in soils and transfer into particular types of foods	
Growing more rice with less water: increasing water productivity in rice-based systems	Understanding of effectiveness of water-saving techniques, in particular alternate wetting and drying, saturated soil culture and aerobic rice	Increased understanding of system-wide water savings from particular techniques Refined tools for water accounting and management of water	Improved understanding of the relationship between institutional arrangements and incentives and adoption of water-saving techniques

Table 1. (continued)

Project	New technologies or practical approaches	Scientific knowledge	Knowledge or models for policy and policymakers
Integrated watershed management for sustainable soil and water resources management: Inabanga watershed, Bohol Island, Philippines	Recommendations on: ▪ farm practices to reduce adverse environmental impacts of activities ▪ farm practices to maintain yields	Current state of natural resources in upper Inabanga watershed	Information and techniques for Bureau of Soils and Water Management and National Irrigation Authority
Integrating effective phosphine fumigation practices into grain storage systems in China, Vietnam and Australia	Development of national fumigation standards and dissemination of information about the safe and effective use of phosphine	Improved knowledge of psocid biology, ecology, distribution and resistance to phosphine Better understanding of resistance and conditions leading to increased toxicity of phosphine	

Capacity development

Most of the projects presented here had explicit objectives to improve the capacity for research and development (R&D) in partner countries. This capacity development included training in basic experimental and research skills as well as the use of modelling techniques to enhance experimental research. Most of the projects involved formal training of partner-country researchers, including some that led to higher academic qualifications. For example, eight students at the Henan University of Technology (China) were awarded MSc degrees based on research on various aspects of insect pest management and phosphine toxicology undertaken as part of phosphine fumigation practices into grain storage systems.

A number of the projects included the enhancement of research infrastructure. For example, in Vietnam, the soybean adaptation and improvement project provided a vehicle to enable researchers to access remote regions, and specialised fumigation equipment was installed at the Plant Protection Quarantine Laboratory in Hanoi through the phosphine fumigation practices in grain storage project. In China, various modelling and simulation techniques were developed and disseminated as part of the 'growing more rice with less water' project, while in the Philippines the integrated watershed management project introduced automated weather station and water sampler technologies. Finally, a modern soil and plant analytical facility was developed in India under the eucalypt plantations project.

In all cases, the research capacity and research infrastructure continue to be used. In a couple of cases, researchers who held junior positions during the course of the project now hold senior positions within the relevant organisations. Table 2 summarises the kinds of capacity developed in the projects covered in this report.

Table 2. Research capacity built by the eight ACIAR projects completed in 2005–06

Project	Partner-country research capacity built	Research infrastructure	Capacity used
Soybean variety adaptation and improvement in Vietnam and Australia	Specific training in agronomy and breeding (for soybean) Development of international research networks	Acquisition of a research vehicle, allowing broader field research access than previously available	Project trainees continuing to higher education Many project staff now in leadership roles Research vehicle still in use
Improving and maintaining the productivity of eucalypt plantations in India and Australia	Skills developed in the Kerala Forest Research Institute, including experimental and field skills Development of research networks	Development of a modern soil and plant analytical facility	Increased skill in the Kerala Forest Research Institute continues to be used Ongoing use of soil and plant analytical facility
Coconut tissue for clonal propagation and safe germplasm exchange	Increased skills for germplasm management in partner organisations through meetings and workshops	Supply of equipment to develop and maintain germplasm banks	Capacity continues to be used in all partner countries
Salinity management in south-eastern Australia, north-eastern Thailand and Lao PDR	Increased skills in geographic information systems, spatial analysis and numerical modelling		Some elements of new capacity continue to be used but others, such as some of the modelling, have not
Arsenic transfer in water–soil–crop environments of Bangladesh and Australia	Increased understanding of arsenic research Training in sample collection and processing		Arsenic contamination remains an important issue in Bangladesh and research capacity continues to evolve
Growing more rice with less water: increasing water productivity in rice-based systems	Training of researchers at Wuhan University (China) in various aspects of water-use analysis and system-wide water-use evaluation	Development and dissemination of various modelling and simulation techniques	Wuhan University remains an important centre for research and techniques learned continue to be used

Table 2. (continued)

Project	Partner-country research capacity built	Research infrastructure	Capacity used
Integrated watershed management for sustainable soil and water resources management: Inabanga watershed, Bohol Island, Philippines	Skills developed in experimental site establishment and instrumentation Training in data management and data interpretation Increased competency in the collection of watershed data at different scales and subsequent modelling	Automated weather station and water sampler technologies introduced	Bureau of Soils and Water Management has continued to use the increased capacity, including in at least two subsequent ACIAR-funded projects
Integrating effective phosphine fumigation practices into grain storage systems in China, Vietnam and Australia	Training students in China on various aspects of insect pest management and phosphine toxicology Training Vietnamese officers and scientists in the study of insects in stored products such as grain	Installation of specialised fumigation equipment (Vietnam and China), and a controlled environment cabinet for insect culturing and air conditioners to maintain controlled temperatures in the laboratory (China)	Capacity continues to be used and extensively disseminated in China and Vietnam

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

Table 3 summarises the adoption outcomes for the projects covered in this report. Whatever the various objectives of the individual projects, the ultimate aim of ACIAR-funded research is to provide producers, processors and/or decision-makers with knowledge, skills, technologies and/or techniques that will ultimately allow them to improve their wellbeing or the wellbeing of others. For this to occur, adoption of project outputs, even when these are knowledge based, is essential.

Most of the projects covered here 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 judgment. For the summary presented in Table 3, a four-level classification scheme (as used in previous adoption reports) has been used.

In this classification scheme, the lowest level of adoption is O, or no uptake of the results by either initial or final users of the outputs of the project. As Table 3 indicates, the coconut tissue and salinity management projects had no adoption of some of the project outputs, although in each of these cases there was adoption by scientists and/or technicians of other project outputs. In the salinity management project, farmers in areas of Thailand adopted some of the project recommendations for managing salinity.

The next level of adoption is *N*, the situation where there has been some uptake by initial users (e.g. scientists, farmer intermediaries) but no uptake by final users of the research. The two outputs from the arsenic transfer project fell into this category, and this was the highest level of adoption reported for the coconut tissue project, where there was some uptake of two of the outputs by the initial users but no uptake of the third output. A further five projects had some outputs falling into the *N* category, although in each case other outputs had higher adoption.

The next level of adoption is *Nf*, a situation where there has been uptake by initial users, and some uptake by final users. The adoption studies revealed that in four of the projects (soybean variety adaptation, eucalypt plantation productivity, growing more rice with less water and effective phosphine fumigation) there was some adoption of outputs by final users.

The highest level of adoption, *NF* (use by initial and final users), was achieved to some degree in at least some of the project components by five of the projects. It is not surprising that these were classified as new technology/practical approaches (e.g. improved management practices by forestry organisations, salinity management techniques, alternate wetting and drying of rice fields, improved land management practices in the watershed by farmers, adoption of phosphine standards by grain handlers).

Note that in some cases the next users of the project results are in effect the final users; for example, heat pulse and sap management techniques and embryo culture techniques are designed to be used by scientists or policymakers and not by farmers. These techniques and results are classified as 'N' because, while an important change along the impact pathway, they are not farm-level changes.

Table 3. Current levels of adoption of key project outputs for the eight ACIAR projects completed in 2005–06

Project	New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Soybean variety adaptation and improvement in Vietnam and Australia	*Nf*—adoption of newly released varieties *N*—adoption of better production practices	*N*—adoption of better breeding and agronomic research techniques and better breeding strategies by researchers	
Improving and maintaining the productivity of eucalypt plantations in India and Australia	*NF*—adoption of the recommended management practices was substantial for five of the six forestry organisations examined in the study *Nf*—one organisation had started to adopt the recommended management practices and there was evidence that independent farmers were also starting to adopt the recommendations	*N*—ongoing application of scientific approach and knowledge by researchers	

Table 3. (continued)

Project	New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Coconut tissue for clonal propagation and safe germplasm exchange	*N*—embryo culture technique *N*—clonal propagation technique *O*—genetic fidelity diagnostic		*N*—information and new techniques adopted and used by researchers in each institution for intended and unintended outputs *N*—findings of the project incorporated by the international coconut community into long-term production practices
Salinity management in south-eastern Australia, north-eastern Thailand and Lao PDR	*O*—simulation models *N*—heat pulse and related sap flow measurement techniques *NF*—salinity management by farmers in areas of Thailand	*O*—drivers of salinity in parts of Laos	*N*—monitoring of irrigation hazards in Laos
Arsenic transfer in water–soil–crop environments of Bangladesh and Australia	*N*—knowledge of which vegetables contain more arsenic	*N*—knowledge of arsenic pathways	
Growing more rice with less water: increasing water productivity in rice-based systems	*NF*— alternate wetting and drying technique continues to be adopted throughout China *Nf*—limited uptake of aerobic rice	*N*—information and new techniques adopted and regularly used by researchers on an ongoing basis	*N*—policymakers in particular regions adopting research findings relating to institutional structures
Integrated watershed management for sustainable soil and water resources management: Inabanga watershed, Bohol Island, Philippines	*N*—establishment of farmer-managed demonstration sites *NF*—around 50% of farmers in the watershed adopting improved practices	*N*—ongoing use of information by researchers	*N*—findings of project incorporated by the national irrigation authority into long-term maintenance practices

Table 3. (continued)

Project	New technology/practical approach	Scientific knowledge	Knowledge, models for policy
Integrating effective phosphine fumigation practices into grain storage systems in China, Vietnam and Australia	*NF*—adoption of phosphine standards in China *Nf*—adoption of phosphine standards in Vietnam	*N*—scientific information on phosphine toxicology and insect ecology used as the basis for changes to standards and practices *N*—knowledge, skills and equipment continue to be used by researchers in each institution	

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 adoption of project outputs

There is always a wide variety of factors underlying particular adoption outcomes. In a broad sense, a number of common factors emerge related to knowledge, incentives and barriers. These factors 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 the ongoing transfer of knowledge?
  - Are the outputs too complex to absorb relative to the capacity of the users (do users have a sufficient knowledge base to support adoption)?
- Incentives
  - Are there sufficient incentives for the project to be implemented in a way that will increase the likelihood of adoption by the ultimate users?
  - Are there sufficient incentives for the next users to pass on the project results?
  - 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 (an extreme form of incentive or barrier)?

- 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 to adoption?

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

Table 4. Factors influencing adoption and impact for the eight ACIAR projects completed in 2005–06—summary of key findings

Factor		Key findings
Knowledge	Do potential users know about the outputs?	Most of the projects had well-defined approaches to dissemination: ▪ Outputs in the Philippine watershed management project disseminated through farmer field days and farmer-managed demonstration sites. ▪ The eucalypt plantation project worked closely with industrial partners (experiments were on their land) so they were aware of the project findings; in essence, experimental sites were also demonstration sites.
	Is there continuity of staff in the organisation associated with adoption?	In aspects of the salinity management project, a change in staffing arrangements appears to have reduced adoption prospects. At the same time, ongoing support and training post-project may have been able to help with this continuity problem.
	Are outputs complex in comparison with the capability of the users?	Some aspects of the modelling components of the salinity management project proved too complex to adopt (relative to the perceived benefits of doing so).
Incentives	Are there sufficient incentives to adopt the outputs?	In the studies where incentives were explicitly considered, these had mixed effects: ▪ There were limited incentives in the Liu Yuan Kuo Irrigation System to adopt findings of the water-saving project. ▪ Short-term land tenure in the Philippines reduced incentive to take up long-term sustainable cropping options. On the other hand, indirect incentives through losses from soil erosion and other production constraints are likely to increase adoption in the future. ▪ Lack of effective seed production, storage and marketing systems limits the availability and distribution of better varieties of soybean in Vietnam.
	Does adoption increase risk or uncertainty?	▪ The short-term land tenure in the Philippines is a case of the effect of risk and uncertainty in adoption. ▪ The use of alternate wetting and drying techniques in rice growing requires a reliable water supply. In the absence of this, adoption would be risky.

