Australian Gains from Investment in International Agricultural R&D 2010 – 2020

Doing Well by Doing Good

John Mullen, Julien de Meyer, Caroline Lemerle,
Garry Griffith and Bill Malcolm

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ADOPT	Adoption and Diffusion Outcome Prediction Tool
AIDAB	Australian International Development Assistance Bureau
AIYA	Australia Indonesia Youth Association
AS	Adoption study
BCR	Benefit cost ratio
BPP	Beef Profit Partnerships
CGIAR	Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CI&I	Continuous Improvement and Innovation
CIE	Centre for International Economics
CRC	Cooperative Research Centre
CRPB	Customary Rights Purchase Block
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DFAT	Department of Foreign Affairs and Trade
EIVSP	Eastern Islands Veterinary Services Project
ENB	East New Britain
FAO	Food and Agriculture Organization of the United Nations
FFT	Family Farm Team
FMD	Foot and mouth disease
GDP	Gross domestic product
GHG	Greenhouse gas
GVAP	Gross value of agricultural production
GM	Gross margin
IARC	International agricultural research centre
IAS	Impact assessment series
ICARDA	International Center for Agricultural Research in Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IP	Intellectual property
IRR	Internal rate of return
ISPC	Independent Science and Partnership Council
JAF	John Allwright Fellowship
JDF	John Dillow Fellowship
KyD	KaonafatsoyaDikgomo – 'improved beef'
LAO PDR	Lao People's Democratic Republic
LSS	Landholder settlement schemes
MIRR	Modified internal rate of return
MLFS	Mama Lus Frut Scheme

MWF	Meryl Williams Fellowship
NARS	National agricultural research systems
NGO	Non-government organisation
NPV	Net present value
NSW DPI	New South Wales Department of Primary Industries
ODA	Office of Development Assistance
OECD	Organisation for Economic Co-operation and Development
PASS	Pacific Agriculture Scholarships and Support
PAU	Punjab Agricultural University
PHARMA	Pacific Horticultural and Agricultural Market Access
PNG	Papua New Guinea
PV	Present value
PVS	Plant variety selection trials
RAID	Researcher in Agriculture for International Development
R,D&E	Research, development and extension
RDC	Research & Development Corporation
RIA1	Research Institute for Aquaculture 1
RSPO	Roundtable on Sustainable Palm Oil
SAT	Seeds of Australian Trees
SARIMA	Southern African Research and Innovation Management Association
SDIP	Sustainable Development Investment Portfolio
TFP	Total factor productivity
UQ	University of Queensland
UTAS	University of Tasmania
VAFS	Vietnam Academy of Forest Sciences

Acknowledgements

This report presents seven case studies that review significant research programs co-funded by ACIAR. We consulted with the scientists who played leading roles in these programs to gain updates and ensure that we had adequately described the programs' achievements. As well, we had exchanges with senior scientists who have become mentors to younger researchers thanks to the Crawford Fund. The people who gave generously of their time included Dr. Robyn Alders, Prof. Heather Burrow, Prof. George Curry, Prof. Shu Fukai, Prof. Vasant Gandhi, Dr. Chris Harwood, Prof. Gina Koczberski, Prof. David Kemp, Prof. Deirdre Lemerle, Dr. Wayne O'Connor, Prof. Barbara Pamphilon, Dr. Cooper Schouten, Dr. Helen Scott-Orr, Gurpreet Singh and Noel Vock. David Pearce from CIE provided advice about methods and data. We would also like to thank Nathan Russell for his editing of our report.

1 Executive Summary

In his book *Doing Well by Doing Good,* Derek Tribe made the case for investing in agricultural research in our developing country neighbours. Tribe argued that Australia not only 'did good' by alleviating poverty and protecting natural resources in these countries – the goals of Australia's overseas development program – but also 'did well', as many benefits flowed back to Australian agriculture and the wider community. Public investment in agricultural R&D has been declining in developed countries, despite high rates of return, and so Tribe's arguments, still valid, need to be presented to policy makers in a contemporary context. The Crawford Fund commissioned such a study in 2013 (Blight et al. 2013) and this report is a further update on Australia's contributions to international agricultural research and its foreign policy goals.

In brief, our aim has been to make the case, cognisant of emerging global trends, for continued investment by Australia in international agricultural research by providing evidence of the strong flow of economic, environmental and social benefits to Australia and its developing country partners.

ACIAR is the primary vehicle for Australia's overseas development program in agriculture.

The Crawford Fund adds value to ACIAR activities by building the capacity of scientists in developing countries through subject-focused Master Classes, targeted training and mentoring. The Fund also has a strong outreach program highlighting the benefits to Australia from involvement in and support of international agricultural R&D.

ACIAR has six strategic objectives which are aligned with the 2030 Sustainable Development Goals:

- Food security and poverty reduction
- Natural resources and climate change
- Human health and nutrition
- Gender equity and women's empowerment
- Inclusive value chains
- Capacity building.

Progress towards these objectives may be thought of as enhancing capital stocks (including human capital). Enhanced capital stocks are a benefit in their own right but are also sources of services enabling further productivity gains. These capital stocks influence the productivity from R,D&E through a complex feedback mechanism. By delivering new technologies that increase farm incomes and alleviate poverty, R,D&E provides a vehicle to deliver on the other objectives, and their growth influences the rate at which new technology is adopted and poverty is alleviated.

We developed case studies of seven research programs to illustrate how investments by ACIAR and the Crawford Fund contribute to ACIAR's six objectives. The studies show how Australian scientists and their developing country partners solve complex problems and thus better enable farm families to improve their lot. The case studies are:

- Productivity in the South African beef industry
- Direct seeding and drought tolerant varieties in the lowland rice sector of Laos
- Developing an oyster industry in Vietnam
- Reducing biosecurity threats to the Australian honey industry
- Improved smallholder livelihoods from oil palm in lowland Papua New Guinea
- Development of the Happy Seeder to incorporate crop stubble in India
- Stocking rate management in China's grasslands.

We chose these because we were able to find evidence of strong causal pathways linking research activities to final outcomes. Hence, the estimated high rates of return were credible, suggesting that these activities also contributed strongly to ACIAR's other strategic objectives.

Other important components of our report are:

- A review of the importance of agricultural productivity to alleviating poverty
- A review of Australian and international evidence that the returns to public investment in agricultural R&D are high
- A review of the evidence from ACIAR's impact assessment studies of the economic, social and environmental impacts of its bilateral and multilateral programs
- A review of the scope of capacity building activities by ACIAR and the Crawford Fund and consequent outcomes
- A review of how ACIAR manages research funds and seeks to understand innovation and adoption processes so as design projects that are more likely to meet its objectives

Key findings of this study include:

Why productivity in agriculture is so important

- An increase in agricultural productivity reduces poverty by twice as much as a comparable increase in productivity in other sectors of the economies of developing countries.
- Adoption of new technologies enhances productivity, alleviates poverty and facilitates the achievement of ACIAR's strategic objectives.
- The challenge for research is to deliver technology that farmers will adopt, thus alleviating poverty and contributing to ACIAR's other objectives.
- Agricultural R&D generates high returns to public investment, and this is evidence of underinvestment.
- Productivity growth in rich countries is slowing, partly because of falling public investment in agricultural R&D.

Case studies

- The seven case studies presented here demonstrate how Australian scientists and their developing country partners devise solutions to complex problems and contribute to ACIAR's strategic objectives and thus to Australia's foreign policy objectives.

- In all cases, the adoption of new technologies has driven increases in the incomes of poor farm families.
- Given the strong economic returns from these efforts, we can be confident that they are also achieving other strategic objectives that are hard to quantify.
- All of the case studies document significant progress in building human and scientific capacity through informal and formal channels.
- The case studies offer examples of:
    - Women's empowerment
    - Protection and restoration of natural resources
    - Reduced biosecurity threats to Australia
    - Farming systems approaches to solving complex problems
    - Farmer participation in the design and management of trials
    - More efficient value chains
    - Benefits to Australian agriculture

ACIAR has delivered strong benefits to its partners and Australia

- ACIAR has had a strong program of impact assessment, which rigorously estimates economic impacts and also documents contributions to its strategic objectives in qualitative terms.
- For a subset of impact assessments rated as 'convincing', the BCR in relation to ACIAR's total investment in bilateral program since 1982 is about 5:1, which may be regarded as a lower bound estimate of the returns to ACIAR's bilateral program.
- The BCR for ACIAR's investment in its multilateral program is likely in the order of 10:1, with a lower bound estimate of about 3:1. Through its support for the CGIAR system, Australia has alleviated poverty in developing countries and furthered other strategic objectives.
- Benefits to Australian agriculture from formal links with the CGIAR centres come in the form of a steady flow of germplasm and management technologies for agricultural enterprises important to Australia.
- A safe ballpark estimate of the BCR for a well-managed portfolio of research projects is perhaps 10:1.

Capacity building, partnerships and networks

- Capacity building, whether for individuals or whole institutions, enhances skills and knowledge through formal training and academic studies as well as by informal means, such as on-the-job training, leadership, mentoring, two-way-transfers of ideas and technologies, and other steps that empower colleagues to undertake research.
- Capacity building, together with the creation of strong research networks and partnerships, are fundamental requirements for effective agricultural research and innovation systems.
- In the last 10 years, over 5,000 Australian and international scientists have participated in training courses supported by the Crawford Fund, and 800 more researchers have received ACIAR fellowships to pursue academic or leadership studies in Australia. This large cohort of

trained men and women use their skills to strengthen their national agricultural sector and to develop professional and personal links which are a source of much goodwill towards Australia.

Promoting efficient use of R,D&E resources

- ACIAR plans and manages research resources with care, particularly in the project development, and monitoring and evaluation phases. In all stages, the Centre relies on impact pathway statements (akin to theory of change statements), which describe a plausible causal link between research activities, inputs, outputs (such as technologies and published papers), and the economic, social and environmental outcomes arising from farmer and other end user adoption of new technology.
- Another tool that aids project design involves encouraging the specification of objectives in a **SMARTT S**pecific, **M**easurable, **A**chievable, **R**elevant, **T**argeted and **T**imeframed) way.
- ACIAR publishes adoption studies (now referred to as evaluations of outcomes) 3-4 years after project completion to report on the legacy of projects particularly the level of adoption of the technology;
- ACIAR commissions external impact assessments of a small proportion of its bilateral projects. These assessments use economic welfare analysis to derive the usual measures of financial performance. They also describe economic, social and environmental outcomes that are difficult to measure;

From research to innovation – understanding adoption

- Smallholder farmers must innovate to survive in rapidly changing rural areas of developing countries. Innovation helps farmers enhance resilience, manage risk better, and contributes to more informed decisions about their agricultural production and livelihoods.
- Agricultural research (to generate knowledge about new technologies) is one part of innovation; adoption is the other.
- Low levels of adoption can limit improvement in smallholder farmers' welfare and slow progress toward ACIAR's other strategic objectives.
- This is why ACIAR also funds projects aimed at better understanding smallholders' incentives (economic, cultural, social and technological) for adopting new technologies.
- Based on such knowledge, researchers can improve project design to better target (i) the technology to the farmers' situations, (ii) the extension program and (iii) capacity building activities resulting in faster more widespread adoption.

2 Recommendations

The evidence is strong that Australia's investment in agricultural research in developing neighbours has been very successful in alleviating poverty and contributing to other UN Sustainable Development goals.

- Australia should continue to invest in agricultural R&D in its developing country neighbours. Many lack strong public agricultural research systems, and public investment in agricultural R&D is low by international standards. The main reason for Australia's continuing support is that this alleviates poverty and promotes stability, thus contributing to Australia's foreign policy goals. Another reason is that this investment generates some benefits (related to biosecurity, for example) back to Australian agriculture.
- Australia should continue to support multilateral organisations such as the CGIAR system, even as support from other developed countries declines. This support not only contributes to poverty alleviation and other UN Sustainable Development Goals but also gives Australian agriculture more direct access to technologies from the international centres. Unless Australian farmers can use these technologies, they will be worse off, as adoption in other countries leads to declines in world commodity prices.
- Research programs should continue to focus on developing profitable technologies that farmers will adopt, thus contributing to higher farm incomes and poverty alleviation. Strong economic outcomes boost the likelihood of better environmental and social outcomes as well.
- Exotic pests and diseases pose a serious threat to Australian agriculture and the wider community. Conducting research on them in neighbouring countries makes sense as a means of protecting Australia from biosecurity risks, while also helping our neighbours control them.
- Climate change threatens agriculture in Australia and neighbouring countries, requiring development of technologies that can help farmers adapt to and mitigate its impacts.
- ACIAR and the Crawford Fund should maintain their commitment to building human capital, both informally through bilateral programs and formally through fellowships, Master Classes and mentoring programs. These efforts benefit both developing countries and Australia in ways that are more difficult to quantify compared to measurable economic impacts but are likely of a similar magnitude. The benefits extend far beyond the life of the projects that produce them, leading to productivity gains years later, while enhancing international collaboration and networks, which are key components of the global agricultural innovation system.
- Research institutions should maintain strong programs to assess the economic, social and environmental impact of their investments, with particular emphasis on estimating the effect of technologies on farm incomes and the subsequent extent of adoption. Determining that technology has been adopted can bolster confidence that research is also achieving its other objectives. Empirical evidence of the returns to research in Australia and elsewhere is becoming dated. It is important to gather new evidence to maintain credibility in the claim that returns to agricultural research are high.

3 Introduction

The first edition of *Doing Well by Doing Good: Feeding and Greening the World* (Tribe 1991) called on Australia (and other rich countries) to continue investing in international agricultural research. Tribe argued that this research offers an efficient means of 'doing good', that is, improving the welfare of poor farm families and others dependent on agriculture in developing countries. But he went on to argue that by 'doing good' Australia is also 'doing well', since its support of international agricultural research creates a flow of benefits that return to Australia in various forms, including advances in technology, gains in scientific and human capacity, and increased trade and goodwill in neighbouring countries, which enhances Australia's interests through 'soft diplomacy'.

Tribe was instrumental in founding the Crawford Fund (1987), which seeks to mobilise support for international agricultural research by raising awareness of its benefits for both Australia and developing countries. The Fund enables Australian scientists to provide training across a broad range of fields for colleagues from developing country neighbours, and also to support and mentor young Australian scientists interested in food and nutrition security.

Australia's investment in international agricultural research forms an important part of its foreign aid program. According to the most recent *Foreign Policy White Paper* (Aust. Govt., 2017):

> As a prosperous country, Australia has a responsibility to contribute to global efforts to reduce poverty, alleviate suffering and promote sustainable development. This also serves our interests because the more that countries can provide economic opportunity for their citizens the more stable they will be (p.87).

Australia is committed to the UN 2030 Agenda for Sustainable Development, which includes goals 'to reduce poverty and hunger, improve health and education, advance gender equality and strengthen economic growth (p.88)'. Australia currently invests about $4b in Official Development Assistance (ODA), mainly in the Indo-Pacific region. Australia's ODA program also creates opportunities to influence partner countries through 'soft diplomacy' in a range of policy areas of interest to Australia[1].

Investment in international agricultural research contributes to Australia's foreign policy goals. The country's main vehicle for this investment has been the Australian Centre for International Agricultural Research (ACIAR), which was founded in 1982 as a statutory authority within the Foreign Affairs and Trade Portfolio. ACIAR's mission is 'to achieve more productive and sustainable agricultural systems for the benefit of developing countries and Australia, through international agricultural research partnerships' (ACIAR 2020, p.2).

ACIAR has six strategic objectives, which contribute to 12 of the 17 UN 2030 Sustainable Development Goals:

- Food security and poverty reduction

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[1] Otor and Dornan (2017) estimated that a $1investment in aid benefits Australia by generating, on average, $7.10 in increased exports. Note that this is not a benefit cost ratio based on traditional concepts of welfare economics.

- Natural resources and climate change
- Human health and nutrition
- Gender equity and women's empowerment
- Inclusive value chains
- Capacity building

ACIAR funds Australian scientists to work with developing country colleagues in pursuit of these strategic objectives. The Australian scientists come from universities, CSIRO and state departments of agriculture. The resources and opportunities that ACIAR provides them make the Centre an integral part of the country's agricultural innovation system. Australian agriculture benefits through new technologies and gains in human and scientific capacity.

The Crawford Fund is financially supported by ACIAR. Its mission is to:

- Increase public awareness of mutual benefits of Australian support for, and involvement in, international agriculture and capacity building.
- Demonstrate and use Australian know-how to enhance food security and nutrition and sustainable production systems via capacity building of overseas and Australian agricultural scientists and managers' (Crawford Fund, 2018).

The Fund adds value to ACIAR's activities by means of:

- Capacity building for Australian and overseas research institutions and professionals, through subject-focused Master Classes; targeted training for professional, technical and managerial staff from developing countries; and mentoring and support for Australian students and early to mid-career researchers and managers.
- Public outreach through communication and engagement that highlight the benefits to Australia from involvement in and support of international agricultural R&D.

In recent decades, public investment in domestic and international research by rich countries has declined (Alston et al., 2020), despite the threats to global food security posed by climate change, pandemics and wars. So, the challenge to maintain public support has been ongoing. In response, the Crawford Fund released a second version of *Doing Well by Doing Good* in 2013 (Blight et al., 2013).

The Crawford Fund's key aims for this third update of *Doing Well by Doing Good* are to:

a) Demonstrate the on-going value of Australia's aid program investments to different dimensions of Australia's agricultural innovation system.

b) Make the case for continued investment in Australian international agri-food systems research and development through this mechanism.

c) Make recommendations on how to focus this investment in response to emerging priority areas and current global trends.'

Chapter 4 of this report makes the case that in developing countries gains in agricultural productivity are likely to be more valuable than gains elsewhere in the economy, and it provides evidence of the high returns from investments in agricultural research. Because of the feedback loops between ACIAR's six strategic objectives, the adoption of new technologies that alleviate poverty serves as an efficient vehicle for meeting ACIAR's other strategic objectives. Chapter 5 presents seven case studies, which describe the kinds of problems that ACIAR-supported scientists address, the means by which they solve them, and the economic, social and environmental outcomes. Chapter 6 reviews the benefits that ACIAR's investment in its bilateral and multilateral programs have delivered to Australia and developing country partners. Chapter 7 examines the efforts of ACIAR and the Crawford Fund to build human, scientific and institutional capacities. Chapter 8 describes trends in ACIAR and Crawford Fund expenditures as well as the means by which ACIAR manages the resources entrusted to it and seeks to better understand what motivates smallholders to adopt innovations. The report concludes with a summary chapter and another offering recommendations. Appendix 1 provides longer, evidence- based versions of the case studies, while Appendix 2, submitted by ACIAR, gives other examples of its projects that have delivered on its strategic objectives.

Note that all dollar values from previous studies have been expressed in 2020 dollars by applying the CPI based in 2020. The present value, PV, of benefit streams and costs have been derived by compounding forward values in 2020 dollars at 5%.

4 Why Productivity in Agriculture Is So Important

4.1 Key points

- An increase in agricultural productivity reduces poverty by twice as much as a comparable increase in productivity in other sectors of the economies of developing countries.
- Adoption of new technologies enhances productivity, alleviates poverty and facilitates the achievement of ACIAR’s strategic objectives.
- New production technologies resulting from R&D contribute importantly to productivity growth.
- The challenge for research is to deliver technology that farmers will adopt, thus alleviating poverty and contributing to ACIAR’s other objectives.
- Agricultural R&D generates high returns to public investment, and this is evidence of underinvestment by government.
- Productivity growth in rich countries is slowing, partly because of falling public investment in agricultural R&D.

Agricultural productivity improves when greater output can be produced from fewer inputs – ‘two blades of grass where one grew before’, as 18th century satirist Jonathan Swift put it. In the 2020 World Bank report *Harvesting Prosperity*, Fuglie et al. (2020, p.3) cite research showing that in poor countries an increase in agricultural productivity has twice as much impact on poverty reduction as a comparable productivity increase in other sectors of their economies. This is a strong argument for Australia to continue funding international agricultural research.

How research delivers on poverty alleviation and ACIAR’s other objectives is complex (Mullen et al. 2015). Annual investments in research and extension can build up knowledge stocks of various types:

- Knowledge or new technologies available to farmers
- Human scientific capacity, enhanced through training, mentoring and learning by doing
- Other knowledge not immediately reflected in new technologies
- Knowledge held by policymakers
- Knowledge held by research managers

These knowledge stocks provide a flow of services, which result in new technologies becoming available. If these technologies lower costs, increase yields or improve quality, farmers have an incentive to adopt them, thus enhancing their productivity, increasing their income and alleviating poverty[2].

However, the extent of adoption and subsequent productivity gains depends on many other factors, such as:

- The extent of poverty
- The health of natural resources (soil, water and air)
- Families' health and nutritional status
- Women's participation in farm family decision-making
- Value chain efficiency before and after the farm gate
- The capacities of farmers and the scientists that work with them

These factors correspond to ACIAR's six strategic objectives and can also be regarded as stocks of human and environmental capital. Low levels of these stocks will likely constrain the adoption of new technologies. Political stability, an objective of Australia's overseas aid program, can have large impacts on the rate of economic development and poverty alleviation as well as ACIAR's other objectives.

The extent of productivity gains and poverty alleviation depends on the level of these stocks. R,D&E can increase some or all of them through various feedback processes.

The most efficient way to increase these stocks is through traditional R,D&E, aimed at developing new technologies that farm families will adopt, thus increasing income and reducing poverty. Technology adoption also serves as a vehicle for increasing the capital stocks and meeting some or all of ACIAR's six strategic objectives.

Conversely, increasing some or all of these stocks leads to gains in income and productivity, for example, if women are empowered or natural resources enhanced. However, it is hard to conceive how some or all of these stocks might be efficiently increased, *except* through farmer adoption of new technology. An important qualification here is that the success of some projects depends on a change in public policy or in the knowledge stock of policymakers.

A strawman counterargument might help make this point clear. Suppose, for example, that a research project achieves a better understanding and improves the measurement of climate change in a particular environment but does not provide farmers with an incentive to change their farm management. While expanding scientific knowledge, project results will have minimal impact on other capital stocks, including the poverty level, though they might lead to a change in public policy.

The challenge then is to design research programs for delivering technology that farmers will adopt and that increase farm income and alleviate poverty, while also adding to other capital stocks, such as natural resource or human health and women's empowerment[3].

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[2] Some new technologies in the value chain may lower on-farm costs and increase demand at the farm gate, leading to poverty alleviation.

[3] Noting that other policy tools can be used to enhance these capital stocks.

Against this background, the case studies presented in this report offer convincing evidence of the economic gains resulting from new technologies. Where there is strong evidence of technology adoption and changes in farm practices, leading to increased incomes, we can have confidence that related outcomes, which are difficult to measure empirically, have also been achieved. The case studies describe such outcomes in detail, as is normal practice for any rigourous impact assessment.

Producers, processors and consumers in the marketing chain all share the benefits of new technology [4]. In developing countries, many semi-subsistence farm families benefit as both producers and consumers, and initially capture most of the benefits of new technology. Such technologies, if profitable for farmers, are a highly effective way of alleviating poverty.

Even though Australia is not a developing country, its experience still illustrates the importance of productivity growth in agriculture (Figure 1). If the country had not achieved the growth it has shown over the past 60 years, the real gross value of its agricultural production would be only about $30 billion per annum (the top of the blue bars in the figure) – half the current value of more than $60 billion (the top of the red bars)[5]. Thus, about half the value of Australia's agricultural production in 2020 can be attributed to past productivity growth (the red area). In countries where agriculture accounts for a much larger share of the economy, productivity growth has an even greater impact.

Agricultural productivity growth has slowed in high-income countries (Sheng, 2020). The productivity of Australia's broadacre agriculture grew at a rate of 2.2% per annum from 1953 to 1994, but from then until 2007, this growth averaged just 0.4 per cent (Sheng et al. 2011). The ABARES (2021) estimate for the period 1978-2020 is 1%. The turning point, according to Sheng et al. (2011), came in the mid-1990s (1994), when TFP growth declined significantly. Econometric testing attributed this change largely to the decline in R&D public investment, with poor climatic conditions also playing a role. Chambers et al. (2020) have noted that climate change is exerting a stronger impact on productivity growth.

[4] For a deeper understanding of how marketing chain actors share the various benefits of new technologies, see Mullen et al. (1989).
[5] This is based on estimates that the productivity of Australian agriculture grew at an average rate of 2% per annum from 1953 to 1994 and 1% since then.

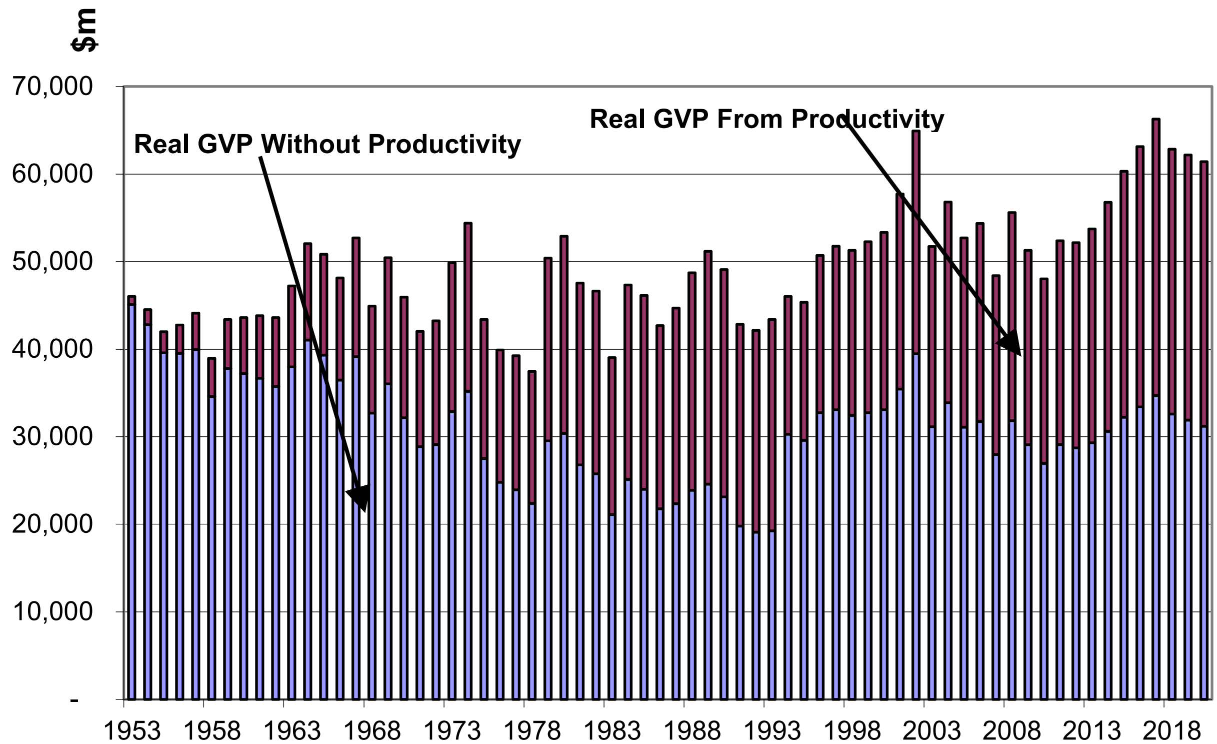

Figure 1: The value of productivity growth to Australian agriculture, 1953–2020.
Source: Derived by the author from ABARES data in *Australian Commodity Statistics.*

4.2 Investment in agricultural R&D is still a winner

In sum, productivity growth contributes significantly to the value of agricultural output. Though such growth can have a number of sources, including improved infrastructure and economic reform, investment in R&D is the most important. However, the lag between research and gains in farmers' welfare often amounts to 30-50 years – hence our use of the term 'slow magic' (Alston et al. 2021) in Figure 2.

Overwhelming evidence points to high returns from domestic and international agricultural research. Most empirical studies have involved benefit cost analyses (also referred to as impact assessments) of projects or sets of projects. These studies relate research investments to economic outcomes, measured as changes in the net income of the population of farmers adopting the technology[6]. The last few decades have seen a number of reviews of analyses of the returns to public agricultural R&D, including those by Alston et al. (2000), Fuglie and Heisey (2007), the Council of the Rural Research and Development Corporations (2010), Productivity Commission (2011) and Mullen (2011). These analyses reflect a consensus that investment in agricultural R&D yields high returns and that this indicates underinvestment.

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[6] See Davis et al. (2008) for the economic theory and practice applied in ACIAR's published impact assessments.

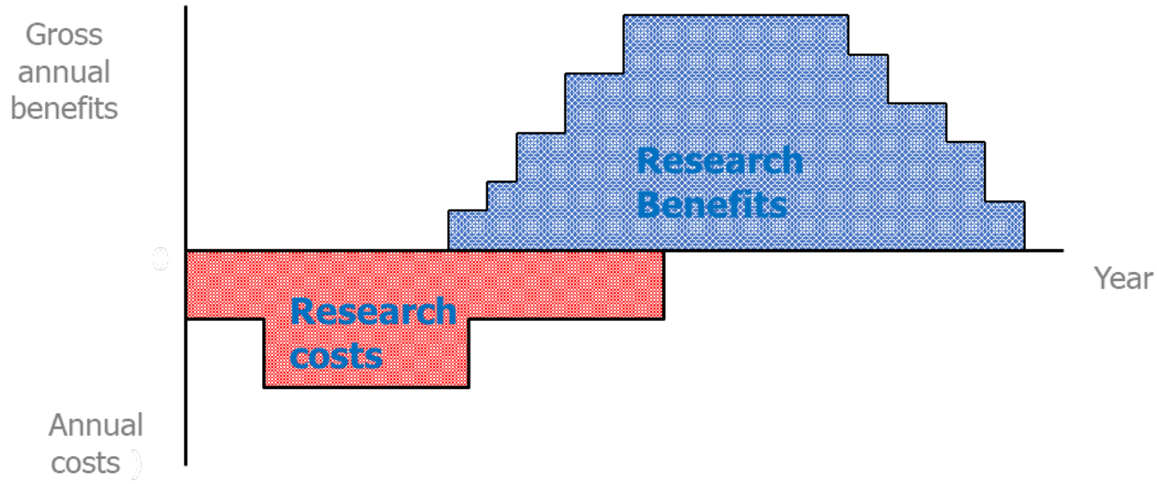

Figure 2: Agricultural R&D is slow magic
Source: Alston et al. (1995)

The most recent Australian study, conducted by Agtrans Research (2019), surveyed impact assessments conducted by the Research and Development Corporations (RDCs) over 5 years (from July 2013 to September 2018)[7]. From a total of 219 evaluations, Agtrans analysed a subset of 111 from 11 of the 15 RDCs, estimating the BCR across this subset as 5.5:1[8].

