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Impact assessment of ACIAR-supported research in lowland rice systems in Lao PDR

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Impact assessment of ACIAR-supported research in lowland rice systems in Lao PDR

John Mullen
Consultant

Bill Malcolm
University of Melbourne

Bob Farquharson
University of Melbourne

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Cover: Rice grower, Lokhan Khomsoikhan, has adopted new rice-sowing technology introduced to farmers in the Savannakhet area of Lao PDR in ACIAR-funded research. Photo: Majken Soegaard

Foreword

The international partnerships that underpin research supported by the Australian Centre for International Agricultural Research (ACIAR) aim to improve the productivity and sustainability of agricultural, forestry and fisheries systems, as well as the resilience of food systems in partner countries. Importantly, this research also helps improve Australian agricultural systems.

ACIAR undertakes independent assessments of research projects to ensure that we are delivering benefits for smallholder farmers and communities in partner countries, and that we learn from past investments to better design and implement future research-for-development projects.

Since its inception in 1982, ACIAR has supported rice research in partner countries to improve productivity and the sustainability of rice production. Typically, this research provides farmers with greater options for rice-based farming systems to increase incomes, diversify production, and respond to environmental challenges, such as climate variability and climate change.

Some lowland rainfed rice cropping areas in Lao People's Democratic Republic often suffer dry conditions during the production cycle. To address this chronic setback, ACIAR supported three projects between 1997 and 2012 that sought to develop more drought-tolerant rice varieties, and introduce techniques of direct seeding rice to farmers.

Compensating for significant difficulties caused by gaps in available data, the assessors drew on the judgement of scientists, anecdotal evidence and their own observations to analyse the links between the resources invested in these projects, and consequent changes in farm practice that improved the welfare of Lao rice growers.

The direct seeding rice methodology, and the technology suited to the lowlands of Laos, which evolved during the three ACIAR projects emerged at a time when farm labour was more scarce and expensive due to increasing job opportunities in a strengthening economy. Proof that well-managed direct-seeded crops could produce yields comparable with transplanted crops was invaluable to farmers deciding whether to adopt the new technology.

Direct seeding is a farming system change that requires new skills, particularly in weed management and attention to soil conditions necessary for successful establishment. The assessors found that the work of the three ACIAR projects laid the foundation for what is now an inevitable progression in dryland rice growing in Laos. They found that had the work of the three projects not been done, it would now be an urgent priority. As such, the ACIAR investment has accelerated by at least five years the introduction of the greatly needed direct-seeding technology.

The adoption of the new dryland varieties and direct-seeding has also produced positive social impacts. Farm families who no longer engage in the onerous task of transplanting rice are finding opportunities for various off- and on-farm activities that benefit their livelihoods and improve the welfare of all, especially women.

Overall, this evaluation suggests that despite some uncertainties—such as adoption and attribution—the three projects generated an excellent return on the ACIAR investment and lasting benefits for the livelihoods and food security of smallholder farmers in Lao People's Democratic Republic.

Andrew Campbell
Chief Executive Officer, ACIAR

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Acknowledgements

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Professor Rob Cramb and the late John Shiller also spent valuable time with us when we visited the University of Queensland. We are very grateful for the generous help provided by many people on our visit to Laos including:

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- Mr Khamphou Phouyyavong, Deputy Director of Economic and Rural Development Research Centre, National Agriculture and Forestry Research Institute, Vientiane Province
- Ms Khanamany Inphayalath, Deputy Director, Rice Research Institute, Vientiane Province
- Dr Chanthakhone Boualaphanh, Director, Rice Research Centre, Vientiane Province
- Mr Somephone Sengdara, Deputy Director, Rice Research Centre
- Ms Vilayphone Sourideth, Agronomist, Rice Research Centre
- Mr Sithouane Sidavong, Director, Pakcheng Agricultural Research Centre, Vientiane Province
- Dr Tamara Jackson, Research Fellow at the Graham Centre, Savannakhet Laos.
- Lao Farmer Network farmer group, Cheng Village, Thourakhone District, Vientiane Province
- Dr Phoudalay Lathvilayvong, Director, Thasano Agricultural Research Centre, Savannakhet Province
- Dr Sysavanh Vorlasan, Provincial Agriculture and Forestry Office, Savannakhet Province
- Dr Jacqui Mitchell, University of Queensland
- Dr Phetmanyseng Xangsayasane, Senior Rice Breeder, Deputy Director for Research, National Agriculture and Forestry Research Institute
- Kingkeo Khonsida and Kangphosi farmer group, Outhoumphone District, Seno Township, Savannakhet Province
- Ms Kaisone Sengsoulichan, Provincial Agriculture and Forestry Office, Savannakhet
- Mr Sisast Rasaphonh, Deputy Director Provincial Agriculture and Forestry Office
- Mr Sayaloun Duangpyseth, Director, Agricultural Development Centre, Xayphouthong District
- Farmer group, Xaytana Village, Champone District.

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
FAO	Food and Agriculture Organization of the United Nations
GIS	geographic information system
Lao PDR	Lao People's Democratic Republic
PVS	participatory variety selection
TGI	total gross income
TVC	total variable cost

Executive summary

This report provides an assessment of the impact of three ACIAR-supported projects dealing with lowland rice production in the Lao PDR:

- *Plant breeding strategies for rainfed lowland rice in northeast Thailand and Laos* (CSI/1995/100)
- *Increased productivity of rice-based cropping systems in Lao PDR, Cambodia and Australia* (CIM/1999/048)
- *Increased productivity of rice-based cropping systems in Lao PDR* (CSE/2006/041).

The projects were led by Professor Shu Fukai from the University of Queensland and Dr Monthathip Chanphengsay from the National Agriculture and Forestry Research Institute in Laos. The projects contributed to the development and adoption by farmers of rice varieties that better tolerate episodic dry seasons common to lowland rice areas in Laos, and to the adaptation and adoption of direct-seeding technologies. These projects spanned a period from 1997 to 2012, but impacts will continue beyond that time.