Table 4. (continued)

Factor		Key findings
	Is adoption compulsory or effectively prohibited?	This did not appear to affect adoption outcomes for any of the studies.
Barriers	Do potential users face capital or infrastructure constraints?	▪ In the case of grain storage in Vietnam, old storage facilities meant that they were not suitable for the adoption of some of the techniques developed in the project. ▪ Alternate wetting and drying techniques in rice growing were not adopted in some study areas because of insufficient irrigation infrastructure.
	Are there cultural or social barriers to adoption?	In the pathways for arsenic transfer project, cultural factors may have affected the ability of villagers to adopt some findings.

Lessons

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

Incentives to improve practices

The Philippine watershed project found that training and information provided to farmers need to explicitly demonstrate sustainable economic benefits, otherwise farmers have little incentive to adopt. At least initially, it is more effective to develop sustainable changes within existing cropping sequences, rather than completely changing the cropping sequence.

The nature of land tenure matters

The Philippine watershed project noted that no land tenure, or limited or short-term land tenure, created incentives to adopt short-term contracts for products that led to depleted soil profiles and extensive soil erosion. Only farmers with long-term tenure were willing to consider more sustainable and long-term cropping options. This form of institutional constraint on incentives to adopt appears in many guises and has often been a lesson emerging in past adoption studies—although in a range of very different contexts.

Working with industrial partners can contribute to adoption

In the eucalypt forestry project, engagement with industry resulted in considerably more adoption than would otherwise have been the case. All of the major organisations in Kerala adopted project findings, as did a number outside the state. There are probably two components to this effect. First, when industrial partners indicate the most useful areas of research, the research is more likely to be aligned with their needs, so their adoption will be quicker. Second, industrial operators generally are able to act quickly on outcomes that they find beneficial. Whether this lesson is applicable to all projects is an open question, as in many cases industrial partners are not available.

Choice of research partner

It is almost a truism in ACIAR adoption study findings to conclude that the choice of research partner is crucial to the effectiveness of any project. The factors behind a good choice vary somewhat between projects. In the salinity management project in Thailand and Laos, some teams within partner organisations had worked previously on ACIAR projects and with Australian scientists. A number had also previously worked together across organisations. In the case of the Indian eucalypt project, the Kerala Forest Research Institute turned out to be a very effective partner, particularly as it is widely respected throughout southern India.

Rigour at the research proposal stage helps project delivery

In the adoption study for the 'growing more rice with less water' project, it was noted that:

> It is not easy to write a research proposal for ACIAR because before giving you money, they require lots of detail on what is to be achieved and what each of the different entities and individuals involved are expected to contribute to the project. However, once approved the management of the project became relatively easy.

The thrust of this comment is that rigour at the proposal stage ultimately helps the project. This lesson is, in effect, a reinforcement of current ACIAR practices. Indeed, another aspect of the comment was that other research funding agencies—some with particularly large sums of money to spend—did not have the same rigour or 'on the ground' understanding, and so were likely to be considerably less effective. Further, it is interesting that this comment comes from the perspective of a researcher seeking funding who might have preferred an easier application process, but who valued the rigour of the process once funding was secured.

Analysis in complex interactive systems requires system-wide techniques

A major outcome of the 'growing more rice with less water' project was examining how water savings scaled up to the field, farm and irrigation-system level. What appears as savings at one scale does not necessarily translate to net savings at the next scale. This finding, while appearing in the context of irrigation systems, may have broader application in areas involving common resources across many activities—particularly in the use of environmental assets.

Availability of complementary infrastructure

In the soybean variety and grain fumigation projects in Vietnam, a lack of appropriate storage infrastructure (in one case for the storage of seeds between seasons, and in the other in the unsuitability of existing storage for fumigation technologies) has meant less adoption of the seed varieties or technologies than could have been the case. Infrastructure limitations are not uncommon in many developing countries. This may suggest scope for coordinated planning among donors to be sure that infrastructure is suited to particular technologies being developed, and vice versa.

Soybean variety adaptation and improvement in Vietnam and Australia (CIM/1995/130)

Robert Lawn

Project number	CIM/1995/130
Project name	Soybean variety adaptation and improvement in Vietnam and Australia
Collaborating institutions	Australia: Commonwealth Scientific and Industrial Research Organisation Tropical Agriculture (now Plant Industry, CPI); James Cook University (JCU) Vietnam: Vietnam Agricultural Science Institute (now Vietnam Academy of Agricultural Science, VAAS); Institute of Agricultural Science of South Vietnam; College of Agriculture and Forestry, Thai Nguyen University (now Thai Nguyen University of Agriculture and Forestry); Hanoi Agricultural University Initial phase only: Oil Plant Institute of Vietnam (now Research Institute of Oil and Oil Plants); Can Tho University
Project leaders	Australia: Dr Andrew James (CPI), Prof. Robert Lawn (JCU) (extension phase) Vietnam: Acad. Prof. Tran Dinh Long (VAAS)
Duration of project	1 July 1999 to 30 June 2006
Funding	A$1,460,135 (ACIAR payment: A$913,403)
Countries involved	Australia and Vietnam
Commodity involved	Soybean
Related projects	PN8405, PN9040

Motivation for the project and what it aimed to achieve

The project was developed in response to a request to ACIAR from the Vietnamese Government for collaborative research to help improve the productivity of soybean and expand production in Vietnam. Most of the soybeans produced in Vietnam are used for human food, and projected production was not enough to meet increasing demands for vegetable oil and for high protein meal for livestock. Average soybean yields in Vietnam in the early 1990s were very low, only about 0.7 tonne/hectare, and made the crop unprofitable and unattractive to farmers. The government was keen to make soybean a more attractive crop, to expand production and reduce the national reliance on imports. As a legume, increasing the use of soybeans in rotations also improves the nitrogen economy and sustainability of cropping systems.

The technical objectives of the project were to help the Vietnamese Government to increase soybean productivity by identifying more attractive varieties, and by developing and promoting good agronomic practices. Improving the knowledge and skills of researchers was also a specific objective. The strategy for achieving these objectives was to share improved, tropically adapted soybean germplasm, and agronomic and breeding experience in the tropics, which had been developed through two previous ACIAR projects in Thailand.

The project established formal links between key agencies responsible for soybean improvement research and development (R&D) in Vietnam: the Vietnam Academy of Agricultural Science (VAAS), the Institute of Agricultural Science of South Vietnam, and Thai Nguyen University of Agriculture and Forestry (TNUAF) with, in Australia, the Commonwealth Scientific and Industrial Research Organisation Division of Plant Industry (CPI) and James Cook University (JCU). Additional informal links were established when the project started with the Hanoi Agricultural University (HAU), the Research Institute of Oil and Oil Plants and Can Tho University.

What the project produced

The project delivered useful outputs in three areas: new, higher yielding tropically adapted varieties, better management practices to improve yield, and enhanced technical and scientific capacity.

From 261 diverse, tropically adapted soybean accessions and breeding lines from countries as varied as Brazil, Nigeria, Thailand, the United States and Australia, several were identified as 'promising varieties' for different regions and for wider evaluation and possible immediate release to farmers. In addition to these promising varieties, elite parental accessions were identified, with attributes like the long juvenile (LJ) trait, semi-dwarf habit, lodging resistance, disease resistance and good seed quality. These lines were used as parents in hybridisations among themselves and with Vietnamese varieties, to create elite segregating breeding populations for evaluation and selection. In the process, appropriate breeding methods were demonstrated for how useful traits (e.g. the LJ trait, the semi-dwarf trait, weathering resistance, disease resistance) could be introduced into a variety through backcrossing or during pedigree breeding. Meanwhile, after their initial evaluation, the diverse accessions and breeding lines were committed to long-term storage to provide the basis for future breeding research.

A key agronomic finding from the project was that many Vietnamese soybean crops failed to produce enough leaf area to ensure complete radiation interception, constraining yield potential. Two factors shown to affect leaf area development were crop duration and plant population density. The LJ trait was shown to enhance yield potential by delaying flowering under warm, short-day conditions, while the semi-dwarf trait enhanced lodging resistance under high plant density. Improved agronomic practices, including optimal sowing dates and plant populations were identified for the different soybean varieties in different seasons and regions. Importantly, it was established that limits to yield due to short crop duration could be partly overcome by increasing the plant population.

Vietnam Academy of Agricultural Science soybean breeders Dr Tran Thi Truong (left) and Mrs Nguyen Thi Loan (right) and soybean physiologist Mr Nguyen Van Thanh (standing), discuss breeding activities with Robert Lawn. Soybean germplasm from the Commonwealth Scientific and Industrial Research Organisation breeding program is being used as parental lines in ongoing breeding programs at the Vietnam Academy of Agricultural Science, Hanoi Agricultural University, Thai Nguyen University of Agriculture and Forestry, the Institute of Agricultural Science of South Vietnam and the Institute of Oil and Oil Plants.

The project was the first large international project with which most of the Vietnamese soybean scientists had collaborated, and it helped lead scientists to gain international experience by attending conferences and visiting researchers in Australia. Younger scientists were trained through links to collaborating universities, with one PhD, 10 MSc and 33 undergraduate students completing training at HAU and TNUAF, sponsored through the project. Forty soybean researchers from various research institutes, universities, and provincial extension services and seed production cooperatives were trained in 'Agronomy and breeding to improve adaptation and yield in soybean' in 2006 during a 3-day course in Hanoi. The project organised the first two National Soybean Conferences in 2001 and 2003, and established the first Soybean Research Network in Vietnam. A Mitsubishi four-wheel drive vehicle, sponsored through the project, allowed VAAS soybean researchers to conduct comprehensive regional research in remote provinces for the first time.

Adoption—how the project outputs are being used

Project varieties have been released and are being grown by farmers in several regions. DT21 is being grown by farmers as an irrigated winter and spring lowland crop in the Red River and Mekong delta regions. CM60 and DT29 are being grown as spring and summer crops in upland hilly areas of the north, while CM60 and VDN3 are being grown as spring and summer crops in the central and south-eastern mountainous provinces. Equally importantly, these varieties and other promising lines from the project germplasm collection are being used to introduce high-yield potential, the semi-dwarf habit, the LJ trait, and disease and lodging resistance into earlier maturing Vietnamese varieties. The first of these breeding populations is now in advanced generations and will soon enter regional variety trials to select the next generation of improved varieties. The main constraint to the adoption of new soybean varieties is the lack of an effective public or private seed production, storage and marketing system to deliver high-quality seed supplies of recommended varieties for the winter and spring seasons.

There is gradual but progressive adoption of improved agronomic practices (in terms of optimal sowing dates and plant populations in different regions and seasons) in those provinces where the soybean research teams are most active. Adoption of improved practices in more remote provinces is slower, and is reflected in slower rates of productivity improvement. Improved irrigation is being practised in winter crops in the Red River Delta and the dry season crop in the Mekong Delta, underpinning productivity gains in both regions. The main driver has been improved irrigation infrastructure supported by sound advice by scientific and extension staff. There is also ongoing research attention on agronomy and breeding to raise yield potential by ensuring crops achieve a closed canopy.

Since the project ended, participants have continued to energetically build on their enhanced English language skills and scientific knowledge. For example, more than a dozen young staff are undertaking or have completed higher degree training at MSc or doctoral level in Vietnam or overseas. Many former junior project staff are now in leadership roles, while others are actively engaged in new international collaborative projects. Links have also been maintained with the Australian program, with ongoing exchange of germplasm with CIP and two project staff undertaking postgraduate training at JCU.