More recently, Alston et al. (2020 and 2021) assessed the payoff from R&D investments in the CGIAR system[9]. Using several methods that gave similar results, they estimated that over the last 50 years the present value of these investments has amounted to $85b[10], with an estimated BCR of about 10:1 for both CGIAR research and also for that conducted by NARS in developing countries.

Various econometric analyses of national agricultural sectors support these benefit cost analyses at a project or program level. Alston et al. (2011) estimated the modified internal rate of return (MIRR) from public investment in the US at an average of 9.9%. For Australia, analysis by Mullen (2007) and extended by Sheng et al. (2011) estimated an IRR in the range of 15.4 to 38.2%. After assessing a range of scenarios, Mullen (2007, p.380) suggested that the BCR for public investment in Australia's agricultural research is around 10:1.

[7] Similar reports had been prepared in 2000, 2010 and 2016.
[8] Estimated as the ratio of the PV of benefits from the set of 111 evaluations to the PV of investment by the RDCs in this set of projects.
[9] Since this is such a large study of R&D in the CGIAR system and in the countries where CGIAR operates, its findings likely indicate the returns to public agricultural research more generally.
[10] US dollar amounts were converted to AUD at an exchange rate in 2016 of 0.74 and then expressed in 2020 dollars.

4.3 Comparing the return to public R&D in agriculture with that in other sectors

While there is an extensive literature on the rate of return to public investment in agricultural research this is not the case for public investment in other sectors like transport, education, health etc – especially for Australia. Public investments should earn a rate of return at least as great as the social discount rate. The social discount rate recommended by the Australian government has been 7%. The present climate of low interest rates has led to a debate questioning whether a lower social discount rate should be applied when evaluating public investments. The Gratton institute (2018) 'Unfreezing discount rates' recommended a discount rate of 3.5% for low-risk infrastructure projects and 5% for projects with a higher level of risk. Public investment in agricultural R&D in Australia has comfortably exceeded this low bar as noted above and in a later chapter on the returns to investment by ACIAR.

Jorda et al. (2017) in a study of the returns to a range of assets in 16 advanced economies estimated that from 1870 to 2015, the returns to 'risky' investments such as housing and equities was 7% and the return to 'safe' assets was in the range of 1 -3 %. In our report we have generally reported benefit cost ratios. Using a formula from Rao et al. (2020), we estimate that a BCR of 10 is equivalent to a modified internal rate of return (MIRR) of 9.5%. The MIRR approximates the rates of return quoted on financial instruments. As will be seen in Chapter 6 and already above, a BCR of 10 would seem to be a reasonable expectation of well managed agricultural R&D programs.

Noted above was the finding by Fuglie et al. (2020) that in developing countries gains in productivity in the agricultural sector improved welfare at twice the rate of gains in other sectors. We don't know how much it costs to achieve productivity gains in these sectors but if the cost of a one percent gain in productivity is the same then the returns to research in the agricultural sector of developing countries might be in the order of twice the returns to research in other sectors, noting that R&D is not the only source of productivity growth. This suggests that investing in international agricultural research may earn higher returns to Australia than other forms of foreign aid.

4.4 Declining public investment in agricultural research

Despite these high rates of return, public investment has contracted, even as poverty and malnutrition remain at unacceptable levels in developing countries (Alston et al., 2021). Alston et al. (2021) concluded that, even if global public investment in agricultural R&D were doubled (from about US$40b), it would remain a good investment. They further noted that public agricultural R&D has shifted from high-income countries (now accounting for only 44.6% of the total) to middle-income countries (especially China, India and Brazil) and that R&D, particularly in developed countries, has shifted its focus away from research aimed at enhancing farm productivity and thus boosting farm income. Pardey et al. (2016) also noted a shift from public to private funding of R&D. In 2011, the private sector conducted just over half of agricultural R&D in rich countries (up from 42% in 1980), while in middle-income countries, the share by the private sector was 35% (up from

16%). This trend has likely continued since then. The low rate of R&D investment in low-income countries with high population growth, is of grave concern.

In Australia, public support for agricultural R&D has most likely declined, as in other high-income countries (Grafton et al., 2015). This has been offset by a steady rise in private sector investment in rural R&D (Milist et al., 2017). Keogh et al. (2010) found that in Australia private sector R&D investment complements public sector investment rather than providing a substitute for it.

5 Case Studies

5.1 Key points

- The seven case studies presented here demonstrate how Australian scientists and their developing country partners devise solutions to complex problems and contribute to ACIAR's strategic objectives and thus to Australia's foreign policy objectives.
- In all cases, the adoption of new technologies has driven increases in the incomes of poor farm families.
- Given the strong economic returns from these efforts, we can be confident that they are also achieving other strategic objectives that are hard to quantify.
- All of the case studies document significant progress in building human and scientific capacity through informal and formal channels.
- The case studies offer examples of:
    - Women's empowerment
    - Protection and restoration of natural resources
    - Reduced biosecurity threats to Australia
    - Farming systems approaches to solving complex problems
    - Farmer participation in the design and management of trials
    - More efficient value chains
    - Benefits to Australian agriculture

5.2 How we selected the case studies

To illustrate how investments by ACIAR and the Crawford Fund contribute to ACIAR's six strategic objectives, we have prepared seven case studies. These demonstrate how Australian scientists and their developing country partners devise solutions to complex problems, thus enhancing the ability of poor farm families to improve their lot. When technologies lead to higher incomes, we can safely assume that this has also contributed to some or all of ACIAR's other strategic objectives.

Appendix 1 provides evidence about how each of the projects we examined contributed to ACIAR objectives. Following are brief summaries of the case studies, describing their purpose, the technologies developed, their economic returns and other strategic outcomes. Table 3 indicates the strategic objectives to which each project contributed.

These case studies do not provide a statistically random representation of ACIAR's portfolio. Nor do they fully represent either the agricultural industries nor the geographical areas in which ACIAR has supported research. The Annual Operating Reports on ACIAR's website offer a more complete view of the Centre's 'spread' but provide little detail about particular research programs and their outcomes.

There is no sensible way to select a set of case studies that would allow us to aggregate or generalise from findings. Instead, we have purposefully ‘cherry picked’ research programs from across the spectrum to illustrate the features of successful programs. Most of the case studies are supported by rigorous ACIAR impact assessments, describing plausible causal pathways from research activities to technology development, their adoption by farm families and outcomes that can be attributed to ACIAR. The projects were completed several years ago, and the impact assessment reports are now somewhat dated. We have consulted with project leaders and ACIAR managers to learn about more recent developments. Several of the case studies report significant benefits to Australian agriculture in terms of new technologies and gains in scientific capacity.

One aim of the case studies is to provide insight into the varying paths by which ACIAR pursues its strategic objectives across a portfolio of projects. Some of the case studies involve a series of projects unfolding over 10-20 years. These studies complement more aggregated reviews of the returns to agricultural research investments by describing the feedback relationship between poverty reduction and ACIAR’s other strategic objectives.

ACIAR carried out impact assessments of four of the projects examined, and Linder et al. (2013) rated three of these as ‘convincing’. The three projects that did not undergo ACIAR impact assessment – South African beef, oysters in Vietnam and grasslands in China – conducted ‘in-house’ benefit cost analyses. The main testament to their likely high economic returns, however, is the high rate of technology adoption reported in the case studies. All of these studies report the development of technologies that farmers adopted and all contributed to poverty alleviation, as indicated in the top row of Table 1.

Table 1 also highlights the projects’ contributions to ACIAR’s other strategic objectives. In a sense, all of the projects examined contributed to all of the strategic objectives, but in each case study, we have highlighted the strategic objectives that the research program specifically targeted and achieved. In some cases, notably air quality in India, the outcomes remain prospective largely because of policy constraints to technology adoption.

All of the case studies report substantial contributions to human, scientific and institutional capacity building through formal and informal channels. Such progress in early projects has helped later projects to evolve and adapt to changing environments and scientists to explore other research areas and rise to prominent leadership positions. As Mullen et al. (2016) have pointed out, the use in later projects of capacities built early on provide strong evidence of their value.

As Mullen et al. (2016) further note, partner scientists in developing countries have said that capacity building is just as important for achieving project outcomes as the research activities, such as conducting trials. Other outcomes that all of the case studies document involve collaboration and networking, which are closely related to capacity building.

Objectives/ vision \ Case studies	Productivity in the RSA beef industry	Lowland rice system in Lao PDR	Oyster industry in Vietnam	Mite pests and biosecurity	Smallholder livelihoods in PNG	Happy Seeder	Rehabilitating grasslands in north-western China
Food security and poverty reduction	✔	✔	✔	✔	✔	✔	✔
Natural resources and climate change	✓	✔	✓		✓	✔	✔
Human health and nutrition	✓				✓	✔	✔
Gender equity and women's empowerment		✔	✓		✔		
Inclusive value chains	✔		✔				✓
Capacity building / collaboration and networks	✔	✔	✔	✔	✔	✔	✔
Submitted to impact assessment		✓		✓	✓	✓	

Table 1: Case study matrix based on ACIAR objectives

The objectives achieved by the projects are represented by large ticks on a green background, whereas smaller ticks represent additional and sometimes unforeseen outcomes achieved.

The case studies on smallholder livelihoods in PNG, direct seeding of rice in Laos and oysters in Vietnam describe how new technology has enhanced the welfare of women. The projects dealing with the Happy Seeder in India and grasslands in China emphasised the protection and restoration of natural resources. The projects on South African beef, grasslands in China and oil palm development illustrate the importance of changes in value chains. The development of drought tolerant rice varieties enhanced the food and nutrition security of subsistence rice farmers in Laos. Reducing biosecurity threats to Australia, though not explicitly one of ACIAR's strategic objectives is an important concern. The projects on mite pests of honey bees and on oysters contributed importantly to reducing pest and disease threats to Australian agriculture.

Another key feature of the projects examined was their emphasis on a farming systems approach, as distinct from a disciplinary focus, to solving complex problems. In addition, the projects often involved farmers in planning and managing trials and in interpreting the results. Especially noteworthy in this regard are the projects on beef in South Africa, rice in Laos, grasslands in China and oil palm in PNG.

5.3 A contribution from ACIAR

ACIAR have provided snapshots of 18 projects, which are presented in Appendix 2. As mentioned earlier, projects usually aim to deliver on several of ACIAR's strategic objectives, but those presented in the appendix are listed against one of their objectives – 4 against the food security objective, 2 against the natural resources objective, 1 against the human nutrition objective, 4 against the gender equity objective, 4 against the value chain objective and 3 against enhancing science and policy capacity objective. Presumably ACIAR considers that these projects successfully delivered on their main objective but it was beyond to scope of our project to assess outcomes from these projects. In reviewing the material in Appendix 2, we concluded that the success of 13 projects (spread across all six ACIAR objectives) in meeting their main objectives could be attributed at least partly to farm families' adoption of technologies that increased their incomes.

The other five projects are also instructive. One aimed to enhance human nutrition in Uganda by enriching maize flour with underutilized fish products and distributing it to breastfeeding mothers through public health measures to reduce the incidence of micronutrient deficiencies in young children.

Another project involved the restoration of coral reefs first in the Philippines and more recently on the Great Barrier Reef by harvesting coral eggs and sperm to grow new coral larvae. Restoring reefs, valuable in its own right, may later deliver gains to fisheries and/or tourism.

A third project worked to change government policy in Pakistan to broaden the range of channels though which farmers could market fresh producer. The success of these three projects depended on responses from the public sector rather than farmers.

Under the fourth project, ACIAR helped CGIAR strengthen its efforts to promote gender equity. The fifth project was a tracer study of ACIAR's John Allwright Fellows. Such studies follow the career paths of alumni, attributing at least part of their progress to the fellowships.

As explained in Chapter 4, even though these five projects may not have poverty alleviation as an immediate objective and may require implementation by the public sector, building up these capital stocks, whether in terms of human health, gender equity, natural resources, value chains or scientific capacity, are likely to lead to productivity gains and the alleviation of poverty in future years.

5.4 Productivity in the South African beef industry

Development opportunities

Following South Africa's 1994 election, agricultural development put more emphasis on what were then called 'previously disadvantaged communities'. Small-scale farmers and so-called 'emerging farmers' who owned cattle wished to become more market oriented. They were excluded from the commercial feeder market, however, because their cattle were assumed to lack the right attributes for feedlot finishing, their production systems were inferior, and they had little market knowledge. As a result, these farmers' cattle businesses were generating only about 5% of the income obtained by an established commercial farmer with the same sized herd. The development opportunity was to overcome discrimination against smallholder farmers' cattle in the commercial market by making information on market conditions more readily available, by showing that indigenous cattle could perform as well in feedlots as the breeds managed by commercial farmers, and by demonstrating that there is little difference between herd types or breeds in terms of carcass and meat quality. With this data, it was expected that the sought-after commercial markets would open up to cattle from smallholder farmers.

Technologies developed and impacts on farm families

Experimental results showed that the growth rate and feed efficiency of steers from emerging and communal farmer herds paralleled those of steers from commercial herds. Disease incidence was low in all experimental steers, with no difference between commercial, emerging and communal herds. Meat quality analyses indicated small or no differences between herd types or breeds in carcass and meat quality. Extension packages were developed to help farmers use best practices to improve the reproductive performance of their breeding herds as well as to enhance animal nutrition, and pasture and rangeland management for the entire herd grazed on each farm.

Apart from gains in animal productivity, the project achieved outstanding success in overall improvement of beef profitability for smallholder farmers. This component of the project was termed the Beef Profit Partnership (BPP), and it was based on the principles of Continuous Improvement and Innovation (CI&I). This success was due mainly to the project's very strong initial focus on marketing. By 2006, BPP farmers were receiving about 95% of the published commercial market prices for comparable animals, whereas in 2001, their sale prices had been about half those for commercial cattle. BPP farmer teams involved in the project during 2002-2006 generated an estimated R2 million in extra income.

As a result, the national KaonafatsoyaDikgomo (KyD) scheme for smallholder farmers ('beef improvement' in the local Sotho language) was significantly expanded, with BPP and CI&I principles at its centre. Anecdotally, project managers estimated that almost 12,000 farmers had signed up for the KyD scheme by 2015, although the number recorded in the official INTERGIS database was only 8,275.

A follow-up project created a better understanding of the beef market in South Africa. It revealed only subtle differences between the country's rural and urban consumers in terms of their quality preferences and willingness to pay for better quality. The project also showed that cuts from older pasture-finished bulls from the indigenous breeds could still produce an acceptable product for rural and urban consumers.

Human and scientific capacity building

The project significantly increased the capacity of farmers, extension officers, technical staff, scientists and managers across all provinces of South Africa. For this purpose, the projects developed a broad range of training materials, held a number of intensive BPP/CI&I workshops (culminating in a Master Class in CI&I funded by the Crawford Fund), and conducted research management workshops for project personnel and their managers. In addition, the projects generated a very large number of publications, with authors from both South Africa and Australia. A number of post-graduate students were trained in Australia and South Africa.

Two PhD students associated with the first project are especially noteworthy. Nkhanedzeni Baldwin Nengovhela completed his PhD at the University of Queensland, and Tshilidzi Percy Madzivhandila completed his PhD at the University of New England, both as recipients of John Allwright scholarships. Dr. Nengovhela's thesis identified factors affecting the use of technology to raise profits for emerging beef farmers in South Africa. Dr. Nengovhela is now a senior manager in the South African Department of Agriculture, responsible for science policy across livestock industries. Dr. Madzivhandila's thesis used data from the BPP project along with data on emerging farmers in South Africa to undertake economic impact analyses in support of the rollout of BPP processes across the country and to investigate new mechanisms of project and program evaluation. Dr. Madzivhandila is now the CEO of FANRPAN, responsible for the design and implementation of large-scale agricultural projects that inform policy development across all of Africa.

Recent developments

The most recent project has built on the successes of the BPP/KyD approach and on results from the meat science and consumer preference studies to overcome obstacles preventing cattle from indigenous herds being accepted by commercial markets including the feedlot sector. Working with retailer and processor partners, it has developed commercial supply chains for grass-fed beef, based on products from indigenous cattle, to specifically target South African consumers. This phase of the project commenced in 2015 and in 2018 received funding for a four-year extension.

Research has shown that cattle from commercial, emerging and communal farmer herds can meet the free-range market specifications demanded by the processors and retailers. Scientists are investigating animal, pasture and business recording systems to ensure that cattle growth rates are high enough to allow the animals to reach target carcass weights within three years.

The Kyd scheme continues to expand, and the CI&I/BPP methodology has now been adopted across the South African goat, poultry and dairy industries, with associated training activities.

5.5 Direct seeding and drought tolerant varieties in the lowland rice sector of Laos

Development opportunities

Some 3/4m families in the lowland areas of Laos grow rice on a semi-subsistence basis, and many families depending on rice are poor. Average farm size is 2.4 hectares, with a third of farms occupying less than 1 hectare. Rice growing is labour intensive, as farmers, including women and children, must transplant seedlings by hand, standing calf deep in water under high temperatures and humidity. Rice growing is also precarious; part of the country experiences drought or flooding every year, causing crop failure and threatening the food security of farm families.

Technologies developed and impacts on farm families

ACIAR and its partners in Laos and Australia have been funding research on lowland rice production since the 1990s. Projects led by Prof. Shu Fukai, University of Queensland, led to the development of drought tolerant rice varieties and direct seeding of rice.

Prof. Fukai brought skills in agronomy and plant physiology, which complemented the skills of breeders at the Laos Rice Research Centre. He also trained them in quantitative methods to assess varieties that have grain quality comparable to that of local rice but are more drought tolerant because of their early maturity (in about 120 days). Laotian scientists identified 15 varieties as suitable for the country's lowland rice systems.

Direct seeding saves labour, requiring only 1-2 days per hectare, compared to 30 days from seedling nurseries to hand transplanting, although direct seeding does require an extra 8 days per hectare for weed control. The technology that Fukai developed has advanced adoption of direct seeding by 5 years.

As economic growth continues, real off-farm wages will rise, and farm labour will become scarce. By freeing up family labour, direct seeding has the potential to increase off-farm income without threatening families' rice supplies. This also enables family members, particularly women and children, to pursue activities such as education; other improvements in family welfare; and the production of fruit, vegetables and household animal products.

Mullen et al. (2019) estimated that the yield gains and cost savings from these two advances encouraged farmers to adopt them, thus increasing family income and alleviating poverty. ACIAR and its partners invested $14.6m in these projects from 1997 to 2012. Their investment has yielded strong returns, with a net present value of $50.1 m and a benefit cost ratio of 4.4:1.

Human and scientific capacity building

This set of projects has contributed importantly to capacity development:

- Eighteen scientists undertook postgraduate studies, about a third of them with ACIAR funding.

- Project scientists generated 144 publications, including conference papers; citations of 11 of Fukai's publications ranged from 100 to 600. He co-authored most of these with Laotian colleagues, who remarked on the resulting improvement in their scientific writing and presentation skills.

- The project provided on-the-job training through mentoring and short courses offered by Australian scientists.

- Nearly 800 farmers took part in variety and direct seeding trials, and this likely enhanced farmers' capacities in all aspects of rice management.

Recent developments

ACIAR is funding another project on weed control in direct-seeded rice systems in Laos. If successful, the project will make farmers less dependent on hand transplanting of rice.

Since 2017, the Crawford Fund has funded the efforts of Dr. Deirdre Lemerle to mentor two volunteers from the AVP program in Laos. One of their main interests is to test alternative means of weed control in direct-seeded rice crops.

5.6 Developing an oyster industry in Vietnam

Development opportunities

Vietnamese oyster farmers occupy coastal villages of low socioeconomic status, and some live on rafts in the bays. Their other sources of marine income include Tu Hai clams and fishing. They engage in land-based enterprises as well, including livestock (particularly pigs and chickens), together with rice, timber, fruit and vegetables. The major constraint to the development of Vietnam's oyster industry has been the availability of seed. The supply of spat, or larvae, collected in the wild was unreliable, and oyster growth rates were low. Low-cost spat made it easier for farmers to take up oyster growing and increased family income.

Technologies developed and impacts on farm families

Prior to 2007, Vietnam's oyster industry produced only about 100 tonnes annually. Since then, it has grown to be larger than its Australian counterpart, and this can be attributed at least partly to ACIAR, which funded projects involving scientists from NSW DPI and fostered a growing scientific capacity in Vietnam. Oyster production now likely exceeds 15,000 tonnes annually from about 2,500 families in 28 provinces.

The first project established the Cat Ba hatchery to produce a stable supply of oyster spat for growers. Using the same technology, several commercial hatcheries and nurseries now also provide spat to the industry. Two impact assessments of the early projects estimated the BCR to be in the range of 1.6:1 to 6.8:1, indicating that ACIAR had made a good investment.

Extra income for oyster-producing families and communities has enabled them to invest in building more toilets and improving access to clean water – both important for human health and the waterways in which oysters grow. Families have also invested in their children's education and in improving their homes and transport. Increased employment in oyster production, processing and marketing is open to both women and men.

Human and scientific capacity building

As the Cat Ba hatchery was being developed, staff gained skills in algal culture, spawning, larval rearing and settlement, and hatchery management, and they used these to breed for oyster attributes such as greater size, growth rate and disease resistance. Capacity building through a sequence of projects permitted more sophisticated research and technology development, as has happened in other ACIAR research programs as well.

Three Vietnamese scientists were John Allwright Fellows, and two others completed PhDs in Australia. Over the life of the projects, many staff were placed in Australian laboratories, and 25 undergraduate students and 3 MSc students received direct support, usually including supervision and mentoring by Australian scientists, with whom students co-authored 15 scientific papers.

Recent developments

Building on strong relationships in Vietnam, ACIAR is funding another project to examine the role of Portuguese oysters in the carbon cycle. Marine ecosystems provide a crucial service in carbon sequestration, thus helping mitigate global climate change. Oyster carbon farming could potentially contribute to carbon off-set schemes.

Benefits to the Australian bivalve industry

With ACIAR funding and in-kind contributions from Vietnam, NSW DPI's research station at Port Stephens has developed an important set of skills and experience in bivalve production. Moreover, many of the Vietnamese scientists who undertook graduate training in Australia have based their research on issues of relevance to the Australian industry.

In parallel with the genetic work in Vietnam, Australian scientists have developed improved molecular tools to assess the genetic diversity of Sydney rock oysters and to breed for traits such as disease resistance, growth and meat condition. This would probably not have occurred without ACIAR funding.

Research on the reproductive cycle of flat oysters led to the development of seed and hatchery technology, and commercial hatcheries now use this to underpin the production of flat oysters, with a farm gate sales value of more than $1m. Projects in Tasmania, Victoria and South Australia have also used the seed for oyster reef restoration.

Research has developed new knowledge on the biology of pipis and their pests, and has demonstrated improved techniques for larval rearing and settlement. These are key steps towards hatchery propagation and pipis farming, which are important for recovering endangered wild stocks.

5.7 Reducing biosecurity threats to the Australian honey industry

Development opportunities

Since its inception, ACIAR has funded bilateral projects with the common objective of using science to manage biosecurity risks. Some projects have focused on protecting animal and plant production in the partner country and consequently the welfare of farm families who rely on it. Some projects are also directly relevant to the biosecurity of Australian agriculture. By helping partner countries monitor and manage pests and diseases, these projects reduce the risks of incursions in Australia. It makes sense to conduct research on the management of pests and diseases where they occur now, even though they are not yet present in Australia.

The Australian honey bee industry is based on the European honey bee (*Apis mellifera*). Honey bees provide an important pollination service to many crops in Australia, and honey itself is a valuable commodity. The value of honey and related products from commercial and recreational beekeepers was about $270m in 2019. Karasinski (2018) estimated that the value of pollination services was $15.1b annually.

Parasitic mites and the viruses they carry, especially from the Tropilaelaps and Varroa genera, pose a significant threat to honey bees, especially in Australia, the only country in the world still free of these mites. Endemic in some neighbouring countries, these mites have significant impacts on smallholder production. Research on how to detect, control and manage them in partner countries is important both to enhance the welfare of beekeepers in these countries and reduce the risk to Australia of mite incursions.

Provided pests and diseases can be controlled, beekeeping is an attractive option for increasing the incomes of smallholders and especially women, because beekeeping requires little land, can be conducted on less productive land, requires little time and can give rapid returns on investment.

Technologies developed and impacts on farm families

The threat from mites has evolved since the first set of ACIAR-supported projects, and so have the resulting technologies. Early on, CSIRO research found that not all strains of the Asian honey bee carry *V. destructor.* Most carry *V. jacobsoni*, which at that time were thought to be harmless to *A. mellifera*. This knowledge led to changes in regulations covering the world trade in live bees, in cost sharing between the Australian government and the bee industry, and in the Ausvet plan.

Monck and Pearce (2007) estimated that gains in honey production and pollination services to the Philippines and Indonesia from better control of these mites amounted to $8.9m from 2004 to 2035. In Australia, focusing quarantine resources on *V. destructor* rather than all Varroa mites reduced the probability of a threatening incursion, with an annual benefit to Australia of $6m ($94.2m from 2004 to 2035). The BCR for this set of projects was 17.2:1.

Since biosecurity threats evolve over time, so must their management. This is why ACIAR has continued to fund bee projects in Australia's near neighbours. Roberts et al. (2019) found that *V. jacobsoni* can now parasitise *A. mellifera* colonies and that *T. mercedesae* may pose a more serious threat than *V. destructo*r*.* These mites are likely the main cause of a serious decline in honey production in the Pacific area, and given their proximity, they represent serious biosecurity threats to the Australian industry.

Australia's biosecurity has been strengthened in a number of areas. Neighbouring bee industries now have greater capacity to monitor and manage these mites before they reach Australia, and research has increased our knowledge of bee populations, and their pest and disease status throughout the Pacific region.

ACIAR projects have also enhanced the profitability of honey production based on *A. mellifera* in the region, particularly in PNG and Fiji. Control measures have usually relied on chemical methods, which are often too expensive and not wholly effective for small producers. Roberts and Schouten found that caging or removing queen bees to manage hives offers an effective and cheap way to control *Tropilaelaps mercedesae* by ensuring that for a period of 3 days there is no brood (honey bee eggs, larvae and pupae) for the mites to feed on (they are unable to feed on adult bees).

Human and scientific capacity building

In a key advance, scientists discovered that *Varroa destructor* is the mite of great economic significance to European honey bees and Australian agriculture (and globally). Anderson and Trueman (2000) described the epidemiology of these mites and their significance worldwide; at one time, theirs was the third most cited paper from CSIRO Entomology.

The projects have assigned much importance to developing the capacity of beekeepers and scientific staff in Indonesia and the Philippines to manage bees and their mite pests.

Recent developments

Recent research has turned towards breeding bees that are resistant to *V. destructor*. ABC Landline (16.7.2021) reported on a program to import mite resistant queen bees from the Netherlands for introduction into the Australian bee industry.

Another ACIAR project has identified the hardwood and rainforest trees from which bees source pollen, and provided guidance for planning agroforestry systems. This included the production of a valuable reference book, *Beekeeping in the Eastern Highlands of Papua New Guinea* (Cannizzaro et al., 2021). Another ACIAR project supports honey bee agribusiness, marketing and branding through research and capacity building.

5.8 Improved smallholder livelihoods from oil palm in lowland Papua New Guinea

Development opportunities

Palm oil production is one of PNG's top three agricultural export industries. In the country's coastal lowlands, some cropping areas were planted to oil palm at the end of the 20th century. Around this time, ACIAR commenced research on palm technologies, covering varieties, pests and diseases, and agronomic practices. Smallholders manage about 40% of the oil palm area, with lower productivity and yields than expected. Moreover, issues around the labour of smallholder women and youth together with ongoing land disputes have given rise to socio-economic constraints in smallholder production. The challenge for agricultural research was to better understand these constraints, while also addressing the biophysical aspects of production. Socio-economic research focused on providing new incentives to improve oil palm productivity that are socially and culturally appropriate. Researchers also explored new collaborative approaches to local extension services, involving oil palm companies and smallholders.

Technology developed and impact on farmers

Based on a better understanding of socio-economic constraints, researchers introduced new payment systems using mobile cards, new land use agreements and better extension. These innovations boosted the uptake of improved agronomic practices to enhance oil palm production. Smallholders have also seen improvements in the quality and quantity of harvested palm fruit. In addition, the project has widened the geographic scope of the 'mama lus frut scheme', which offers women an incentive to take part in oil palm production.

Fisher et al. (2013, IAS 80) estimated a BCR of 22.4 for research undertaken until 2012. Impacts on PNG's oil palm industry include increased participation by women and youth, with associated financial gains. Women's empowerment and enhanced status have better enabled them to pay for household necessities and children's school fees, while reducing the incidence of household disputes.

Human and science capacity building

Smallholder farmers, the PNG government, NGO and private sector personnel, and post-graduate students in PNG and Australia have all benefited from their association with socio-economic research on oil palm productivity. Partner agencies built new capacity to undertake such research through two John Allwright and three John Dillon Fellowships and six Australian post graduate students funded by ACIAR as well as Master Classes supported by the Crawford Fund. Capacity building also contributed to a strong record of publishing and events, including 36 peer-reviewed journal articles and book chapters, 16 substantial industry reports, 7 brief technical papers for industry, 56 conference papers and 5 Crawford Fund workshops.

Recent developments

These are exciting times for PNG's oil palm industry, as it moves towards consistency with international sustainability standards (Roundtable for Sustainable Palm Oil). Moreover, smallholders are interacting more effectively with oil mills, showing improved trust and productivity. Vegetable intercropping on oil palm plots, with no loss of palm productivity, has improved family nutrition.

Palms reach senility at 25-30 years, depending on the conditions, and many in PNG are reaching this stage. A new scheme for smallholders is reducing the financial stress associated with replanting senile palms, which is normally a costly process.

5.9 Development of the Happy Seeder to incorporate crop stubble in India

Development opportunities

Across India's northern Gangetic Plain, the rice-wheat rotation has become the predominant cropping system and a mainstay of the country's efforts to achieve food security since the 1960s. From that time, CIMMYT made semi-dwarf wheat varieties widely available, and the government introduced subsidies for electricity, fertiliser and tube wells to enhance access to groundwater for irrigation, while also providing price supports for rice and wheat.