The greatest difficulty faced in conducting the assessment was the lack of data—published or otherwise—on the area of rice plantings by variety, and the area of direct-seeded rice. There was also great diversity in rice production methods across the target population for these two technologies. This reflects variations in soil type, climatic conditions, and economic and social incentives facing farm families, most of whom operate at a semi-subsistence level.

Discussions with Australian and Lao scientists, and with farmer groups in Laos were invaluable in forming the judgements we had to make in assessing the impact of the new technologies.

Lindner et al. (2013) classified each of a series of ACIAR impact assessments as being either conceivable, plausible or convincing, as the level of transparency and objective support for key assumptions increased. Given our reliance on the judgement of scientists, anecdotal evidence and our own observations, as well as the lack of objective data on adoption of the technologies, we self-classify this impact assessment as being plausible.

Despite the uncertainties around key parameters, such as adoption, it is likely that this set of projects has been a good use of ACIAR funds, generating net benefits, and earning returns commensurate with other investments in agricultural research, development and extension.

A proportion of Lao rice growers in lowland areas have already benefited from the two technologies—more drought-tolerant rice varieties and the direct-seeding technology—and the flow of benefits is likely to increase as adoption spreads.

Other benefits, though difficult to measure and value, have also resulted from these projects. For example, significant new scientific knowledge was built, as evidenced by a strong publications record. Scientific capacity has also been built through informal means, such as mentoring and 'learning by doing', which often led to Lao scientists involved in the project to pursue higher degrees, some as John Allwright Fellows.

The direct-seeding technology enables farm families to reduce their time on the onerous task of transplanting rice, providing opportunities for other activities, including employment, growing vegetables, tending livestock, managing the household and more leisure.

Our aim was to develop a plausible narrative that links the resources, of ACIAR and its partners invested in these projects in Laos and Australia, with changes in farm practice and then to estimate changes in the welfare of Lao rice growers.

Potential gross benefits were estimated using welfare analysis in a market model for Lao rice. A time stream of benefits (in real terms) was derived by applying projections about the adoption of the technologies and the share of benefits attributable to the ACIAR projects, which was then offset against the investment stream.

The present value in 2017 of ACIAR and partners' investment in the three projects, estimated using a 5% discount rate, was A$14.1 million (all monetary values in 2017 A$).

The present values in 2017 of the streams of measurable benefits from the adoption of more drought-tolerant varieties and direct-seeding technology were A$18.5 million and A$44.1 million, respectively, for a total of A$62.6 million (at a 5% discount rate).

The net present value of these streams of benefits and costs in 2017 was A$48.5 million.

The benefit:cost ratio was 4.44:1, and the internal rate of return was 16.0% (based on the assumption that interim benefits are reinvested at the rate of 16.0%).

The modified internal rate of return allows for a market rate of reinvestment to be applied. We have assumed that the net benefit stream can be reinvested through the life of the investment, at a rate of 5%, giving a modified internal rate of return of 11.5%.

By these three measures, the three projects, whose impact has been assessed in this report, are likely to have been a good investment from ACIAR's perspective. This conclusion is quite robust to the uncertainty surrounding our assumption about the rates of adoption of the technologies, and the share of benefits from the two technologies attributable to the ACIAR projects. If both these parameters are halved (approximately) for both technologies—an unlikely scenario in our view—the investment in the projects still earns the required rate of return.

1 Introduction

For many years, ACIAR has invested in research to improve the welfare of farm families in Laos (and other South-East Asian countries) who grow rice for their major source of food. This report provides an assessment of outcomes from three projects focused on new technologies for lowland rice producers.

Impact assessment requires outcomes to be plausibly linked to project resources. The boundaries of these sets of outcomes and resources are not independent—changing the set of outcomes changes the set of projects, and vice versa. So, the scope of an impact assessment depends critically on the informed, but still subjective, judgements of the analysts.

Fukai et al. (2016) suggested that drought-tolerant varieties of rice, and direct-seeding technologies are the outputs of the ACIAR programs that have had the greatest influence on lowland rice farmers.

Working backwards, we identified three ACIAR-supported projects that were likely to have made significant contributions to the development and adoption of these outputs (recognising that other earlier projects are likely to have built some of the capacity applied in these three projects).

This report provides an assessment of the impact of the following projects dealing with lowland rice production in the Lao PDR:

- *Plant breeding strategies for rainfed lowland rice in northeast Thailand and Laos* (CSI/1995/100)
- *Increased productivity of rice-based cropping systems in Lao PDR, Cambodia and Australia* (CIM/1999/048)
- *Increased productivity of rice-based cropping systems in Lao* PDR (CSE/2006/041)

While the focus has been on economic outcomes in delineating the boundaries of the impact assessment, outcomes, including contributions to scientific capacity and knowledge and changes affecting people in farm households from changes to farm systems, were also identified.

Professor Shu Fukai from the University of Queensland and Dr Monthathip Chanphengsay from the National Agriculture and Forestry Research Institute in Laos were leaders in all three projects.

1.1 Objectives

The terms of reference of this impact assessment:

- identify and quantify the investments by ACIAR and its partners in projects CSI/1995/100, CIM/1999/048 and CSE/2006/041
- describe the project outputs, including new technologies developed, scientific capacities developed and scientific knowledge disseminated
- assess changes in yields, inputs, crop rotations and risk at the farm level for lowland wet and dry season rainfed and irrigated farming systems in Laos
- summarise the changes at farm level in net returns to rice enterprises, and their volatility
- extend the adoption study by Fukai et al. (2016) to develop actual and projected (2015–2050) adoption profiles for these technologies and farming systems
- assess how much Lao research, development and extension staff use agro-climatic geographic information system (GIS) mapping established during the projects to develop dynamic crop calendars to help with planting, management and harvesting decisions in the face of climate uncertainty
- assess the potential for more widespread adoption of non-rice crops in the dry season on irrigated farms
- develop plausible scenarios about how the lowland rice farming systems in Laos might have developed without the ACIAR-supported projects
- conduct economic and financial analysis of these flows of net returns, and project investments out to 2050
- describe the social impacts of technologies, particularly if direct-seeding technology has changed the demand for labour provided by women (requiring an understanding of the opportunity cost of this labour)
- describe how human scientific capacities developed during these projects has been applied elsewhere in agriculture in Laos to improve the welfare Lao farmers
- describe likely ‘spillovers’ of these technologies to Cambodia and Thailand.