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

The project was part of a wider set of activities that have contributed and will continue to contribute to advances in soybean productivity and production in Vietnam. In the past 9 years, annual soybean production in Vietnam increased by around 85% to about 270,000 tonnes. This was achieved through an increase of nearly 50% in the area sown and a 25% increase in the yield per hectare. The gains in productivity per hectare have arisen through the greater use of inputs, especially irrigation, better production practices and use of improved varieties by farmers. The improved varieties and practices developed during the project will contribute to productivity gains as adoption increases. The enhanced R&D capacity developed through the project will contribute to further advances in production practices and varieties. The improved soybean germplasm introduced into Vietnam by the project will help underpin future genetic gains.

In upland areas, soybeans are often intercropped with other crops like maize (pictured), sorghum, cotton, tobacco and sugarcane

The immediate beneficiaries of the adoption of better production practices and improved varieties are the smallholder farmers who grow the crop. Most are poor with land areas of 0.25–1.50 hectares and depend on the crop as a source of food and for a major part of their cash income. The higher productivity flowing from adoption enhances their food security, and increases the profitability of the crop and so their income. Benefits accrue to the wider community in the form of a greater and more reliable supply of a high-protein traditional food source. For the Vietnamese economy as a whole, increased soybean production will help to satisfy demand for feed for the rapidly expanding livestock industry, currently met through imports.

There are large areas where soybeans can potentially be grown, and increased production is a government priority. There are about 960,000 hectares of land in the Red River Delta in the north, and likewise large areas in the Mekong Delta, which currently remain fallow following summer rice production but where irrigation will allow winter soybean production. There are also several million hectares in upland provinces of the north, and eastern part of central and southern Vietnam where spring or summer soybean crops could be grown. The main factor that will affect the rate of expansion of soybean production in Vietnam is future grain prices. Assuming prices are favourable, more farmers in more regions will start to grow the crop in more seasons. The varieties released through the project expand the options available to farmers in the less traditional winter and spring seasons where there is large potential for expanding production. Most of these varieties are higher yielding (20–40%) than existing winter and spring varieties and continued diffusion to more farms can be expected over the next 5 years.

Improving and maintaining the productivity of eucalypt plantations in India and Australia (FST/1995/106)

Daniel Mendham

Project number	FST/1995/106
Project name	Improving and maintaining the productivity of eucalypt plantations in India and Australia
Collaborating institutions	Australia: Commonwealth Scientific and Industrial Research Organisation (CSIRO) India: Hindustan Newsprint Limited, Kerala Forest Department, Kerala Forest Development Corporation, Kerala Forest Research Institute (KFRI)
Project leaders	Australia: Daniel Mendham (CSIRO); previous project leaders were Tony O'Connell (CSIRO) and Tim Grove (CSIRO) India: K.V. Sankaran (KFRI)
Duration of project	1 July 1997 to 31 December 2005
Funding	A$3,270,247 (ACIAR payment: A$1,861,116)
Countries involved	Australia and India
Commodity involved	Timber
Related projects	FST/1994/025, LWR1/1994/014

Motivation for the project and what it aimed to achieve

The project was initiated because plantation productivity in India was very low by international standards, and declining over multiple rotations. India was also facing a 'wood famine' with increasing demand for wood products driven by rapid development, and a declining resource base to feed the demand. The key objectives of the project were to explore inter-rotation site management options and sustainable management options to improve the productivity of plantations and thus ensure that they could be sustainably grown into the future, and also to build capacity in India, specifically at the Kerala Forest Research Institute (KFRI).

What the project produced

The technical outputs from the project were combined into a package of three silvicultural management options/practices to improve and sustain plantation productivity:

- Inter-rotation site management
  - retained harvest residues on site to ensure that the site nutrient status was not depleted; this contrasted with previous management, which was to burn or remove the residues, and had resulted in a long-term reduction in site nutrient status
  - ensured high-quality genetic stock was used; plantations established before this project were grown using local land races with inferior seed. The project demonstrated that use of selected planting material rather than local land races could potentially double the productivity even without further intensive management.
- Sustainable long-term management of eucalypt plantations
  - used regular and intensive weed control; weed control in plantations before this project was minimal and one of the main causes of low productivity
  - intercropped plantations with legumes
  - built trenching on steep slopes.
- Nutrient management recommendations
  - demonstrated that targeted fertiliser application could give good return on investment; before this project, little, if any, fertiliser was used in the management of plantations.

Overall, it was demonstrated that the use of appropriate genetic material could give a twofold increase in productivity, and application of the silvicultural package of practices could give an additional twofold increase in productivity.

Capacity development was an important outcome from the project, and KFRI staff report greater ability and confidence in:

- designing experiments to address specific questions
- designing and implementing field experiments

- laboratory skills and their application
- field skills and their application
- rigour of science
- improved connections with scientists from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and other international organisations.

Adoption—how the project outputs are being used

The project package of practices was widely adopted, both in Kerala and in other states of southern India. The involvement and interaction with forestry organisations was a key contributor to ensuring that the project outputs were of relevance and able to be adopted rapidly by the companies involved. The three key industrial partners in the project, the Kerala Forest Department (KFD), the Kerala Forest Development Corporation and Hindustan Newsprint Limited (HNL) all showed significant adoption of the project findings, and a number of other organisations who attended the final workshop also demonstrated significant adoption of the outcomes. Smallholder growers within Kerala have also adopted the project outcomes, but the level of adoption has not been quantified. Two smallholder growers were interviewed

Loading *Eucalyptus* logs near Mr V.S. Jayaraman's property as a part of this study, and both growers had substantially adopted the findings to the best of their ability. Some of the more expensive operations (e.g. fertiliser management) were not feasible for them to adopt because of their cash flow situation.

Much of the capacity that has been developed is still being used by KFRI staff through their development and management of research projects, but also is being passed on to others such as Indian Forest Service officers through the training courses that KFRI provides, and to students at the Kerala Agricultural University.

KFRI is now a primary and trusted contact for all of the major forestry partners in the original project; for example, KFD now relies on KFRI for its forest management plans and biodiversity plans, and to oversee its internal research program. Also, KFRI now supplies high-quality clonal planting stock to HNL and KFD, based on the material used in the ACIAR experiments. KFRI is now the first port of call for any technical questions that these organisations have.

KFRI is also recognised by all of the major eucalyptus growers in the southern Indian states of Tamil Nadu, Andhra Pradesh, Karnataka and Orissa, as well as Kerala, through their participation in the final project workshop. The involvement of KFRI in the ACIAR project has earned respect across the industry, and many of these organisations have expressed a keen desire to participate in new projects with KFRI.

Operational weeding at Mr P. Alumuttil's plantation; approximately 10 women are employed, each paid about Rs150 per day

New instrumentation and methodologies introduced to KFRI through the project continue to be used; for example, sap flow instrumentation has been used in two externally funded projects. Another example is that the methods introduced by the project for estimating standing volume continue to be widely applied, and have been used in court cases where accurate estimates of wood volumes are required. This technique has also been adapted to teak. The chemistry laboratory established by the project has been upgraded with new instrumentation, and is now a central facility for use by KFRI staff and students.

Some of the methodologies applied in the project are being taught at the College of Forestry at the Kerala Agricultural University by one of the project scientists. This university is recognised as one of the top forestry training colleges in India, and produces a disproportionate number of graduates accepted into the Indian Forest Service.

KFRI is recognised as a national training centre, and regularly hosts training of Indian Forest Service officers from all parts of India. The outcomes of the ACIAR project are explicitly focused on in a training course on weed management in plantations, and aspects of the ACIAR project experience also appear in many of the other training courses.

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

The project has had a significant impact, both in Kerala and other states of southern India. Because most of the project outputs have been adopted, productivity has increased threefold across the organisations in Kerala, and substantially in the other organisations. This has resulted in a recurring net benefit from the project of (conservatively) A$25 million each year and 120,000 jobs. These are the direct benefits up to plantation harvest and delivery to the mill gate, but there are substantial benefits that are not accounted for in this analysis, including the capacity for these mills to remain viable, the requirement for less land to be used in the production of the material, and a reduction in the pressure of logging native forests.

The adoption of the project outputs by farmers is much harder to quantify, but two farmers who grow eucalypts and have been influenced by the project outcomes were interviewed. They are both quite different, and so should be treated as case studies rather than fully representative of eucalyptus-growing farmers in Kerala. These farmers attended the field day run by KFRI, and this was how contact was made for this study.

Case 1: Mr Ponambalam Alumuttil

Mr Alumuttil has 1.5 hectares (ha) of eucalpyts growing in Chinnakanal district (near one of the project's experimental sites). He grows only eucalypts on this land, as other agricultural ventures have not prospered as well, and earns off-farm income by labouring for others. He follows most of the recommendations made through the ACIAR project, as he was impressed with the productivity at the experimental site. However, he cannot afford fertiliser for his plantation. From his 1.5 ha, Mr Alumuttil expects to clear around Rs300,000–400,000 (around A$7,000–10,000) over a 4-year rotation, which is considered to be a substantial profit. This was evident from the fact that he is now building a house to live in, whereas his residence thus far has been a palm-frond hut. When we visited, about 10 women were weeding, as per the project recommendations. From his 1.5 ha of plantation, Mr Alumuttil anticipates around 20 trees will be big enough (over 40 centimetres in diameter) to sell to the plywood factory for a premium return. The remainder will go to HNL.

Case 2: Mr V.S. Jayaraman

Mr Jayaraman grows 12 ha of eucalypt plantations in the Vattavada area, on a parcel of land that was used for vegetable growing. Mr Jayaraman also jointly farms around 20 ha of vegetables with his family. Mr Jayaraman follows the recommendations of the ACIAR project in his eucalypt plantation, and anticipates around Rs1 million per hectare (around A$24,000) profit after 7 years, with approximately 75% (three truck loads in four) of sufficient size (over 40 centimetres) to go to the plywood mill, and 25% going to the pulp mill. He harvests a proportion of his farm each year, so has an annual source of income. Mr Jayaraman commented that he is much better off planting 1 acre (0.4 ha) of eucalyptus for his new daughter so that in 20 years time when she is ready to marry the trees will return a sizeable dividend of around Rs1.3 million (A$32,500), compared with investing in life insurance, which is a common but less profitable alternative.

Dr Muralidharan with a newly commissioned segmented flow analyser in the central analytical facility of the Kerala Forest Research Institute

Coconut tissue culture for clonal propagation and safe germplasm exchange (HORT/1998/061)

Stephen Adkins

Project number	HORT/1998/061
Project name	Coconut tissue culture for clonal propagation and safe germplasm exchange
Collaborating institutions	Australia: School of Land, Crop and Food Sciences, the University of Queensland (UQ) Indonesia: Indonesian Coconut and Other Palms Research Institute (ICOPRI) Papua New Guinea: Cocoa Coconut Institute (CCI) Philippines: Philippines Coconut Authority, Albay Research Center, (PCA); University of the Philippines, Los Baños, Institute of Plant Breeding (UPLB) Vietnam: Oil Plant Institute of Vietnam (now Research Institute of Oil and Oil Plants, RIOOP)
Project leaders	Australia: Prof. Stephen Adkins (UQ) Indonesia: Dr Hengky Novatianto (ICOPRI) Papua New Guinea: Dr Mathias Faure (CCI) Philippines: Ms Erlinda Rillo (PCA), Dr Pablito Magdalita (UPLB) Vietnam: Mrs Vu My Lien (RIOOP)
Duration of project	1 July 2002 to 31 December 2005
Funding	A$1,315,332 (ACIAR payment: A$805,329)

Countries involved	Australia, Indonesia, Papua New Guinea, the Philippines and Vietnam
Commodity involved	Coconut
Related projects	HORT/2006/006

Motivation for the project and what it aimed to achieve

Coconut (*Cocos nucifera*) is a tropical palm grown by more than 11 million smallholder farmers in more than 90 countries around the world. In recent years, coconut production has declined in the south-east Asian and Pacific regions because the majority of palms are becoming too old for optimum fruit production and are being affected by a number of new devastating pests and diseases. Thus, the replanting of this region with new, high-yielding, disease-resistant cultivars will be an important part of re-establishing the traditional coconut-based farming system of the region.