A major shortcoming of the rice-wheat rotation is that it involves burning of rice stubble because of the short time available to prepare land for the following wheat crop. An estimated 2.5 m farmers burn about 23 m tonnes of stubble in October and November. The smoke is a major source of air pollution and greenhouse gas emissions. As many as 66,000 annual deaths have been attributed to poor air quality. The burning of agricultural biomass comprises 15% of agriculture's greenhouse gas emissions and 29% of India's total emissions. Fischer has estimated that wheat yields in 2010 could have been 30% higher than in 1970 were it not for increases in tropospheric ozone and aerosol pollution, with yield losses exceeding those caused by climate change. Unless farmers have incentives to change, they are unlikely to abandon stubble burning. India has laws prohibiting the practice, but these have not been enforced.

Another hazard of the rice-wheat rotation is rampant depletion of groundwater, especially in Punjab and Haryana States. Groundwater quality has also been compromised by fertiliser and pesticide use.

Technologies developed and impacts on farm families

ACIAR funded several projects that led to development of the Happy Seeder, which is designed for direct drilling of wheat into heavy rice residues. Providing an alternative to stubble burning, this tractor-powered machine cuts and lifts the rice stubble, sows wheat seed into the bare soil, and leaves the stubble over the sown area as mulch (Milham et al., 2014).

Several economic models suggest that cost savings should offer farmers a sufficient incentive to adopt the Happy Seeder, even under the conservative assumption of no yield gains. Saunders et al. (2012, IAS 77) estimated that adopting the technology would reduce farm costs by almost 10%, and they projected that by 2031 adoption would reach 3.7%, with an estimated benefit cost ratio of 17.2:1 for the ACIAR projects.

Retaining rice stubble significantly improves soil health and structure, while also enhancing retention of water, nutrients and organic matter. The resulting yield gains are estimated in the range of 2-5%, with consequent gains in profitability of about 40%. The Happy Seeder can also save 8.5cm of water per hectare, thus reducing the need for groundwater and power to pump it. However, since it takes several years for these gains to become apparent, they alone may not offer farmers a strong enough incentive to adopt the technology.

In response, ACIAR funded a project (Milham et al., 2014)) to examine policy options for controlling air pollution in Indian agriculture as well as their implications for adoption of the Happy Seeder. The researchers found that subsidies on fertilisers and electricity skewed farmers' decisions about the rice-wheat rotation. A sophisticated whole-farm model suggested that farmers have little incentive to adopt the Happy Seeder. However, with no subsidies and the introduction of a third crop in the rotation, such as mungbean, researchers concluded that farmers would likely adopt the Happy Seeder.

Human and scientific capacity building

Saunders et al. (2012) noted that the ACIAR projects led to significant gains in human and scientific capacity. Project staff published 19 peer-reviewed papers, presented 35 conference papers, and published 13 extension papers. Four research fellows undertook PhD studies (three in Australia), and a field coordinator completed BSc and masters degrees. One scientist, who earned a John Dillon Fellowship, went on to play a leadership role in a large cereals program in South Asia. The project also fostered greater cooperation between scientific disciplines at Punjab Agricultural University. The project leader noted that Australian scientists enhanced their capacity to undertake international collaborative research.

Recent developments

Since the Happy Seeder is an expensive capital item, a more viable option for many farmers is to hire this service on a contract basis. The government of Punjab State has subsidised the purchase of Happy Seeders, in the expectation that this will lower contract rates for farmers. In Punjab State, the subsidy increased to 80% for farmer groups and 50% for purchase by individuals. By 2019, 12,000 Happy Seeders were being used in Punjab on 500,000 ha (about 15% of the area sown to wheat), and farmers using the technology were reporting increased yields.

The policy arena involves many players, including government departments, universities, private lobbying groups and non-profit institutions, such as the World Bank and the CGIAR centres. For two reasons, it is likely that the Milham et al. study influenced policymakers in India. First, the report provides a comprehensive and rigorous review of the issues involved in formulating policy with respect to air quality. And second, the project team comprised skilled economists from Australia and India (the National Council of Applied Economic Research), who worked closely with various public institutions in Punjab that are influential in policymaking.

5.10 Stocking rate management in China's grasslands

Development opportunities

China has 400m hectares of natural grasslands (of which 90% is degraded to varying degrees), with 1b sheep equivalents across the Tibetan, Mongolian and Loess Plateaux and neighbouring areas. The grasslands' 16m herders, who were formerly nomads, are among the poorest people in China. Raising livestock in this part of China is tough. According to traditional practice, herders take livestock out to feed every day, even in winter, when temperatures are well below freezing. It takes skill and experience to find pasture for animals. Over winter stock lose 20-30% of their body weight. Enabling livestock to regain weight over summer has become problematic, as stocking rates have increased and pastures have degraded, Sale animals are rarely in good enough condition to attract good prices. As herders become more integrated into markets, they must develop the necessary skills to achieve better production performance.

Stocking rate has increased from about 0.6 sheep equivalents per hectare ha in 1950 to about 2.4/ha in 2015. Initially, this production increase was welcome, helping to feed a rapidly growing population. However, poverty remained a problem, and environmental degradation resulted, as herders granted their own land began to increase the number of animals. Overgrazing led to degradation of grasslands and increased the occurrence of serious dust storms. Formerly, Beijing experienced a severe dust storm every 4 or 5 years, but recently it has seen as many as 4 or 5 dust storms a year, which at times have extended to Korea and Japan.

Technologies developed and impacts on farm families

Starting in 2001, ACIAR co-funded a series of projects until 2017 aimed at developing sustainable livestock grazing systems for temperate grasslands in China. Led by Prof. Kemp and other staff from Charles Sturt University, the projects involved partner scientists from five Chinese universities and research institutes. ACIAR invested $2.5m in the projects, and Chinese agencies contributed $40m.

A key component of the projects was an ongoing survey of about 1,600 households to gather animal production data at key times of the year. The survey gave scientists a better understanding of the biophysical and financial aspects of the production systems, and provided data for various models used to investigate management options. Another component of the research involved demonstration and control farms, where herders could observe the outcomes from alternative management strategies.

The optimal stocking rate depends on the interaction of animals, plants and economic responses at a whole farm level and the constrained resources of each family farm. The decision is further complicated by the environmental degradation caused by overgrazing. Animal and plant scientists and economists worked together on this stocking rate problem, taking a whole farm systems approach. The outcomes were not intuitively obvious to herders or scientists because of year-to-year seasonal variation. The participation of herders at all stages proved critical for giving scientists new insights and for increasing herders' adoption of new approaches.

The research showed that herders can increase incomes and reduce grassland degradation through a 50% reduction in their stocking rate (from high levels in the 1990s). This puts animal production per head and per hectare at about 75% of its potential and in the vicinity of optimal economic returns. The challenge, though, was not merely to determine the optimal stocking rate but to inform herders' choices about technology packages, which protect farm income while lowering stocking rate and potentially helping regenerate grasslands over the years, with a subsequent increase in household income.

Though ACIAR has not commissioned an impact assessment of this program, experience in Siziwang Banner (one of the program's main centres) gives an idea of its economic, environmental and social outcomes. In this district, where there are some 20,000 households, about 2,000 herders have reduced their stocking rate by about 40%. Presumably they would have been unwilling to do this had their incomes fallen. From survey results on family incomes, Kemp et al. (2020) made a 'back-of-the-envelope' estimate that, if 1m households (6%) adopted the technology, the annual net benefit may be about $1b, which over 15 years gives a BCR of 11:1 for investment in the projects.

Professor Kemp has received the Dunhuang Award from the government of Gansu, the Golden Steed Award from the government of Inner Mongolia government and the Friendship Award from the Chinese government. These awards suggest that the ACIAR projects had a strong influence on the direction of government policy and management with respect to the grasslands.

The environmental gains from the ACIAR project are still emerging and have not yet been measured in a comprehensive manner.

Human and scientific capacity building

Capacity building has formed an important part of the program. At least 38 post-graduate students (10 PhD and 28 MSc) worked on the program while studying at Chinese universities. Four of the Chinese scientists who had leadership roles received John Dillon Fellowships. Informal capacity building through mentoring and training developed skills that included the use of models, and survey and data collection techniques. Through their ongoing participation in the program, particularly on the demonstration farms, many herders gained skills in livestock and pasture management as well as livestock marketing, which will serve them well over many years. The program provided 20,520 person days of training at 120 events, with about half held on farms. With support from the Chinese government, NSW DPI hosted 29 delegations (including herders) from 11 provinces to study sustainable production and livestock marketing in relation to program results.

From 2009 to 2018, the program generated 376 papers – of which 273 were refereed papers published in international (186) and Chinese (87) journals. The balance of papers (103) were presented at international and domestic conferences and workshops, and published as book chapters. The international journal papers were cited 1,060 times or 5.7 times per paper. Co-authoring scientific papers has helped build the capacity of young Chinese scientists in ways that add to the stock of scientific knowledge.

6 ACIAR has delivered strong benefits to its partners and Australia

6.1 Key points

- ACIAR has had a strong program of impact assessment, which rigourously estimates economic impacts and also documents contributions to its strategic objectives in qualitative terms.
- For a subset of impact assessments rated as 'convincing', the BCR in relation to ACIAR's total investment in bilateral program since 1982 is about 5:1, which may be regarded as a lower bound estimate of the returns to ACIAR's bilateral program.
- The BCR for ACIAR's investment in its multilateral program is likely in the order of 10:1, with a lower bound estimate of about 3:1. Through its support for the CGIAR system, Australia has alleviated poverty in developing countries and furthered other strategic objectives.
- Benefits to Australian agriculture from formal links with the CGIAR centres come in the form of a steady flow of germplasm and management technologies for crops important to Australia.
- A safe ballpark estimate of the BCR for a well-managed portfolio of research projects is perhaps 10:1, which is consistent with Mullen and colleagues' econometric estimate for the agriculture sector and with the estimates of Alston et al. (2020) for CGIAR and NARS in CGIAR partner countries.

ACIAR must be able to demonstrate that it earns high returns on the resources for which it is responsible. This builds confidence that projects earning good returns meet the Centre's objective of alleviating poverty. Moreover, as explained in Chapter 4 and demonstrated in the case studies, ACIAR can have confidence that projects earning high returns also deliver on some or all of its other strategic objectives, which are more difficult to measure empirically. Unless farmers find it profitable to adopt a technology it is unlikely that other objectives will be met.

6.2 ACIAR's bilateral program

Since its early years, ACIAR has a strong record of assessing the impact of its bilateral research program. The Centre has commissioned external consultants to assess the economic impact of a project or group of linked projects, using economic welfare analysis, as described in Davis et al. (2008). Impact assessment reports have focused on rigourously estimating economic impacts, though later reports have described other social and environmental outcomes that are difficult to measure (see, for example, Mullen et al., 2019).

ACIAR's impact assessments have set the standard for such work done by economists in state departments of agriculture and by the Council of the Rural Research and Development Corporations. ACIAR selects projects for impact assessment that are expected to have been successful rather than using some random sampling process. The Centre has published 102 reports in its Impact Assessment series since 1998 some of which are methodological in content, not estimating economic returns.

ACIAR has funded two lines of analysis to aggregate over time the economic benefits measured in the IAS reports and to relate these benefits to its investment. The first comprises an ongoing series of reports prepared by the Centre for International Economics (CIE). ACIAR commissions CIE to maintain the economic data and results from impact assessments and to report at regular intervals a summary of assessment results. Earlier reports were published as IAS 39 (Pearce et al. 2006) and IAS 63 (Harding et al., 2009), followed by an as yet unpublished report in 2020 (CIE, 2020).

Second, given that impact assessment reports vary in their plausibility, ACIAR commissioned Raitzer and Linder (IAS 35, 2005) and Lindner, McLeod and Mullen (IAS 86, 2013), hereafter referred to as the Lindner studies, to review the reports and rate them for their plausibility. One end result was the identification of a subset of reports for which the estimates of benefits were rated 'convincing', establishing a lower bound estimate of the returns to ACIAR's bilateral research.

The challenge is to make sense of the bewildering array of estimates of financial returns. One key measure is the BCR. In considering a range of BCR estimates, one must clearly understand what is in the denominator (benefits) and numerator (costs), and this depends on the question being asked. We used the usual methods of financial analysis to express the stream of benefits and costs in 2020 dollars, and convert these into PV terms.

6.2.1 Results from the CIE report

We focus here on the 2020 CIE report, which covers impact assessment analyses up to 2020[11]. Encompassing 169 projects, these analyses provided estimates of economic returns for only 56 of them. The report poses two questions:

1. What is the BCR when the benefits from these 56 projects (or benefit streams) are related to investment in the whole set of projects for which impact assessment was performed?
    - 82:1
2. What is the BCR when the benefits from these 56 projects are related to ACIAR's total expenditures since 1982?
    - 6.8:1

As for the first question, the PV of total benefits attributable to ACIAR from this set of projects amounted to $45.6b, while the PV of ACIAR 's total investment was $0.55b. This gives a BCR of 82:1, which likely overstates the average rate of return to ACIAR's investments, given that impact assessment is generally done on what are considered to be successful projects.

[11] See Blight et al. (2013) for a review of the earlier reports.

With respect to the second question, the benefits (the numerator) remain the same, but the denominator is the PV of ACIAR's total expenditures since 1982. Though the amount of this investment is not entirely certain, we estimate its PV to be in the order of $6.6b (2020$s) giving a BCR of 6.8:1. The stream of benefits covers total investment since 1982 by a factor of almost 7, a strong rate of return.

6.2.2 Results from the Lindner, McLeod and Mullen 2013 Review

IAS reports vary in their plausibility, and the high rates of return reported in some have met with scepticism. Most IAS analyses were conducted 5-10 years after completion of the projects so as to capture some evidence of actual adoption of the technologies under review. Nevertheless, many of the benefits are forward projections and as such are unrealised at the time of the assessment. These often rely on heroic assumptions about key parameters, such as the on-farm impact (rather than trial performance) of the technologies, and the rate and extent of their adoption. There is also great uncertainty about how the industry would have developed in the absence of these technologies and about the contribution of ACIAR projects relative to others working in the area. Some reports lack plausibility because the analysts did not make transparent the evidence for key parameters or the estimation methods they applied. We focus here on the Linder et al (2013) study. A review of the Raitzer and Lindner (2005) study can be found in Blight et al. (2013).

The Lindner et al. (2013) study comprised 27 IAS reports (from a set that included IAS36 to IAS80). These reports covered 103 bilateral projects, with 38 independent quantitative estimates of benefit streams. They rated the benefit streams as 'conceivable' (all 38), plausible' (28) and 'convincing' (15), using criteria similar to those of Raitzer and Lindner[12].

The most interesting questions posed by the Lindner studies are as follows:

1. What is the BCR, when all *conceivable* benefits estimated in the corresponding IAS reports are related to ACIAR's investments in these conceivable benefit streams?
    - 66:1
2. What is the BCR, when all *convincing* benefits estimated in the IAS reports are related to ACIAR investments in the convincing benefit streams?
    - 103:1
3. What is the BCR, when all *conceivable* benefits estimated in the IAS reports are related to ACIAR's total *bilateral* investments since 1982 (not its total investment, as in the CIE studies)?
    - 5.2:1
4. What is the BCR, when all *convincing* benefits estimated in the IAS reports are related to ACIAR's total *bilateral* investments since 1982?
    - 4.0:1

[12] Note that the convincing benefit streams are included among the plausible ones, which in turn are included among those considered conceivable.

The PV of the benefits and costs associated with the 15 benefit streams rated 'convincing' can be found in Table 2. Some of these projects provide the basis for case studies presented in this report. The BCRs ranged from 0 to 324. The BCR for the 15 benefit streams relative to their investment was just over 100:1.

If the total benefits from these 15 streams ($11,506m) are related to the PV of ACIAR's total expenditures on bilateral projects between 1982 and 2012 (with a PV of $2,868m), the benefits exceed the costs four times over, giving a BCR of 4:1. Lindner et al. (2013) combined the benefit streams they considered 'convincing' with the ones that Raitzer rated as 'substantially demonstrated' and then related the PV of this combined set to that of ACIAR's investments in all bilateral projects from 1982 to 2012, giving a BCR of 4.9:1. The authors suggested that this is a lower bound estimate of the returns to ACIAR's investments since 1982. Thus, every dollar that ACIAR invested gave at least $5 in benefits, representing a healthy rate of return.

Lindner et al. noted that the sum of benefits realised (as distinct from those projected) from all of the streams considered 'convincing' almost matched ACIAR's total expenditures since 1982. Five of these benefit streams provide the basis for case studies presented in our report.

IAS report	Benefit stream	Benefits ($m)		Costs ($m)		B/C ratio
		Total	ACIAR	Total	ACIAR	
36	Mudcrab hatchery technology in Vietnam	27	9	8.0	2.6	3.4
43	Irrigation water management in Vietnam	84	627	4.9	3.3	17.4
48	Bee mite pest control in Australia	184	123	9.3	6.3	19.7
47	Improved tree species in Vietnam	231	127	3.0	1.6	79.7
52	Pig breeding in Vietnam	4,793	1,878	51.5	20.2	118.1
52	Pig feeding in Vietnam	1,293	507			
56	Fruit fly biosecurity benefits to Australia	76	34	80.7	36.5	1.6
56	Fruit fly biosecurity benefits in Pacific and Australia	54	24			
57	Endoparasite control in goats in the Philippines	55	5	9.7	0.8	5.6
59	Grain drying in the Philippines	0	0	6.8	4.4	0
62	Integrated pest management in stored grain in the Philippines	2,858	2,065	16.1	11.6	177.4
71	Indonesian forestry – sandalwood in Australia	1,067	425	50.2	20.1	323.9
71	Indonesian forestry – Australian trees in Indonesia	15,216	6,062			
75	Rice yields in Laos	146	120	1.0	0.8	144.6
80	Oil palm in Papua New Guinea	120	73	5.4	3.3	22.4
	Total	**26,202**	**11,506**	**246**	**111.7**	**103.0**

Table 2: Benefits, costs, and benefit:cost ratios for 'convincing' benefit streams

Impact assessment reports offer quantitative estimates only for economic impacts and even then not for all of them. These reports thus understate the benefits from the bilateral projects assessed, resulting from other outcomes such as gains to human and scientific capacity, environmental impacts (noting projects are designed to avoid poor environmental outcomes) and social impacts such as women's empowerment and food security.

6.3 ACIAR's multilateral program

Largely through ACIAR, Australia co-funds a wide range of multilateral and regional initiatives. Most of this expenditure (Table 5) is directed to the CGIAR system – a worldwide group of 15 agricultural research centres dedicated to reducing rural poverty, increasing food security, protecting the environment and advancing important social outcomes, such as developing scientific capacity. CGIAR also shares responsibility for gene banks covering the world's major food crops. For many years, Australian scientists have played key leadership roles in CGIAR.

Through its support, Australia contributes to CGIAR outcomes, which are aligned with the objectives of the country's ODA program. CGIAR has also benefitted Australian agricultural industries through research that helps keep Australian farmers competitive in world markets by increasing yields and/or reducing costs.

Alston et al. (2020) estimated that over the last 50 years, the PV of investment in CGIAR has amounted to $85b. Its total annual funding peaked at about $1.4b in 2014 but has since declined to about $1.1b, reflecting weaker public support in high-income countries for both domestic and international agricultural R&D. Five donors accounted for 45% of CGIAR funding in 2017, and Australia was the seventh largest donor. The share of funding for R&D aimed at boosting farm productivity has also declined, and this seriously undermines efforts to reduce poverty amongst farm families. The Alston et al. study found that, excepting Mexico and India, middle-income countries, though benefitting from CGIAR research, have provided little support for it but have developed stronger national research systems. CGIAR research focuses mainly on low-income countries, with weak national systems.

As noted earlier, Alston et al. (2020) estimated the BCR for investments in CGIAR research at about 10:1. Assuming Australia's contributions are used as efficiently as other donor funds implies that the BCR to its investment was also 10:1.

McClintock and Griffith (2010) assessed the benefits of Australia's support for CGIAR more conservatively. Using Raitzer and Lindner's (2005) approach, they rated 17 impact assessments of CGIAR projects in ACIAR mandate regions (as of 2010) to derive lower bound estimates of returns to the CGIAR (and by implication ACIAR) investment. The benefit flows from 10 projects were rated as 'substantially demonstrated', giving a BCR of about 2.7:1 in relation to total CGIAR expenditures from 1972 to 2008 (which exceed those in the regions of interest to ACIAR). If benefit streams rated as 'plausible' are included, the BCR increases to about 4:1.

6.3.1 Brennan's analyses of the benefits to Australia from CGIAR crops research

John Brennan and colleagues (1999, 2002, 2004) assessed the benefits flowing to Australia, as indicated in Table 3, from its support of the International Center for Agricultural Research in Dry Areas (ICARDA), International Maize and Wheat Improvement Center (CIMMYT) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

ICARDA, which was established in 1977 with headquarters at Aleppo, Syria, has seen its operations severely curtailed over the last decade. Nonetheless, it still covers Central and West Asia and North Africa, which have environments similar to those in many parts of Australia. ICARDA has provided germplasm of barley (with drought tolerance), chickpeas (disease resistance) and durum wheat. CIMMYT, based in Mexico, is well known for its work on semi-dwarf wheat varieties, which offers an important source of germplasm for Australia's wheat breeding programs. ICRISAT, which was founded in 1972 near Hyderabad, India, conducts research on sorghum, millets, chickpeas, pigeon pea and groundnuts. Its work on sorghum and chickpea have proved particularly relevant to Australia.

Brennan and colleagues did not explicitly assess the impact of ACIAR's investment in these international agricultural research centres (IARCs). However, for an annual investment in the centres of around $13m (ACIAR's contribution at that time), Australia might have expected an annual flow of benefits on the order of $113m, giving a BCR of almost 10:1 (Blight et al., 2013). Derived largely from the use in Australia of germplasm from the three centres, this might be a good ballpark estimate of the returns to Australia.

		Producers ($m)	**Consumers ($m)**	**Australia ($m)**
CIMMYT	Wheat	68.1	0.2	68.1
ICARDA	Barley	4.8	1.6	6.3
	Durum	-3.2	0.8	-2.4
	Chickpeas	2.8	0.2	3.0
	Faba Beans	15.8	0.2	16.1
	Lentils	12.9	0.0	12.9
	Total	**33.2**	**2.8**	**36.1**
ICRISAT	Sorghum	-2.1	6.4	4.3
	Chickpeas	-3.1	4.4	1.5
	Total	**-5.1**	**10.8**	**5.7**
Total		**96.2**	**13.9**	**110.2**

Table 3: The annual benefits to Australia from ACIAR's funding of three IARCs
Source: Table extracted from Brennan reports and rebased to millions of 2020 dollars.

Brennan and colleagues improved our understanding of how Australian farmers are affected by new technologies developed by the IARCs through their impact on world prices as well as yields.

For some of these crops, Australian farmers actually lost out, because their yield gains (and cost savings) were countered by the fall in world prices resulting from the higher yields achieved by their competitors. As shown in Table 3, the durum wheat, sorghum and chickpeas varieties developed by ICARDA (Brennan et al., 2002) and ICRISAT (Brennan and Bantilan, 1999), which delivered larger yield gains in developing countries than in Australia, actually left Australian growers worse off. As Brennan and colleagues observed, however, these losses would have been much larger if the new varieties had not available to Australian farmers. Australian consumers (often in the livestock sector) benefited from lower grain prices, and these benefits were generally large enough to offset the losses to producers, delivering substantial net gains to Australia.

In contrast, Brennan and Quade (2004) found that at the time of their analysis the benefits for Australia from CIMMYT's semi-dwarf wheat germplasm were being realised (as opposed to remaining prospective), because the first semi-dwarf varieties based on CIMMYT material had been released in 1973. Brennan and Fox (1995) estimated that by 1994 over 90% of Australia's wheat area was sown to these varieties: 'By the end of 2003, 193 varieties had been released in Australia incorporating CIMMYT genetic material, either as direct CIMMYT introductions (3%), Australian varieties using a CIMMYT line as a parent (20%), or Australian varieties with some CIMMYT ancestry in at least one of the parents (77%)' (Brennan and Quade, p.vii).

Brennan and Quade estimated that by 2001 yield gains attributable to CIMMYT research averaged 4.6% across Australia. However, they noted that CIMMYT germplasm also helped raise world wheat yields by 12.2%, on average, contributing to an estimated 7.4% reduction in world wheat prices. This means that, if Australian growers had not used CIMMYT material, they would have been worse off by $128m (less to the extent that CYMMT germplasm would have entered Australia by less formal paths). The introduction of CIMMYT germplasm, by reducing this loss to $59m, delivered a benefit (in terms of losses averted) of almost $68m[13].

Australian breeding programs contributed importantly by adapting the CIMMYT material to local conditions. This shows that to capture spillover benefits from CGIAR research, Australia must invest not only in the IARCs but also in its own national research institutions. The clear pathways that ACIAR has helped create between these institutions and the IARCs have facilitated the flow of germplasm to Australia, which otherwise might have been irregular and haphazard. Opportunities for Australian scientists to collaborate with IARC scientists have likely strengthened Australian research institutions, and this is particularly important with the small crops, for which it is challenging to create a critical mass of research resources.

Since the work of Brennan and colleagues has not been updated, we do not know whether Australian breeders have managed to narrow the gap between the yields of IARC varieties in Australia and those in other countries where the varieties were first introduced. However, a CIMMYT derived variety, Borlaug 100, gave a record yield of 8.72 t/ha in the 2021 Royal Agricultural Society of Queensland's Crop Competition.

[13] The CIMMYT analysis suggests that by not considering a scenario in which there was no germplasm flow from ICARDA and ICRISAT, Brennan and colleagues likely understated significantly the net benefits from ACIAR's support of these two IARCs.

7 Capacity building, partnerships and networks

7.1 Key points

- Capacity building, whether for individuals or whole institutions, enhances skills and knowledge through formal training and academic studies as well as by informal means, such as on-the-job training, leadership, mentoring, two-way-transfers of ideas and technologies, and other steps that empower colleagues to undertake research.
- Capacity building together with the creation of strong research networks and partnerships are fundamental requirements for effective agricultural research and innovation systems.
- In the last 10 years, over 5,000 Australian and international scientists have participated in training courses supported by the Crawford Fund, and 800 more researchers have received ACIAR fellowships to pursue academic or leadership studies in Australia. This large cohort of trained men and women use their skills to strengthen their national agricultural sector and to develop professional and personal links which are a source of much goodwill towards Australia.

As explained in Chapter 4, the extent of technology adoption and subsequent productivity gains depend, amongst other factors, on the capacities of farmers and the scientists that work with them. Capacity building is one of ACIAR's six strategic objectives and is a key activity of the Crawford Fund. It is widely accepted that capacity building for individuals and institutions together with the creation of strong research networks and partnerships are fundamental requirements for effective agricultural research and innovation systems (e.g., Ryan et al., 2012; ISPC, 2015).

ACIAR (2018) considers that capacity building must take place at both the individual, and institutional levels, including not just training to build skills and knowledge but also on-the-job training, leadership, mentoring, two-way-transfers of ideas and technologies, and empowerment to undertake research. In 2007, Gordon and Chadwick presented a framework for assessing the impact of capacity building, which Templeton in 2009 and then Mullen et al. (2016) further developed. As defined recently in ACIAR's theory of change for capacity building (ACIAR 2021a), the framework includes three interconnected change domains: the **individual level** in Australian and partner country professionals, **institutional level** in the organisations for which they work and **ACIAR**. We focus below on the individual and institutional benefits.

7.2 Aims and approaches

Australia invests in capacity building for international agricultural research, with the aim of better enabling people and institutions in developing countries and Australia to work for improved social welfare. At ACIAR, this aim always forms an explicit or implicit part of its investment in research for development. Australia funds capacity building for international agricultural research through formal and informal means.

The most visible approach aims to enhance the capacities of **individual researchers** in Australia and partner countries. **Individual capacity development** may be defined as improving one's ability to conduct and manage research and development aimed at enhancing the productivity and sustainability of agricultural systems. Such gains result from processes and activities designed to enhance the individual's abilities in academic settings and through experience gained by working in the field (Hiruy et al., 2020).

Formal approaches are academic, taking the form of PhD and masters studies, funded through ACIAR fellowships or completed within ACIAR-funded projects, or consisting of short courses, Master Classes or fellowships funded by ACIAR or the Crawford Fund.

Informal capacity building includes workshops, seminars and study tours (Gray et al., 2015) but most importantly, consists of experiential learning within projects, where researchers work side by side, permitting the less experienced to learn from the more experienced. This approach is central to ACIAR's research partnership model. Experiential learning may also include mentoring, in which an experienced senior scientist provides guidance to a small number of less experienced researchers, resulting in focused and tailored capacity building (Markham and Moorhead, 2020). Mullen et al. (2016) conclude that 'capacity building … through learning by doing and mentoring, contributes directly to the outcomes of a particular project', but they identify no theoretical or empirical way to distinguish the contribution of capacity building from that of project trials and experiments.

Capacity building is also a key element of the 'slow magic' described in Chapter 4, as it adds to the stock of scientific knowledge. Moreover, it offers potential to enhance economic welfare many years into the future, when applied to the development of profitable farm-ready technologies in later research programs. Capacity building thus adds to potentially valuable stocks of knowledge for later R&D efforts. As the case studies show, ACIAR-supported research programs have generated a large number of scientific publications and conference papers, and some of these have been cited frequently in the scientific literature. Most of the papers were co-authored by Australian scientists and colleagues in partner countries, and this has improved the latter's ability to prepare papers and conference presentations. Various of the case studies presented in this report cover a sequence of projects, in which the later ones relied heavily on capacities built in the earlier projects, serving as a testament to the value of capacity building.

International research partnerships and mentoring build bonds that go beyond scientific exchange. A recent ACIAR internal report (de Meyer, 2020) analysed key variables contributing to the resilience of agricultural research partnerships, with the aim of informing ACIAR's business continuity plan in the face of the COVID-19 pandemic. The report shows that the ability of partnerships to deliver outputs and outcomes successfully under these conditions (with restrictions on travel) depends on the team's capacity as well as the social capital developed between team members.

Institutional and organisational capacity development may be defined as processes and activities designed to improve the ability of Australian and partner agencies to conduct and manage research and development, aimed at improving the productivity and sustainability of agricultural systems and resources. Such efforts complement investment in building the capabilities of individual researchers.