1.2 Collecting information for this impact assessment

The information on which this assessment is based came from various sources. The ACIAR databases provided the information on investment by ACIAR and its partners in these projects.

Many project outputs were described in project annual reports and publications arising from the projects. These reports also provided some estimates of likely on-farm impacts of the technologies, and described features of lowland rice production in Laos.

Data on area, production, and price of rice in Laos were found in Food and Agriculture Organization of the United Nations (FAO) databases. Many other reports, referenced in this report, were also used to give us an understanding of lowland rice production, and the likely contribution of the ACIAR projects to the development and adoption of these technologies.

We visited Professor Fukai and others involved in the projects at the University of Queensland, and have had ongoing correspondence with him throughout this assessment.

Finally, we spent 10 days in Laos talking with the following scientists and institutions:

- Mr Khampheng Mounmeuangxam, Assistant Manager, ACIAR, Australian Embassy, Vientiane
- Dr Bounthong Bouahom, Director General, National Agriculture and Forestry Research Institute, Vientiane Province
- Ms Siriphone Chanthala, Senior Officer Administration, International Rice research Institute, Laos Office, National Agriculture and Forestry Research Institute, Vientiane Province
- Mr Khamphou Phouyyavong, Deputy Director of Economic and Rural Development Research Centre, National Agriculture and Forestry Research Institute, Vientiane Province
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- Mr Sisast Rasaphonh, Deputy Director, Provincial Agriculture and Forestry Office
- Mr Sayaloun Duangpyseth Director, Agricultural Development Centre, Xayphouthong District
- Farmer group, Xaytana Village, Champone District.

Three farmer groups (Table 1) generously gave their time as we sought to understand lowland rice production, and how drought-tolerant varieties and direct seeding fitted into their farming systems.

Table 1: Farmer group meetings

Date	Village	District	Province	Farmers	
				Male	Female
31 May 2018	Cheng	Thourakone	Vientiane	5	5
4 June 2018	Kangphosi	Outhoumphone	Savannakhet	5	6
5 June 2018	Xaytana	Champhone	Savannakhet	5	3

1.3 Structure of the report

The starting point for rigorous impact assessment is an explicit impact pathway that describes plausible links between the resources used in ACIAR research projects and economic outcomes, as well as, if relevant, environmental and social outcomes for the target population of lowland rice farmers in Laos and the whole Lao community.

Developing explicit impact pathways is a key recommendation of reports by Davis et al. (2008), and Gordon & Chadwick (2007) about the method of impact assessment.

Impact pathways need:

- a clear narrative about the target population for the technologies
- a clear narrative about potential changes in farming operations (key inputs in estimating consequent changes in farm costs and returns)
- evidence (or plausible assumptions) about the rate and extent of adoption of the technologies
- description of plausible environmental and social impacts, including additions to scientific capacity.

All resources used by ACIAR and partners to achieve these outcomes need to be described. Impact pathways also require a credible assessment of the extent to which outcomes can be attributed to ACIAR-supported projects (the 'with' and 'without' ACIAR support scenarios).

The structure of this impact assessment report derives from these key components of an impact assessment pathway.

- Section 2 describes the target population for the technologies assessed
- Section 3 describes the objectives and key outputs of the three projects, and presents the investment by ACIAR and its Australian and Lao partners.
- Section 4 describes the method used in assessing economic outcomes.
- Sections 5 and 6 present the impact of drought-tolerant varieties and direct seeding, in terms of changes in yields, production costs, and enterprise and farm profitability. Projections are made about the adoption of the technologies, and about how the industry would have developed without the ACIAR-supported projects.
- Section 7 is a summary of the estimated flows of benefits from the two technologies. These benefits are offsets against the flow of investment in the projects by ACIAR and partners to derive the usual measures of returns to investment. The projects made considerable investment in human and scientific capacity. Direct seeding released household members, especially women and those working off-farm, from transplanting rice seedlings, making other activities possible.
- Section 8 describes and assesses social outcomes more fully.
- Section 9 provides a summary of findings.

2 Rice in Laos

2.1 The rice industry

Rice is a staple crop for more than 700,000 families (World Bank 2012). Rice was traditionally grown on a subsistence basis, but by 2011 71% of households sold some rice.

Average farm size is 2.4 ha, with about one-third of farmers having 1 ha, one-third having 2 ha and one-third having more than 2 ha (Onphanhdala 2009). Glutinous rice accounts for 95% of paddy production.

In the 1990s, total annual rice production in Laos was about 1.5 million t, after growing slowly from 0.5 million tonnes annually in the early 1960s.

Since then, the production of rice has grown steadily to more than 4 million t/year in 2016 (Table 2; Figure 1).

Table 2: Area, production, yield and price of rice in Laos, by year, 1990–2016

Year	Area (ha)	Production (t)	Yield (t/ha)	Price real (kip/t)
1990	650,300	1,491,495	2.29	
1991	556,878	1,223,830	2.20	3,484,848
1992	565,749	1,502,361	2.66	3,428,571
1993	551,708	1,250,630	2.27	3,378,378
1994	610,960	1,577,023	2.58	3,250,000
1995	559,900	1,417,829	2.53	2,974,771
1996	553,741	1,413,500	2.55	3,241,093
1997	601,295	1,660,000	2.76	6,093,750
1998	617,538	1,674,500	2.71	4,932,773
1999	717,577	2,102,815	2.93	3,044,280
2000	719,370	2,201,700	3.06	2,507,375
2001	746,775	2,334,700	3.13	2,439,024
2002	738,104	2,416,500	3.27	2,450,980
2003	756,317	2,375,100	3.14	2,335,288
2004	770,320	2,529,000	3.28	2,275,649
2005	736,020	2,568,000	3.49	2,229,753
2006	742,905	2,663,700	3.59	2,235,306
2007	727,863	2,710,050	3.72	2,571,127
2008	786,265	2,969,910	3.78	2,919,773
2009	818,561	3,144,800	3.84	3,195,156
2010	855,114	3,070,640	3.59	3,303,501
2011	817,250	3,065,760	3.75	2,983,247
2012	933,767	3,489,210	3.74	2,427,033
2013	891,190	3,414,560	3.83	2,804,758
2014	957,836	4,002,425	4.18	2,673,323
2015	965,152	4,102,000	4.25	2,633,244
2016	973,327	4,148,800	4.26	2,556,264

Source: FAO (2018) FAOSTAT.