This project was designed to underpin an earlier established International Coconut Genetic Resources Network (COGENT) program of international coconut genebanks (ICGs) by providing the ICGs with a series of new tissue culture techniques that could be used for the safe collection, conservation and use (replanting programs) of the region's unique coconut genetic resources.

The agencies involved with the project were selected because of their strength in coconut tissue culture and their close association with the newly developed COGENT ICG program. The partner organisations included the Cocoa Coconut Institute of Papua New Guinea (PNG) (a merger of the PNG Cocoa and Coconut Extension Agency and the Cocoa and Coconut Research Institute; host to the South Pacific ICG), the Indonesian Coconut and Other Palms Research Institute (host to the South-East and Southern Asian ICG), the Research Institute for Oils and Oil Palms (formerly known as the Oil Plant Institute of Vietnam), the Philippines Coconut Authority, Albay Research Center, and the University of the Philippines Los Baños, Institute of Plant Breeding. The Australian partner was the School of Land, Crop and Food Sciences, the University of Queensland, which had gained an international reputation for high-quality coconut tissue culture work. Before the project, all partner organisations had undertaken collaborative work on coconut tissue culture and had been involved in staff exchange programs. The project content was finalised after consultation with Dr Ponsciano Batugal, the then Director of COGENT, a trip to consult with scientists within CIRAD (Agricultural Research Centre for International Development), France, and following attendance at the International Symposium on Coconut Biotechnology, held at the Yucatan Center for Scientific Research (CICY), Mérida, Mexico, in 1997. This symposium was attended by all the major international players in coconut tissue culture, and through a consultation and modification process, the final project proposal was developed.

The project was designed to complement coconut production in the South-East Asian and Pacific regions by:

- developing an improved method for embryo culture so that coconut elite germplasm could be collected and exchanged nationally or internationally, or routinely revived after cryopreservation; this work was to be concentrated in all partner organisations

- contributing to a worldwide attempt to develop methods to rapidly clone true-to-type coconut palms. Such a method would be used to mass-propagate planting materials from elite, disease-resistant germplasm in the replanting process—aspects of this work were undertaken in the Philippines and Australia
- developing a technique that could assess the degree of genetic stability found in palms that had come through tissue culture—this work was undertaken in the Philippines and Australia
- creating a network for the exchange of information and skills, and providing equipment needed for the future operation of all partner tissue culture laboratories.

What the research project produced

From the Australian, Indonesian and PNG partners there have been three major technical outputs from the project that were intended and one that was not anticipated. The first intended output was the development of a highly efficient embryo culture technique for coconut that raised the efficiency of producing healthy palms growing in soil from the pre-project success rate of 20% to the post-project success rate of 80%. The same technique shortened the time for this process by about 4 months (from 12 to 8 months), thus reducing certain inputs and making the process more cost-effective.

The second intended output was the development of a clonal propagation technique for coconut that was capable of producing clonal plants at a moderate level of efficiency. For the first time, true clonal plants were produced from somatic inflorescence tissue rather than the pre-project approach that used zygotic embryo tissue, which does not produce true-to-type plants.

A small coconut research plantation established using high-value coconut varieties (Aromatic) that had been raised using the embryo culture technique

The third intended output was the development of a genetic fidelity test/diagnostic for coconut that was capable of identifying 'off-types' that may have been produced by the tissue culture approaches, especially clonal propagation. The diagnostic developed was the first of its kind for coconut and was able to show that there was no measurable genetic change to be found in the regenerated plants coming from embryo culture, clonal propagation or following cryopreservation.

One unintended output was the development of an approach to better propagate the high-value coconut mutant varieties (those with a tasty endosperm). Such coconut types fetch a very high price on the local market as a fresh fruit, but their production is limited due to flaws in their germination process in nature. The embryo culture technique developed in this project is now being used by the partners in Indonesia and PNG to raise plants of these unique types. Such plants are now being used to establish research plantations in Indonesia from which, over time, plantlets will be developed for the future expansion of the fresh-fruit market for coconut by smallholder farmers.

All the technical developments described above have given confidence to the policymakers of the Indonesian and PNG partner organisations, and they have embarked on coherent strategies for the collection and conservation of coconut germplasm from remote national sources and from some international sources. By providing a safe, moderately efficient clonal propagation protocol, new elite germplasm (Kopyor, Garuk etc.) is now being targeted for multiplication and for the future establishment of new, elite variety plantations.

The commitment shown by the Indonesian and PNG partner organisations following these technical developments led to policy changes that resulted in further resources being provided to continue the work after the ACIAR project had finished. In PNG, a government grant in excess of A$3 million has been obtained to develop facilities for the downstream use of coconut palm products, while in Indonesia, funding has been provided to set up a plantation of Kopyor coconut using embryo culture and then to increase the palm numbers using clonal propagation.

Finally, the development of close working relationships between all partner institutions has led to a shared understanding of the technical and cultural issues needed to further progress the collection, conservation and use of coconut germplasm. This strong working relationship was facilitated through joint research experimentation and publication, aided by sharing developed technology and the exchange of coconut genetic materials, while taking advantage of opportunities for presenting work at scientific and industry meetings.

Adoption—how the project outputs are being used

Since the completion of the project in 2005, all partner organisations have continued their investment in improving coconut farming. The newly found confidence with coconut tissue culture has caused all partner organisations to expand their research programs in this area. In Indonesia, the recently discovered ability to culture embryos within upgraded tissue culture facilities has led to many Kopyor plantlets being produced and planted to establish a new plantation from which further embryos will be isolated and, over time, used to create further Kopyor seedlings for sale to farmers. This action will have a significant impact upon all the coconut-producing regions of Indonesia, given the high value of the fruit from this type of palm, which is currently achieving A$3 a fruit in Jakarta.

One of the partner scientists evaluating the procedure used to germinate coconut seed nuts at the partner organisation seed garden

The project outputs are all being used by the partner organisations, but not to the same degree. The first project output—the development of a highly efficient embryo culture technique—is in its final form and is being used by all partner organisations to collect and conserve coconut germplasm, and to multiply planting materials of high-value coconut varieties. As a result of this project, this approach (or a slightly modified approach) is also being used by other countries in their coconut improvement programs (e.g. Brazil, India, Ivory Coast, Sri Lanka etc.). The new technique has been adopted in two ways; firstly, to raise plants from imported and nationally collected germplasm (the original aim of the project) and secondly for the propagation of high-value coconut mutant varieties.

The second project output—the development of a clonal propagation technique for coconut capable of producing clonal plants at a moderate level of efficiency—is not in its final form and therefore has not yet been widely adopted. One partner organisation (the University of Queensland) is working to improve the technique for the mass propagation of high-value coconut mutant varieties. It is anticipated that Indonesia will use this same approach later in 2010. When in an improved form, it is anticipated that all coconut-producing countries will want to adopt this technique to rapidly produce high numbers of elite coconut seedlings.

The third project output—the development of a genetic fidelity test for coconut capable of identifying ‘off-types’ that may have been produced by the tissue culture approaches—is in its final form, but has not been used often as only a few clonally propagated plants have been produced. However, the University of Queensland has used the technique to analyse plants grown from cryopreserved embryos, a new methodology the team has developed for the long-term conservation of coconut genetic resources. This technique has only been perfected recently but is anticipated to become the approach that all coconut-producing countries will need to use to assess their elite coconut plants produced through tissue culture. It is likely to find its way into the hands of private companies that want to mass-propagate elite coconut varieties, especially when clonal propagation is to be used.

The features of the project that supported good adoption were the ongoing, close communication between the partner organisations and the appreciation of the community requirements for productive outcomes. Adoption rates have also depended upon the activity of the two ICGs (Indonesia and PNG), which has been relatively slow during the past few years; however, the activity of the ICGs is anticipated to improve dramatically in the coming years.

The close interactions that took place between the partner organisations and the local coconut-farming communities led to the discovery of a new, high-value coconut variety, Garuk, in PNG. The communities were unaware of the potential value of this kind of fruit type on the fresh-fruit market.

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

The project has made a considerable difference to the way partner organisations view coconut as a future viable crop in their region. Before the start of the project, a common view was that there was just one profitable use for coconut—copra production. Since copra production could not be easily increased, the view was that there was no real future in the ongoing cultivation of the crop, a crop that farmers had tended for hundreds of years. This project has helped to change this attitude. With the newly developed tissue culture techniques, it is now relatively easy to collect, exchange and use new coconut germplasm. Farmers can gain access to elite planting materials that are disease resistant or to other high-value varieties that are impossible to germinate in nature but have a tasty endosperm and command a high market price. The consequences of moving towards growing either new elite, disease-resistant varieties for coconut production or high-value varieties is a significantly greater income for farmers, the partial removal of income risk, the provision of a healthier living environment, and the continued production of a plant that provides so many other by-products for the home and that commands a high social status.

The recent discovery of a high-value mutant variety in PNG (Garuk) by the partner organisation has increased significantly the impact of the project outcomes in the long term. At the start of the project, this form of coconut was known only by a few farmers who owned the rare palms. The interaction with the farming communities and the techniques developed during the course of the project can now be used to identify high-value palms and then to raise seedlings from this type for wider planting.

Salinity management in south-eastern Australia, north-eastern Thailand and Lao PDR (LWR/1997/150)

William Milne-Home

Project number	LWR/1997/150
Project name	Salinity management in south-eastern Australia, north-eastern Thailand and Lao PDR
Collaborating institutions	Australia: University of Technology Sydney (UTS); Hall Resource Economic Modelling Lao PDR: Department of Irrigation (DI); Ministry of Agriculture and Forestry (MAF) Thailand: Khon Kaen University (KKU); Land Development Department (LDD); Royal Forest Department (RFD)
Project leaders	Australia: Dr William Milne-Home (UTS), Prof. Michael Knight (UTS) Laos: Mr Boun Souk (DI), Mr Thanousay Ounthouang (MAF) Thailand: Dr Jesada Luangjame (RFD), Dr Arunee Yuvaniyama (LDD), Dr Seksan Yongvanit (KKU)
Duration of project	1 January 2001 to 31 March 2005
Funding	A$1,027,573 (ACIAR payment: A$729, 073)
Countries involved	Australia, Lao PDR and Thailand
Commodity involved	Rice
Related projects	8431/94, LWR1/1992/022, FST/1993/016, FST/1995/107, FST/1997/077

Motivation for the project and what it aimed to achieve

Salinity is a major cause of land and water degradation and economic losses in Australia and Thailand, and may become so in parts of the Lao PDR. Dryland salinity has developed gradually in Australia since European settlement and the introduction of broad-scale agriculture, accompanied by the clearing of native vegetation. In contrast, dryland salinity in north-eastern Thailand has been a problem historically but has developed rapidly with major clearing of vegetation. The situation in Laos is considered to be analogous to a very early stage in the salinisation of north-eastern Thailand, with accelerated forest clearing and proposed major irrigation developments being triggers for increases in salinity.

The motivation for the project was to provide a framework for understanding the dryland salinity problem, which is manifested in various forms and occurs at different stages of development in the three countries of interest. The project aimed to achieve mutual interchange of technology between Australia and Thailand, coupled with raising awareness of the potential problem in Laos. The dominant paradigm of salinity in Australia is that of increases in soil salinity and salt loads in rivers following the large-scale clearing of the native eucalypt vegetation. Clearing the native vegetation led to the release of salt stored in the soil and disturbed the water balance by increased infiltration of rainfall because of the reduced ability of the replacement vegetation cover to remove the water by evapotranspiration. In turn, the increased infiltration resulted in rising watertables so that the salt stores were dissolved and mobilised in the groundwater. Transport of the mobilised salt by groundwater flow systems ranging in scale from local to regional has led to the widespread development of salt scalds and the export of salt by rivers, especially within the Murray–Darling Basin.