The Crawford Fund's capacity building activities complement those of ACIAR by providing both formal and experiential opportunities. Their combined formal suite of capacity building initiatives includes the following:

- Master Classes are the flagship training initiative of the Crawford Fund. Since 1992 approximately 1200 people, predominantly overseas nationals have attended 50 Master Classes held in 14 overseas countries and Australia. (Crawford Fund, 2021)
- John Allwright Fellowship (JAF) Program – This ACIAR flagship program provides PhD and master's level scholarships to Australian universities. Since its establishment in the late 1990s, JAF has trained 495 students, graduating with either a master's degree or PhD. As a matter of policy, at least half of JAF recipients have been women since 2017.
  The John Dillon Fellowship, an annual program first funded in 2002, is designed to strengthen the leadership and management skills of **mid-career professionals**, particularly agricultural scientists, researchers and economists working in agriculture research for development from ACIAR partner countries.
- A new program launched in 2020 is the Meryl Williams Fellowship, which enables women agricultural researchers across the Indo-Pacific to improve their leadership and management skills. The fellowship contributes to more secure food systems by providing women in agricultural science with greater access to resources and decision making, building collaborative networks, supporting career advancement and driving institutional progress towards gender equity.
- Pacific Agriculture Scholarships and Support (PASS) Program – Redesigned in 2020 to build on a previous partnership for scholarships at the University of the South Pacific (USP), PASS supports scholarships for postgraduate study at USP and Fiji National University, and for building research management capacity at both institutions.
- Other offerings – The Crawford Fund provides a mentoring and e-mentoring program. The latter was particularly relevant during the COVID 19 pandemic and involved 35 mentors from Australia mentoring 35 mentees from partner countries in 2020 and 2021. It provides as well as training, links with Australian-based networks, and an annual conference in Parliament House. The Fund also supports the Researchers in Agriculture for International Development (RAID) network, which enables early career Australian scientists to engage in agricultural research for development.

Case study information in Chapter 5 and Appendix 1 illustrate the extent to which scientists from partner countries took advantage of these opportunities as well as their later career paths.
In 2021, there are an estimated 800 past and current participants in JAF, JDF, MWF and PASS, representing 28 countries across Asia, the Pacific and Africa (ACIAR, 2021b). A 10-year tracer study of the JAF program (ACIAR, 2021c) revealed excellent results. Up to 10 years after completing their studies in Australia, more than 60% of alumni still have current, active links with ACIAR staff. Also, a

significant majority (85%) of alumni remain active agricultural researchers. The survey covered 378 alumni over the period 2010-2019, including 108 women and 270 men.

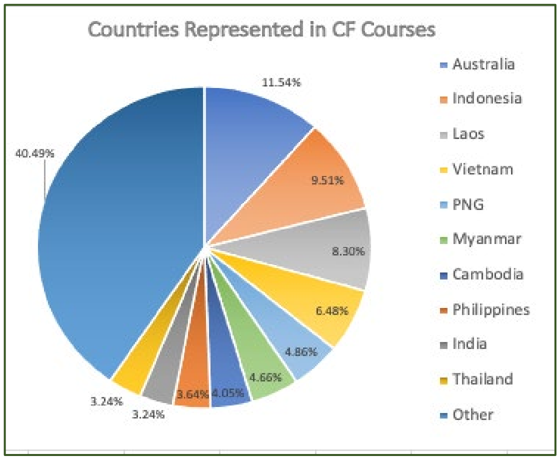

Figure 3: Top 10 countries in Crawford Fund courses and Master Classes since 2012

ACIAR alumni typically work in government, research institutions and the private sector across a diverse range of disciplines and sectors.

Since 2012, the Crawford Fund has supported 395 short training courses, individual training and over 50 Master Classes attended by over 5,000 participants representing 71 countries (Figure 3 shows the 10 countries most represented in these courses). The training covered a wide variety of topics, including animal and crop science, data-IT management, economics, fisheries, forestry, land and water resources, post-harvest technology, research management and communications. The length of the courses and number of participants varied. Some were attended by over 100 male and female participants, as was a 5-day course on crop health held during 2015 in Laos by Prof. Burgess. Others involved individual training over 3-4 months for scientists working in an Australian academic institution. During the same period, 318 young Australians were awarded scholarships to attend the Crawford Fund Annual Conference and the Fund's special Scholar Program. This large cohort of scientists in neighbouring countries represents a pool of much goodwill towards Australia and helps create an environment that is potentially receptive to Australia's other interests.

BOX 1: Comprehensive capacity building in fisheries research

Over 15 years, the ACIAR Fisheries Program has provided training and other capacity development activities to partner country researchers, technicians, officials and community members. Overall, more than 120 project staff have participated in visits and educational tours and over 2,500 in workshops. About 30 have attended Master Classes; 28 have received master's degrees; and at least 6 have completed PhDs. These activities have helped individuals improve their skills in experimental design and data analysis and increase their research output. The Fisheries Program has also contributed to improvement in the human resources, systems, processes, policies and infrastructure of partner institutions, and this, in turn, has improved the efficiency and effectiveness of their work. In addition, the program has used capacity building activities to empower local fishing and farming communities (including finfish and other aquaculture farmers, hatchery growers, and women and youth, religious and other community groups) in partner countries (Hiruy et al., 2016).

7.3 Benefits at the individual level

Formal capacity building for Australian and partner country scientists completing their PhDs or MScs as part of an ACIAR project or under a JAF scholarship offers benefits that range from career progression and rewards to greater professional credibility (Harvey and Skerritt, 2004; Webb, 2021).

Many researchers from Australia, Cambodia, Indonesia, Laos, New Guinea, the Philippines, the Pacific region and Vietnam have received training with ACIAR support and then continued their research in senior positions with government departments, ministries and agricultural research institutions. In addition, Australian researchers have mentored local counterparts in ACIAR projects, notably benefitting their careers. ACIAR-trained researchers have flourished after post-graduate training, obtaining further funding for their work from agencies such as FAO or partnering with Australian research counterparts. Still others have gone on to build careers and occupy significant positions in the private sector (Webb 2021).

Informal capacity building involves experiential learning to acquire skills in areas such as trial management, experimental design, data analysis, scientific writing, making presentations in English and scientific networking as well as the technical skills required in the project. It is difficult to assess the benefits of such skills for individuals, and the pathway from such capacities to changes in farm practice is indirect. Nevertheless, these generic skills were valued as highly as more technical skills by scientists in Vietnam and likely increase their access to the international scientific community, making new knowledge more accessible to them more quickly (Mullen et al., 2017).

Additionally, agricultural scientists who work or study abroad gain a better understanding of other cultures and of their host country as well as a greater appreciation of human differences. This experience also enhances their knowledge of international issues and increases their curiosity about other cultures, while also helping them better understand their own (Butcher et al., 2017). These scientists tend to thrive in an open society like Australia.

Many of ACIAR's projects also help enhance the capacity of smallholder farm families to better manage their farms in a risky and ever-changing environment. Some of the case studies presented in this report mention how farmers (both men and women) participated in the design, planning and maintenance of trials and in the interpretation of results. Other opportunities for capacity building came from short courses associated with the projects or supported by the Crawford Fund covering not only the technologies developed during the project but also more general issues, like business management and leadership.

7.4 Benefits at the institutional level

The benefits of capacity building for research institutes in Australia and partner countries are related to their organisational capacity and performance. Research institutions in Vietnam, for example, recognised that their partnership with ACIAR contributed to their institutions' ability to plan and manage research portfolios with respect to priority setting and project design (Morris et al. 2017). Other benefits take the form of sustained partnerships, resulting from various interconnected steps, such as encouraging scientists to work in multidisciplinary groups, using a farming system approach. This is best illustrated with the concrete examples given below and in the case studies presented in this report.

BOX 1: Building the foundation for a successful career in wheat improvement

Following is a condensed and edited excerpt from a recent interview with Dr. Alison Bentley, who recently took up a senior position at CIMMYT, a CGIAR centre (Crawford Fund 2020). Her experience illustrates especially well the benefits of capacity building and networks for individual scientists.

'I had my first experience with CIMMYT in 2003 as a participant in the first Crawford Master Class on Soil-Borne Pathogens of Wheat in Turkey. Including field visits, lab practicals and lectures from leading scientists, the course was an incredible experience for me as a beginning PhD student at the University of Sydney. Financial support from the Crawford Fund NSW Committee permitted me to stay on in Turkey and conduct a survey of soil-borne wheat diseases as part of my PhD research. This helped me gain a clearer vision of the context of my research and appreciate the value of working with partners. From these early months to the completion of my PhD, including collaboration with the South Australia Research and Development Institute and Western Australia Department of Agriculture, I spent time talking to agronomists, visiting farms and conducting field surveys. This experience proved valuable for my PhD work and provided the foundational starting point for my subsequent work on wheat improvement'

The case study on the South African beef industry describes overall improvements in the profitability and productivity of smallholder farmers' beef production. It also notes the benefits of capacity building at the institutional level both for farm communities in South Africa as well as the meat industry in both Australia and South Africa. Communities applied the skills they acquired to set up community managed markets and gained confidence to negotiate better prices for their cattle. In addition, a group of South African scientists earned their PhDs and MSc degrees in Australia. They also attended research management courses, which contributed to the adoption of the Beef Profit Partnership (BPP) and Continuous Improvement and Innovation (CI&I) principles by the South African goat, poultry and dairy industry, leading to increased efficiency and effectiveness in the sector. This research contributed as well to building capacity in Australia, where South African experience informed the application and development of the CI&I model.

The case study on rice systems in Lao PDR presents evidence of benefits from institutional capacity building. As a director of the Laotian Rice Research Institute pointed out, Professor Fukai brought skills in agronomy and plant physiology that complemented the skills of breeders in Laos. Laotian and Australian scientists say that the capacity building was as important as trials and experiments to achieving economic impacts.

Australian veterinary scientists have a long history of contributing significantly to regional research on animal health, and to agricultural research partnerships aimed at prevention, management and control of foot and mouth disease (FMD). In the 1980s and 1990s, Australia funded the Eastern Islands Veterinary Services Project (EIVSP), which improved animal health services and disease surveillance capacity in east Indonesia, where its islands are very close to Australia's remote northern coastal region. Under the EIVSP, a group of young Australian veterinarian scientists were posted in Indonesia to work alongside local counterparts. Together, they improved animal health services and disease surveillance capacity. The EIVSP helped create a critical mass of scientists in Indonesia capable of running and maintaining a robust disease surveillance system. Within a decade, these scientists had used their improved capacity and experience to eradicate FMD in that region of Indonesia, thus also protecting Australia.

Success in the Indonesia FMD campaign inspired a significant FMD control and eradication campaign in the Philippines, following the incursion of a porcinophilic strain of the virus in 1994. The campaign proved successful, generating evidence of the economic benefits of vaccination and leading eventually to disease eradication, with no cases recorded since 2005 (Windsor, 2011). Resulting in better trained farmers, traders and veterinary scientists, the campaign also contributed to major improvements in animal health surveillance and response capacity for other important livestock diseases in the Philippines. Several leading veterinary scientists from the Philippines subsequently rose to senior positions in regional animal health agencies of Southeast Asia. Australian veterinarians contributed importantly to the success of the FMD eradication campaigns, leaving Indonesia and the Philippines free of this disease, the former without vaccination in 1990 and the latter with vaccination in 2011.

EIVSP yielded other, less expected benefits, as Dr. Bruce Christie, then Deputy Director General of Biosecurity and Food Safety with the NSW Department of Primary Industries, explained in a 2017 interview with the Australia Indonesia Youth Association. As one of the young Australian health advisors who worked in EIVSP during 1989, Dr. Christie recognises that the skills and the experience he gained then helped him both in his career and personal life (AIYA, 2017). While working in Indonesia, he started teaching young Indonesians to play cricket, and they went on to become founding members of Indonesian Cricket, and all are strong advocates of friendship between Australia and Indonesia.

8 How ACIAR ensures efficient use of resources

The extent to which ACIAR achieves its strategic objectives depends in part on how well it manages its portfolio of research projects. In this chapter, we describe how ACIAR and the Crawford Fund manage the resources at their disposal; critical steps are project design, management and reporting. ACIAR has also invested in gaining a better understanding of smallholder innovation and technology adoption.

8.1 ACIAR and Crawford Fund expenditures on international agricultural research

Since 1982, ACIAR has funded more than 1,500 research projects in 36 countries, with scientists from more than 50 Australian research institutions contributing through bilateral projects in developing country neighbours and through multilateral groups, such as CGIAR. In 2019-20, these expenditures amounted to $104m (about 2.5% of the ODA budget).

ACIAR's investment grew strongly from $83.6m in 2010 to a peak of $125.6m in 2013 and has drifted downward since then (Table 4). Expenditures in 2020 were only $104.2m, reflecting widespread Commonwealth budget cuts. COVID-19 has led to large increases in government debt, raising concerns about ACIAR's budget in the coming years.

ACIAR reports its expenditures for five program categories, and real spending in each of these is given in Table 5. The research category includes spending on bilateral projects and co-investment in alliances and partnerships. The multilateral category includes unrestricted funding mainly to CGIAR centres. Education and training include ACIAR fellowships and other formal means of capacity building, separate from that in bilateral projects. The remaining categories involve expenditures on communicating ACIAR's achievements and assessing the impact of its programs. As shown in Table 5, the budget shares of these five categories have changed little since 2010.

The research category accounts for a little over 70% of total spending, the multilateral program about 20%, and the education and training program about 8%.

Close to half of ACIAR's expenditure on the research program in 2019-2020 went to the east and south east Asia region (Figure 4) followed by the Pacific region,, south Asia and Africa.

Crawford Fund expenditures have also been quite stable over the same period, at about $1.6m per year in real terms until a sharp fall in 2019-2020.

	CPI	ACIAR Expenditure		Crawford Expenditure	
		Nominal	2020$s	Nominal	2020$s
	2020=100	$m	$m	$m	$m
2010	83.7	70.0	83.6	1.042	1.245
2011	86.7	97.0	111.9	1.492	1.721
2012	87.8	103.2	117.6	1.461	1.664
2013	89.9	112.9	125.6	1.449	1.613
2014	92.6	107.2	115.8	1.550	1.674
2015	94.0	110.0	117.1	1.509	1.606
2016	94.9	100.1	105.4	1.519	1.600
2017	96.8	111.3	115.0	1.432	1.479
2018	98.8	112.5	113.9	1.688	1.709
2019	100.3	113.2	112.8	1.739	1.733
2020	100.0	104.2	104.2	1.244	1.244

Table 4: ACIAR and Crawford Fund expenditures, 2010-2020

	Real ACIAR Expenditure (2020$s)				
	Research	Multilateral	Education	C'unicaton	Impact assessment
	$m	$m	$m	$m	$m
2010	61.7	12.7	8.4	0.7	0.7
2011	68.4	33.4	9.2	0.8	0.8
2012	84.8	26.2	5.8	0.8	0.7
2013	90.9	25.7	8.2	0.9	0.8
2014	83.5	23.7	7.9	0.8	0.4
2015	86.6	21.1	8.8	0.7	0.5
2016	75.4	20.9	8.5	0.7	0.5
2017	83.5	22.6	7.8	1.1	0.5
2018	80.0	24.2	8.4	1.3	n.a.
2019	76.9	22.8	10.3	2.9	n.a.
2020	72.1	23.8	6.2	2.1	n.a.

Table 5: ACIAR expenditures on programs

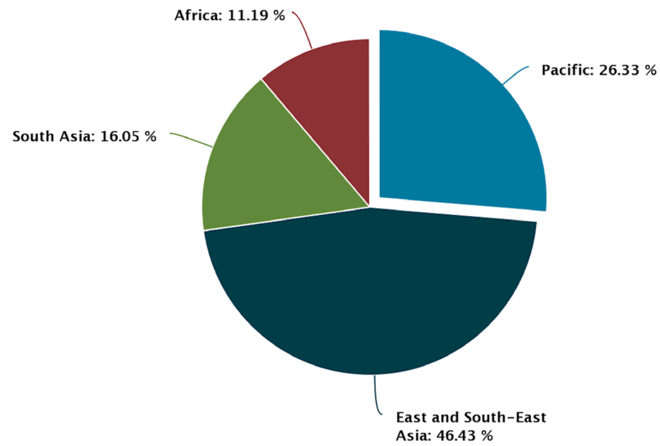

Figure 4: ACIAR Research Program Expenditure by region 2019-20
Source: ACIAR Annual Review 2019-20

8.2 Promoting efficient use of R,D&E resources

8.2.1 Key points

- A key element unifying research management processes from project design to final reports and impact assessments is an impact pathway (theory of change) describing a plausible causal link between research activities, inputs, outputs and final economic, environmental and social outcomes;
- Another aid to project design is to specify objectives in a **SMARTT** way;
- ACIAR publishes adoption studies (now referred to as evaluations of outcomes) 3-4 years after project completion to report on the legacy of projects particularly the level of adoption of the technology;
- ACIAR commissions external impact assessments of a small proportion of its bilateral projects. These assessments use economic welfare analysis to derive the usual measures of financial performance. They also describe economic, social and environmental outcomes that are difficult to measure;

Research is complex and time consuming, and different researchers have different ideas about how to do things and what the priorities should be. Such complications grow, as research projects become broader and deeper, and as more researchers, disciplines and partner institutions become involved. To achieve their objectives, research projects must therefore be properly managed.

Broadly speaking the term 'research management' refers to all administrative and operational functions that lead to positive outcomes and impacts, that is, benefits (Green and Langley, 2009;

Hughes and Kitson, 2012; Jain et al., 2010). These functions include project conceptualisation and design, personnel recruitment, partner institution selection, implementation of key governance arrangements, provision of access to facilities, sourcing and purchasing of inputs and supplies, and routine administrative tasks, such as financial and human resource reporting. Given the importance of achieving outcomes and impacts, research management also involves the development of research strategies together with operational plans and targets. Also important are cross-discipline activities, such as measuring and monitoring adoption, and evaluating outcomes, communicating key messages, and in some cases IP management, commercialisation and the like.

ACIAR has devoted considerable resources to research management, particularly in the project development, and monitoring and evaluation phases. The key element unifying these phases is the Inputs to Impact Pathway which describes a plausible causal link between research activities, inputs, outputs (such as technologies developed and papers published), and the economic, social and environmental outcomes that result when farmers and other end users find the technology profitable to adopt. Figure 5 shows a generic example used by the Australian Research Council, CSIRO and other Commonwealth institutions. The Cooperative Research Centre program and most agricultural RD&E funding bodies use a similar framework. Davis et al. explain the genesis of impact pathways (2008, IAS 58).

Best practice in research management always aims to embed something like the Inputs to Impact Pathway in all aspects of project conceptualisation and design, right through to project monitoring, evaluation and reporting. As described in Chapter 7, a combination of experiential learning and formal training achieves best results for institutionalization of best practices. The Crawford Fund Master Class in Research Management and Leadership has trained 125 researchers and research managers from partner countries since 1992, complementing ACIAR effort to improve research management.

8.2.2 Project planning and design

ACIAR develops project proposals through an intensive process that takes many months; proposals often undergo external review in Australia and the partner country. Sometimes scientists are funded to undertake a year-long scoping study, which leads to a well-defined project proposal.

Project proposals typically have a clearly defined impact pathway linking inputs in a plausible manner to outputs and potential economic, social and environmental outcomes. Another tool that aids project design involves specifying objectives in a way that is **SMARTT** (**S**pecific, **M**easurable, **A**chievable, **R**elevant, **T**argeted and **T**imeframed), and links directly to the Inputs to Impact Pathway.

Well-designed projects are more likely to have high impact and also provide insights that help ACIAR managers to match ACIAR's portfolio against its strategic objectives.

Research Impact Pathway				
Inputs	**Activities**	**Outputs**	**Outcomes**	**Benefits**
• Research income • Staff • Background IP • Infrastructure • Collections	• Research Work and Training • Workshop/Conference Organising • Facility Use • Membership of Learned Societies and Academies • Community and Stakeholder Engagement	• Publications including E-Publications • Additions to National Collections • New IP: Patents and Inventions • Policy Briefings • Media	• Commercial Products, Licences and Revenue • New Companies – Spin offs, Start Ups or Joint Ventures • Job Creation • Implementation of Programs and Policy • Citations • Integration into Policy	• Economic, Health, Social, Cultural, Environmental, National Security, Quality of Life, Public Policy or Services • Higher Quality Workforce • Job Creation • Risk Reduction in Decision Making

Figure 5: Input to impact pathway

8.2.3 Project reporting and evaluation

ACIAR's project reporting and evaluation processes have several components, and projects that have well-designed impact pathways and SMARTT objectives facilitate these processes. Project leaders submit annual and final reports, which provide information on research activities, project outputs and on-farm level impacts leading to outcomes. Projects may also be subject to mid-term and end-term external reviews, which often focus on assessing whether the project has met its milestones and on noting project outputs.

ACIAR publishes the final reports of all completed projects on its website. It also publishes various technical reports and monographs, which cover feasibility and methodological studies, and in the case of monographs, thoroughly review lessons learnt about an important farming system after an extensive research program (as in Monograph 210). A recent technical report (TR092), for example, presents six short papers on agricultural water management, outlining the findings from ACIAR-supported research over the past decade.

ACIAR adoption studies and impact assessments seek to provide accountability for the way the Centre uses resources and to find ways of better designing future projects. Adoption studies are typically undertaken 3-4 years after a large project is completed to assess the level of uptake and the project's legacy. AS001, the first of 14 AS reports so far, was published in 2004, covering projects completed in 1999-2000; the most recent, AS014, was published in 2018, dealing with projects completed in 2012-2013.

About 10% of ACIAR's bilateral program have been subject to a rigorous impact assessment. Such analyses estimate the economic impact of the research program, using economic welfare analysis, as prescribed in Davis et al. (2008, IAS58). They are generally conducted by external consultants, who are expected to estimate the usual measures of financial performance – NPV, IRR and BCR.

Early IAS reports focused almost entirely on economic impacts, but since IAS 58 they have also described, at least in qualitative terms, other outcomes related to ACIAR's strategic objectives, such as capacity building, natural resource protection, strengthening value chains and women's empowerment. Tight budgets for impact assessments have limited the scope for data collection and hence the sophistication of both the economic analysis and qualitative assessment of social and environmental outcomes. Difficulties are compounded when in the earlier stages of project design, impact pathways and project objectives have been poorly defined.

So far, 102 impact assessment reports have been published. The first, IAS001, released in January 1998, covers 12 years of investment in projects aimed at finding ways to protect chickens from Newcastle disease in village communities across several developing countries. A more recent report, IAS098, details the impact of four ACIAR-funded projects that focused on citrus rootstock, scion and production improvement in China, Vietnam, Bhutan and Australia.

Not all the reports cover projects that have achieved economic impacts through new farm technology, value chain improvements or a change in rural policy. Some of them review sets of IAS reports on bilateral projects (e.g., IAS086 in 2013) or broader CGIAR programs (e.g., IAS068 in

2010), with the aim of measuring economic impact for the wider portfolio (as described earlier). More recently, IAS reports have covered such issues as COVID-19 impacts on food system security and resilience in mandate regions (IAS095 and IAS096). Some reports deal with methodologies, for example, approaches to carry out impact assessment (IAS58), measure changes in poverty (IAS78), and monitor and assess capacity building (IAS 43 and 93).

Throughout this report, we have emphasized the importance of determining the economic impact of ACIAR's research on farm families. New technologies that farmers find financially attractive to adopt are often an efficient means to pursue ACIAR's other strategic objectives.

8.2.4 Evolution of ACIAR's research management processes

Research management at ACIAR continues to evolve. The Centre is currently developing what it calls a Performance and Results Framework (PRF), as shown in Figure 6 (ACIAR, 2021). The PRF offers a consistent way to link all of ACIAR's design, management and reporting, and assessment processes (from project inception to final outcomes) with each other and to ACIAR's strategic objectives. For this purpose, each project will have a theory of change, which has evolved from the impact pathway concept. The idea is that, as a project progresses, it will collect management information of value for the next stage, which should facilitate the evaluation of outcomes (an evolution of an adoption study) and impact assessment, using quantitative and qualitative methods.

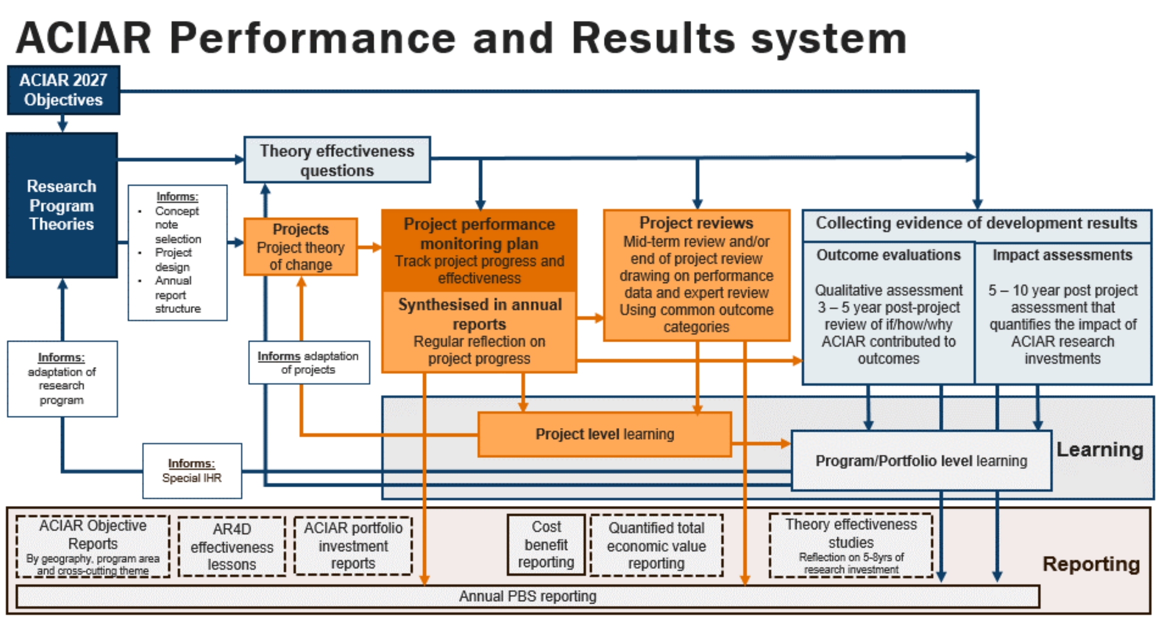

Figure 6: ACIAR performance and results framework

8.2.5 Research management fellowships

As described above ACIAR funds two fellowship schemes that focus on developing research management capacity.

8.3 From research to innovation – Understanding adoption

8.3.1 Key points

- Smallholder farmers must innovate to survive in rapidly changing rural areas of developing countries. Innovation helps farmers enhance resilience, manage risk better, and contributes to more informed decisions about their agricultural production and livelihoods.
- Agricultural research (to generate knowledge about new technologies) is one part of innovation; adoption is the other.
- Low levels of adoption can limit improvement in smallholder farmers' welfare and slow progress toward ACIAR's other strategic objectives.
- This is why ACIAR also funds projects aimed at better understanding smallholders' incentives (economic, cultural, social and technological) for adopting new technologies.
- Based on such knowledge, researchers can improve project design to better target (i) the technology to the farmers' situations, (ii) the extension program and (iii) capacity building activities resulting in faster more widespread adoption.

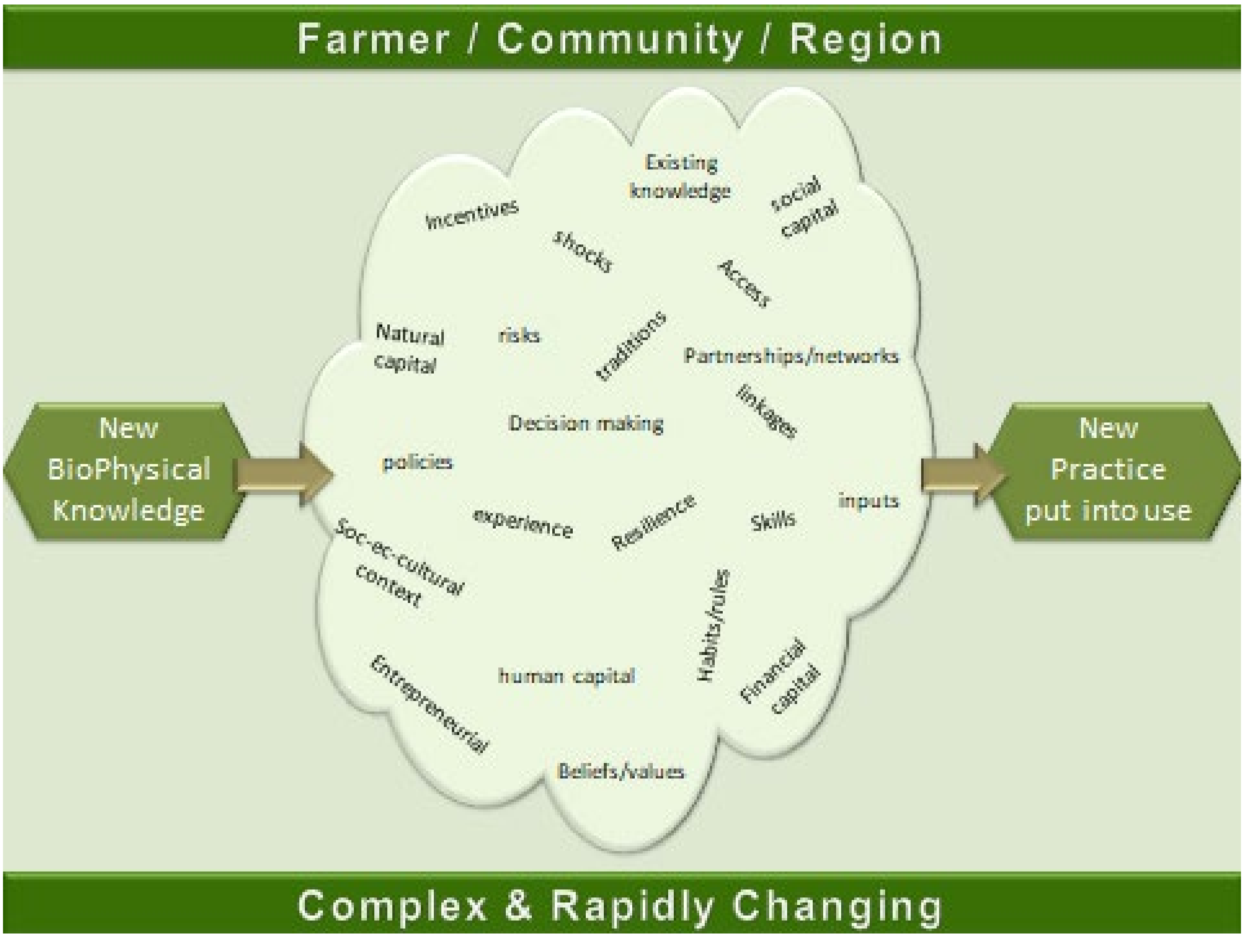

Figure 7: Issues affecting smallholder farmers' adoption of R&D outputs.