Some of this increase is the result of an increase in the area sown to rice. From about 0.6 million ha in the late 1990s, the area sown grew to almost 1 million ha in 2016 (Figure 2), at an average annual rate of 2.2% (1990–2016).

Adoption of new varieties, and expansion of irrigation infrastructure are the other main reasons for the increase in rice production in Laos (World Bank 2012). The average annual rate of growth in production from 1991 to 2016 was 4.6%, perhaps slowing in recent years.[1]

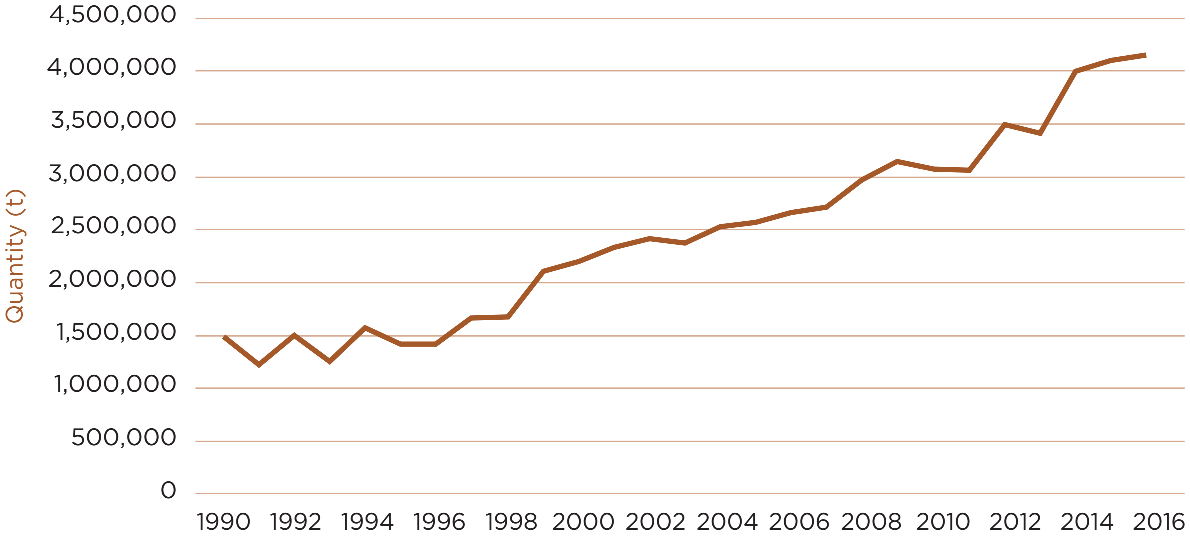

Figure 1: Production of rice in Laos, 1990–2016

Source: World Bank 2012.

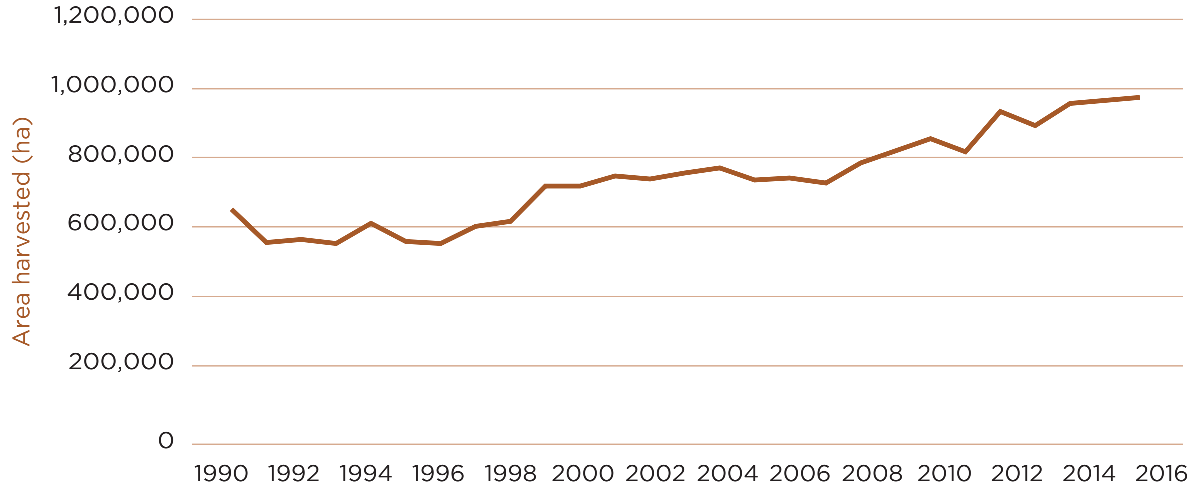

Figure 2: Area of rice harvested in Laos, 1990–2016 (ha)

Source: FAO (2018) FAOSTAT.

1 Growth estimated by regressing the natural log of production against a constant and a time trend, using the LINEST estimator in Excel.

Increases in yield have made an important contribution to the increase in annual rice production in Laos. Before 1980, the average yield of rice was less than 1.5 t/ha (Figure 3). In the next decade to 1992, yield increased to 2.5 t/ha. Shiller et al. (2006) argued that changes in government policy—including a large increase in price, and, particularly, improved incentives for farmers—contributed to the increase in yield. The first improved seed varieties had also appeared by the 1980s (World Bank 2012).

The World Bank (2012) identified two phases in the growth in yield from 1991 to 2011. Yield per hectare grew strongly to 2002 (to 3.3 t/ha) at an annual rate of 4.1%. This was attributed to the introduction of improved varieties from International Rice Research Institute sources in the mid-1990s.