Salinity problems on a major scale in Thailand are largely confined to the Khorat Plateau in the north-eastern part of the country. While some aspects of salinisation in north-eastern Thailand are broadly similar to those in south-eastern Australia, a major difference is the widespread occurrence of evaporites or rocksalt within the Maha Sarakham Formation, which underlies most of the Khorat Plateau. These salts are

Department of Irrigation staff sampling the piezometer at Ban Phondok, Champone district, Savannakhet province, Lao PDR, for groundwater chemistry. Departmental technicians were trained in the basics of sampling groundwater and measuring water levels. Curious village children observe the activity.

dissolved and transported by flowing groundwater, resulting in the widespread development of salinised lowland areas and the export of salt to the Mekong River by its tributaries: the Chi and Mun rivers. Parts of Laos, mainly the lowlands north-east of Vientiane and some areas of Savannakhet province, show incipient occurrences of salinisation. The equivalent of the Maha Sarakham Formation underlies these regions and it was considered likely that the analogous geological and hydrogeological conditions would cause major increases in salinised soils and salt export. The planned construction of large irrigation schemes could provide the trigger for salinisation, a precedent for which had occurred in north-eastern Thailand.

In view of the considerable knowledge base on dryland salinity in south-eastern Australia and north-eastern Thailand, the development of socioeconomic models of the effects of land-use changes was the preferred approach. This approach was coupled with a continuation and extension of work on tree water use undertaken in a previous ACIAR project (LWR1/1992/022). The main work in Laos consisted of hydrogeological and hydrogeochemical investigations in Savannakhet province to establish the nature and extent of salinisation.

What the project produced

The project outputs are:

- increased knowledge of dryland salinity in north-eastern Thailand
- confirmation that dryland salinity in Laos occurs in regions where the geology and hydrogeology are similar to that of the adjacent areas of north-eastern Thailand; the effects of deforestation are of minor importance in this respect
- scoping of the risk of salinisation from the proposed expansion of irrigation schemes in Savannakhet province, Laos
- development of a socioeconomic modelling package, Isaan Catchment Hydrological and Agricultural Model (ICHAM) for use in north-eastern Thailand (Isaan); a version of this model was developed for the Liverpool Plains, New South Wales.

The capacity built includes:

- training of postgraduate students in groundwater and environmental modelling, tree water-use measurement techniques and statistical data analysis (Australia and Thailand)
- increased knowledge of the role of vegetation in the management of salinity by landcare groups (Australia) and staff of the Land Development Department and local government (Thailand)
- implementation and data analysis of socioeconomic surveys (Thailand)
- increased numerical modelling skills of the researchers through the development of the ICHAM software
- increased awareness of salinity issues in Laos
- availability of an array of piezometers in the Champone district of Savannakhet province (Laos) for monitoring groundwater levels and salinity in the main irrigation area
- acquired knowledge and skills by the Department of Irrigation in Savannakhet to continue workshops and community meetings, which provide the basic information to enable extension agents, farmers and other stakeholders to become aware of salinity and its management, especially in relation to irrigation in the Champone district.

Adoption—how the project outputs are being used

The increased knowledge of dryland salinisation processes in north-eastern Thailand has been incorporated into engineering drainage work by the Land Development Department (LDD) to mitigate its effect. Revegetation has been part of this process. Results have been included in planning future research by other agencies. These activities have focused on Kham Tale So, an area characterised by extensive salt scalding and saline soils north-west of the city of Nakhon Ratchasima. The design of the drainage channel network included locating the main drain within the groundwater discharge zone of the local groundwater flow system, which had been identified and mapped by the project. Complementary to the improved drainage has been the construction of boreholes in the upland recharge area of the groundwater flow system. Groundwater pumped by these boreholes is diverted from the groundwater flow system to the water supply for farms and the irrigation of high-value crops. This groundwater investigation was undertaken by Khon Kaen University for the LDD, and both organisations are collaborating in training the local farmers to measure water levels in observation boreholes and to estimate the pumped water volumes as part of the program for monitoring the operation.

In contrast, the modelling package ICHAM has not been adopted by the LDD as a routine management tool. The main reason for the lack of adoption appears to be operational difficulties with integrating the code with MODFLOW, a computer program for groundwater modelling. Input for ICHAM depends on the output from MODFLOW; additionally, the latter package is run by Khon Kaen University and not by the LLD, so logistical concerns are an issue. Further development of the software within both organisations may lead to the gradual adoption of the models as a tool for land management.

In Laos, awareness of salinity risk has increased such that it is included in irrigation planning. On the local scale, this has resulted in the incorporation of shallow piezometers into the national hydrometeorological monitoring network. These piezometers were installed by the project to monitor groundwater levels and salinity in the main irrigation area of the Champone district of Savannakhet province.

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

The main impact of the project is the inclusion of salinity management in policy development for north-eastern Thailand and Laos. Because the influence is indirect, it is difficult to assess the overall impact as many other factors from related non-ACIAR research projects are also important in affecting future developments. A further consideration is the long timescale over which the reduction of recharge to the groundwater flow systems is reflected in a corresponding reduction in their discharge. The timescale in Isaan and Laos is estimated to be in the order of decades. Nevertheless, the example cited from Kham Tale So shows that immediate changes can have measurable impacts in terms of saline drainage, the establishment of irrigation-based, high-value crops and improved water supply.

Arsenic transfer in water–soil–crop environments of Bangladesh and Australia (LWR/1998/003)

Ravi Naidu

Project number	LWR/1998/003
Project name	Arsenic transfer in water–soil–crop environments of Bangladesh and Australia
Collaborating institutions	Australia: Centre for Environmental Risk Assessment and Remediation; University of South Australia; Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC-CARE) Bangladesh: Dhaka Community Hospital, University of Dhaka
Project leaders	Australia: Prof. Ravendra Naidu (CRC-CARE) Bangladesh: Prof. Imamul Huq
Duration of project	1 January 2000 to 30 June 2005
Funding:	A$1,506,425 (ACIAR payment: A$954,889)
Countries involved:	Australia and Bangladesh
Commodities involved:	Rice, vegetables, wheat and fruit
Related projects:	LWR1/1993/022 and LWR1/1994/054

Motivation for the project and what it aimed to achieve

High concentrations of arsenic have been detected in the groundwater of Bangladesh. Groundwater extracted from domestic tube wells is the primary source of drinking water for the Bangladeshi population. Arsenic concentrations above 50 micrograms per litre (μg/L) have been detected in the groundwater of 50 of the 64 districts in Bangladesh, and levels above 10 μg/L in 60 districts. The World Health Organization guideline value for arsenic in drinking water is 10 μg/L, while the Bangladesh standard is 50 μg/L. The British Geological Survey and the Department of Public Health Engineering (Bangladesh) analysed 3,534 tube wells across Bangladesh (excluding hill tract areas) and reported that 35 million people are exposed to arsenic above 50 μg/L and 57 million are exposed to arsenic concentrations above 10 μg/L (<www.bgs.ac.uk/arsenic>). Chronic exposure to arsenic causes health problems including skin conditions, lung disease, neurological problems, obstetric problems, diabetes, hypertension, cardiovascular disease, and cancers of the skin, lung, liver, kidney and bladder.

When the project was implemented, it was assumed that poisoning is through the consumption of water per se. However, the chronic arsenic toxicity symptoms recorded indicate that exposure to arsenic may have involved a number of pathways. Arsenic-contaminated groundwater is used for irrigation as well

A dug well that provides arsenic-safe water to 200 families as for cooking, and it is likely that the last 30 years of irrigation have led to diffuse contamination of land throughout the districts relying on arsenic-contaminated groundwater. This indicates that soil–crop–food transfer, as well as cooking and direct ingestion of drinking water, may be the major exposure pathways of arsenic transfer. Before this project, there had been no work to quantify the pathways of arsenic transfer.

Drinking water and food are two main sources of arsenic exposure for humans. The main aim of the project was to assess the extent of contamination of soils at selected sites subjected to long-term irrigation with arsenic-contaminated water and where soil–plant transfer of arsenic occurs, with a view to developing management strategies that minimise soil–plant arsenic transfer. The specific aims of the project were to:

- develop a database for arsenic in soils, surface water and groundwater and carry out a water quality risk assessment in two selected districts in Bangladesh
- quantify and predict the fate and behaviour of arsenic in soils subjected to irrigation with arsenic-contaminated groundwater
- quantify the pathways for arsenic transfer into the human food chain using field and glasshouse studies
- provide a scientific basis for establishing management strategies that minimise this transfer.

What the project produced

The project investigated the arsenic content of soils subjected to irrigation (including background arsenic) and of food crops grown in areas where arsenic-contaminated groundwater was used for agricultural irrigation, the dynamics of arsenic in soils subjected to irrigation, and surveyed the diet of two villages impacted by arsenic poisoning and one village that was considered free from arsenic poisoning, including the pathway of exposure to arsenic.

The project also investigated the health risks of consuming food crops grown in arsenic-contaminated districts of Bangladesh. Field sampling was conducted in selected arsenic-affected districts of Bangladesh where groundwater contained arsenic above 50 μg/L. Foods such as rice grain, cooked rice and a variety of vegetables were sampled and analysed for arsenic content by inductively coupled plasma mass spectrometry, allowing the total daily intake of arsenic from common food crops to be measured. Samples of drinking water, cooking water and irrigation water were also analysed. The soil of agricultural fields was also tested to ascertain its arsenic content.

Detailed investigation of the exposure pathway to arsenic, shown in Figure 1, demonstrated:

- a significant build-up of arsenic in soils irrigated with groundwater contaminated with arsenic
- a significant transfer of arsenic from groundwater to vegetable crops, including rice, via uptake from soil, although most vegetable crops and rice had arsenic content less than the threshold concentrations set under the 'Australia New Zealand food standards code'[1]

1 Food Standards Australia New Zealand 2010. Australia New Zealand food standards code. Anstat Pty Ltd: Melbourne. Accessible at <www.foodstandards.gov.au/foodstandards/foodstandardscode>.

- leafy vegetables contained a high concentration of arsenic compared to nonleafy vegetables
- some vegetables, such as arum and kalmi shak, contained notably high levels of arsenic
- rice was the major component of the diet, with seasonal vegetables and rice being ingested on a daily basis
- ingestion of meat was occasional, although villages that were economically better off would ingest meat weekly
- the amount of rice ingested varied depended on sex and age; males ingested almost 1.2 kilograms of wet rice per meal, with the female adults ingesting about 0.9–1.0 kilograms
- although total arsenic content of rice was generally less than the threshold concentration for food set under the Australian food standard, the amount of rice ingested daily meant that the total allowable limit was significantly exceeded. This, coupled with the ingestion of arsenic from vegetables, placed most of the community subjected to groundwater arsenic at significant risk from exposure to arsenic and hence poisoning.

The project concluded that food is an important source of arsenic exposure for the Bangladeshi community. Even people living in the arsenic-safe areas of the country are exposed through food crops grown in contaminated areas and traded to other parts of the nation.

The project developed strategies that help minimise community exposure to arsenic. These strategies were presented to the local community via day-long workshops and included:

- the promotion of vegetables that are safe to grow rather than those that bioaccumulate arsenic
- use of pond water for irrigation and potable purposes
- filtered water using a kit approved by the United Nations Children's Emergency Fund (UNICEF) for drinking
- a database of vegetables and rice, including their arsenic content.