Innovation is about *creating knowledge (R&D)* and *putting it to use (adoption)*. To innovate is to change established practice, especially by adopting new methods, ideas or products. R&D to generate knowledge is one part of innovation; the other is technology adoption. In developing countries, adoption has often proved to be slower than anticipated (Alexander et al., 2020).

Most ACIAR projects focus on developing technologies to achieve economic outcomes on farm as well as other environmental and social outcomes. Technology adoption is a key factor determining the returns to investment in these projects.

This is why ACIAR also funds projects aimed at better understanding smallholders' motivations for adopting new technologies. This knowledge can be used to improve project design (and perhaps the use of resources within projects), and also to boost rates of adoption or at least determine why some technologies may never be adopted.

In developing countries, agricultural innovation is particularly complex. Smallholder farmers make decisions about their farming and livelihoods, based on a variety of economic, cultural, social and technological factors. Their decisions also depend on the scale of their farm operation and their knowledge of issues affecting agricultural production. Smallholders may operate anywhere along a continuum from subsistence farming to engagement in the formal cash economy.

A better understanding of the factors affecting agricultural innovation can help rural development practitioners respond more effectively to socio-economic issues that either foster or limit the adoption of new agricultural technologies; technologies that have been developed to improve agricultural productivity and livelihoods, and hence reduce poverty in rural areas.

Innovation requires knowledge from multiple sources, including users (Hall, 2007). As participants in innovation share and combine ideas, the different sources of knowledge interact in ways that are unique to a given context, which is shaped by historical routines and traditions reflecting culture, politics, policies and power. This is why socio-economic analysis of the circumstances of families or communities is so crucial. Such research offers insights into livelihood assets (capital stocks), farmers' decision-making, and their perception of risk, which can help design and implement more realistic projects that deliver people-centred research outcomes. This increases the probability that research will have a positive impact, improving the food security and livelihoods of rural people (Adato and Meinzen-Dick, 2002). Livelihood assets for development take the forms listed below with examples:

- *Social* - Strong family traditions
- *Natural* - Available land and water
- *human* - Labour availability and education
- *physical* - Infrastructure
- *financial* - Cash and capital

If particular, livelihood assets are inadequate, this can limit farmers' access to or uptake of new technologies.

A systems approach offers the most effective way to understand issues affecting rural households and to deliver technologies that smallholders are more likely to adopt and that enhance their resilience to shocks such as droughts or commodity price crashes. Norman et al. (1995) explain the rationale behind agricultural systems research for development.

Agricultural research is often organised along disciplinary lines or on a commodity basis, however, and this hinders an effective systems approach. Yet, such an approach is vital for addressing issues that affect agricultural productivity, such as gender, water scarcity, natural resource use and climate change.

Typical research outputs/outcomes from a systems approach include the following:

- New analytical tools
- Changes in agricultural management practices
- Future scenarios for smallholder households, communities and regions
- Better approaches to agricultural extension
- Improving farm productivity through a multi-disciplinary systems approach, generally across mixed enterprises
- A better understanding of social and economic barriers to the uptake of new technologies
- New ways for agricultural production to enhance rural livelihoods
- Better fit between farm production and market demand
- A better understanding of how farming interacts with other aspects of rural development (e.g., human health, education, human nutrition, and early childhood and maternal wellbeing)

Several of the case studies presented in this report demonstrate the value of a systems approach.

The relationships between smallholder agriculture and off-farm livelihood strategies as well as farmers' perception of risk in decision-making may also determine whether they adopt a new agricultural technology. In addition, rural institutions (because of local governance, policy and regulatory issues) may not succeed in creating an enabling environment for new technology, thus slowing adoption. Hence the importance of institutional research conducted at different scales, involving farmers, communities, or regional, provincial and national institutions. See Pearce (2010) for an overview of issues affecting the adoption of agricultural technologies.

The time it takes for farmers to adopt a new technology and the extent of adoption depends to varying degrees on all the factors described above. The ADOPT (Adoption and Diffusion Outcome Prediction Tool) model offers a means (Keuhne et al., 2011) to assess these factors in specific contexts. The tool has been tested in developing countries (Llewellyn and Brown, 2020), and though the outputs were variable, the tool provided a good basis for group discussions with researchers and development or extension managers and practitioners, which made knowledge about technology adoption clearer and more transparent.

Other factors influencing technology adoption in developing countries include farmers' various constraints, capabilities, attitudes and priorities; the influence of cultural norms; the relative priority of subsistence over profit; and reliance on agriculture as a primary source of income. Moreover, landless farmers may be less able to capture the benefits of an innovation, and diffusion of information across the farming population may be slow, depending on extension quantity and quality.

Against this background, researchers should explore options below to facilitate technology adoption:

- Boost smallholder farmers' incentives to adopt new technologies.
- Design interventions that overcome institutional constraints to adoption.
- Design approaches to scale out the adoption of new technologies.
- Address gender issues, such as roles in decision-making, when designing adoption strategies.

- Take into account the circumstances of marginalised groups.
- Analyse the implications of demographic factors (such as age, education, household size, labour migration) that may foster or discourage technology adoption.
- Assess the socio-economics aspects of innovation from a smallholder farmer perspective (considering issues such as income, household assets, expenditures, credit, land size and ownership, access to transport, farm size, farm practices and number of organisations).
- Explore geographic issues, such as distance to markets and land quality, and design new technologies that are fit for purpose.

Box 3: Landcare and the 'extension' services that evolved from it in the southern Philippines

Australian and Philippine colleagues carried out collaborative research with smallholder farming communities over 20 years to assess means of improving smallholders' agricultural productivity in the southern Philippines. The researchers explored ways to enhance farmer adoption of simple conservation practices, sustain and expand landcare systems, determine the economic impacts of conservation farming in marginal environments, and improve extension services in remote and often conflicted areas. The program improved development outcomes for smallholder farmers through closer collaboration between Philippines Landcare and other ACIAR projects.

The research program demonstrated workable approaches to multidisciplinary socio-economic and biophysical research in marginal smallholder communities. It also empowered smallholders and local communities through quick and reproducible extension approaches, to such an extent that PCCAARD is now co-funding the expansion of these approaches into a wider area of the Philippines. In addition, the program built the capacity of farmers, researchers, local and regional governments, and national R&D providers in both Australia and the Philippines.

Take-home messages: The program enabled farmers in South Cotabato to transition from environmentally destructive and illegal charcoal making in native forests to more sustainable and economically rewarding production of vegetables and nursery trees. It also helped farmers in steep upland areas of Mindanao to transition from maize monocropping without soil erosion control measures to a diversified agroforestry cropping system, using contour natural vegetative strips that minimise erosion. By forming and nurturing farmer groups in Maguindanao, the program improved farmers' access to coconut seeds, fertilisers and other inputs from the Philippine Coconut Authority, and this enabled them for the first time to grow coconuts as a viable alternative cash crop.

Box 4: Using family farm teams to improve the livelihoods of impoverished female farmers in Papua New Guinea

Research carried out by the University of Canberra with colleagues in PNG aims to improve agricultural extension and training for marginalised women farmers. These women have low education levels and are often stuck in poverty. Researchers initially considered how to improve rural women's business acumen in Highlands and Lowlands. This led to a broader family farm team (FFT) approach for extension delivery in Highlands, Lowlands, East New Britain and New Ireland. Current research addresses the role of youth in farming, with emphasis on how and where family farm teams can play a stronger role in extension delivery and farm innovation. Research also seeks to adapt the FFT approach to a wider area of the Pacific (including Fiji, Tonga and Samoa) as part of the DFAT-funded Pacific Horticultural and Agricultural Market Access (PHARMA) initiative. Key outcomes include improved farm production, women's empowerment and improved research capacity in both countries. Research demonstrated the need for men and women to work together in improving agricultural productivity, with associated gains in social cohesion and gender equity in rural communities of PNG.

Take-home messages: Research improved gender equity and women's livelihoods, while also enhancing the use of indigenous knowledge. Farm families developed short- and long- term goals, emphasizing higher and more diverse agricultural production and regular income. Families see the benefit of working together as a team to achieve their shared goals. They also see how their gardens can become a family farm business. Women and men have experienced the benefits of shared decision-making, and mutually agreed roles and responsibilities, leading to more united and peaceful families and communities.

9 Summary

In his book *Doing Well by Doing Good,* Derek Tribe made the case for investing in agricultural research in our developing country neighbours. Tribe argued that Australia not only 'did good' by alleviating poverty and protecting natural resources in these countries – the goals of Australia's overseas development program – but also 'did well', as many benefits flowed back to Australian agriculture and the wider community. Public investment in agricultural R&D has been declining in developed countries, despite high rates of return, and so Tribe's arguments, still valid, need to be presented to policy makers in a contemporary context. The Crawford Fund commissioned such a study in 2013 (Blight et al. 2013) and this report is a further update on Australia's contributions to international agricultural research and its foreign policy goals.

Australia is committed to the UN 2030 Agenda for Sustainable Development, which includes goals 'to reduce poverty and hunger, improve health and education, advance gender equality and strengthen economic growth (p.88)'. Australia currently invests about $4b in Official Development Assistance (ODA), mainly in the Indo-Pacific region. Australia's ODA program also creates opportunities to influence partner countries through 'soft diplomacy' in various policy areas of interest to the country.

Agricultural R&D has proved to be a potent tool for pursuing these goals. Many analyses conducted in Australia and other countries have demonstrated high returns to research. In their 2020 World Bank report, *Harvesting Prosperity*, Fuglie et al. (p.3) cited research showing that in poor countries an increase in agricultural productivity has twice as much impact on poverty reduction as comparable productivity increases in other sector. This is a strong argument for Australia to continue funding international agricultural research.

ACIAR is the prime vehicle for Australia's overseas development program in agriculture. Its budget has been relatively stable over the last decade at about $115m per year, until 2019-2020, when it was cut to $104m. A high level of public debt in the wake of the COVID-19 pandemic raises doubts about when Australia will be able to restore its ODA budget. Public investment in agricultural R&D has been declining in developed countries, despite high rates of return.

ACIAR has six strategic objectives, which contribute to 12 of the 17 Sustainable Development Goals:

- Food security and poverty reduction
- Natural resources and climate change
- Human health and nutrition
- Gender equity and women's empowerment
- Inclusive value chains
- Capacity building

These objectives can also be thought of as capital stocks which influence the gains in productivity from R,D&E. There is a complex feedback mechanism. New technologies profitable for farmers to adopt are efficient means of delivering on these other strategic objectives.

We present seven case studies to illustrate how investments by ACIAR and the Crawford Fund contribute to ACIAR's strategic objectives. The case studies show how Australian scientists and their developing country partners devise solutions to complex problems, thus helping often poor farm families to improve their lot. When new technologies raise incomes, this generally also contributes to some or all of ACIAR's other strategic objectives.

The case studies are as follows:

- Productivity in the South African beef industry
- Direct seeding and drought tolerant varieties in the lowland rice sector of Laos
- Developing an oyster industry in Vietnam
- Reducing biosecurity threats to the Australian honey industry
- Improved smallholder livelihoods from oil palm in lowland Papua New Guinea
- Development of the Happy Seeder to incorporate crop stubble in India
- Stocking rate management in China's grasslands

We chose these because most had undergone an ACIAR impact assessment, which found strong causal pathways linking research to final outcomes and resulting in credible high rates of return to ACIAR's investment. Poor smallholders likely captured most of the benefits.

All projects contributed significantly to human, scientific and institutional capacities, particularly in partner countries but also in Australia. For this purpose, the projects relied both on informal channels but also formal means, such as fellowships funded by ACIAR for graduate study and short courses supported by the Crawford Fund. The case studies highlight other forms of capacity building as well.

The case studies show how the programs, having harvested 'low -hanging fruit', later evolved as human and scientific capacity developed, enabling them to adopt more sophisticated approaches to increase productivity and respond to emerging threats and opportunities. Without the early gains in capacity, later advances would not have been possible or at best would have been delayed by several years.

Another notable feature of the projects was the way in which Australian scientists formed multidisciplinary teams to address problems through a whole-farm systems approach rather than the more common disciplinary approach. Farmer participation in the design and management of on-farm trials increased the rate and extent of technology adoption. This also strengthened institutional capacity to manage research resources as well as farmers' capacity to adapt their farming system to a changing environment.

Capacity building has also resulted from expanding networks of scientists in Australia and neighbouring countries. These networks serve scientists as important sources of knowledge and professional development, and increase the efficiency of R,D&E programs. They have also helped build up a store of goodwill towards Australia amongst scientists in the countries where ACIAR has fostered formal and informal capacity building. Many of these scientists have risen to positions of influence in their research institutions and wider communities.

The projects dealing with the Happy Seeder in India and grasslands in western China had important implications for natural resource management. Poor air quality from burning stubble is a major issue in India, and in response, governments are subsidising the purchase of Happy Seeders. But this incentive is offset by subsidies on water, electricity and fertiliser. Overstocking grasslands in China, as nomadic herders take up farming, has led to grassland degradation and major air quality issues. Governments at different levels in China have helped finance this research and the associated extension campaigns demonstrating technology packages that allow stocking rates to be reduced while maintaining farm income.

Various research projects have had important social impacts, in addition to poverty alleviation. The oil palm and honey projects in PNG, the work on oyster production in Vietnam and the direct seeding technology in Laos have all enriched women's role on family farms, often giving them access to new sources of family income. The technology for direct seeding of rice in Laos, for example, freed women and children from laborious and time- consuming hand transplanting, giving them more time for other enterprise, like small livestock and vegetables, and for managing the household.

Several projects contributed to improved biosecurity for Australian agriculture. By helping partner countries monitor and manage pests and diseases, they reduced the risks of incursions in Australia. Even for pests and diseases not yet present in Australia, it makes sense to conduct research on their management where they occur now. One example is a program focused on mite pests of honey bees in neighbouring countries. The projects alleviated poverty, and helped Australia and its neighbours manage and control biosecurity threats.

Some projects in partner countries had direct implications for Australia. Through genetic work on Portuguese oysters in Vietnam, for example, the project team developed improved molecular tools to assess the genetic diversity in Sydney rock oysters, leading to more efficient breeding for growth rates, size and disease resistance. Australian scientists say that these advances would probably not have occurred without ACIAR funding. The project team also made a major contribution to the development of a commercial flat oyster industry. Spat or larvae supplied to the NSW oyster industry has underpinned the production of more than $1m in flat oyster sales. The seed has also been used for oyster reef restoration projects in Tasmania, Victoria and South Australia.

ACIAR must be able to demonstrate that it earns high returns on the resources for which it is responsible. This creates confidence that projects earning good returns alleviate poverty. Moreover, as explained in Chapter 4 and demonstrated in case studies, ACIAR can have confidence that projects earning high returns also deliver on some or all of the Centre's other strategic objectives, which are more difficult to measure empirically.

Since its early years, ACIAR has built a strong record of assessing the impact of its bilateral research projects. The Centre's Impact Assessment Series reports the economic impacts of a subset (about 10%) of these projects. Regular reports from the CIE have summarised these analyses, and Raitzer and Lindner (2005) along with Lindner, Mcleod and Mullen (2013) have critically reviewed them.

Lindner et al. (2013) determined a BCR of 103:1 when relating the benefit streams from research projects whose impact assessments they judged to be 'convincing' to the investment only in these projects. By a more conservative estimate, they obtained a BCR of about 5:1, when benefits from impact assessments rated as 'convincing' are related to ACIAR's total investment in bilateral program since 1982, the. This may be regarded as a lower bound estimate of the returns to ACIAR's bilateral program.

The BCR from ACIAR's investment in its multilateral program, mainly through the CGIAR system, is likely in the order of 10:1 with a lower bound estimate of about 3:1. Benefits to Australian agriculture from the CGIAR centres come from a steady flow of germplasm and management technologies for crops important to Australia.

A BCR of 10:1 is perhaps a safe ballpark estimate for a well-managed portfolio of research projects. This is consistent with Mullen and colleagues' econometric estimate for the agriculture sector and Alston et al.'s (2020) estimates for CGIAR and NARS in CGIAR partner countries.

Human, institutional and scientific capacity building has formed an important part of all ACIAR research projects. Its benefits may well be as large as the economic outcomes but are not quantified, at least not in dollar terms. Our report examines in detail the efforts of ACIAR and the Crawford Fund to build capacity and their outcomes. Informal means of capacity building include mentoring and training offered by scientists engaged in international collaboration as well as experiential learning in projects. ACIAR also funds fellowships for developing countries scientists identified in research projects to undertake formal post-graduate studies. In addition, the Crawford Fund supports various training and mentoring programs, which are often linked to ACIAR projects.

Since 2012, the Crawford Fund has supported 395 short training courses or Master Classes attended by over 5,000 participants representing 71 countries. In the same period, 318 young Australians earned scholarships to attend the Crawford Fund Annual Conference and the Fund's special Scholar Program. The Fund has also developed mentoring and e-mentoring programs linking Australian scientists and young scientists in developing countries. Its Master Class in Research Management and Leadership has provided training in research management for 125 scientists from partner countries since 1992.

By 2021, there were an estimated 800 past and current ACIAR fellows representing 28 countries across Asia, the Pacific and Africa. In this report, we present individual and institutional case studies, which demonstrate how these alumni can use the skills they have obtained to advance their scientific careers and benefit farming communities in their country. The studies also show how alumni can help increase the efficiency and effectiveness of their institutions and create scientific networks that benefit both their country and Australia.

ACIAR plans and manages research resources with care, particularly in the project development, and monitoring and evaluation phases. In all stages, the Centre relies on impact pathway statements (akin to theory of change statements), which describe a plausible causal link between research activities, inputs, outputs (such as technologies and published papers), and the economic, social and environmental outcomes arising from farmer and other end user adoption of new technology. Another tool that aids project design involves encouraging the specification of objectives in a **SMARTT** way.

In addition to annual and final reports, project reviews and technical publications, ACIAR relies on adoption studies and impact assessments to evaluate its work. Adoption studies have typically been undertaken 3-4 years after a large project is completed to assess the level of uptake and the project's legacy. So far, the Centre has published 14 AS reports.

Some of ACIAR's bilateral programs (previously about 10%) undergo rigorous assessment of the research's economic impact, using economic welfare analysis. Impact assessments have been conducted by external consultants, who derived the usual estimates of financial performance – NPV, IRR and BCR. Throughout this report, we have emphasized the importance of establishing the economic impact of ACIAR's research efforts on farm families. New technologies that farmers find financially attractive to adopt have proved to be an efficient vehicle for pursuing ACIAR's other strategic objectives.

Earlier IAS reports focused almost entirely on economic impacts, but starting with IAS 58, the reports have also described, at least in qualitative terms, other outcomes related to ACIAR's strategic objectives, such as capacity building, natural resource protection, strengthening of value chains and women's empowerment. So far, ACIAR has published 102 impact assessment reports, some of which are more methodological than empirical in nature.

ACIAR's research management continues to evolve. Currently, the Centre is developing what it calls a Performance and Results Framework (PRF), which should provide a consistent way to link its project design, management, and reporting and assessment (from project inception to final outcomes) processes both to each other and to ACIAR's strategic objectives. Each project will be guided by a theory of change. As a project progresses, it will collect management information of value to the next stage, which can facilitate outcome evaluation (an evolution of an adoption study) and impact assessment, using quantitative and qualitative methods.

Smallholder farmers must innovate to survive in rapidly changing rural areas of developing countries. Through innovation, they can enhance resilience, manage risks better and make more informed decisions about their agricultural production and livelihoods. Agricultural research to generate knowledge is one part of the innovation continuum; the other consists of technology adoption. Limited adoption of new technologies can slow improvement in the welfare of smallholder farmers. This is why ACIAR also funds projects aimed at better understanding what motivates smallholders to adopt new technologies. The results can help improve project design through adaptive management and also boost technology adoption. Smallholder farmers make decisions about their livelihoods, based on various economic, cultural, social, and technological factors. Examining these factors through a multidisciplinary systems approach is crucial in revealing what accounts for the success or failure of new agricultural technologies.

10 Appendix 1: Detailed Case Studies

10.1 Productivity in the South African Beef industry

This case study summarises the outcomes and impacts of a series of three projects (LPS/1999/036; LPS/2008/013; LPS/2005/128), all based at the University of New England, which aimed to link smallholder beef farmers in South Africa to commercial value chains. The first project built on scientific relationships between livestock researchers with CSIRO in Australia and the Agricultural Research Council (ARC) in South Africa, and was closely associated with research undertaken in Australia during the various phases of the Beef Cooperative Research Centre (Beef CRC). The second project investigated meat quality and consumer preferences, in parallel with similar work in the Beef CRC. The third project, though originally conceived in 2005 to follow up on earlier work, had difficulty aligning objectives, personnel and approvals, and thus did not commence until 2015, well after the Beef CRC concluded. It was, however, based on many of the results and lessons learnt from the Beef CRC. This project was extended for a further 4-year term and is due for completion in mid-2022.

Professor Heather Burrow has been associated with the management of all of these projects and is the project leader for the current project.

10.1.1 Background

After South Africa's landmark election in 1994, more emphasis in agricultural development was directed to what were then called the 'previously disadvantaged communities'. Some of these were referred to as 'small-scale farmers', who managed their cattle (mainly indigenous breeds, such as the Nguni) on communal grazing land. Others were referred to as 'emerging farmers', who owned or leased land and generally managed indigenous crossbred or exotic breeds. The majority of small-scale and emerging farmers were located in the former homeland territories of the Limpopo, Mpumalanga, North-West, KwaZulu-Natal, Free State and Eastern Cape Provinces. Both previously disadvantaged groups included many cattle farmers who were desperately attempting to become more market oriented.

With the advent of a large feedlot sector in South Africa during the mid -1970s, the commercial cattle market required animals that were earlier maturing, efficient converters of high-quality feed and possessed superior carcase attributes – not considered to be characteristic of the cattle managed by smallholders. Local butchers or meat required for local festivities, the only markets available to these farmers, were both unpredictable and unreliable. As well, the beef cattle production systems used by small-scale and emerging farmers gave inferior animal performance, as illustrated in a study by Tapson (1990). Finally, since feedlot buyers knew very little about the characteristics of the cattle raised by these farmers, they were reluctant to purchase these animals or offered prices much lower than market prices. Tapson found that in 1990 emerging farmers were receiving only R3.50/kg, when the market price for cattle from the commercial sector was R8.00/kg. Thus, emerging farmers were generating from their cattle only about 5% of the income obtained by an established commercial farmer with the same sized herd.

The first project focused on overcoming discrimination against the cattle of smallholder farmers in the feedlot market. Scientific results showed that indigenous cattle could perform as well in feedlots as the breeds managed by commercial farmers, and results from the second project indicated small or no differences between herd types or breeds in carcase and meat quality attributes. Nonetheless, the sought-after feedlot markets still did not open up to cattle from smallholder farmers. Fortuitously, consumer preferences for beef in South Africa were changing, and a major supermarket chain began promoting ‘free-range’ and related product categories. The most recent project thus shifted its focus to developing new value chains that deliver high-quality grass-fed beef to South African consumers.

10.1.2 Economic benefits to smallholder cattle farmers in South Africa

No formal Impact Assessment Series report has been published on any of these projects. However, impacts have been measured during both projects and reported in various internal and external reports. For example, an adoption study on the first project was completed in 2016 (Griffith 2016), and both the first and second projects were reported on favourably in the publication *ACIAR’s Activities in Africa: A Review* (Fisher and Hohnen 2012).

The first project achieved outstanding success in generating overall improvements in beef profitability and productivity for participating smallholder farmers. This component of the project, termed the Beef Profit Partnership (BPP), was based on the principles of Continuous Improvement and Innovation (CI&I). This success was due mainly to a strong initial focus on marketing. By 2006, BPP project farmers received about 95% of the published commercial market prices for comparable animals, whereas in 2001, their sale prices had been about half those of commercial cattle prices. The rapid increase in sale prices resulted primarily from the use of on-farm auctions, which enabled farmers to join together and pre-weigh their cattle, and negotiate close-to-market rates for larger numbers of animals. Although auction sales increased the farmers’ sale costs significantly, sale incomes also improved markedly, more than offsetting the increased costs, and in turn improved their profit. Towards the end of the project, the BPP farmers changed their focus to herd throughput, reflected by the improved reproduction rate, numbers of sale animals and pre-weaning mortalities in the herds, which in 2005 and 2006 were close to the performance of ‘established farmers’. These figures indicate that BPP farmers were well on their way to becoming commercial farmers. As shown in Table 6, farmer teams involved in the project between 2002-2006 generated an estimated R2m in extra income.

Data on actual profitability for KaonafatsoyaDikgomo (KyD) members are not available for later years. Nonetheless, based on assumptions like those used to calculate the data in Table 6, it is possible to make a ballpark estimate of the net benefits accruing to the small-scale and emerging cattle sectors from the ACIAR project and its subsequent rollout across the country (Griffith 2016). Assuming a conservative estimate of average improvement in gross margins and carcase weights, then the increase in profit for each animal is R400. In 2014, 3,492 KyD members had all of their details properly recorded (Table 7) – these farmers manage 81,000 cattle and sell about 60% each year or close to 50,000. These farmers, who are arguably the most willing and able to make improvements in their herds, therefore saw an aggregate annual increase in profit of R20m, based on 2014 values. If the same average values are applied to the other KyD members listed on INTERGIS, a total of 8,275 members, then the aggregate increase in profit would be R47m. If the same average values are applied to all 12,000 estimated KyD members, whether listed on INTERGIS or not, the aggregate increase in profit would be R68m. These very large but conservative numbers indicate that the BPP/CI&I/KyD methods are achieving impacts of a magnitude that has not been documented in other projects with small-scale beef farmers.

The third project provided 'proof of concept' that cattle from smallholder herds can meet the specifications of the high-value free-range beef market, based on a relatively small number of cattle slaughtered through Cradock Abattoir in May 2016. Cattle were sourced from commercial, emerging and communal farmer herds and carcasses evaluated for their compliance with market specifications as well as aspects of beef quality. Cattle from all three production systems were shown to be capable of meeting free-range market specifications (Burrow et al., 2019).

However, once the project involved a larger number of farmers across the six provinces, it quickly became clear that most of their cattle did not immediately meet the target free-range specifications. Animal, pasture and business recording systems were not in place, and significant adjustments to stocking rates and/or supplementary feeding practices were required to ensure that cattle growth rates were high enough for the animals to reach target carcase weights by 3 years (Burrow et al., 2019). The impacts of these changes on profitability have been delayed until the project's second phase is completed.

10.1.3 Other benefits to South Africa

The first project delivered technical outputs from evaluations of the growth and carcase quality evaluations of a number of tropically adapted indigenous southern African breeds and cattle from collaborating small-scale and emerging farmer herds, to determine their value in contributing to the rapidly increasing demand for high quality beef in South Africa. Representative steers were sourced from emerging and communal farmer herds after weaning at two years and transferred to the ARC's Irene campus for comparison with steers sourced from commercial herds. All animals were finished under commercial conditions, with animals fed a grain-based diet. Data were collected between weaning and slaughter, including measurements of growth rate, feed intake, flight time as a potential indirect indicator of meat tenderness, real-time ultrasound scans for carcase attributes and commercial carcase characteristics, and incidence of disease at slaughter. Full carcase and meat quality attributes were also measured.

Results showed that the growth rate and feed efficiency of steers from emerging and communal farmer herds paralleled those from commercial herds. The incidence of disease was low in all experimental steers, with no difference between commercial, emerging and communal herds. Meat quality analyses indicated small or no differences between herd types or breeds in carcass and meat quality attributes. The key result was that cattle from emerging and commercial farmer herds can meet the specifications of South Africa's commercial beef markets.

Another major output was validation of the CI&I approach for empowering small-scale and emerging farmers to improve the profitability of their beef businesses during the project and beyond, as demonstrated through the design and execution of the BPP.

Item	2001	2002	2003	2004	2005	2006	Total/ Av.
Number of network teams	15	15	14	13	24	28	
Number of selected farmer teams (who calculate and report gross margins)		2	8	7	5	6	
Price – actual commercial market annual average (R/kg)	6.96	8.71	7.96	7.73	9.31	13.23	8.98
Price – expected emerging farmer price (based on 2000 market situation) (R/kg)	3.48	4.36	3.98	3.87	4.66	6.62	4.49
Price – actual farmer team annual average (R/kg)	4.56	8.5	7.13	7.23	8.8	11.18	7.90
Improvement in price due to BPP (R/kg)	1.08	4.15	3.15	3.37	4.15	4.57	3.41
Growth – average weight of calves sold (kg)	150	188	210	205	194	200	200
Improvement in weight over 2000 market situation (estimate 150kg) (kg)		38	60	55	44	50	50
Throughput – number sold per year	20	23	187	219	389	322	1160
Improvement in numbers sold over 2000 market situation (estimate 1.3 per team)		3	167	199	354	280	1002
Total amount of beef sold (kg)	3,000	4,324	39,270	44,895	75,466	64,400	231,355
Improvement in total beef sold over 2000 market situation (estimate 3000) (kg)		1,324	36,270	41,895	70,216	59,150	208,855

* Enterprises include communal herds, for which the number of individual beneficiaries is sometimes >300 but are counted here as a single enterprise. Source: Madzivhandila et al. (2007).

Table 6: Aggregate outcomes of the South African BPP project, 2001-2006

In response to the increasing interest of small-scale and emerging farmers in improving their herds, a project known as KaonafatsoyaDikgomo (KyD), or 'beef improvement' in the local Sotho language, had commenced in 1997. It targeted small-scale and emerging farmers who were interested in recording and improvement but could not meet the criteria for entry into the formal National Beef Cattle Performance Testing Scheme used by commercial producers. The first Beef Performance Test Day for Emergent Farmers was held in North-West Province in November 1999.

Following the successful final BPP Forum held in May 2006, the National Department of Agriculture requested the BPP team to submit a proposal for expanding the network to other provinces. Funding was approved later that year, resulting in the recruitment of seven technical officers within ARC to service seven provinces as part of the BPP sustainability plan. The BPP philosophy was adopted as a key principle for future beef industry empowerment projects.

The ACIAR LPS program manager, Bill Winter, wrote a glowing tribute to the project and its proponents – published in the newsletter of the National Beef Recording and Improvement Scheme as well as ACIAR's *Partners* magazine (Winter 2007) – in which he said the following (p.12):

> The most inspirational and compelling sessions were those presented by representatives of the focus groups. I heard that one of the earliest community-run cattle sales, where 100 head were up for sale, was deemed a great success, even though no animals were sold. The farmers had flatly refused to take the price offered and sent the traders packing. What a feeling of empowerment this must have been for these farmers. They held their ground and, over the ensuing weeks, all those cattle were sold at a reasonable price. The farmers had sent a strong message to the buyers that they were not going to be taken advantage of. That same community-managed market continues and has grown to be an all-encompassing market for local wares.