Traditional varieties had accounted for 95% of production. By 2002, 80% of production came from improved varieties (65%–80% for wet season crops, and 100% for dry season crops).

The World Bank (2012) report noted some evidence that farmers began applying fertiliser during this time. There was also a shift in production from uplands to the dry and wet season lowlands systems, where returns were higher. The World Bank reported that from 2002 to 2011, yield grew more slowly, at an annual rate of 0.9% (3.75 t/ha).

Recent FAO data found that in 2016, average yield was 4.5 t/ha. Using these data, we estimated that from 1990 to 2016, yield grew at an average rate of 2.5% per year.

There is some evidence that the rate of growth in yield has slowed. From 1990 to 2002, the average annual rate of growth was 3.0%, and from 2002 to 2016 it was 1.2% (Figure 3). Estimated growth rates are sensitive to starting and finishing points, particularly over short periods when climate is variable. In our view, it seems unlikely that the rice industry in Laos is experiencing the same constraints to increasing yields as is occurring in other developed countries.

Several factors are likely to have influenced rice yields in recent decades, including:

- a flow of varieties better suited to local environments from breeding programs, and extension programs to encourage their adoption
- better crop husbandry, in the form of plant nutrition and weed and disease control
- increased use of fertilisers
- expanding irrigation infrastructure and dry season cropping
- increased adoption of direct-seeding technologies, in response to the rising opportunity cost of farm labour, with concomitant weed control issues, which might have constrained yield growth in some systems.

Modelling the future impact of policy changes in Laos, the World Bank report assumed that wet season yield per hectare would continue to grow at a rate of 0.7% per year from 2016 to 2020, and dry season yield would grow at an annual rate of 1.7%.

The focus of this impact assessment is on the contribution of ACIAR-supported research to economic and other gains from more drought-tolerant rice varieties, and from direct seeding of rice.

These issues are discussed in depth later in this report.

2.2 The price of rice

FAO data on farm-gate price of paddy in Laos have been used. The FAO reports prices in standard local currency units. These nominal prices have been deflated by the Lao gross domestic product deflator to arrive at a real-farm gate price.

The real price of paddy in Laos was about 3.5 million kip/t in 1991. There is an anomaly in the data in the late 1990s, which we don't attempt to explain. Our interest is in the price of rice since 2000, when the outputs from the ACIAR projects under review emerged.

In nominal terms, the price of rice has risen from 1.0 million kip/t in 2001 to more than 2.5 million kip/t in 2016. The real price was 2.4 million kip/t in 2001, and 2.5 million kip/t in 2017 (2017 prices). It grew strongly from about 2006 to a peak of about 3.3 million kip/t in 2009 (Table 2; Figure 4). Farmers and research and extension staff commonly suggested a price for rice of 2,500 kip/kg (2.5 million kip/t).

In some districts, farmers said the price they received was 1,800–2,000 kip/kg. This might reflect distance from the market, or few buyers in their area. Most farmers said that price did not vary between varieties. This was difficult to understand, given the quality difference between varieties. One group identified a premium of 500 kip/kg for TDK8.

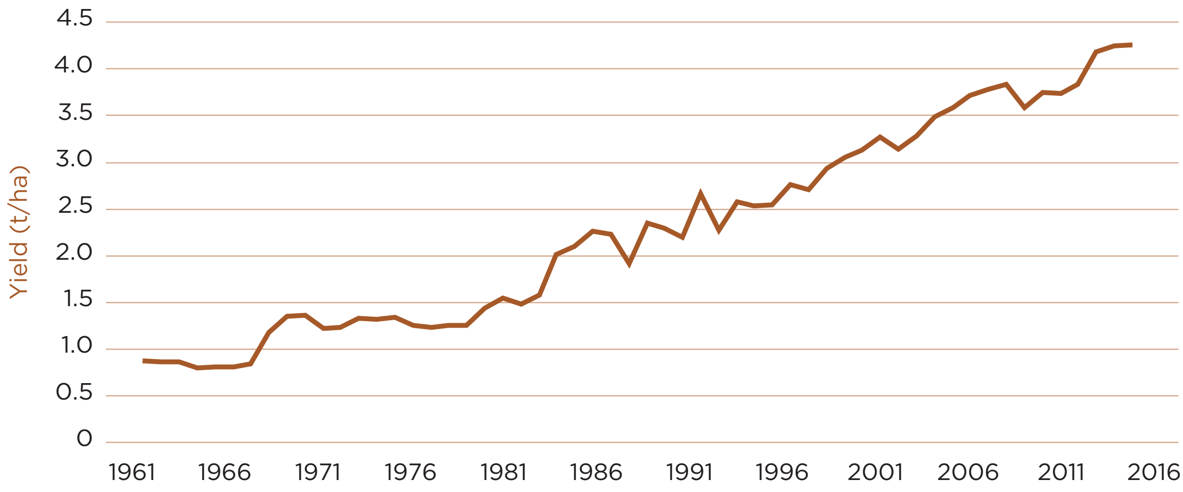

Figure 3: Average yield of rice for Laos, 1961–2016 (t/ha)

Source: FAO (2018) FAOSTAT.