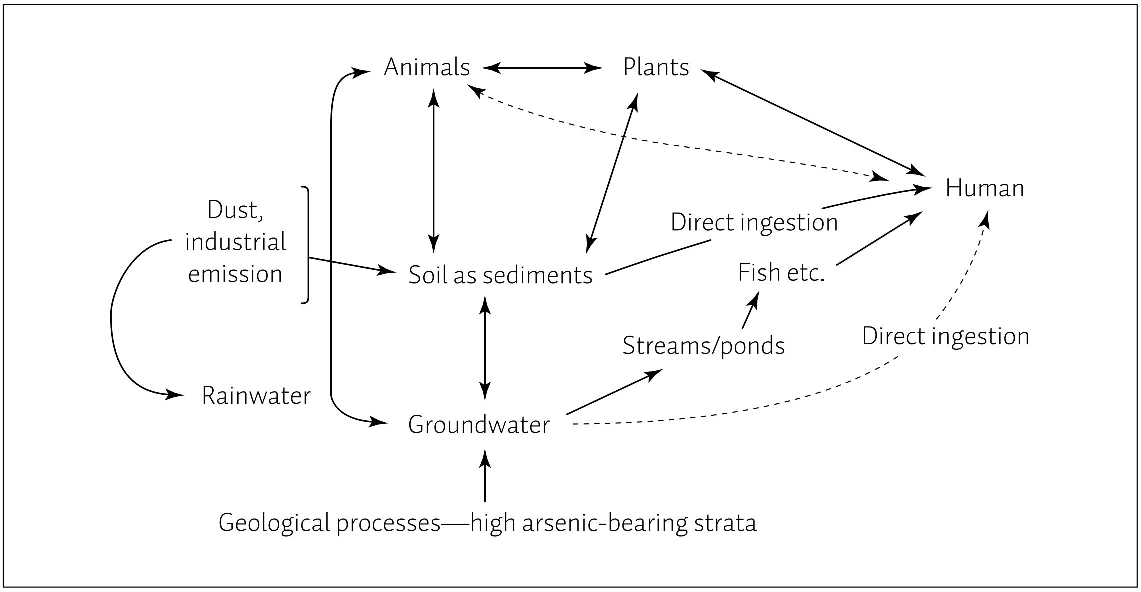

Figure 1. Exposure pathway to arsenic

Discussion with the community about the adoption issues

Adoption—how the project outputs are being used

There has been a very high level of attention given to mitigating the arsenic problem by the Bangladeshi government, with the support of aid agencies. This took the form of measuring arsenic levels in tube wells across the whole country, screening patients for symptoms of arsenicosis and running national awareness campaigns. Much attention has also been focused on measuring arsenic concentration in food crops grown in contaminated areas, especially paddy rice.

The study found that most of the people living in the project areas are aware of the issue and are drinking water from sources which are arsenic-safe. All safe water options such as dug wells, rainwater and filtered river water are in continual use by the community. These options have received widespread acceptance. The study noted that some villagers are still consuming arsenic-contaminated water from tube wells, although they are aware of the risks of arsenic contamination from the government's awareness campaign. Both social and socioeconomic issues make some villagers reluctant to collect arsenic-safe water from their neighbours' houses. Sometimes they do not want to walk a long distance to collect safe water from the community sources. The project also found that most of the villagers now use pond water for cooking and for irrigating their home gardens.

The study found that foods such as arum and some leafy vegetables contained considerable amounts of arsenic. Based on the project data, people in the villages have been informed about which vegetable crops accumulate less arsenic and are currently growing them, which will reduce arsenic exposure from crops.

The project did not investigate the different arsenic species present in food crops. However, it has laid a foundation for further research into arsenic species as the exact nature of the arsenic is essential in determining the true extent of the risk to human health. The project has also helped in further research into the uptake mechanisms for arsenic in the vegetable crops found to contain exceptionally high concentrations of arsenic. The project's findings also encourage the investigation of the role of iron, phosphorus and other metals in assisting arsenic uptake by plants. The project data are helpful in future research into hyper-accumulating plants that take up very large amounts of arsenic from contaminated lands. The use of blue-green algae for reducing soil arsenic loads should also be investigated. Blue-green algae are also useful for screening different varieties of paddy rice to determine their uptake rates. We concluded that the Bangladeshi Government should implement further awareness programs about the risk of growing paddy rice in contaminated irrigation lands, as well as the risks from consumption of contaminated rice and vegetables.

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

The project received extensive attention in the scientific community worldwide. Its findings advanced existing knowledge about the extent of arsenic contamination in food crops grown in contaminated land. It had significant impact on capacity building among the Bangladeshi partners in broadening their understanding of arsenic research. They also received training in the sampling and processing of collected samples. During the research period, the knowledge generated was shared with many Australian scientists in different research fields to broaden their understanding of arsenic issues. Six peer-reviewed journal articles and one edited book were published based on the project data, which increased the international scientific understanding of the impact of arsenic in the food chain. The project has also helped the Bangladeshi Government to develop advice on better ways to manage arsenic in agricultural soils so as to reduce human exposure from contaminated food crops. One PhD student from Bangladesh was trained in Australia during the project to better understand the health risks from eating arsenic-contaminated foods.

Growing more rice with less water: increasing water productivity in rice-based systems (LWR/2000/030)

Randolph Barker, Dong Bin, T.P. Tuong, Shahbaz Khan and David Molden

Project number	LWR/2000/030
Project name	Growing more rice with less water: increasing water productivity in rice-based systems
Collaborating institutions	Australia: Commonwealth Scientific and Industrial and Research Organisation (CSIRO) China: Wuhan University International Rice Research Institute (IRRI) International Water Management Institute (IWMI)
Project leader	Australia: Elizabeth Humphreys (CSIRO) China: Li Yuanhua (Wuhan University) To Phuc Tuong (IRRI) Randolph Barker (IWMI)
Duration of project	1 July 2001 to 31 December 2005
Funding	A$3,917,840 (ACIAR payment: A$1,008,357)
Countries involved	Australia and China
Commodity involved	Rice

Related projects	LWR2/1994/004, LWR2/1998/034, LWR1/1997/016, LWR1/1998/066, LWR1/1998/069, LWR2/2000/089, LWR/2001/001 The Challenge Program for Water and Food: system of tropical aerobic rice (STAR) Foundation for Advanced Studies on International Development (FASID), Research on the role of institutions and policies for the adoption of water saving technology in rice

Motivation for the project and what it aimed to achieve

Indications suggest that Asia is facing a water crisis. There is a growing demand for water for non-agricultural purposes, limiting the possibility of expanding crop production and hence irrigation. Rice is one of the largest consumers of water, thus there is a need to find ways to save water in the production of rice.

China, with a large part of its population dependent on rice production, is promoting water-saving irrigation techniques based on alternate wetting and drying (AWD—intermittent irrigation with shallow flooding of the paddy soils). AWD techniques and other water-saving irrigation practices are currently being adopted in different parts of China. However, there are a number of questions surrounding the nature, success and wide adaptability of AWD techniques to other areas.

Although at a very different stage of economic development, Australia is facing water problems similar to those of China. Declining water availability, increasing water prices, and the environmental degradation of agricultural lands and riverine ecosystems drive the demand for water savings. Past research by Industry and Investment New South Wales and more recently by the Cooperative Research Centre for Sustainable Rice Production has indicated the potential for saving irrigation water using AWD and saturated soil culture (SSC—which involves growing rice on beds with permanent water in the furrows). Changes in rice cultural practices and other on-farm and regional options (e.g. SSC, sowing method, recycling, conjunctive water use, off-river storages) lead to changes in irrigation demand patterns. The potential benefits of these changes to river flow patterns have yet to be determined.

The ultimate goal of this project was to promote water management techniques in rice-based irrigation systems that sustain the environment and allow crop production to be maintained or increased in the face of growing demands for competing uses of water.

The specific objective was to understand the complexities of water saving in rice, or what has been defined as 'real water savings', not just at the farm level but at the system level. There were both technical and socioeconomic questions to be answered. It was also of interest to learn the potential for water saving by AWD, which was being promoted in China, and to continue a collaborative relationship with Wuhan University College of Water Resources and Hydroelectric Engineering that would strengthen its research capacity in water management.

Technical outputs

Field experiments in the Zhanghe Irrigation System (ZIS) and water balance studies confirm that AWD can be practised with significant savings of irrigation water at the field level, without a loss in crop yield. Furthermore, farm surveys indicate that AWD can be practised with no reduction in either yield or farm profitability. However, SSC and aerobic rice result in considerable water saving but with a significant loss in yield. The results from using AWD or SSC would be very different in a situation of water scarcity. Nevertheless, farmers in the Liu Yuan Kuo Irrigation System (LIS) showed interest in aerobic rice as labour requirements could be reduced by 50%.

One of the concerns is whether water saving at the farm level results in water saving at the system level (scaling up). Studies on water balance at the farm, meso-scale and sub-basin level in ZIS produced varying results. Field-level agricultural water management practices in ZIS are extremely effective at converting water supplies from rivers and rainfall into evapotranspiration essential for crop production. Field studies

A pond in the Zhanghe Irrigation System capturing excess irrigation water that can be used later downstream showed that 60–70% of rain plus irrigation water was transformed into evapotranspiration, with many farmers practicing a form of AWD. At the meso-scale site of a few hundred hectares, other factors played a role in the overall irrigation system water balance, including the role of small ponds in storing water, and that villages and forested areas played an important role in generating run-off that could be used for rice production downstream. At the scale of the entire irrigation system, only about 10% of water input from rain and reservoir releases flows out of the basin due to a combination of farm practices, as well as capturing, storing and recycling water, indicating that there is little scope left for water saving. Consequently, it is expected that the surface outflow cannot be further exploited without negative downstream effects. ZIS employs a variety of strategies to save water, and provides a model for other irrigation systems around the world.

In LIS, the situation was quite different. Rice farmers upstream applied ample surface irrigation water, while downstream users pumped from groundwater. Similar to ZIS, the combined effect was that very little surface or groundwater outflow was lost from the irrigated area. However, another important water balance component was identified that pointed to where water could be saved. Lateral seepage from Yellow River and from unlined irrigation canals raised the groundwater table to 0.5 metres from the soil surface, leading to around 130 million cubic metres of non-beneficial evaporation from fallow lands. A strategy would be to reduce non-productive evaporation and make this available for crop production. MODFLOW and VENSIM models were used in a hydrologic–economic analysis of different scenarios for water savings. These scenarios consisted of different combinations of (i) canal lining, (ii) pumping groundwater in the northern part (above the railway line) of LIS and (iii) shifting surface water to below the railway line. The combination of canal lining and pumping above the railway line appears to be the most effective and economical way to reduce non-beneficial evapotranspiration above the railway line and increase water availability.

Policies and institutions

The results of the project show, surprisingly, that the institutional arrangements that have evolved in the water-abundant ZIS are more conducive to water saving than in the water-scarce environment of LIS. The experience from ZIS and LIS shows that policies and strategies for changed water use and management must aim at aligning the objectives and incentives for different groups who influence effective use of water (farmers, system managers, basin managers, broader society) so that society-wide goals for improved water use, in and outside the agricultural sector, can be obtained. Another lesson learned was that creating water scarcity at the farm level (e.g. in ZIS) may be a good way to 'force' farmers to adopt water-saving options. At the same time, however, the government has provided extension services for training farmers in water-saving technologies and subsidies for development or improvement of farm-level ponds and reservoirs.

Capacity building

A major focus of the research was on capacity building—helping to develop the research capacity of Wuhan University in water resources and to develop a collaborative relationship between Wuhan, other research centres, irrigation system managers and experimental station directors. The collaboration continues today.

Numerous workshops and training activities were held throughout the course of the project. The project participants met annually to discuss project results and workplans. These meetings were held at one of the two sites in China, with the exception of 2003 when, due to severe acute respiratory syndrome (SARS), the meeting was held in the Philippines. The meetings in China were normally built around workshops and dialogues involving not only researchers but also systems managers and experiment station directors. In addition, a number of Chinese staff visited Australia, the International Rice Research Institute and the International Water Management Institute, to work with counterparts on the models ORYZA2000, OASIS and MODFLOW, and on data analysis.