The early successes of the project, as shown in Table 6, together with strong legislative and financial support from the national Department of Agriculture has prompted massive growth in the number of small-scale and emerging farmers involved in the scheme (Table 7).

As a result of new funding and legislative backing for the CI&I process through declaration of the KyD scheme during the project extension, the number of farmers involved immediately increased from 553 to 917 (Table 7). Their numbers further increased from 2010 onwards, as funding increased, the last two provinces came on board and the focus shifted to growing the scheme. Anecdotally, project managers say that almost 12,000 farmers had signed up for the KyD scheme by 2015, though only 8,275 are recorded in the official INTERGIS database (apparently, details on many new participants are not recorded, as required by database protocols). All are beef farmers, excluding farmers in other agricultural industries where the BPP processes are used.

Province	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EC	-	-	-	-	90	90	90	144	81	325	365	365
FS	-	-	-	-	80	80	80	114	118	459	576	576
GP	-	-	-	-	44	44	44	65	122	289	388	388
KZN	-	-	-	-	60	60	60		62	592	1859	3900
LP	342	342	342	342	342	342	342	386	307	744	727	727
MP	-	-	-	-	90	90	90	159	233	642	890	890
NC	-	-	-	-	-	-	-	47	180	379	457	457
NW	211	211	211	211	211	211	211	65	158	348	569	569
WC	-	-	-	-	-	-	-	-	18	297	403	403
Total	**553**	**553**	**553**	**553**	**917**	**917**	**917**	**980**	**1288**	**4075**	**6234**	**8275***

**Preliminary as at April 2015.*

EC - Eastern Cape, FS - Free State, GP - Gauteng Province, KZN -KwaZulu Natal, LP - Limpopo Province, MP - Mpumalanga Province, NC - Northern Cape, NW - North West, WC - Western Cape.

Table 7: Growth trend in BPP/KyD members since 2002

The second project resulted in improved knowledge about the beef market in South Africa. First, researchers found only subtle differences between rural and urban consumers in South Africa, and also between South African and Australian consumers in terms of quality preferences and willingness to pay for quality improvements. Second, cuts from older pasture-finished bulls from the indigenous breeds still produced an acceptable product for rural and urban consumers. Third, the capacity exists to create a new supply chain for indigenous breeds.

In spite of the results achieved, obstacles still prevented cattle from indigenous herds being accepted by the feedlot sector. So working with retailer and processor partners, knowledge gained from this project led to the subsequent supply chain project, focusing on a niche market for grass-fed beef based on products from indigenous cattle to specifically target South African consumers. This research continues, with increased farmer engagement, continued development of two value chains, repeated profitability and behaviour change surveys, and a focus on improving the reproductive performance of farmers' breeding herds as well as improved animal nutrition and pasture and rangeland management for the entire herd grazed on each farm.

10.1.4 Capacity building

The project significantly increased capacity amongst farmers, extension officers, technical staff, scientists and managers, focusing initially on the two provinces (Limpopo and North-West) where most of the research was undertaken. In the final two 2 years of the first project, capacity building was extended over another five provinces (Gauteng, Mpumalanga, KwaZulu Natal, Free State and Eastern Cape). The project developed various training materials, making these available in electronic and printed formats. Upon concluding in 2007, the first project held three weeks of intensive workshops at ARC's Irene campus, culminating in a Master Class in CI&I supported by the Crawford Fund.

Two PhD students associated with the first project, Nkhanedzeni Baldwin Nengovhela and Tshilidzi Percy Madzivhandila, received John Allwright scholarships to study at the University of Queensland and University of New England, respectively.

Dr. Nengovhela's thesis, titled 'Improving the wellbeing of people dependent on the low income beef industry of South Africa', identified factors that impact the use of technology to improve profitability amongst emerging beef farmers in South Africa. Dr. Nengovhela is now a senior manager in the South African Department of Agriculture, responsible for science policy across the livestock industries.

Dr. Madzivhandila's thesis was titled 'Designing an effective evaluation model for the South African government and public organizations in the socio-economic development arena'. He used BPP project and additional data on emerging farmers in South Africa to analyse economic impact in support of the rollout of the BPP processes across South Africa and to investigate new project and program evaluation mechanisms. Dr. Madzivhandila had earlier completed a master's thesis (titled 'Continuous Improvement and Innovation as an alternative development methodological approach to improve sustainable livelihoods of the previously disadvantaged beef farmers: the Beef Profit Partnerships project') at the University of the Free State. Dr. Madzivhandila is now CEO of FANRPAN, responsible for the design and implementation of large-scale agricultural sector projects that inform policy processes across Africa.

The third project has also provided capacity building, conducting various workshops on research management for project personnel and their managers, and funding three PhD and one MSc student. Additionally, the Farmer Training Manual developed by the project, once accredited by AgriSeta, will significantly enhance the capacity of students in South Africa's vocational training system.

The CI&I/BPP methodology has been adopted across the South African goat, poultry and dairy industries, with associated training activities.

Finally, as detailed in the projects' final reports, they have generated a large number of publications, with authors from South Africa and Australia.

10.1.5 Benefits to Australia

During the 1980s and 1990s, Australian beef producers increasingly relied on crossbreeding as a management option. In the tropical north, however, the poor adaptation of European breeds commonly used in crossbreeding, limited the options. Results from research by CSIRO and the

Beef CRC showed that Sanga breeds from southern Africa have carcase and meat quality attributes similar to those of British breeds. However, these breeds are much better adapted to tropical environments than European breeds and hence enable beef producers in northern Australia to improve beef quality, while retaining adaptation to environmental stressors. A potential limitation to this option is the possible negative correlation between productive traits, such as growth and fertility, in the absence of environmental stress, and stress resistance in tropical environments. A knowledge of these relationships should make it possible to design breeding programs that are targeted specifically at cattle breeders in tropical environments both in Australia and South Africa.

The projects on beef in South Africa, particularly the first, have extensively benefited the Australian beef industry. Technical results were integrated into the education and delivery packages used by extension specialists, and new genetic parameters were incorporated into BREEDPLAN. Australian commercial beef producers have imported cattle from several indigenous South African breeds (Bonsmara, Drakensberger, Nguni and Tuli) to improve the reproduction and meat quality of Brahman and Brahman-derived herds in Northern Australia. The composite Belmont Red, based on an Afrikander cross, is a rapidly growing breed in norther Australia.

10.2 Lowland rice system in Lao PDR

Some 3/4m families, many of them poor, grow rice on a semi-subsistence basis in lowland areas of Laos. The average farm size (World Bank 2012) was 2.4 ha and a third of farms were less than 1 ha.

Rice growing is precarious, with part of the country experiencing drought or flood every year (Shiller et al., 2006), and crop failure threatens family food supplies. Rice growing is also extremely labour intensive for many farm families, including women and children, who must transplant seedlings by hand, standing calf deep in water under high temperatures and humidity.

ACIAR and its partners in Laos and Australia have funded research on lowland rice production since the 1990s. One set of projects led by Prof. Shu Fukai from the University of Queensland, has led to marked improvement in the welfare of lowland rice farmers (Mullen et al., 2019 IAS97), and benefits can be expected to continue through 2025 and beyond, as the adoption of new technologies expands.

ACIAR and its partners invested $14.6m in these projects from 1997 to 2012, generating strong returns. Mullen and colleagues estimated NPV from the projects (projected out to 2025) at $50.1 m, giving a BCR of 4.44:1 and an MIRR of 11.5%. The benefits derive from two technologies – drought tolerant rice varieties and direct seeding of rice (in place of hand transplanting). Other significant outcomes that the study did not quantify include gains in scientific knowledge and human capital, and in the opportunities provided by the release of family labour from transplanting.

10.2.1 Drought tolerant varieties

The Rice Research Centre in Laos predates the ACIAR projects. As the director of the Centre has pointed out, according to Mullen et al., Prof. Fukai brought skills in agronomy and plant physiology that complemented those of Centre breeders. In addition, he trained them in quantitative methods to identify and assess earlier maturing varieties (about 120 days), which were more tolerant of dry conditions and had eating qualities comparable to local rice varieties. The Laotian scientists pointed out that rice varieties have to be bred for Laotian conditions and cannot simply be imported from other countries. Fukai et al. (2016) reported that 15 varieties were identified as suitable for lowland rice systems in Laos.

Mullen et al. based their analysis on an average yield of 3t/ha for lowland wet season rice, which is consistent with FAO data since 2000. Reflecting gains from new varieties, this yield is referred to as the 'with better varieties' scenario. From project experimental results, the authors assumed that the yield 'without better varieties' was 5% lower. They estimated that this 5% yield difference was equivalent to a cost saving of 3.33%/kg, which, when applied to the real value of rice production, gave an estimate of the potential welfare gains from drought tolerant varieties.

Data on adoption of the drought tolerant varieties were scarce. Mullen et al. determined that adoption of the new varieties had begun in 2008, soon after widespread farm trials. Since later projects led by Fukai emphasised farm mechanisation, the authors assumed that the contribution of ACIAR projects to rising rice yields in Laos declined after 2016 to a small level by 2020 (see Figure 8).

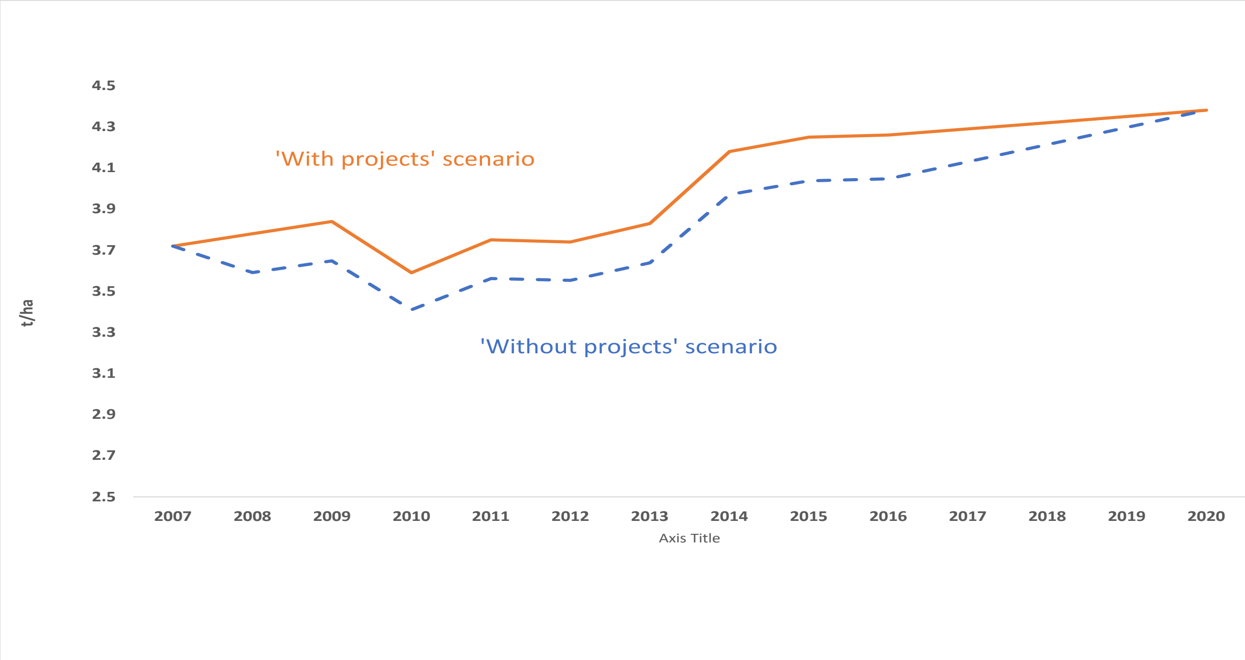

Figure 8: The yield of rice 'with' and 'without' the ACIAR projects

Farmers might use five different varieties, and the spread of varieties across districts in the lowlands is diverse. Statistics on varieties sown are scarce. Based on informal surveys and discussions with research and extension staff and farmer groups, Mullen et al. estimated that after 2008 10% of lowland rice came from varieties developed during the ACIAR projects.

The PV of benefits from drought tolerant varieties was estimated to be $19.1m. If these varieties account for 20% of production, as in some provinces, the PV of the benefit stream doubles to $38.3m.

10.2.2 Direct-seeding technology

Adapting direct seeding (which includes broadcasting, drum seeding and drill seeding) to lowland rice systems in Laos has generated even larger benefits than new varieties. Mullen et al. estimated that the PV of benefits from this technology that can be attributed to the ACIAR projects at $45.6m.

Rapid economic growth in Laos and its neighbours, particularly Thailand, has given rural labourers strong incentives to seek more lucrative employment. Direct seeding is labour saving. requiring 1-2 days/ha compared to 30days/ha from nursery to hand transplanting. These savings are offset later in the season, as direct seeding requires an additional 8 days/ha for weed control and because yields may be lower whilst farmers are learning the technology.

Direct seeding offers great flexibility. For example, if the rain comes late, delaying the start of nursery operations, rice can be sown 'dry' before the rain.

Farmers may choose to hand transplant a portion of their crop and direct seed the rest to control weeds, manage farm labour and guarantee enough rice production to meet household needs in the coming year. ACIAR is funding research on weed control in direct-seeded rice systems in Laos and Cambodia.

For wet season crops, Mullen et al. estimated a gross margin of $260/ha for transplanted crops and $394/ha for direct-seeded crops, assuming a rotation in which a hectare was directed seeded for 3 years and then transplanted for 2 years to manage weeds. This resulted in cost savings of 8.3%. Similarly, the adoption of direct seeding for dry-season irrigated rice gave a cost savings of 9.7% per ha.

Statistics on the adoption of direct seeding were scattered. Mullen et al. discussed adoption with research and extension staff and farmer groups. Fukai et al. (2016) estimated that, in 2016, 6% of lowland rice (50,000 ha) was direct seeded, and there was apparently no direct seeding before 2014. Mullen et al. projected that 60% or almost 500,000 ha might be direct seeded by 2026.

Others, including Vorlasan et al. (2016) and Clarke et al. (2016), have also encouraged the adoption of direct seeding. So, how much time would adoption of this technology have taken without Fukai's work, and what share of the benefits can be attributed to the ACIAR projects?

Mullen et al. argued that the rising price of rural labour would have eventually made the adoption of direct seeding likely. But because research was required to adapt the technology, adoption would have been delayed by 5 years in the absence of Fukai's work. Mullen et al. attributed 60% of the benefits to the ACIAR projects, because they provided the technological base on which those following built. The time path of adoption of direct seeding is illustrated in Figure 9.

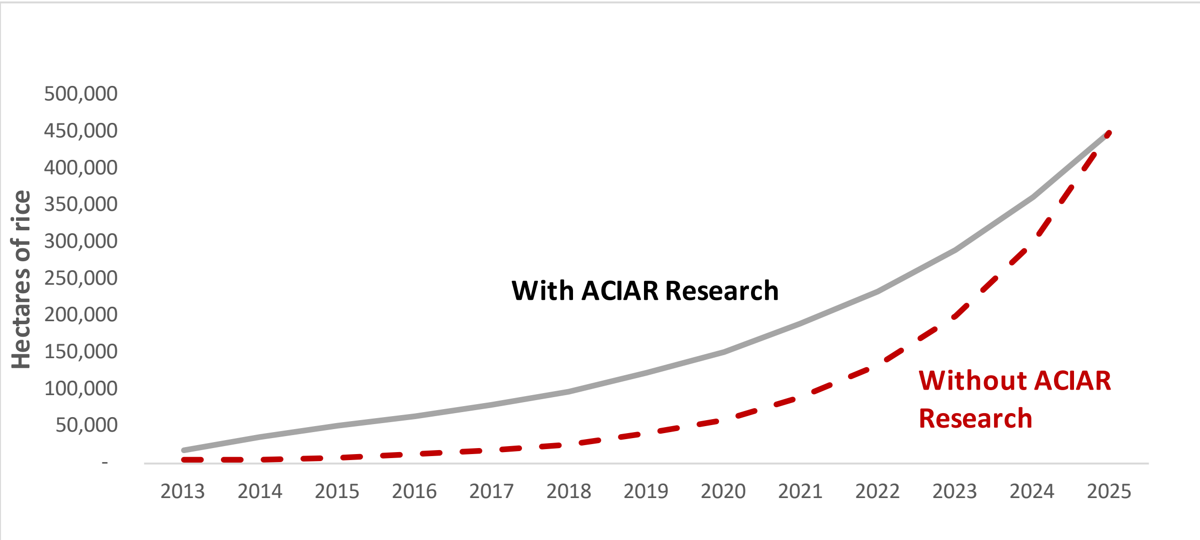

Figure 9: Adoption of direct seeding 'with' and 'without' the ACIAR projects

10.2.3 Capacity building

The project helped build capacity in various ways. Laotian and Australian scientists would likely say that capacity building delivered benefits that were as significant as those of the projects' estimated economic impacts. Moreover, the benefits of capacity building are likely to continue long after completion of these projects, as scientists apply their increased capacity in subsequent efforts.

Mullen et al. reported that the projects had generated 144 papers, including conference papers, noting that the number of citations to 11 of Fukai's papers ranged from 100 to 600. Most of these papers are co-authored with Laotian scientists, who remarked on how this improved their scientific writing and presentation skills.

Projects like these involve much informal 'on-the-job' training through mentoring and short courses. Listed below are the skills that Laotian scientists said they had developed in this way:

- Trial management, including methods for on-farm participatory variety selection
- Experimental design
- Data analysis
- Scientific writing
- English language presentation skills
- Joining scientific networks

Succeeding projects used capacities built in earlier projects and developed new capacities.

The projects also developed capacity through formal training. Mullen et al. reported that 18 people who had worked on the projects undertook post-graduate studies, with ACIAR funding 5 PhD students and 1 master's student. The projects funded 1 masters student directly, while 5 PhD and 4 masters students received funding from other sources.

Much of the projects' trial work was undertaken on farm. Nearly 800 farmers took part in participatory variety selection trials, and direct-seeding technologies were also tested extensively on farms. This likely enhanced the capacities of participating farmers in all aspects of rice management.

10.2.4 Broader social outcomes from the spread of direct seeding

As economic growth continues in South East Asia, real off-farm wages will rise, and farm labour will become scarcer. This gives rice farmers a strong incentive to adopt labour-saving technologies, so direct seeding will inevitably become more prevalent. Prof. Fukai followed up his work on this technology with another ACIAR project on mechanisation of other rice growing operations, including harvesting and grain drying (Fukai et al. 2018).

As Mullen et al. pointed out, these trends have important implications beyond the economic benefits. Farm families depending on a largely subsistence rice system run the risk of a poor crop, if they release labour for off-farm pursuits. Direct seeding has the potential to increase family income from off-farm labour without reducing household rice supplies. This also frees up time, particularly for women and children, to pursue other activities in the household as well as education and the production of fruit, vegetables and household animals, which also contribute to family welfare.

ACIAR is funding another project on weed control in direct-seeded rice systems in Laos, titled 'Weed management techniques for mechanised and broadcast lowland crop production systems in Cambodia and Lao PDR'. Led by Dr. Jaquie Mitchell with the University of Queensland, the project aims to develop a package of weed control techniques that are suitable for direct-seeding practices in rice systems of Laos and Cambodia. This will permit farmers to revert to hand transplanting less often (if at all), thus enhancing the profitability of lowland rice in Laos and increasing the returns from ACIAR's investments in this area (Mullen et al., 2019).

Since 2017, the Crawford Fund has supported the efforts of Dr. Deirdre Lemerle to mentor two volunteers from the AVP program in Laos. One of their main interests is to test alternative means of weed control in direct-seeded rice. Lemerle (2017) found that technologies to control weeds in direct-sown rice are a high priority for Lao farmers. A 2018 survey on current weed control practices and dominant weed species has helped guide the work of the volunteers.

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10.3 Development of the oyster industry in Vietnam

Before, 2007 Vietnam's oyster industry produced only about 100 tonnes, based on haphazard wild collection of spat or larvae. Since then, the industry has grown to be larger than its Australian counterpart, and this can be attributed at least partly to ACIAR as well as to scientists from NSW DPI and Vietnam's growing scientific capacity fostered during a series of ACIAR-funded projects (FIS/2005/114, FIS/2011/073 and FIS/2010/100). Though reliable data on oy.ster production in Vietnam are unavailable, it likely exceeds 15,000 tonnes (some estimates are twice this amount) from about 2,500 families in 28 provinces (O'Connor et al. 2019).

Vietnamese oyster farmers typically live in coastal villages or communes, which are generally of low socioeconomic status; some live on rafts in the bays. They are 'mixed farmers', whose other sources of marine income include Tu Hai clams and fishing. They also engage in land-based enterprises, which include livestock, such as pigs and chickens, as well as rice, timber, fruit and vegetables. Some family members engage in off-farm work. An important attraction of growing oysters is the low cost of entry – for rafts made from local timber – and low production costs. The opportunity cost of labour to grow oysters is also low, because at most times it does not reduce the labour available for other farm enterprises (though perhaps it does reduce leisure time). To quote O'Connor (ACIAR Fisheries and Partners Magazine 2017):

> People can buy just a few strings of oysters from the hatchery, so it's affordable. They hang them in the water to grow, and keep an eye on them while they carry on with their other activities. Oysters are filter feeders, so they feed themselves. It's mostly straightforward – that's one of the reasons it has spread so quickly.

Poor families' limited resources likely mean that the opportunity cost of growing oysters is low. But as the oyster enterprise grows and competes with other enterprises for resources, such as labour and management, then the opportunity cost of growing oysters also increases.

The industry's major constraint in Vietnam was the availability of seed. The supply of spat collected as wild fall was unreliable, and oyster growth rates were low. Attempts to build commercial hatcheries failed, largely because of poor design and a lack of trained staff.

During reciprocal visits in 2005, the Vietnamese Minister for Fisheries and scientists from NSW DPI recognised the potential for developing an oyster industry in Vietnam. A principal objective of the first ACIAR project was to establish hatchery facilities (the National Marine Broodstock Centre at Cat Ba Island, part of the Research Institute for Aquaculture No. 1, RIA1) capable of producing a stable supply of oyster spat. While investigating several species, the project devoted particular effort to *Crassostrea angulata*, known as Hau Sua in Vietnam (literally 'milky oysters') and Portuguese oysters elsewhere. Several commercial hatcheries and nurseries, using skills acquired from the Cat Ba research station, now also provide spat to the industry.

Several provinces in Vietnam have succeeded in culturing oysters, including Quang Ninh, Thua Thien-Hue and Binh Dinh. Bai Tu Long Bay (in Quang Ninh Province) is the most developed oyster culture site, with a total area of nearly 900 hectares and 3,000 floating rafts.

10.3.1 The economic benefits to oyster farmers in Vietnam

Though not formally through ACIAR, O'Connor commissioned Johnston to undertake an impact assessment of the project in 2012 (Johnston 2012). ACIAR and its partners invested a total of $5.8 million. Johnston estimated that at a price of 12,000 VND/kg and production costs of 9,000 VND/kg, the profit was 3,000 VND/kg. He applied this change in profit to production growth (estimated as a logistic function) until 2036, which plateaued at 20,000 tonnes in 2018. On this basis, he estimated the BCR for the project was in the range of 2.4:1 to 8.4:1[14]. In reviewing Johnston's analysis, Mullen et al. (2017) found that, even though production fell 20% short of projections, the BCR might be in the range of 1.6:1 to 6.8:1, still a good investment from ACIAR's viewpoint.

Staff of the Cat Ba hatchery gained skills in:

- Algal culture
- Spawning
- Larval rearing and settlement
- Hatchery management

These skills made it possible to supply low-cost spat consistently to oyster farmers, and also proved useful in research on other species.

In addition, these skills made possible a project (FS/2010/100) focused on breeding for attributes such as size, growth rate and disease resistance. As in other ACIAR research programs, this demonstrates how capacity building through a sequence of projects can lead to more sophisticated research and technology development.

The project initially confirmed that the major oyster species in Vietnam is *Crassostrea angulata*, allowing scientists to establish oyster 'families' with known 'pedigrees'. Through controlled breeding between and within families, researchers can select for traits such as survival, growth rate and disease resistance, resulting in genetically improved oysters for hatcheries and farmers. Van Sang et al. (2019) reported that selection for whole weight resulted in significant gains (17.4%) over three generations, with further gains possible. Farmers benefit from higher prices for larger oysters or from a shorter growing period. Breeding also lead to gains in soft tissue weight and shell shape, traits that are likely to influence oyster prices.

The economic impact of these developments has not been assessed. However, enhanced survival and growth rates have likely improved the profitability of oyster farming. Johnston based his analysis on the assumption that the industry produces 20,000 tonnes, within the range mentioned earlier of at least 15,000 tonnes and perhaps twice that amount. Assuming that these economic benefits exceed the cost to ACIAR and its partners in later projects, then Johnston's estimated BCR in the range 2.4:1 to 8.4:1is likely to hold.

The project also put in place food safety and water quality monitoring, both important to continued growth of the industry.

[14] Johnston (2012) estimated annual welfare gains to the ACIAR project using the kPQ approximation.

Building on its strong relationships with RIA1 in Vietnam, ACIAR is funding O'Connor and Ugalde from the University of Tasmania to examine the role of Portuguese oyster (*Crassostrea angulata*) aquaculture in the carbon cycle and rates of carbon sequestration in northern Vietnam. Carbon sequestration is a crucial service provided by marine ecosystems, which helps mitigate global climate change, but the role of bivalves in this process is not fully established. One objective of the project is to identify the potential value of oyster carbon farming and contribution to carbon off-set schemes.

10.3.2 Other impacts in Vietnam

Three studies by Pierce (2011, 2018 and Pierce and O'Connor, 2014) provide insights into the impact of growth in oyster farming on farm families and their communities. The extra income has enabled them to invest in sanitation facilities, such as toilets, and improved access to clean water, which enhance human health and the waterways in which oysters grow. Families have also invested extra income in their children's education and in improving their homes and transport. Growth in the industry has also created new jobs, open to both women and men, in oyster production, processing and marketing. Pierce (2018) noted that farmers are increasingly concerned about the threat to their economic returns posed by severe climate events as well as disease and parasite outbreaks.

The projects have permitted broader gains in human and scientific capacity, in addition to the technical hatchery management skills noted above. Three RIA1 staff members involved with the ACIAR project received John Allwright fellowships (JAF) to study in Australia. The first, Dr. Vu Van In, completed his PhD on oyster genetics at the University of the Sunshine Coast and returned to Vietnam, where he oversees the oyster breeding program of the National Marine Broodstock Centre at Cat Ba. The second JAF, Cao Truong Giang, completed his PhD at the University of the Sunshine Coast on selective breeding to develop a genetically improved strain of Pacific white leg shrimp *(Litopenaeus vannamei).* He now works for the National Marine Broodstock Center – RIA1 as head of the Crustacean and Mollusc Research Division. A third JAF, Vu Van Sang, undertook a PhD program at the University of the Sunshine Coast, investigating selective breeding of the Portuguese oyster, *Crassostrea angulata*.

Two other members of the oyster breeding team in Vietnam have completed PhDs in Australia. Dr. Nguyen Viet Khue studied at the University of Technology Sydney, under the supervision of Drs. Dove and O'Connor. His research involved molecular assessment of changes in bacterial communities in and around oysters resulting from disease and of the microbiome variability within Sydney rock oyster family lines. Dr. Le Tuan Son investigated 'Bacteriophage control of pathogenic *Vibrio sp.* resulting in mortality of larval oysters in hatchery production' at the University of the Sunshine Coast under the supervision of Dr. O'Connor.

Drs. Dove and O'Connor have provided significant intellectual and material support to other Vietnamese students still studying in Australia. RIA1 students have published 15 scientific papers under the supervision of Drs. O'Connor and Dove.

During the projects, 25 RIA1 & RIA3 staff received training through workshops and placements in Australian laboratories, and 25 undergraduate students and 3 MSc students took part in the program.

Vietnamese scientists developed other more general capacities during the project that, while not essential for achieving its original objectives, may still prove helpful for future technology development. Some considered improved skills in preparing scientific papers to be an important outcome. The project's final report lists 9 publications and 5 extension products, about half with Vietnamese co-authors. A manual on producing Pacific oysters (Le Xan et al. 2009) proved influential in extending this technology to farmers and private hatcheries, while also helping the authors improve their writing skills. Dr. Le Xan suggested that the professionalism and work ethic of the Australian scientists and technicians was a great example to their Vietnamese colleagues. He found working with the DPI scientists and technicians to be very rewarding, using the term 'growing together' to describe this experience.

Long after completion of the ACIAR projects, O'Connor and Dove continued to mentor Vietnamese colleagues and collaborate in publications.

10.3.3 Benefits to the Australian bivalve industry

The projects in Vietnam have benefited Australia's oyster industry (including its scientists) in several ways. ACIAR funding and in-kind contributions from research institutions in Vietnam have helped maintain and enhance skills and experience in bivalve production at NSW DPI's Port Stephen's research station, and this would not have been possible solely with DPI funding. Moreover, many of the Vietnamese scientists who undertook graduate training in Australia conducted research on issues directly relevant to the Australian industry.

One goal of Australian research has been to diversify the molluscs that can be profitably farmed, partly to reduce risk. If farmers have a range of enterprises, this can mitigate the costs of a serious disease (such as QX disease and winter mortality in Sydney rock oysters) and weather events.

One strand of research has involved the pipi (*Donax deltiodes*), a species of both economic and ecological interest in southeastern Australia, with major pipi fisheries in New South Wales (NSW) and South Australia. O'Connor et al. (2019) reported that, for over a decade, the pipi fishery in NSW had harvested between 200 and 400 tonnes annually (valued at more than $2m). In 2009, reductions in commercial harvests suggested the population was in danger and raised interest in reseeding juveniles into affected areas to promote the recovery of wild stocks and increase the potential for pipi mariculture. Researchers studied the biology of pipis and their pests (aporocotylids or fish blood flukes), and developed larval rearing and settlement techniques, which are important steps towards future hatchery propagation and pipis farming.

In research that parallels the genetic work with Portuguese oysters in Vietnam, the project developed improved molecular tools to assess genetic diversity in Sydney rock oysters. Now the breeding program is based on selection amongst over 200 pedigreed families for traits such as disease resistance, growth and meat condition. Breeding stock from this program is now being introduced to the industry – an advance that is unlikely to have occurred without ACIAR funding.