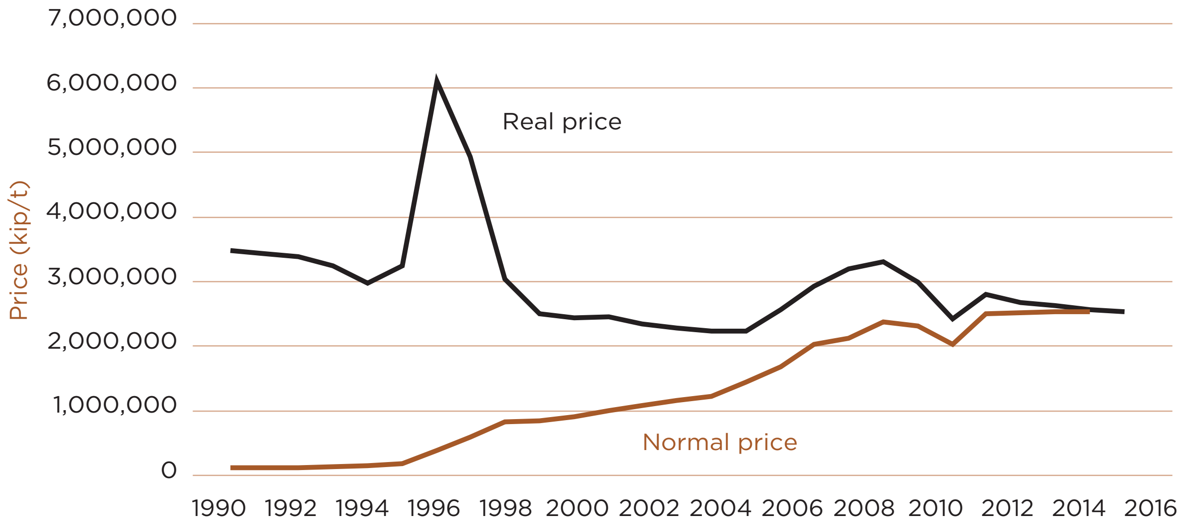

Figure 4: Nominal and real prices for rice in Laos, 1990–2016 (kip/t)

Source: FAO (2018) FAOSTAT.

Seasonal price variation was a problem for all farmers. One group reported that price varied between 1,800 and 2,300 kip/kg, while another reported a range of 1,500 to 2,500 kip/kg.

We used a price of 2,500 kip/kg in the rice gross margin budgets that form the basis of estimates of net benefits from the research. This is a little below the projected price from recent World Bank reports, although these projections also suggest the real price of rice will continue to drift down in coming years. The World Bank (2012) noted that glutinous rice markets in Laos are not closely linked to world rice markets, which are dominated by Indica varieties.

An important assumption of the simple market model we used to estimate welfare gains is that there are no distortions in the market for rice. When governments intervene to support prices, subsidise inputs to farmers or lower prices to consumers, the incentives faced by farmers and consumers are altered. The estimates of potential welfare impacts of new technology depend on how these distortions are treated.

The World Bank (2012) reported that, at least from 2005–06 to 2010–11, Lao rice growers were in effect being taxed in all but one of these years. It noted that most support was in the form of irrigation subsidies (lower electricity prices and investment in infrastructure) and subsidised credit, with most of this support going to farmers involved in irrigated cropping.

These subsidies were dwarfed by the extent to which the external border price (for Thai rice in this case) exceeded the farm-gate price of glutinous paddy in Laos (after adjusting for transport and other costs).

Laos farm-gate prices of rice were lowered below external prices by export bans and price ceilings. This price divergence—the nominal protection rate—varied markedly over the 6 years, from +13% in 2008–09 to –34% in 2006–07.

The effect of the artificially-reduced Lao farm-gate prices of rice is that the rice sector in Laos would likely have been larger. In this case, the estimates of the net benefits of the technologies would have been larger under a Lao rice economy that was more market oriented.

A mitigating factor is the extent of informal exporting of rice over the Thai and Vietnam borders. The World Bank (2012) estimated that this informal trade might have amounted to 100,000 tonnes over that time—about 15% of production—and was much larger than official exports. In view of this uncertainty we did not attempt to re-estimate and adjust the analysis for the extent to which Lao rice growers are being taxed (or subsidised).

2.3 The lowland rice industry

Droughts and floods are a characteristic of lowland farming systems in Laos. Shiller et al. (2006) noted that 'in the 37-year period from 1966 to 2002, for every year, at least part of the country was affected by either drought or flood, or a combination of both'.

Such climatic variability influences many crop management choices that farmers make. It motivated the direction of the ACIAR research program towards developing and promoting varieties of rice that were more resistant to drought than the varieties that were available.

While labour saving is a dominant attraction of direct seeding, this technology also gives farmers some flexibility in sowing decisions at a time when rainfall is uncertain. Considering how technologies change the risks farmers face is an important component of assessing their impact.

The main ACIAR research sites were in the provinces of Vientiane, Savannakhet and Champasak. But the project team suggested that their work on drought-tolerant varieties and direct seeding was relevant to all lowland rainfed and irrigated rice areas in Laos. This is the target population for this impact assessment.

The great majority of rice production in Laos occurs in:

- rainfed lowlands in the wet season
- bunded fields under paddy conditions, with some grown as irrigated rice, in the dry season

The rest is grown in uplands (Schiller et al. 2006). Production during the wet season in lowland systems accounts for about 80% (630,000 ha) of total paddy production.

Irrigated dry season production has increased to almost 15% (100,000 ha), and upland production consequently has declined to about 8% of total paddy production. In the dry season, non-irrigated land is used for low intensity livestock production.

Figure 5 shows a map of Laos and provinces.

Figure 5: Provinces of Laos

Source: Wikipedia.

Table 3 provides information on harvested rice area, production and yields in 2016, by province. More than half (56%) of total wet season rice production was from the central region, and 29% from the southern region. Rice yields were about 4.5 t/ha.

Many factors influence the variety of rice farmers grow. Much rice is still grown on a semi-subsistence basis, so, as well as crop performance, the eating quality, aroma and colour of glutinous varieties are important in the selection of varieties to grow.

Before the 1990s, nearly all rice varieties were traditional glutinous and photo-period sensitive varieties. From the mid-1990s, farmers adopted newly released varieties, and by 2002, more than 80% of rice grown was newly released varieties, though still mostly glutinous. In 2018, a proportion of the crop is grown to sell, so market demand also influences variety choice. Non-glutinous varieties might be grown, but similar quality characteristics remain important.

Yield, particularly for the marketed share of the crop, is an important consideration. Soil and climatic conditions influence the choice of variety through their impact on yield. Currently, farmers use 4–5 varieties of rice in their systems. Typically, they retain seed for several years, and yields fall as seed quality declines.