Adoption—how the project outputs are being used

As noted above, the outputs of the project differed by system and hence how the outputs are used also varies by system.

Zhanghe Irrigation System

The ZIS case study has been cited in several international initiatives and publications about how water productivity can be increased and how water is reallocated from irrigation to urban and industrial uses. In terms of the adoption of the project outputs:

- AWD is now practised over 90% of the area of ZIS (up from approximately 50% when the study was first initiated).
- Reliable water availability is the key to a farmer's willingness to adopt AWD. In ZIS, reliability has been achieved by expanding farm ponds and improving their management.
- Over a period of almost 50 years, the percentage of water diverted from the Zhanghe reservoir for non-agricultural uses—industry, urban, hydropower—increased from 25% to 80% without a loss in rice production. More recently, the reduction in water diverted to agriculture has been achieved by the adoption of AWD.

Liu Yuan Kuo Irrigation System

In a recent field trip to LIS, it was evident that while rice farmers were aware of water-saving practices such AWD, they were still unable to follow them. There were encouraging signs in that lining of the south main canal was being extended to facilitate transfer of surplus water from the rice-growing area. This is a necessary step in reducing the evaporation losses in the rice-growing area. It also improves canal management and enhances the reliability of water delivery, which is one of the prerequisites for the adoption of AWD.

The earlier interest in aerobic rice had not led to adoption because of its lower yield compared with the traditional method of flooding the rice field.

One of the most important policy outcomes of the project is contained in a communication from team member Li Yuanhua (who is currently Deputy Director-General, Department of Irrigation, Drainage and Rural Water Supply, Ministry of Water Resources), which relates directly to the research at LIS and reads as follows:

> In Henan Province our suggestions have been applied for the '11th –five-year' planning for the modernization and rehabilitation of LIS and other irrigation systems in Henan Province, such as Sanyizai Irrigation Scheme. As the planning aims at integrated surface and groundwater management, and more surface water from the Yellow River could be sent downstream of the system, the planning and the budget has been approved by the Ministry of Water Resources.

In short, it appears that the findings of the research at LIS will be more widely adopted in the Yellow River basin. This will allow more water to be shifted downstream to provinces that are short of water.

Murrumbidgee Irrigation Area

The methodology for tracking unaccounted flows and up-scaling irrigation water-use efficiency developed under this project, and related activities, is considered 'state of the art' by the Australian Government and irrigation companies. The Water for a Healthy Country Flagship has decided to use this methodology across the Murray–Darling Basin. This project will provide major inputs into the National Water Initiative aimed at securing 500 gigalitres (million cubic metres) of water for the environment, largely through irrigation efficiency improvements.

Elsewhere—outside project sites

The AWD technique has been widely promoted in China and is now practised on an estimated 1.5 million hectares. The principle for implementation of AWD and the field experiments on water productivity have been input to the National Standard for Irrigation Experiment and the National Standard for Water-saving Irrigation.

Monitoring a groundwater table

There has been a spillover effect to other countries. AWD is now being practised by tens of thousands of farmers in Bangladesh, more than 60,000 in the Philippines and thousands in An Giang, Vietnam and Sri Lanka, and is likely to spread throughout the Asian rice-growing world as the competition for scarce water resources increases.

The main findings of this project have been incorporated into a book, 'The theory and techniques of water saving in China[2]', which is used by postgraduate students across China. The methodology and principles for field experiments on water productivity have been included in the 'National standard for irrigation experiments[3]'.

Factors affecting adoption

Key factors affecting the adoption of AWD include the reliability of water supply when needed, the physical environment and infrastructure, and government policies.

ZIS was a suitable physical and socioeconomic environment for introducing water-saving technologies. For example, the government provided subsidies to farmers to expand and improve farm ponds and small reservoirs.

By contrast, at LIS it was not possible to practise AWD without substantial improvements in infrastructure, some of which have been occurring in the 5 years since the end of the project.

Even in ZIS, however, some areas are more suitable than others for the use of AWD. A study by Wuhan University and the International Rice Research Institute in 2007–09 used a topographic wetness index to indicate the soils most suited for the adoption of AWD.

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

Research and scientific level

The scientific outputs of the project have been widely referred to by scientific community and have contributed greatly to the understanding of scale effects within irrigation systems. Much of the irrigation literature is about reducing waste from irrigation focusing on one scale or activity—for example, field water savings or canal lining. We found that at both ZIS and LIS the scope for additional real water savings is less than originally anticipated. Water scientists and irrigation managers are now more aware of the cross-scale effects of water savings and the interactive factors that influence the overall water balance and water productivity—AWD, reuse of drainage flows, internal pond and groundwater storage.

2 Li Yuanhua (chief ed.) 2003. The theory and techniques of water saving in China. Press of Wuhan University: Wuhan, China (in Chinese).

3 Li Yuanhua (chief ed.) 2005. National standard for irrigation experiments. China Water and Hydro Publishing: Beijing, China (in Chinese).

Increasingly, Chinese postgraduate students and researchers will contribute to the ways research on water saving and water management are carried out in China.

Given the complexities of the water management problems facing China and the rest of Asia, answers to the questions of how to save water and improve water management will not be solved immediately. The strengthening of research capacity in water management at Wuhan University and building links between it and other centres has resulted in a continuation of collaborative research activities beyond the end of the project.

Community impacts—the beneficiaries of the project

Special workshops and training sessions have been held to teach various aspects of crop and hydrologic modelling. Managers at the two irrigation systems (ZIS and LIS) also acknowledge that their knowledge has increased via the scientific interaction.

As a result of the project, Tuanlin research station (in ZIS) became a training centre for irrigation experiments and water management, especially the application of water-saving techniques. In June 2003, Tuanlin was approved by the Ministry of China as one of 30 central experiment stations. In 2005, the chief engineer of ZIS was selected as a 'national model worker'.

Integrated watershed management for sustainable soil and water resources management: Inabanga watershed, Bohol Island, Philippines (LWR/2001/003)

John Bavor

Project number	LWR/2001/003
Project name	Integrated watershed management for sustainable soil and water resources management: Inabanga watershed, Bohol Island, Philippines
Collaborating institutions	Australia: Centre for Water and Environmental Technology, University of Western Sydney (UWS) Philippines: Bureau of Soils and Water Management (BSWM); Forest Management Branch, Department of Environment and Natural Resources; Department of Agriculture Promotion Centre Bohol
Project leaders	Australia: Assoc. Prof. H.J. Bavor (UWS) Philippines: Dr Rogelio Concepcion (BSWM), Dr Gina Nilo (BSWM)
Duration of project	1 July 2002 to 30 June 2006
Funding	A$1,670,254 (ACIAR payment: A$754,154)
Countries involved	Australia and the Philippines
Commodities involved	Rice, corn, cassava, oil palm, vegetables, forestry and pasture
Related projects	ASEM/1998/052, ASEM/2002/051 and FST/1999/035

Motivation for the project and what it aimed to achieve

The management of water resources for islands of the Philippines is critical for their agricultural and economic development and environmental management. This is particularly the case where there is strong competition between the urban, industrial and agricultural sectors for water allocation. Such a situation had developed within a number of island provinces in the mid-Visayan region of the Philippines. On the island of Bohol, infrastructure support for agriculture and application of land-use management for sustainable agricultural production were identified to be at very low levels.

The project concept originated from discussions between the staff from the Centre for Water and Environmental Technology, University of Western Sydney, Australia, and the Bureau of Soils and Water Management, Department of Agriculture, the Philippines.

Regional natural resources problems in the watershed were also discussed with the agricultural officers of the local government units and representatives of non-government organisations. Through these discussions, it was determined that ongoing natural resource management programs in the watershed were community-based development activities (in particular, the World Bank- and AusAID-funded projects) and involved little research or capability enhancement. The proposed project was discussed with researchers from the International Centre for Research in Agroforestry (now the World Agroforestry Centre). Current soil and water management programs being undertaken by the World Agroforestry Centre were identified. Input was obtained from provincial agricultural officers from the Philippine Department of Agriculture and provincial officers from the Department of Environment and Natural Resources (DENR). Agricultural opportunities, constraints and natural resources problems associated with the watershed were identified, to be addressed through the project objectives.

What the project produced

The project initially produced a detailed analysis of the current state of the natural resources in the upper Inabanga watershed. The analysis included data on land characteristics, water use and water resources, and identified problems associated with these resources. The mapped data, linked with satellite imagery, highlighted soil and water resource problem areas in the watershed. The identified problem areas were then studied in much greater detail.

A picture emerged of high poverty levels, rising unemployment and low per capita income. Farm productivity, with the exception of irrigated rice, fell below the national average. The data were then further analysed, including farming practice scenario assessment using WEPP (Water Erosion Prediction Project) and GeoWEPP modelling tools, in a geographic information system (GIS) framework developed for the project. These tools identified areas of the upper Inabanga watershed that were at high risk of soil erosion.

Specific key outputs included:

- new knowledge and maps of areas at highest risk of soil erosion ('hotspots')
- understanding of the effects of cultivation practices on soil erosion

- the cultivation of corn/cassava on steeply sloping, highly erodible soils was the major contributor to soil erosion, resulting in about 57 tonnes of soil per hectare per year being lost compared to 0–5 tonnes per hectare per year for the other cropping systems studied
- corn/cassava also resulted in the highest run-off in total and as a percentage of rainfall—34% compared to 27%, 17% and 18% for grassland, irrigated rice and agroforestry, respectively
- the high soil loss combined with high run-off indicated that corn/cassava cultivation contributed significantly to siltation of the Malinao Dam
- corn/cassava cropping resulted in the lowest economic returns to the farmers.

Project outputs led to recommendations that farmers could reduce some of the negative aspects of current practices, especially those used for the cultivation of corn/cassava on steep, marginal soils, by implementing better soil management practices and using community-based, farmer field-school approaches to provide training and encourage adoption. Practices with the highest likelihood of making improvements were identified, and include:

- establishing natural vegetative strips—leaving 1–2-metre contour strips uncultivated or planted with perennial crops, as a way of reducing soil erosion
- planting alternative crops to corn/cassava with a higher value such a bitter gourd, runner beans, squash and sweetcorn
- growing cover crops or crops that produce high organic matter residues (e.g. sweetcorn) and can be incorporated into the soil or left on the soil as a surface mulch; an additional benefit of this practice is weed suppression
- using aspects of a minimum-tillage annual crop production system, which the team has trialled in Australia, where a soil-covering crop or cover-crop residue is maintained and vegetable crops are planted through this mulch layer; improvement in the soil profile and reduction in the need to cultivate have been demonstrated

Staff from the Philippine Bureau of Soils and Water Management maintaining an installed automatic water sampler/flow meter with security housing. Samplers are operated at field sites on a flow-integrated schedule, with flow data cross-linked to precipitation monitoring data.

- improved management of crop nutrient supply by planting legumes, which can provide significant amounts of nitrogen to subsequent crops
- higher planting densities, which are likely to improve crop yields and returns.

Importantly, the project has increased the team's experience and competency in watershed-scale data collection, monitoring and assessment, and in-house capacity to use empirically derived data to model hydrology and soil erosion at the watershed scale. Additionally, the Philippine Bureau of Soils and Water Management capability in georeferencing and mapping soils, slope, elevation, land use and many other land attributes using GIS techniques has been greatly enhanced.

Adoption—how the project outputs are being used

Use of the capacity built by the project has been achieved through bringing together a range of departments, agencies and groups which had each independently collected needed data, but had not shared and used the information in a collaborative manner. The use of new monitoring tools, collaborative farmer field-school presentations, collaborative review of soil management practices and cropping outcomes, the provision of alternative crop options and marketing advice workshops have been initiated.