The project team have also contributed importantly to the development of a commercial flat oyster industry through greater understanding of the reproductive cycle. Flat oyster seed and the associated hatchery technology have been distributed to commercial hatcheries, and flat oyster production is being trialled in southern Australia. O'Conner et al. (2019) report that spat supplied to the NSW oyster industry have underpinned the production of flat oysters with a sales (farmgate) value of more than $1m. The seed has also been used for oyster reef restoration projects in Tasmania, Victoria and South Australia.

Although the prospective benefits to Australia's oyster industry have not yet been estimated, it seems highly likely that, given the benefits realised in Vietnam, the projects funded by ACIAR and its partners are also earning a high rate of return in Australia.

10.4 Mite pests and biosecurity in the Australian honey industry

The Australian honey bee industry is based on the European honey bee (*Apis mellifera*). Honey bees provide an important pollination service to many crops in Australia, and honey is itself a valuable commodity. The value of honey and related products from commercial and recreational beekeepers amounted to about $270m in 2019 (derived from Clarke and le Feuvre, 2021). The authors referenced a number of studies providing estimates of the value of pollination services to Australian agriculture, including Gill (1989), Gordon and Davis (2003) and Karasinski (2018). Karasinski's analysis covered 53 crops, using new data on crops' dependency on pollination. He estimated the value of pollination services at $15.1b annually.

Parasitic mites and the viruses they carry, especially from the Tropilaelaps and Varroa genera, pose a significant threat to honey bees, especially in Australia, the only country in the world still free of these mites. The mites threaten feral honey bee colonies particularly (which provide free pollination services), but would also impose significant management costs in managed colonies and threaten the organic status of many Australian honey bee businesses. These mites are exotic to Australia but endemic in some neighbouring countries, including the Philippines and Indonesia. Some of these mites have spread to other Pacific islands, including Papua New Guinea, the Solomon Islands and Fiji, where they have had significant impacts on honey bee industries and smallholder honey producers (Schouten et al., 2020). Hence, it makes sense to conduct research where the pests are prevalent in neighbouring countries, aimed at better understanding how to detect, control and manage them. ACIAR has funded a series of projects in PNG, Indonesia, Timor-Leste the Philippines and other neighbouring countries where the pests are prevalent aimed at understanding the epidemiology and control of parasitic bee mites, both to enhance the welfare of beekeepers in these countries and reduce the risk to Australia from incursions.

The first projects were led by Denis Anderson from CSIRO (AS2/1990/028; AS2/1994/018; and AS2/1999/060), focusing on the Varroa genus. In A key scientific discovery, Anderson and his team determined that not all mites from the Varroa genus pose significant threats to European honey bees. They distinguished between *Varroa jacobsoni* and *Varroa destructor*, with the latter being the mite of great economic significance to European honey bees and Australian agriculture (and globally). A paper by Anderson & Trueman (2000) describing the epidemiology of these mites and their significance worldwide was at one time the third most cited paper from CSIRO Entomology.

Anderson and his team found that not all strains of *Apis cerana*, the Asian honey bee commonly prevalent in Australia's neighbouring countries, carry *V. destructor*; hence quarantine costs can be significantly lowered by focusing on the strains that do carry this mite. Most strains of *A. cerana* carry *V. jacobsoni*, which at that time were thought to be harmless to *A. mellifera*. This knowledge led to changes in regulations covering the world trade in live bees, in cost sharing between the Australian government and the bee industry, and in the Ausvet plan.

Importantly, the projects have built the capacity of beekeepers and scientific staff in Indonesia, the Philippines to manage bees and their mite pests.

Monck and Pearce (2007) assessed the impact of these first projects. Some benefits resulted from better mite control, leading to gains in honey production and pollination services to the Philippines and Indonesia, with the PV of these benefits from 2004 to 2035 estimated at $8.9m.

In Australia, focusing quarantine resources on *V. destructor* rather than all Varroa mites reduced the probability of a mite incursion, giving an annual benefit of $6m, with a PV of $94.2m from 2004 to 2035, ten times larger than the benefits to partner countries.

ACIAR and its partners invested $6m in these projects, giving a PV of $103m, a BCR of 17.2:1 and an IRR of 27%. Lindner et al. (2013) rated the impact assessment made by Monck and Pearce (2007) as convincing. The benefits will be larger, if the risk and persistence of incursions turn out to be higher than that assumed by Monck and Pearce and if the value of the industry grows. Bees and Varroa mites have frequently been intercepted at Australia's ports. While the number of beekeepers (especially recreational beekeepers) has increased, the volume of commercial honey production over the last two decades (Clarke and le Feuvre, 2021) is still in the range of 20,000 to 30,000 tonnes noted by Monck and Pearce.

Hafi et al. (2012) developed a model to assess the benefits and costs of responding to an incursion of *Varroa destructor*. They estimated that an unhindered incursion could cause huge losses to consumers and producers of pollination-dependent crops, with a potential PV of as high as $1.49b over 30 years.

Some recent research has turned towards breeding bees that are resistant to *V. destructor*. ABC Landline (16.7.2021) reported on a program to import mite resistant queen bees from the Netherlands and introduce this resistance to the Australian bee industry. ACIAR-funded projects are testing how Australia's best queen bees perform under *Varroa* and *Tropilaelaps* pressures in PNG and Fiji.

Biosecurity threats evolve over time and so must their management. ACIAR has continued to fund bee projects in Australia's near neighbours, and they will likely deliver significant benefits both by improving the livelihoods of beekeepers in partner countries and by protecting Australian agriculture from pests of the European honey bee. ACIAR has funded a team from Southern Cross University, NSW DPI and CSIRO to develop better pest management techniques for the honey industries of PNG and Fiji.

Roberts and Schouten et al. (2019) found that *Varroa jacobsoni* and *Tropilaelaps mercedesae* are likely the main cause of a serious decline in honey production in the Pacific area; they also pose serious biosecurity threats to the Australian industry. Honey production in PNG, the authors noted, declined from a peak of 100 tonnes to about 35 tonnes.

The recent emergence of these two pests illustrates how biosecurity threats evolve. Previously, *V. jacobsoni* could not parasitise *A. mellifera* colonies, but that is no longer the case in PNG. *T. mercedesae* may pose a more serious threat to the Australian industry than *V. destructo*r. It is in Australia's interest to continue monitoring bee populations for emerging pest and disease problems, and to develop technologies for management of honey bees in near neighbours.

ACIAR projects has helped strengthen Australia's biosecurity in a number of ways. Bee industries in neighbouring countries now have greater capacity to monitor and manage these mites before they reach Australia. The country also has greater capacity at its borders to detect mites as well as greater knowledge of bee populations and their pest and disease status throughout the Pacific region.

These projects have also enhanced the profitability of honey production based on *A. mellifera*, particularly in PNG and Fiji. Control measures have usually relied on chemical methods, which are often too expensive and not wholly effective for small producers. Roberts and Schouten found that caging or removing queen bees, leaving a period of 3 days when there is no brood (eggs, larvae and pupae of honey bees) in the hive for the mites to feed on, offers an effective and cheap control strategy for *Tropilaelaps mercedesae*. The mite is unable to feed on adult bees. This strategy is less effective with Varroa mites, which require integrated pest management, including the rotation of suitable chemicals.

Provided that smallholders can control pests and diseases, beekeeping offers them an attractive option to increase incomes, especially for women, since it requires little land (or can be conducted on less productive land) and little time, and can give rapid returns on investment.

The projects have done much to increase the skills of beekeepers. This has included training days to improve the effectiveness of beekeeping training (Schouten and Calderia, 2021), capacity building in pest and disease management and biosecurity, development of queen bee breeding, women's beekeeping associations and mentorship programs as well as research aimed at determining the factors that influence beekeeper's income, productivity and welfare (Schouten, 2020; Schouten et al., 2020). Project research has also highlighted the significant potential for improving the impact of current and future beekeeping programs throughout the Pacific region (Schouten and Lloyd 2019), and for enhancing finance options (Hinton et al., 2021), participation and benefits amongst women's groups (Austin et al., 2020).

This project, in collaboration with another ACIAR project (FST/2014/067), has identified the hardwood and rainforest trees from which bees source pollen, information that can help guide planning for agroforestry systems and conservation efforts. The project also produced a valuable reference book, 'Beekeeping in the Eastern Highlands of Papua New Guinea' (Cannizzaro et al., 2021). In collaboration with an ACIAR sister project (AGB/2014/057), the project has developed honey bee agribusinesses, conducted marketing and branding research, and contributed to capacity building.

Although these more recent projects have not yet undergone formal impact assessment, they will likely deliver the same types of benefits identified by Monck and Pearce. Low-cost mite control should make beekeeping more profitable, leading to increased honey production. This will also likely contribute significantly to biosecurity in Australia, particularly given the increased risk of incursion posed by new threats in close proximity from *Varroa jacobsoni* and *Tropilaelaps mercedesae*.

10.4.1 Broader biosecurity concerns

Biosecurity concerns the protection of human, animal and plant life from pests and diseases. As an island continent, Australia has some natural protection from exotic pests and diseases but faces increasing threats from international trade and travel. Factors such as climate change, biodiversity loss and urbanisation increase biosecurity risks. An extensive and expensive quarantine service provides protection at the borders, but regular incursions of exotic pests occur and are costly to extinguish. A recent review of biosecurity (CSIRO, 2020) reported that the number of interceptions exceeded 37,000 in 2017, an increase of 50% since 2012.

Since its inception, ACIAR has funded bilateral projects with a common objective of using science to manage biosecurity risks. Some of the projects have focused on protecting animal and plant enterprises in partner countries and thus the welfare of farm families. In addition, these projects enhance the scientific capacity of partner countries to identify, monitor and manage future biosecurity threats. These skills and scientific knowledge also prove useful in managing biosecurity threats to Australia.

Some projects are directly relevant to the biosecurity of Australian agriculture. Helping partner countries monitor and manage pests and diseases reduces the risks of incursions in Australia. It makes sense to conduct research on the management of pests and diseases where they occur, even though they are not yet present in Australia. This research will likely to lead to significant scientific discoveries, gains in the welfare of farmers in partner countries and large gains to Australia in the form of losses averted from pest and disease incursions.

In 2020, ACIAR joined with the Plant Biosecurity Research Initiative to strengthen plant biosecurity in Australia and its near neighbours. At that time, ACIAR was investing more than AUD$26m in 14 plant biosecurity projects across the Indo-Pacific region. The Centre contributes to the partnership through the efforts of the Australian scientists it funds to develop diagnostic, surveillance and management capacities in partner countries.

10.5 Improved smallholder livelihoods from oil palm in lowland Papua New Guinea

10.5.1 Background

The oil palm industry is an important part of the economy of Papua New Guinea (PNG) and in 2010, accounted for 56% of the value of its agricultural exports (Fisher, Winzenried and Sar, 2012). Palm oil is used in around 50% of the products that consumers purchase and use daily (Palm Oil Investigations, 2021), including pre-packaged foods, cosmetics, cleaning and hair care products, soaps and personal care items (Palm Oil Investigations, 2021). Smallholders can obtain good returns from production but face a number of constraints (Fisher et al., 2012). While plantation estates dominate the industry in PNG, smallholders account for about 40% of the planted area. In 2012, 144,183 ha were planted to commercial oil palm in PNG, operated by two companies and 19,777 smallholders (on 60% and 40% of the area, respectively). The industry has expanded at about 3,000 ha/year over the last decade (PNGOC, 2013; Nelson et al., 2014).

Oil palm planting started in PNG in the early 20th Century on formerly cropped land (Nelson et al., 2010), but commercial production did not take off until the 1970s. A typical oil palm block lasts about 25 years before becoming senile. Consequently, massive oil palm replanting commenced in the late 1990s. A good overview of the industry was provided by Fisher et al (2012).

Smallholder oil palm production in PNG centres on Landholder Settlement Schemes (LSS), Village Oil Production (VOP), and Customary Rights Purchase Blocks (CRPB). As is typical for export crops in developing countries, producers face many challenges, including technical aspects of crop husbandry, access to land for planting, and availability of labour for crop management and harvest. The situation in PNG is further complicated by a complex overlay of customary land tenure and various cultural and kinship issues.

10.5.2 ACIAR and PNG oil palm

ACIAR and its partners in Australia and PNG have funded research projects on smallholder palm oil production since the 1990s. The research has focused on biophysical and socio-economic aspects of production to address low productivity on smallholder lands (PNGOPRA, 2021 website - smallholders and socio-economics). There is strong evidence that ACIAR's oil palm research has improved smallholders' welfare.

ACIAR's research on the biophysical aspects of oil palm has addressed all aspects of crop husbandry – agronomy and crop management, soil improvement, fertiliser use, and pests and diseases. However unless improved husbandry practices are enacted by smallholders there will be no improvement in oil palm productivity in the smallholder sector of the industry. It is critical we understand the dis-incentives to smallholder adoption of improved agronomic practices. In PNG, these mainly involve smallholders' use of labour and land for oil palm production.

An impact assessment (IAS 80) of seven ACIAR projects on oil palm estimated the overall BCR at 22.4:1 (Fisher et al., 2012), which Lindner et al. (2013) found to be 'convincing'. Four of the projects dealt with biophysical aspects of oil palm (biocontrol of pests, pest management, magnesium deficiency, and soil and water management) and three with socio-economic issues (biophysical and social interactions, participation of youth and women, and partnerships between the commercial sector and smallholders).

ACIAR's oil palm research has relied on a multidisciplinary approach for examining both biophysical and socio-economic issues. The Centre has also worked to build 'research momentum' that evolves and grows by funding a series of projects over a number of years and to foster collaboration with industry, government and smallholders.

10.5.3 Socio-economic research on smallholder oil palm production

ACIAR's early research on oil palm assessed the interplay between the biophysical and socio-economic aspects of smallholder production (Koczberski and Curry, 2004).

Subsequent research:

- Investigated incentives for overcoming under-harvesting of oil palm fruit.
- Developed novel payment schemes that shared oil palm income more equitably between and within households.
- Assessed and developed new land tenure agreements that lowered smallholder risk and uncertainty about land access.

More recent research is exploring the food insecurity and environmental concerns of smallholder oil palm producers, and devising strategies to address these issues. Current work is identifying opportunities and constraints in rural women's engagement in small- scale agricultural enterprises.

Interplay between biophysical and socio-economic aspects of oil palm production

By the 1990s, mounting population pressure (Koczberski and Curry, 2004) meant that multiple generations of families had to live off the family's original oil palm block. Family members contested remuneration for labour on the block and as a result, withheld labour from oil palm. Population pressure also forced greater reliance on gardens for staple foods, particularly when families lacked cash income to meet household needs.

A further key constraint to oil palm productivity was the diversity of economic activities on which smallholders and their families relied. Land insecurity provided a further disincentive for smallholders to invest in long-term block improvements, such as fertiliser use and replanting of senile palms.

In response, the research team designed and tested a new mobile card payment system, which permitted more flexible use of labour across blocks and provided an agreed payment mechanism for labour supplied. This also gave unemployed youth from highly populated blocks an incentive to engage in oil palm harvesting and block maintenance.

Overcoming under-harvesting of oil palm fruit

The Mama Lus Frut scheme (MLFS) was introduced in 1997 to create incentives for harvesting fallen oil palm fruit, which would otherwise rot on the ground. Traditionally, this was considered 'women's work', but since it offered no financial rewards, women were disinclined to harvest the fallen fruit. An early ACIAR project evaluated and modified the earlier MLFS, and extended it to new areas. The project also broadened participation in the scheme to include unemployed youth. Their incentive to participate was the use of cards (mama, papa, mobile) which allowed direct payment to individuals, giving them greater financial autonomy.

An impact assessment (Warner and Bauer 2002, IAS20) demonstrated the positive impact of the enhanced MLFS. Household income increased because of less wasted fruit and better block maintenance (to access the fallen fruit), which also enabled men to collect palm fruit bunches more easily. In addition, the MLFS modified the distribution of income within households. Women were paid via their own 'mama card', giving them a degree of financial autonomy and empowerment, and making them 'credit worthy'. Women spent their earnings on household goods and education, and some established small businesses, while supporting the extended family.

New land tenure agreements

Socio-economic research identified land security and lack of clarity about land tenure as constraints of oil palm productivity on Customary Rights Purchase Blocks (CRPBs). In response, researchers designed a new template (Fisher et al., 2012) to deliver Clan Land Use Agreements (CLUA) for CRPBs, in compliance with the criteria of the Roundtable on Sustainable Palm Oil (RSPO). CLUAs provide smallholders with land certainty, hence motivating them to participate in extension programs, and block maintenance and harvest. The intent was for any new oil palm development to be consistent with RSPO criteria.

Land pressure, food insecurity and environmental degradation

As noted by Curry et al. (2019), 'Declining access to land has been exacerbated by smallholders increasing their oil palm plantings from 4 ha to 6 ha on their 6.07 ha LSS blocks. The old strategy of maintaining 2.07 ha of land for food gardening has been largely abandoned'. Consequently, smallholders now inter-crop newly replanted oil palm with food crops, which also generate cash for the household from the sale of surplus garden produce.

Traditionally, oil palm has been replanted 2 ha a time on LSS blocks, putting smallholders at a double disadvantage: They must go into debt for replanting, while at the same time losing a third of their block's productive capacity and income. This constitutes a strong disincentive to replant, resulting in a gradual decline in income from the block, as palms become more senile. Moreover, without block maintenance, weeds and other pests emerge, potentially affecting neighbouring blocks.

The research team developed an innovation (Curry et al., 2019) in association with the local oil palm industry that involved a 1-ha replant option (instead of the earlier 2-ha option). This doubles the period during which food crops can be intercropped with young oil palms on the block and relieves the financial stress associated with replanting senile oil palm by lowering replant debt and reducing repayment periods. Increased gardening in the block also takes pressure off environmentally sensitive areas, such as buffer and riparian zones. The 1-ha option thus has potential for strengthening social, financial and environmental sustainability in the smallholder oil palm sector.

Women and agribusiness

The operating environment for smallholder women in the oil palm sector has fundamentally changed over the past 25 years (Koczberski, 2021; Hamago, 2021). Recent research on smallholder women in oil palm production has highlighted these constraints:

- Lack of financial literacy and low levels of education in general
- Rapidly changing market and labour systems
- Entrenched gender norms
- Impacts of the cash economy on traditional labour exchange used by women

These factors limit smallholder women's potential to play a stronger role in agribusiness and to improve household livelihoods, and also affect how women are taught financial literacy and business acumen (Pamphilon and Mikhailovich, 2017; Koczberski, 2021). New approaches resulting from ACIAR socio-economic research include the delivery of education on a community basis, assuming no prior education.

10.5.4 Overall positive benefits

Women and youth – More empowerment and status

Social cohesion – Enhanced within and between households and clans

Household livelihoods – Less poverty and food insecurity together with increased cash for education and other household needs

Improved extension services for government and industry – New socio-economic knowledge and processes for delivery that are consistent with cultural and social settings

Capacity building and networks – benefits for post-graduate students from PNG and Australia as well as for oil palm industry and government extension staff, and women and men smallholder farmers

Soft power partnerships and trust between PNG and Australia – Government-to-government research partnerships, research networks, and collaboration between PNG industry, government and smallholders

10.5.5 Concluding comments

ACIAR's socio-economic research on oil palm is action-oriented, meaning that the identification of constraints to smallholder oil palm productivity goes hand in hand with the design of strategies to overcome them.

In PNG, the key socio-economic constraints to oil palm production centre around access to and the availability of, land and labour. New land use agreements and novel payment systems for harvested fruit have improved productivity in the smallholder oil palm sector. ACIAR's socio-economic research proved to be pivotal in delivering these innovations and continues, as men and women seize new agribusiness and other opportunities in the industry.

In PNG society, women's roles are changing, as they gain greater influence on household decision-making, greater financial autonomy and an emerging role in agribusiness. All of this contributes to greater social cohesion, household stability and more effective use of women's contributions to the oil palm industry.

10.6 The Happy Seeder stubble mulcher

Over many years, ACIAR has funded projects on the Indian subcontinent, with the aim of alleviating poverty as well as conserving water, while improving soil fertility and air quality. The Centre is one of seven partners in a wide-ranging development program known as the Sustainable Development Investment Portfolio (SDIP), which addresses growing water, food and energy insecurity in the basins of the Ganges, Indus and Brahmaputra Rivers. This region of South Asia has a growing population of nearly 1.7 billion and is home to more than 40% of the world's poor.

SDIP is now in the second 4-year phase (2016-2020) of a 12-year strategy, with an investment amounting to about $90m so far. ACIAR has 20 projects related to SDIP, many in the state of West Bengal, which cover various dimensions of conservation agriculture. Scientists from the University of Adelaide estimate that 120,000 farmers in West Bengal have adopted more productive and sustainable farming techniques (T. Jackson, Pers. Com.; ACIAR SDIP Update March, 2021).

Here we focus on just one technology, the Happy Seeder, which has the potential to alleviate poverty and improve air quality in northern India.

10.6.1 The Happy Seeder

The states of Punjab, Haryana, and Uttar Pradesh have become major producers of rice and wheat, particularly since the Green Revolution. The present dominance of the rice-wheat rotation in these states can be traced back to India's efforts to become food self-sufficient in the 1960s (Singh, 2021). CIMMYT made semi-dwarf wheat varieties widely available, and the government introduced subsidies for electricity, fertiliser and tube wells to access groundwater for irrigation as well as price supports for rice and wheat.

However, the rice-wheat rotation required the burning of rice stubble because of the short time available to prepare the land for the following wheat crop[15]. Keil et al. (2021) estimated that 2.5 million farmers burn about 23 million tonnes of rice stubble in October and November. The smoke from burning is a major source of air pollution and greenhouse gas emissions, and can drift as far as Delhi (250 km from Punjab). The air quality index around Delhi can be as high as 999, with a reading of 300 classed as 'hazardous' (Singh, 2021). Keil et al. referenced studies attributing about 66,000 annual deaths to poor air quality.

In an ACIAR-funded project (CSE/2006/132), Milham et al. (2014) estimated that burning a tonne of rice stubble cost the people of Punjab state ₹4.97, on average,[16] based on the costs of medical and mitigation expenditures as well as the opportunity cost of workdays lost (but not including expenses on averting activities, and costs associated with discomfort caused by smog and motor vehicle accidents caused by low visibility, which amounted to ₹76.09 million annually

[15] Wheat stubble is often used to feed livestock.
[16] In 2021 ₹100 is equivalent to about $1.80 AUD.

for Punjab). Agricultural biomass burning also accounts for 15% of agriculture's greenhouse gas (GHG) emissions, which in turn comprise 29% of India's total emissions (Gujral et al 2010).

More recently, Fischer (2019) has highlighted a previously little recognised cost to agriculture from poor air quality, estimating that wheat yields in 2010 could have been 30% higher than in 1970 but for increases in tropospheric ozone and aerosol pollution. He suggested that these losses exceed the losses to date from climate change. [17]

Since air quality is a public good, individual farmers will not change their crop management to mitigate the impact of stubble burning, unless they have incentives to do so, and this, in turn, requires collective action. India prohibits stubble burning under the Air (Prevention and Control of Pollution) Act 1981 and Environment Protection Act 1986, but it has not enforced these laws. Government agencies in Punjab likely consider it unfair to ban rice stubble burning, without offering farmers economic alternatives. In 2019, the Supreme Court ordered northern states to pay farmers who do not burn stubble ₹2,400 per acre, but the Punjab government has not been able to afford to implement this policy.

Another issue that affects both crop production and the environment is groundwater depletion in the Punjab and Haryana, as a consequence of the dominant rice-wheat rotation. In addition, food insecurity has become a major problem in these states, which are India's main source of cereals (Singh, 2021).

ACIAR funded various projects (LWR/2000/089; CSE/2006/124 and LWR/2006/132) that led to the development of the Happy Seeder and examined factors affecting adoption of this technology. Designed for direct drilling of wheat into heavy rice residues on smallholdings, the Happy Seeder provides an alternative to stubble burning. This tractor-powered machine cuts and lifts the rice stubble, sows wheat into the bare soil, and deposits the stubble over the sown area as mulch (Milham et al., 2014, p. iii).

Singh et al. (2008), Keil et al. (2021) and others, based on economic modelling, argued that farmers have an incentive to adopt the Happy Seeder. In their baseline scenario, Singh et al. assumed that, while it gave no yield gains, the technology did permit these cost savings:

- Reduced cost of machinery operations for crop establishment
- Reduced fertiliser inputs through improved soil fertility
- Reduced weed control costs through suppression of weeds by mulching
- Irrigation water savings through suppression of soil evaporation
- Labour savings through fewer tillage operations and reduced irrigation time
- Electricity savings through reduced pumping time

Saunders et al. (2012, IAS 77) assessed the impact of ACIAR projects, using farm data from Singh et al. They assumed, conservatively, that the Happy Seeder gave no change in yield but reduced costs by ₹2,163 per ha, a 9.4% reduction relative to stubble burning. At that time, farmers were using the Happy Seeder on only 0.077% of the rice-wheat cropping area in Punjab, and the authors projected that by 2031 adoption would reach 3.7%. On this basis, they estimated the present value of total benefits at $118.2m, more than offsetting the PV of project costs of

[17] Stubble burning is but one source of these types of pollution.

$6.9m, giving an NPV of $111.3m, a BCR of 17.2:1 and an IRR of 20% – a good return on ACIAR's investment.

Stubble retention offers potential agronomic benefits through significant improvements in soil health and structure, leading to better retention of water, nutrients and organic matter. Singh (2021) reviewed a series of analyses showing substantial gains to farmers from adopting the Happy Seeder, with yield increases in the range 2-5% and consequent gains in profitability of about 40%. Additionally, Sidhu et al. (2010) found that the Happy Seeder could save 8.5cm of water per hectare, reducing the need for groundwater and the power to pump it, with savings of ₹50.53 crore per annum for Punjab. However, as these gains may not be apparent for some years, farmers may not recognise them.

Saunders et al. (2012) also noted that the projects led to significant gains in human and scientific capacity. Researchers published 19 peer-reviewed papers, presented 35 papers at conferences and workshops, and published 13 extension papers. Four project research fellows from Punjab Agricultural University (PAU) undertook PhD programs (three in Australia); a field coordinator completed bachelors and master's degrees; and one PAU scientist who received a John Dillon fellowship went on to play a leadership role in a large cereals program in South Asia. The projects also increased cooperative research between departments (disciplines) at PAU. The Australian leader, Humphries, noted that the Australian scientists enhanced their capacity to undertake international collaborative research.

Saunders et al. (2012) based their analysis on a level of adoption that is far too low to improve air quality. In response, ACIAR funded a project (Milham et al., 2014) to examine policy instruments for air pollution control in Indian agriculture and their implications for adoption of the Happy Seeder. The researchers found that longstanding subsidies on fertilisers and electricity – introduced at the time of the Green Revolution to increase production – have skewed farmers' choices about the rice-wheat rotation. Using a more sophisticated whole-farm model than that used by Singh et al. (2008), they found that under these conditions farmers have little incentive to adopt the Happy Seeder.

The researchers further concluded that, if the subsidies were removed and a third crop, such as mungbeans, were added to the rotation, then farmers would likely adopt the Happy Seeder[18]. The policy options they examined included a tax on carbon emissions in conjunction with an agricultural offsets scheme that would allow farmers to 'sell' their abandonment of stubble burning. These would provide farmers with a stronger incentive to cease stubble burning and adopt the Happy Seeder, the most likely (but not the only) option. However, governments would find it politically difficult to adopt these policy options.

Happy Seeders are expensive capital items, so it is more efficient for poor farmers to hire these machines on a contract basis. One policy lever used to encourage adoption of Happy Seeders involves subsidising their purchase, in the expectation that this will lower contract rates for

[18] The Punjab Government was encouraging farmers away from rice-wheat crop rotation into new areas like vegetables, fruits, oil seeds, pulses, etc (Kumar and Joshi 2010) as a strategy to protect both the natural resource base and stabilise farm income.

farmers. Milham et al. estimated that a subsidy of 25% of the capital cost would encourage greater adoption of the Happy Seeder. They noted that Punjab was already offering a 35% subsidy at the time of their study, but Kumar and Milham (2010) found that few were taking advantage of this subsidy.

Goyal (2019) reported that in Punjab the subsidy had risen to 80% for farmer groups and 50% for purchase by individual farmers, leading to a marked increase in adoption. By 2019, he reported, that 12,000 machines were being used in Punjab on 500,000 ha (about 15% of the area sown to wheat), up from 620 machines used on 64,000 ha in 2016. Farmers experienced with the technology were reporting increased yields.

More recently, Singh (2021) quoted a government estimate of 15,000 Happy Seeders in Punjab, noting that about 60,000 could be used at present production levels in Punjab. Also noting the 'personal' factors that usually influence farmers' adoption of any new technology, Singh suggested that government agencies have slowed adoption of the Happy Seeder in two ways. First, there have been long delays in the payment of subsidies on the purchase of Happy Seeders. And second, farmers have found that government extension staff promote other technologies that are more expensive than the Happy Seeder. It is unclear what incentives extension workers face in advising farmers about stubble management practices.

Singh (2021) argued that to protect groundwater and improve air quality resources while maintaining farm incomes, farmers must have incentives to broaden their crop rotations beyond wheat and rice.

Government subsidies on the purchase of Happy Seeders have likely driven adoption of the technology, and ACIAR's substantial contribution to their development has generated strong returns to initial investments.

But to what extent has ACIAR's project (CSE/2006/132) been in the formulation of government policy in Punjab and other states. Over the years, the Centre has funded a number of policy projects such as this, and they pose the same question as do technical projects: Have they proved influential and hence made good use of ACIAR's limited resources?

The policy arena encompasses many players, including government departments, universities, private lobby groups and other non-profit institutions, such as the World Bank and CGIAR centres. Rarely is it possible to determine objectively the share of benefits from policy reform that can be attributed to a particular project.

In this case, the optimal policy change identified by the ACIAR project – eliminating subsidies on electricity and fertiliser – has not yet been adopted, and this no doubt came as no surprise to Milham et al. Instead, a subsidy on the purchase of the Happy Seeder has been used to drive adoption, and a higher subsidy than that estimated by Milham el al. proved necessary. This shows that the government assigns high priority to promoting adoption of the technology to improve air quality.

There are two reasons to think that the Milham et al. study may have proved influential with policymakers in India. First, the report offers a comprehensive, rigorous review of the issues involved in formulating air quality policy. And second, the project team comprised skilled economists from the NSW Department of Industry and Investment in Australia (I&I NSW) and the National Council of Applied Economic Research (NCAER) in India. They worked closely with the agencies that influence agricultural policy in Punjab, including the Punjab Department of Agriculture and Agriculture Technology Management Agency, Punjab Agricultural University, Punjab State Farmer's Commission, Punjab State Council for Science & Technology, Punjab State Planning Board and Punjab Pollution Control Board.