Table 3: Rice area harvested, production and yields, by province, 2016

	Lowland wet season rice				Irrigated dry season rice			
	Planted area (ha)	Harvested area (ha)	Yield (t/ha)	Production (t)	Planted area (ha)	Harvested area (ha)	Yield (t/ha)	Production (t)
Province								
North								
Phongsaly	7,720	7,720	4.94	38,100	5	5	4.40	22
Luangnamtha	9,585	9,585	4.54	43,500	230	144	4.65	670
Oudomxay	15,260	14,299	4.63	66,200	253	206	4.66	960
Bokeo	14,565	14,565	4.89	71,200	1,520	1,100	4.85	5,340
Luangprabang	14,095	14,012	4.85	68,000	1,560	1,558	4.77	7,430
Huaphanh	12,770	12,754	4.56	58,200	1,500	1,468	4.41	6,468
Xayabury	32,390	32,390	4.79	155,000	3,364	3,364	4.85	16,300
Total	*106,385*	*105,325*	*4.75*	*500,200*	*8,432*	*7,845*	*4.74*	*37,190*
Central								
Vientiane Capital	53,850	53,850	4.56	245,600	18,118	18,118	4.95	89,700
Xiengkhuang	18,390	18,390	4.43	81,500	–	–	–	–
Vientiane Province	52,950	52,950	4.43	249,000	8,136	8,136	4.85	39,450
Borikhamxay	37,345	37,325	4.12	153,600	1,637	1,587	4.88	7,750
Khammuane	80,380	80,380	4.29	345,000	9,040	9,040	5.37	48,500
Savannakhet	191,940	191,940	4.33	830,800	29,270	29,270	5.19	151,800
Xaysomboon	7,170	7,170	3.63	26,000	15	15	4.00	60
Total	*434,855*	*434,835*	*4.38*	*1,905,500*	*66,201*	*66,151*	*5.10*	*337,200*
South								
Saravane	76,520	76,520	4.53	346,500	12,895	12,895	5.27	67,900
Sekong	9,250	9,250	4.35	40,200	600	600	4.50	2,700
Champasack	114,650	114,650	4.47	512,000	10,760	10,760	5.32	57,200
Attapeu	21,300	21,300	3.88	82,600	412	412	4.25	1,750
Total	*221,720*	*221,720*	*4.43*	*981,300*	*24,667*	*24,667*	*5.25*	*129,550*
Grand total	**762,960**	**761,880**	**4.45**	**3,387,000**	**99,300**	**98,663**	**5.11**	**503,940**

Source: Unpublished data from Provincial Agriculture and Forestry Offices.

The choice of varieties is also driven by the availability of seed from either government or private sources. Government research stations play a role in organising, with farmers, systems of multiplication of a limited number of preferred varieties.

The annual cropping cycle begins in May or June, when the wet season arrives. Harvest is during the dry season in October and November.

Traditionally, in growing wet season lowland rice, the nursery seedbed is prepared, and seeds sown. The fields are ploughed 2–4 weeks before transplanting. The field is flooded, ploughed again and puddled. Seedlings are transplanted about one month after sowing, with the use of hired labour.

Fertiliser is used in lowland rice production, but sparingly, partly because rainfall is unreliable. Harvesting is done manually, and usually bundled and left in the field to dry. The rice is then threshed.

Mechanisation of land preparation, harvesting and threshing has markedly reduced the need for manual labour. Straw is grazed, and might be burned.

The water required by rainfed rice varies with the stage of growth. During the establishment phase, 200 mm of rain per month is needed, with another 125 mm needed during the vegetative stage. During ripening, standing water is not required, but soil moisture needs to be near field capacity (Schiller et al. 2006).

Moisture stress at any of these stages can reduce yields significantly. The regular variability of annual rainfall across Laos—both drought and flood, at all stages of growth of the rice plant—is the major natural challenge for rice farmers. Too little and too much rain both affect yield differently, depending on the position in the terrace in the paddy field landscape. Fields high in the toposequence are more drought prone than lower fields.

Some farms will have irrigated and rainfed systems. Most farms will have other small enterprises, such as livestock (goats and cattle) grazing fallow land in dry season on rainfed farms, small vegetable plots, or fruit and nut trees.

2.3.1 Changes in rice production methods

Growing rice in Laos is a complicated business, which involves an array of methods, across diverse landscapes, and differs between villages and between farmers. Innovations in rice farming have been the use of two-wheel tractors, improved varieties of rice and the relatively recent development of direct seeding instead of the traditional method of transplanting rice seedlings from nurseries.

Adoption of changes by rice farmers to their farming systems is influenced by the characteristics of the farmer, the farm family and the farm system, many of which are unique to each farm family. Further, the situations of the farmer/farm family and the farm in the wider economic, social and natural environment all influence the nature and rate of innovation in farming rice. Interpreting the processes of adoption by farmers, in villages and regions, must be careful.

For instance, rice farmers in a village near the Mekong River in Vientiane Province—who are close to alternative sources of employment, and farm deep, heavy clays soils with reliable wet season rainfall and unlimited inexpensive water for irrigation in the dry season—might be less concerned about drought-tolerant varieties, and be able to take some risk in changing their system. With shortages of labour at critical times a low-labour system has developed, based on direct seeding by hand, with innovative weed control methods that use slashing and flooding, as well as machine harvesting.

Those who farm sandy soils in a more drought prone region, and find labour scarce, might be interested in using drought-tolerant varieties and trying direct seeding to establish the rice plants, even though weed problems will increase.

Rainfed wet season rice producers experience drought, flood, pests, diseases, fluctuating prices of rice and rising costs of key inputs, such as labour, fertiliser and fuel.

Intensifying rice production by using more inputs, such as fertiliser, has not been a high priority for many farmers, including the poorest ones. Once enough rice is grown for the household for the year, diversifying income through alternative crop, animal and off-farm activities—including some members of the family moving away to earn a wage—has become an attractive alternative to intensified rice production.

Newby et al. (2013) reported that 42% of households in Outhoumphone, Savannakhet, had at least one member of the family working over the Mekong river in Thailand, while job opportunities in urban Laos also drew labour away from the traditional semi-subsistence agriculture. A significant consequence of this migration of labour was that the supply of labour for farm work, especially at transplanting and harvest times, had diminished markedly, and the labour cost had risen considerably.

They reported that 75% of the households surveyed in the lowland provinces of Savannakhet and Champasak used two-wheeled tractors, while 60% of households owned them. In 2010, the first transplanters, drill seeders, drum seeders and harvesters were starting to be tried, and their use has since increased.