A significant positive adoption of the project recommendations is the establishment of five farmer-managed demonstration (FMD) sites in four Inabanga municipalities (Danao, Dagohoy, Pilar and Sierra Bullones), which have signed an operation and support memorandum of understanding with the Bureau of Soils and Water Management (BSWM), DENR and CIFOR. The memorandum included an ongoing commitment to contribute funds to cover site running costs. The sites are located on highly erodible upland soils where a corn–cassava rotation was the previous land use; a cropping activity identified in the project as the most highly degrading cropping practice of those which were evaluated. Funding for the implementation of the FMD improvements has come from the collaborators. The municipalities have provided consumables such as fertiliser, seed and cuttings; BSWM provides instrumentation, training and soil management/cropping expertise, while CIFOR contributes to training costs. The establishment and ongoing community management of the FMDs has assisted in the process of improving adoption by provincial farmers.

BSWM and CIFOR training staff, and local municipal agriculture officers, have estimated that approximately 50% of the farmers in the upper Inabanga watershed have adopted improved farming practices as a consequence of project training and dissemination of project results, cropping advice and the supply of planting materials. The improved practices include use of contour cultivation, natural vegetated strips (including strips with crops such as pineapple), minimum tillage planting, cover crop plantings, alternative cropping including vegetables, natural residue and/or plastic mulching, accelerated composting and vermiculture.

It is expected that adoption will progress significantly. Farmers are faced with increasing fertiliser, labour, seed and supply costs, which are likely to increase even more in the future. Options for reducing these costs via improved land management and cropping practice techniques are difficult to ignore.

Farmer field-school training session on the establishment of natural vegetated strips to reduce erosion and water run-off on sloping sites

Poverty and population pressures have forced many farmers onto sloping marginal lands with shallow, low-nutrient soil profiles. The findings from the project identified cropping practices that were most commonly linked to soil and nutrient loss and to low economic returns for farmers. Options were presented to farmers to minimise erosion if traditional crops—corn and cassava—were grown and alternatives to the traditional crops were introduced. The participatory nature of the farmer field-school approach has resulted in more farmers adopting alternatives than have rejected the improved options.

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

The project has had, and is expected to continue to have, a beneficial impact on the Philippine collaborators. BSWM, DENR and CIFOR now have experience in integrating small field-site, sub-watershed and full watershed-scale data into a manageable GIS framework. Additionally, the predominantly objective-oriented BSWM approach to soil and water management has been enriched through experiencing a more subjective CIFOR approach to management. Equally, CIFOR has gained through participation in the objective evaluation of a number of practices and approaches, which had not been rigorously evaluated in the Philippines.

Farming communities that are most impacted are those on marginal sloping lands. These communities are well aware of the consequences of repeatedly cropping such areas and have had few options other than to move their farming area using slash-and-burn approaches. The project has provided an alternative to that approach, offering opportunities to minimise erosion, improve soil properties and improve economic yield.

The impact will be greatly influenced by the priorities and continued support of the Philippine Government. Agricultural challenges and constraints are expected to increase as commodity prices and global warming impacts are realised. Issues such as use of palm oil, industry support for 'new' cropping options, including intensive vegetable production, coffee, cocoa and even oil energy crops, such as *Jatropha*, may potentially affect the magnitude of the impact. These options are currently being actively pursued by a number of agro-industry groups.

An additional factor is the problem of land tenure of agricultural areas within the Visayas. Many of the farmers are 'tenant' farmers who have little influence over cropping or land management decisions. The Department of Agrarian Reform has an important role in the development of fair and equitable land tenure legislation. Farmers who have long-term tenure or ownership are willing to consider longer term cropping options or land management options. Farmers with no land tenure are willing to adopt short-term contracts for the production of crops, such as cassava, which if cropped repeatedly lead to depleted soil profiles and extensive erosion.

Integrating effective phosphine fumigation practices into grain storage systems in China, Vietnam and Australia (PHT/1998/137)

Patrick Collins

Project number	PHT/1998/137
Project name	Integrating effective phosphine fumigation practices into grain storage systems in China, Vietnam and Australia
Collaborating institutions	Australia: Queensland Department of Primary Industries and Fisheries (now Agri-Science, Department of Employment, Economic Development and Innovation, DEEDI); Grainco Australia Ltd (now part of GrainCorp Ltd) China: State Administration of Grain (SAG or ChinaGrain); Zhengzhou Grains College (now Henan University of Technology, HAUT); Chengdu Grain Storage Research Institute (CGSRI); Guangdong Institute for Cereal Science Research (GICSR) Vietnam: Plant Protection Department (PPD), Ministry of Agriculture and Rural Development; Vietnamese Institute for Agricultural Engineering and Post-Harvest Technology (VIAEP)
Project leaders	Australia: Dr Patrick J. Collins (DEEDI) China: Mr Li Fujun (SAG), Prof. Cao Yang (HAUT), Prof. Guo Daolin (CGSRI), Dr Zeng Ling (GICSR) Vietnam: Mr Dam Quoc Tru (PPD), Dr Duong Minh Tu (PPD), Dr Nguyen Kim Vu Nguyen (VIAEP), Mr Trinh Dinh Hoa (VIAEP)
Duration of project	1 January 2001 to 31 December 2005
Funding	A$1,116,306 (ACIAR payment: A$897,566)

Countries involved	Australia, China and Vietnam
Commodities involved	Cereal grains
Related projects	PHT/1994/015 and CP/2006/083

Motivation for the project and what it aimed to achieve

Effective disinfestation systems for grains are essential for China, Vietnam and Australia to access international markets, maintain commodity quality, retain quarantine integrity and to assure food security. Currently, the fumigant phosphine is the major tool used to maintain an insect-free product. This situation is unlikely to change in the foreseeable future because of the lack of practical, cost-effective alternatives to phosphine. Moreover, phosphine is accepted internationally as a residue-free treatment.

However, resistance in target insect pests, out-of-date fumigation standards and poor fumigation practice have contributed to many control failures costing millions of dollars in remedial treatments, physical losses and actual or potential loss of markets. Managing the use of phosphine is now the major challenge facing pest managers in the grain industry.

Researchers at the Queensland Department of Primary Industries and Fisheries (now Agri-Science, Department of Employment, Economic Development and Innovation) had already been working with Chinese partners in a previous ACIAR project (PHT/1994/015). Recommendations of the external review of that project and a direct request from researchers and industry managers in China gave rise to this project. In addition, the importance of the phosphine resistance problem in Vietnam was communicated to Dr Greg Johnson (ACIAR Post-harvest Technology Program Manager) during discussions with officials of the Vietnamese Ministry of Agriculture and Rural Development.

The aims of the project were to:

- establish national fumigation standards for various storage types aimed at controlling strongly resistant insects and including best management practice
- improve fumigation practices in China and Vietnam through training programs
- investigate potential innovations to enhance the efficacy of phosphine fumigation
- determine the key factors preventing effective control of psocids with phosphine
- decrease losses to stored food suffered by poor farmers by researching and extending improved household storage techniques.

What the project produced

The major outputs of the project included:

- the establishment of national fumigation standards for various types of grain storage, aimed at controlling strongly resistant insects and including best management practice; these standards were based on broad surveys of insect populations to identify resistant phenotypes, laboratory characterisation of resistance levels and extensive field trials of proposed protocols
- increased capacity
    - during the project, more than 3,500 Chinese grain-storage staff received training in best practice fumigation and grain protection
    - about 700 farmers in seven provinces in northern and central Vietnam were trained in food protection and storage methods
    - trials were held in farm households and villages, particularly in poorer regions, to demonstrate the practical use of improved practices and new technologies

Demonstration of a phosphine fumigant generator to participants at a re-circulation workshop in Xinlong, China

- innovations to enhance the efficacy of phosphine including the application of carbon dioxide and split application of fumigant were developed; extensive experiments characterising the interactions of temperature, concentration and fumigation time on toxicity, and the effect of changing concentrations were completed
- increased knowledge of the ecology of psocids in relation to pest management and their environment.

In addition, eight students were awarded MSc degrees by the Henan University of Technology, China, based on work undertaken as part of this project; several younger scientists from all collaborating institutions received training; leading project scientists presented research papers at the International Conference on Controlled Atmospheres and Fumigation in Australia in August 2004; and the institutes in China and Vietnam have maintained their close level of cooperation.

Finally, the project provided essential insect-rearing and experimental equipment to the Chinese and Vietnamese institutes.

Adoption—how the project outputs are being used

The research groups in China had, and continue to maintain, close links with grain storage companies and have strong support for their work from provincial and national governments. Since completion of the project, each of the institutions has continued to provide training to storage personnel and to research

Ms Bui Thi Tuyet Nhung inspecting a rice warehouse for insect infestation

Ms Bui Thi Tuyet Nhung undertaking a phosphine resistance bioassay

improvements in grain protection. In Vietnam, resistance to phosphine continues to be a priority and a follow-up survey to that undertaken during the project is now underway. Training of storage personnel and farmers is also continuing.

In both China and Vietnam, project partners developed national standards that prescribe the use of phosphine in grain storages and form the basis for accreditation of storage staff and quarantine officers. All storage personnel, in both systems, must adhere to these standards. The standards are based on results of various aspects of research undertaken in this project. In addition, about 1,000 farmers and extension staff have been trained in best practice food preservation and storage, particularly in poorer provinces of Vietnam.

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

In Vietnam, the Vietnamese Institute for Agricultural Engineering and Post-Harvest Technology researched appropriate technologies, undertook demonstration trials of various improvements and provided training courses aimed at reducing postharvest losses of farmers, particularly those in poorer regions. In addition, it developed and trialled several small-scale drying, ventilation and storage systems compatible with village life. The current and future impacts of this work are many, including reduction in food losses, increased quality of food, increased income and reduced dependence on collection of wood from depleted forests.

Improvements to national fumigation and pest-management standards provide benefits at several levels. These standards are applied in domestic and international trade, improving access to markets and providing an alternative to the ozone-depleting methyl bromide for quarantine treatments. These standards incorporate workplace health and safety provisions that reduce the risks to workers and nearby communities. The primary purpose of these standards is to prevent insect infestation of grain; adoption of the standards results in better grain quality in storage, reduced chemical residues, and contributes significantly to food safety and food security.

Safe protection of grain is still a major issue in both Vietnam and China. In China, the previous partner institutions are researching alternatives to phosphine and trials with these technologies are underway. This represents a new, chemical-free phase in grain storage technology. In Vietnam, initial research indicates that the phosphine resistance problem is increasing; however, any significant improvement to grain protection is contingent on major changes to grain storage infrastructure in that country. Continuation of the research and extension work with farmers in Vietnam is dependent on further external funding.

Reports in the Adoption Studies Series

McWaters V. and Templeton D. (eds) 2004. Adoption of ACIAR project outputs: studies of projects completed in 1999–2000. Australian Centre for International Agricultural Research: Canberra.

McWaters V., Hearn S. and Taylor R. (eds) 2005. Adoption of ACIAR project outputs: studies of projects completed in 2000–2001. Australian Centre for International Agricultural Research: Canberra.

McWaters V. and Davis J. (eds) 2006. Adoption of ACIAR project outputs: studies of projects completed in 2001–2002. Australian Centre for International Agricultural Research: Canberra.

Gordon J. and Davis J. (eds) 2007. Adoption of ACIAR project outputs: studies of projects completed in 2002–2003. Australian Centre for International Agricultural Research: Canberra.

Pearce D. and Davis J. (eds) 2008. Adoption of ACIAR project outputs: studies of projects completed in 2003–2004. Australian Centre for International Agricultural Research: Canberra.

Pearce D. and Templeton D. (eds) 2009. Adoption of ACIAR project outputs: studies of projects completed in 2004–2005. Australian Centre for International Agricultural Research: Canberra.

ADOPTION OF ACIAR PROJECT OUTPUTS: STUDIES OF PROJECTS COMPLETED IN 2005–06

ACIAR

Research that works for developing countries and Australia

www.aciar.gov.au