10.6.2 Benefits to Australia

Saunders et al. found that the Happy Seeder offered Australian rice farmers no incentive to shift from burning rice stubble. However, they also noted that small gains in the efficiency of the technology could change the incentives. Moreover, in a bid to meet carbon emission targets, the Australian government may employ policy instruments that force rice farmers to abandon stubble burning. Since carbon emissions are a global public good, their reduction in in Indian agriculture benefits Australia as well.

10.7 Rehabilitating grasslands in northwestern China

ACIAR has ceased funding new bilateral research projects in China, given its growing wealth and success in lifting many of its citizens out of poverty. Previously, the Centre had already shifted its focus to alleviating poverty in less developed regions of the country. Then, early in the 2000s, it began to emphasise to collaborative projects in which ACIAR provided contacts and leadership, while China funded much of the field work.

Based on planning in 2001, ACIAR co-funded a series of projects ending in 2017, aimed at developing sustainable livestock grazing systems on temperate grasslands in China. The program was led by Prof. David Kemp and other staff from Charles Sturt University and involved scientists from five Chinese universities and research institutes. ACIAR invested $2.5m in the projects, and Chinese agencies contributed $40m (Kemp et al., 2018).

China has 400m hectares of natural grasslands (of which 90% is degraded to varying degrees), with 1b sheep equivalents across the Tibetan, Mongolian and Loess Plateaux and neighbouring areas, where mean annual temperatures are close to zero and rainfall is 50-500mm. The 16m herders occupying these lands are amongst the poorest people in China, and while many live in communities now, they were formerly nomads.

Stocking rate in sheep equivalents (SE) increased from about 0.6/ha in 1950 to about 2.4/ha in 2015. On similar land areas (400m), China had about 1b sheep equivalents, whereas Australia had about 200m sheep equivalents (Kemp et al., 2018).

Initially, increased production was welcomed, as it helped feed a rapidly growing population. However, poverty remained a problem, and environmental degradation resulted, as herders rapidly increased the number of animals on land allocated to them. Overgrazing led to a change in the composition of pastures, from desirable to less desirable species of low nutritional value, and increased wind and water erosion, as total herbage biomass declined.

Grassland degradation contributed to increased occurrence of serious dust storms in China. Kemp et al. (2018) reported that, whereas formerly Beijing had experienced a severe dust storm every 4 or 5 years, more recently 4 or 5 dust storms occurred each year, at times extending across the Korean Peninsula and Japan.

The Chinese government recognised the problems of poverty and grassland degradation from the 1990s. In response, it enacted the Grasslands Laws, which provide herders in Inner Mongolia with access to subsidies for either total cessation of grazing for up to 5 years, for resting pastures or for reducing stocking rates at the start of summer to give pastures a better chance of regeneration. Moreover, the Chinese Government spends about $2b yearly on grassland programs.

Raising livestock in this part of China is tough. Traditional practice is to take livestock out to feed every day, even in winter when temperatures are well below freezing. It takes skill and experience to find pasture for animals in such challenging conditions. Over winter stock lose 20-30% of their body weight, with the expectation that they will regain this weight by the end of summer. Animals are subsistence herders' stock of wealth, and they make every effort to preserve this stock through winter and increase stock numbers over time. However. as stocking rates have increased and pastures have degraded, regaining weight has proved problematic. Important contributors to productivity, such as body weight, rates of weight gain, and lambing and calving percentages are all low. Sale animals are rarely in good enough condition to attract good prices. As herders become more integrated into markets, they need to develop skills that will improve production performance.

The ACIAR-supported projects began when Prof. Kemp visited China at the invitation of Prof. Nan Zhibiao (of Lanzhou University) to develop a program of grasslands research. The program included an ongoing survey of about 1,600 households on their production system, including animal production data collected at the start and end of summer and in the middle of winter, when possible. The survey gave scientists a greater understanding of the biophysical and financial aspects of the production systems and provided data for models used to investigate management options.

Researchers also established demonstration and control farms, so that herders could observe the outcomes from alternative management strategies. The models identified options for herders to evaluate and fine-tune on the demonstration farms. Participating herders received an allowance (using Chinese funds), in case results were not as expected. The Chinese government financed the surveys and establishment of the demonstration and control farms .

Determining the optimal stocking rate is complex, involving the interaction of animal, plant and economic responses. This also depends on the farm family's physical and financial, and labour and management resources. Externalities associated with overgrazing further complicate the issue. It cannot be resolved by experimenting with key parameters in a piecemeal (or partial equilibrium) fashion. Instead, the research team took a whole farm systems approach, requiring animal and plant scientists and economists to work in a multidisciplinary manner.

The outcomes of changing the stocking rate are not intuitively obvious to herders or scientists, because they emerge, not in one season, but over many years. Year-to-year seasonal variation adds to the difficulty of discerning these outcomes. Hence, another critical dimension of the program was the participation of herders at all stages, including the design and management of experiments. This enhanced scientists' understanding of grassland grazing systems, and increased the likelihood that herders would adopt new approaches.

Several case studies used the whole farm systems approach, involving multidisciplinary teams and farmers. Scientists in partner institutions welcomed this departure from the usual disciplinary approach, which helped build institutional capital, consisting of an improved capacity to address complex problems by integrating diverse skills.

The key result of this research is that grassland herders can increase incomes and reduce grassland degradation by reducing their stocking rate. Figure 10 illustrates why this might be the case. As stocking rate is increased, most dimensions of animal production decrease on a per head basis, as more animals compete for the supply of pasture, as shown by the diagonal in Figure 10. As stocking rate increases, production on a per hectare basis at first increases, passing through point A on the curve in Figure 10. Eventually, as the quantity and quality of pasture become limiting, production per hectare reaches a maximum and then declines through point B, as stocking rate is further increased.

As we move along the curve from A, the marginal gains in production are smaller for each unit increase in stocking rate and are more than offset by the increasing costs associated with each increase in stocking rate. Feeding costs through winter increase exponentially as the stocking rate increases. The most profitable stocking rate is somewhere to the left of the top of the curve towards point A.

Over much of the grasslands, herders had gradually increased stocking rates, so they were typically operating at a point like B. Points A and B give the same level of production per hectare; but the relative stocking rate at A is 0.5 as against 1.5 at B, and per head production is much higher at A than B. Through winter and other adverse seasons, the effective stocking rate is far to the right, where animals lose weight. To achieve higher growth rates at point A requires higher levels of herbage mass per hectare, whereas at point B, herbage mass is very low.

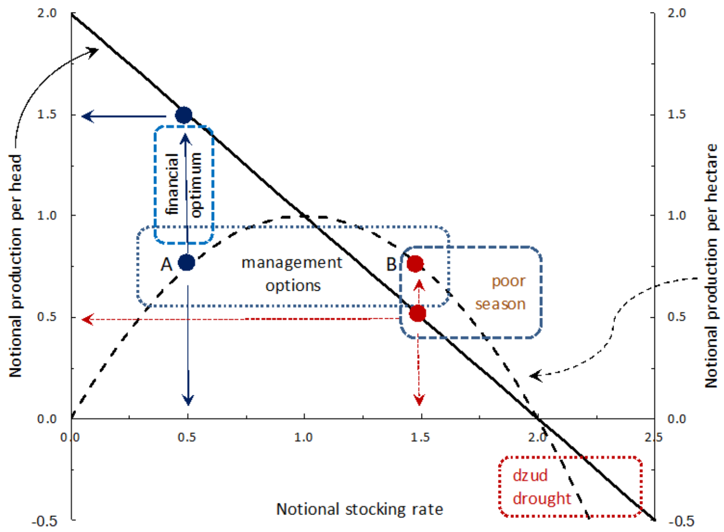

Figure 10: Relationships between stocking rate and production per head and per hectare. Source: Adapted from Jones and Sandland (1973).

There are many pathways or technologies by which to lower the stocking rate and allow grass regeneration without lowering family incomes. Researchers first modelled alternative pathways for their impacts on animal and pasture production and farm income, and then trialled them on demonstration farms. The pathways included pasture rest phases, time of lambing, shedding and supplementary feeding in winter, farm size, livestock breeds and competitive marketing options. So, the decision was not merely about stocking rate but concerned choices between technology packages, which protected farm income while lowering stocking rate and potentially leading to grassland regeneration over the years, with a consequent increase in household income.

The program recommended that herders could reduce stocking rates by 50% (from high levels in the 1990s), putting animal production per head and per hectare at about 75% of the potential and in the vicinity of optimal economic returns. The stocking rate that pastures can withstand is closely linked to seasonal conditions. Kemp et al. (2018) recommended that herders aim to keep pasture dry matter above 0.5 tonnes per hectare.

Recommended technology packages varied between regions. Chinese institutions (funded by various levels of government) and the program team undertook the task of extending these packages beyond the demonstration farms. The research team provided 20,520 person days of training at 120 events, about half on farms. The project also focused strongly on reaching government and university policymakers and scientist as well as agribusiness leaders. According to Michalk et al. (2020), NSW DPI 29 hosted delegations (including herders) from 11 provinces to study sustainable production and livestock marketing in the context of program results, with financing from the Chinese government.

ACIAR has not commissioned a formal, independent assessment of the economic, environmental and social outcomes from these projects, though final reports and publications (Kemp, 2020) do provide useful insights.

The extent to which herders have reduced stocking rates across the grasslands is not known at this stage in many places, as statistics lag behind the changes in practices and do not reflect the numbers of animals that may not graze the grasslands but rather are kept in sheds and hand fed. Nonetheless, the experience in Siziwang Banner, one of the program's main centres (with some 20,000 households), may be indicative of wider changes. By 2014, studies in Siziwang covered about 100 farms in 15 villages. Surveys of herders in the region found that average stocking rate was about 0.8 sheep equivalents per hectare and as low as 0.5 SE/ha for some. Herders who had taken up other elements of the management package had increased their incomes more than those who had simply reduced stocking rate. As expected, those with larger farms generally had lower stocking rates and higher incomes. Kemp et al. (2020, p 259) reported that in Siziwang District, about 2,000 herders had reduced their stocking rate by about 40%. Presumably, they would not have done so if it had reduced their incomes. The data on livestock numbers in Siziwang Banner (Figure 11) show a large decline in 2008-2009 and the halving in stocking rates recommended by the ACIAR program. By then, national policies had evolved to allow reduced stocking rates (instead of total grazing bans) as a means of rehabilitating grasslands. Figure 10 also shows the decline in large herbivores (cattle, horses, camels) in the mid-1980s. Locals attributed this change to the grass being too short for large animals to sustain themselves.

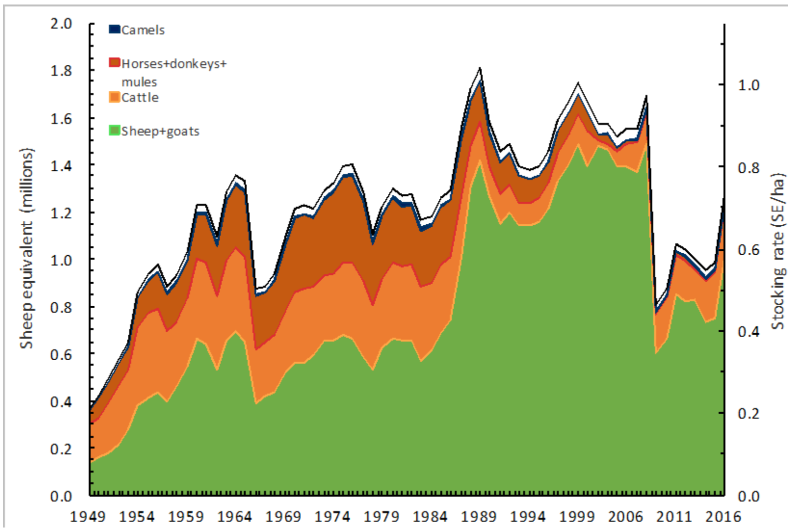

Figure 11: Livestock numbers in Siziwang Banner, 1949-2016

In a 2010 survey of 1,200 households across six grassland types (classified into five net income /SE groups), the household income of the median group was RMB5,000 per household, compared to an average household income for the next highest group of RMB11,400. The latter group had started adopting the technology package that included reduced stocking rate and improved management practices. While not meeting the standards of a rigorous impact assessment, these differences in household income are indicative of potential gains from adoption of the technology packages. Kemp et al. (2020, p258) made a 'back-of-the-envelope' estimate that, if 1m households (6%) adopted the technology, the annual net benefit may be in the order of $1b. Michalk et al. (2020, p239) projected these rough benefit estimates out 15 years to derive a BCR of 11:1 for investment in the projects.

ACIAR provided the core ideas and training for this program, but others can lay claim to some share of the benefits. As already noted, several government departments (from local to central) and universities were partners in the program, and the Chinese financial contribution exceeded that of ACIAR. Moreover, government institutions had their own parallel programs to address poverty and grassland degradation, supported by the World Bank in earlier years. A key feature of the ACIAR research program was that it involved all levels of government and universities in development and implementation. No doubt, the delegations to Australia as well as the conferences and workshops held across the grasslands increased awareness of program findings. In December 2019, leaders of the Grassland Department in the Chinese Ministry of Agriculture travelled to Orange for discussions with Prof. Kemp to help them develop their policies. The research team observed that the parallel programs contained elements of the ACIAR program. It seems highly likely that the ACIAR program has influenced management of the grasslands and deserves a share of the credit for benefits resulting from adoption of the technology packages.

The ACIAR program also likely influenced government policy on grassland management. For example, Kemp et al. (2018) argued that the policy of total bans on grazing (for up to 5 years in some grasslands areas) may actually encourage the proliferation of less desirable species. Though this policy is still in place, another policy that mandated a delay in the start of summer grazing in some areas has been modified, in light of the ACIAR program recommendations, to include a required lower stocking rate as well.

Prof. Kemp received that Dunhuang Award from the Gansu government, the Golden Steed Award from the Inner Mongolia government and the Friendship Award from the Chinese government. These awards indicate that the ACIAR projects had a strong influence on the direction of government policy and on grassland management.

Environmental gains from the ACIAR project are still emerging and have not yet been measured in a comprehensive manner. Biophysical modelling projects that, as stocking rate is reduced, the quantity of forage available will increase, and its composition will shift to a higher proportion of desirable species. Some herders have observed this shift already. As the grasslands regenerate, they may be able to sustain higher levels of animal production.

In addition, restored grasslands provide greater protection against wind and water erosion, lessening the severity of dust storms and silting of waterways. Biophysical models developed by the group (Behrendt et al., 2020, p 116), project that the frequency and intensity of dust storms will be reduced, though not eliminated, as the dust comes partly from desert grasslands that always have low grass cover. The risk of wind erosion is greater on summer grazing lands, which tend to be over-stocked compared to winter grazing areas.

The program has contributed importantly to capacity building, as described in Michalk et al. (2020) and Chapter 11 in Kemp (2020) and summarised here. At least 38 post-graduate students (10 PhD and 28 MSc) worked on the program while studying at Chinese universities. Four of the Chinese scientists playing leadership roles in the program received John Dillon Fellowships in research management.

Informal capacity building through mentoring and training programs developed the skills of program staff, for example, in using models, and survey and data collection techniques. Through their ongoing participation in the program, particularly the demonstration farms, many herders gained skills in livestock and pasture management and in livestock marketing that will serve them for many years.

Michalk et al. (2020, p 226) reported that from 2009 to 2018 the program generated 376 publications – of which 273 were refereed papers in international (186) and Chinese domestic (87) journals. The balance of the papers (103) was presented in international and domestic conferences and workshops and as book chapters. The international journal papers were cited 1,060 times or 5.7 times per paper. By co-authoring scientific papers, young Chinese scientists gained new skills, while also adding to the stock of scientific knowledge.

11 Appendix 2: Examples from ACIAR of projects aligned with its strategic objectives

11.1 Food security and poverty reduction

Landcare in the Philippines
(ASEM/1998/052) (ASEM/2002/051)

The ACIAR-funded Landcare projects in the Philippines built directly on tested and proven conservation agriculture practices, complementing these with approaches and mechanisms that would support widespread adoption of conservation agriculture.

A 2019 assessment of results from these investments found that in an up-scaling site in Bohol low income farmers who had adopted contour farming had an increased income in comparison to non-adopters. These changes were more pronounced for farmers who were below the poverty line, suggesting the project had a greater impact for the poorest of the poor. While income improvements were modest, the beneficiaries claimed that the additional income generated from vegetables, banana, coconut, fruit and forest trees enabled them to buy more food, acquire assets, send their children to school and build or repair their houses, among other things.

Additionally. adoption of contour farming resulted in positive environmental changes (reduced soil erosion in their farms, improved farm conditions and less occurrence of landslide). Some beneficiaries even said that their participation in the Landcare project led to some social changes, including gaining for farming expertise recognition and personal growth and confidence building.

Flagship project culminates in increased food security
Eastern and Southern Africa | Crops | International Maize and Wheat Improvement Center

One of our flagship projects—the Sustainable Intensification of Maize–Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA)—concluded in October 2019. This ambitious project sought to help create more productive, resilient, profitable and sustainable maize–legume farming systems across seven African countries. Over the nine years of the project, an estimated 484,000 farmers adopted reduced tillage, cutting their time spent in manual labour by half while increasing farm labour productivity, food production and household income. The project resulted in the release of 40 new maize and 64 new legume varieties, the establishment of 58 agricultural innovation platforms and 57 policy briefs. At the farm level, the impact of adoption rates of at least two conservation agriculture practices could lead to yield increases of 4–6% per year across the region, compared to recently reported increases in Australian crop productivity of about 1.2%.

Improving income of smallholder sandalwood
Vanuatu | Forestry | University of Western Australia

ACIAR has supported sandalwood research in Vanuatu for more than 15 years. A 2020 assessment of the impact of this work found a clear, positive and enduring impact on institutional capacity and smallholder capacity. The economic impact for smallholder farmers is expected to be positive, with sector-wide returns of A$3.8 million from mature trees at harvest, reflecting a benefit: cost ratio of 5.7:1 from our investment. Social analysis of the policy context identified that future policies will play a critical role in maximising returns to smallholders. This relates to the transparency of prices and alternative policy systems that allow for public auctioning of heartwood.

Returns from research partnerships in conservation tillage

Between 1992 and 2003, the Australian Centre for International Agricultural Research (ACIAR) invested in two projects on aspects of conservation tillage (CT) in China and controlled traffic farming (CTF) in Australia (LWR2/1992/009 and LWR2/1996/143). An initial impact assessment of this work conducted in 2005 found a benefit cost ration (BCR) of 36:1. In 2019, ACIAR commissioned an updated, independent assessment of the return on investment from this work.

This study found that adoption levels were much higher than previously predicted. In China, CT adoption was 4x higher than assumed in the 2005 assessment, whereas in Australia adoption of CTF was 3 to 5x higher. Based on the most conservative estimates, the assessment found a BCR of 180.5:1, with a realistic scenario showing that the returns were likely to have been much higher still.

While not seeking to detract from the positive findings, the study also highlighted the challenges of attempting to assess returns on investment after such a long time. The assumptions built into the current impact assessment framework and the requirement to quantify attribution based on these, can risk ACIAR presenting BCR estimates that stretch credulity and fail to reflect the many concurrent factors that contribute to rapid change and development in a sector.

However, the message from this study is clear: timely agricultural research partnerships can accelerate adoption of transformational practices and deliver extraordinarily high value to both Australia and our partner countries. Along with similarly high value returns from collaborations on livestock, citrus production and forestry, this study shows the value to both countries of ACIAR’s collaboration with our Chinese research partners.

11.2 Natural resources and climate change

HORT/2008/033
Improving livelihoods through climate resilience in Fiji Papaya industry

The Fijian papaya industry was fragile, being susceptible to natural disasters, shortages of air freight capacity, and post-harvest losses during the wet season.

New production knowledge, communicated to growers through training and factsheets, on the use of drip irrigation, crop thinning to improve papaya quality, cultivar selection, pre-harvest fungicides, and cyclone management. Cyclone management and recovery techniques are now used by most papaya growers in Fiji.

As a consequence of the Project, the Fiji papaya industry is more resilient. The industry has more capacity to recover from natural disaster. Growers, extension officers, researchers and the value chain have all been trained. Pre and post-cyclone mitigation measures have been adopted and additional production knowledge ensures rapid and high quality post-disaster crops. The industry is following Project recommendations and slowly relocating to less disaster prone areas (sheltered and sloped land to avoid floods and cyclone damage).

Women and youth have benefited from a more resilient papaya sector. Smallholder papaya is grown by family units but around 30% of these enterprises are headed by females and 5% are headed by growers under 30 years of age. Skills required for modern commercial horticulture are substantially greater than the sugar industry and the quality of employment available for rural women and young people has been enhanced by the Project.

Both women and young people are attracted to papaya by the crop's favourable financial returns and year-round cash flow. Smallholder enterprises adopting Project recommendations are estimated to have realised a 20.5% increase in annual income. In total, a present value benefit of $A0.822 million has been estimated for rural women in Fiji as a result of the Project.

Restoring Australia's Great Barrier Reef
Philippines | Fisheries | Southern Cross University

Techniques developed through Southern Cross University to restore degraded coral reefs in the Philippines are now being trialled on the Great Barrier Reef. Results from 3 years of an ACIAR-funded 'coral IVF' research in the Philippines and at Heron Island, off the central Queensland coast, show it is possible to regenerate coral reefs through harvesting millions of coral eggs and sperm to grow new coral larvae. The research is globally significant because more than 60% of the world's coral reefs are under direct threat or have been seriously degraded by human activities and some reefs have been destroyed. The coral reef restoration program is a critical step in protecting Australia's Great Barrier Reef and has the potential to regenerate reefs around the world.

11.3 Human health and nutrition

Enhancing nutrition through COVID-19
Uganda | Fisheries | Cultivating Africa's Future

During the COVID-19 pandemic, innovations to improve nutrition security have become more urgent. ACIAR is investing in the NutriFish project to harness the nutrients of underused fish-based products to address nutritional deficiencies in Uganda's poor communities. In response to COVID-19, the project fast-tracked the development of a maize flour enriched with nutritious silver fish and amaranth seeds. More than 2.5 tonnes of the flour was distributed to breastfeeding mothers, reducing the incidence of micronutrient deficiencies in children under five years of age.

11.4 Gender equity and women's empowerment

Women gain financial independence through household gardens
Indonesia | Soil and Land Management | NSW Department of Primary Industries

A 16-year presence in Indonesia demonstrates the value of playing the long game to build trust and focus on working with women. An ACIAR project enjoyed great success in changing soil management practices by engaging with women farmers in Aceh. The project helped to introduce dry season crops and improve fertiliser management in these systems, resulting in improved livelihoods for farming families. Vegetable production in household gardens managed by women increased household income by A$402 to A$2,000 per year. A total of 725 women were supported in the project to develop a home garden, with some of these women gaining financial independence as a result and some creating businesses out of the production.

Agroforestry improves gender equity in African smallholder communities
Ethiopia, Rwanda, Uganda | Forestry | World Agroforestry

In most East African countries, agroforestry is spearheaded by women and youth because they comprise most of the labour force on the farm. A critical component of the Trees for Food Security project's success has been the efforts to ensure capacity development activities encompass women and youth. The four-year project has trained more than 7,000 community members on proper methods of tree planting, stakes selection, and fodder production across Ethiopia, Rwanda and Uganda. Of these, more than half were women. Through these initiatives, women have raised their level of disposable income from the sale of timber, firewood, tree seedlings and fruits. The training has also empowered the women to take leadership roles in the cooperatives and groups to further influence decision making.

Family farm teams - ASEM/2014/095

The project sought to support women's economic development in order to improve gender equality, family livelihoods and food security. The **aim** was to enhance the economic development of PNG women smallholders by building their agricultural and business acumen.

As a project focused on empowerment of women smallholder farmers, the project delivered strong **gender equity outcomes at the individual, household and community level**. Many farming families improved communication within their households and began to better understand and re-balance gender roles around household and farming labour. There are many examples of women broadening their goals and taking up leadership roles following their participation in leadership training. In all project areas some women indicated that they gained respect in their village due to their new skills and knowledge, and some men shifted their attitudes towards women's leadership, through it is important to note that many women continued to face barriers and resistance. While these were very positive steps to improve family dynamics and relations, there were mixed reports on whether and the extent to which this led to a reduction in family violence and further exploration of this assumed impact is required.

The project has also delivered important **economic outcomes**. There was evidence of widespread adoption of family team-based farming practices, new agricultural practices and business-like approaches to farming which led many farmers to increase their incomes and food security. New family-based farming practices also contributed to women's economic empowerment by leading families to more regularly make joint decisions about money. There was also some evidence that other farming families have begun to adopt these practices and positive indications from ripple effect mapping undertaken on previous pilot locations that some uptake is likely.

ACIAR plays key role in development of the CGIAR Gender Platform

ACIAR (along with other leading donors including the Bill and Melinda Gates Foundation, USAID and the Canadian IDRC) was instrumental in the establishment of the new CGIAR Gender

(Generating Evidence and New Directions for Equitable Results) Platform. We are committed to tackling gender inequality in research design, delivery and impact and have been a strong and engaged supporter of the platform. Integrating gender in agricultural research-for-development in CGIAR is a smart and sensible development as it addresses the needs of both women and men, while recognising and addressing unequal access to resources and decision-making.

11.5 Inclusive value chains

Unlocking Pacific pearl potential
Fiji, Tonga, Papua New Guinea | Fisheries | University of the Sunshine Coast

Cultured half-pearls are the Pacific's most valuable and promising aquaculture commodity. ACIAR-supported researchers are working with communities to harness this ocean resource to empower women and improve coastal livelihoods. Through ACIAR, the women have been trained in handicraft, and jewellery production using hand-held tools, as the village does not have electricity. The jewellery is made from mabé pearls and polished to value add and sold at a range from A$20-90. Ravita village women in Fiji have had two successful harvests with each harvest bringing about A$6,000 to the community. The pearl farms have contributed towards household funds and future village development such an evacuation centre. With the region prone to natural disasters, the women are building an evacuation centre from the money they have collected from pearl farming.

Indonesian farmers cash in on higher quality milk
Indonesia | Agribusiness | University of Adelaide

Smallholder Indonesian dairy farmers in West Java are being paid more when they deliver "better" milk as part of an ACIAR-supported trial to boost the quality of milk production in the country. Low milk quality is a problem for Indonesia's dairy sector, with high bacterial counts impacting product shelf-life and restricting the number of products it can be used for. The trial was conducted in the village of Cisarua in West Java, with the local milk processor Cimory, and the village level cooperative KUD Giri Tani and its farmer members. Farmers typically make about 2,150 Indonesian Rupiah (19 Australian cents) profit per litre of milk, but under the trial, they can receive up to 1,000 rupiah on top of this for high-quality milk. The trial follows training for local dairy farmers which introduced them to practices that reduce bacterial counts.

Dairy in Pakistan - LPS-2010-002

The projected aimed to produce model dairy farms and extension approaches that could be scaled out throughout Pakistan by piloting pro-poor dairy farming extension approaches.

Farmers' adoption of scientific and extension knowledge and practices developed through the project have resulted in recorded increases in sales and profits from increased milk yields, healthier calves, and farmer diversification into milk value added products such as ghee, cream, ice-cream, and yogurt.

Extension workers delivered inclusive extension services that utilized a **'whole family extension approach'**. The approach recognises the value of women, young people and children's participation in the smallholder farm system and has resulted in adoption rates of up to 80% of extension knowledge and practices, much higher than previous adoption rates. Reducing the productivity impacts of barriers that limit women's participation is important to sustaining gains as women contribute up to 80 per cent of work inputs in dairy farms.

Enhancing private sector-led development of the Canarium nut industry in Papua New Guinea *FST/2014/099*

The galip nut project built on a decade of ACIAR research on galip processing techniques and previous EU funding to establish a pilot galip processing factory at NARI in Keravat in ENB. It employed a whole of value-chain approach, researching markets, providing technical advice, building capacity, mentoring businesses, and giving private and public sector stakeholders access to infrastructure. It aimed to attract the private sector into this new agribusiness at three different scales: smallholder and small scale entrepreneurs, SMEs, and large scale processors.

The existence and success of this model did influence other private sector investors to enter the industry. By the conclusion of the project, four private sector processors were processing and selling galip nut products commercially. Given the lack of interest from SMEs and large-scale processors at the beginning of the project, this is a significant achievement. Over the life of the project the NARI factory has directly purchased over 400,000 kina of unprocessed galip nut from small holder farmers and entrepreneurs in ENB and surrounding areas, supporting the livelihoods of over 1300 farmers by the end of 2018. The other processors are now also buying galip nut from smallholders, with an estimated farm-gate value of 300,000-400,000 kina per annum. Sase studies indicate that this additional income is assisting women smallholders to cover living expenses and pay for costs associated with schooling and health care.

11.6 Enhancing Science and Policy Capability in partner countries

Pakistan policymakers drive policy reforms with ACIAR evidence
Pakistan | Agribusiness | Monash University

An ACIAR project in Pakistan has provided evidence for policymakers to drive much-needed reform to marketing of fresh produce. Despite being a major world horticultural producer, government regulation dictated that farmers could only sell produce at agricultural produce markets. There was considerable appetite for reform, and a growing understanding that this outmoded marketing model was holding Pakistan's horticultural industry back. The project took a multipronged approach to provide empirical evidence to support policymakers. The federal government has been receptive, and in July the Prime Minister announced a PKR309 billion national agricultural 'emergency' program, including a PKR23.6 billion (A$223 million) scheme to transform Punjab's agricultural produce markets.

ACIAR research outcomes reach thousands
Global | Water and Climate | Sustainable Development Investment Portfolio

ACIAR-funded research outcomes underpinned a massive open online course run by Bihar Agricultural University and the International Maize and Wheat Improvement Center. More than 4,000 participants from 60 countries enrolled in the course, which was presented in both Hindi and English. The course drew on eight years of successful ACIAR activities across the Eastern Gangetic Plains, focusing on conservation agriculture-based sustainable intensification approaches, which have been adopted by more than 90,000 farmers and have been shown to reduce labour and crop establishment costs, improve farm incomes and decrease greenhouse gas emissions from agriculture.

Evaluating the impact of ACIAR's capacity building program
Global | Capacity Building

A 10-year tracer study of the John Allwright Fellowship Program (JAF) has revealed impressive results. Up to ten years after completing their studies in Australia, more than 60% of alumni still have current, active links with ACIAR staff. Also, a significant majority (85%) of alumni remain active agricultural researchers. The survey covered 378 alumni over the period 2010-2019, including 108 women and 270 men.

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