Table 4: Transplanted rice gross margin budget, lowland wet season rice

Gross income			**Rice (kip/ha)**	**Rice (A$/ha)**
Rice	3,000 kg/ha	2,500 kip/kg (on-farm)	7,500,000	1,190
	Minus threshing	5% of revenue	375,000	60
Total income			**7,125,000**	**1,131**
Variable costs	**Quantity**	**Price**		
Rice seed	60 kg/ha	4,500 kip/kg	270,000	43
Urea 46-00-00	10 kg/ha	4,000 kip/kg	40,000	6
Fertiliser 16-20-00	50 kg/ha	4,600 kip/kg	230,000	37
Urea 46-00-00	50 kg/ha	4,000 kip/kg	200,000	32
Fuel	30 litre/ha	10,000 kip/litre	300,000	48
Labour costs	75 days	60,000 kip/day	4,500,000	714
Total variable costs			**5,540,000**	**879**
Gross margin	TGI – TVC		**1,585,000**	**252**
Unit cost	TVC/yield	Kip/kg rice	**1,847**	**0.29**

Table 5: Transplanted rice gross margin budget, lowland dry season rice

Gross income			**Rice (kip/ha)**	**Rice (A$/ha)**
Rice	4,000 kg/ha	2,500 kip/kg (on-farm)	10,000,000	1,587
	Minus threshing	5% of revenue	500,000	79
Total income			**9,500,000**	**1,508**
Variable costs	**Quantity**	**Price**		
Rice seed	60 kg/ha	4,500 kip/kg	270,000	43
Urea 46-00-00	10 kg/ha	4,000 kip/kg	40,000	6
Fertiliser16-20-00	50 kg/ha	4,600 kip/kg	230,000	37
Urea 46-00-00	50 kg/ha	4,000 kip/kg	200,000	32
Fuel	30 litre/ha	10,000 kip/litre	300,000	48
Irrigation fee		625,000 kip/ha	625,000	99
Pumping cost		415,000 kip/day	415,000	66
Labour costs	75 days	60,000 kip/day	4,500,000	714
Total variable costs			**6,580,000**	**1,044**
Gross margin	TGI – TVC		**2,920,000**	**463**
Unit cost	TVC/yield	kip/kg rice	**1,645**	**0.26**

2.3.2 Budgets for lowland rice in Laos

Gross margin budgets for transplanted rice in puddled soils, in the wet and dry seasons, were developed based on:

- Manivong 2014
- Laing et al. 2015
- information from rice farmers and industry specialists
- author observations.

The budgets are expressed on a per hectare basis. Gross income is rice sales minus threshing costs. Variable costs include rice seed, urea and compound fertiliser (16-20-00), fuel, irrigation and labour.

Family labour is costed at the rate of hired labour of 60,000 kip/day, because for some family members who work off-farm and return for the busy times of planting and harvest, for example, this would be a genuine opportunity cost. For some, opportunity cost might be lower, but the way farm families might value the release of labour for other farm or household activities, including leisure, is unknown.

The rice gross margin is calculated as total gross income (TGI) minus variable costs. This is expressed in kip/ha and A$/ha (at an exchange rate of 6,300 kip/A$). The unit cost is calculated as the total variable cost (TVC) per kilogram of rice produced.

Tables 4 and 5 show the gross margin budgets for transplanted rice in the wet and dry seasons. Specific assumptions for the budgets are provided in Table 6.

Table 6: Rice gross margin budget assumptions

Item	Unit	Wet season		Dry season	
		Transplant	Direct seed	Transplant	Direct seed
Rice sale price	Kip/kg	2,500	2,500	2,500	2,500
Labour price	Kip/day	60,000	60,000	60,000	60,000
Rice seed price	Kip/kg	4,500	4,500	4,500	4,500
Rice seed rate	Kg/ha	60	40	60	40
Urea 46-00-00	Kip/kg	10	10	10	10
Fertiliser 16-20-00	Kip/kg	50	50	50	50
Urea 46-00-00	Kip/kg	50	50	50	50
Fuel price, two-wheel tractor	Kip/litre	10,000	10,000	10,000	10,000
Fuel usage	Litre/ha	30	30	30	30
Threshing costs	% of revenue	5	5	5	5
Irrigation fee	Kip/ha	n.a.	n.a.	625,000	625,000
Pumping cost	Kip/ha	n.a.	n.a.	415,000	415,000
Labour days required					
Nursery cultivation	Days	1	0	1	0
Nursery sowing	Days	1	0	1	0
Nursery fertiliser	Days	2	0	2	0
First land preparation	Days	3	2	3	2
Seedbed preparation & sowing	Days	2	4	2	4
Second preparation including sowing	Days	24	0	24	0
Apply 46-00-00	Days	6	6	6	6
Apply 16-20-00	Days	3	3	3	3
Hand weeding	Days	11	16	11	16
Harvesting, hauling, threshing	Days	22	20	22	20
Total labour	Days	75	51	75	51

3 ACIAR-supported research

This section presents the objectives and outputs from the three projects, and the investment by ACIAR and its partners.

3.1 *Plant breeding strategies for rainfed lowland rice in northeast Thailand and Laos* (CSI/1995/100)

This project ran from July 1996 to March 2000.

The final report stated that 'the major aim of this project was to assess the existing and alternative breeding strategies to increase the yield and improve the stability of yield of rainfed lowland rice in drought prone areas in north-east Thailand and Laos and to identify appropriate strategies for genetic and agronomic improvement of yield in this area' (Fukai et al. 2000).

Much of the breeding work under the project was done in Thailand, but it focused on identifying genotypic characteristics associated with higher yield under drought conditions. Another important component of the project was to investigate agronomic methods for direct seeding of rice. A model of lowland rice growth was developed to estimate the effects of drought on grain yield.

Our impression is that the main achievement of this project was capacity building, rather than developing farm ready technologies.

3.2 *Increased productivity of rice-based cropping systems in Lao PDR, Cambodia and Australia* (CIM/1999/048)

This project ran from July 2000 to June 2005.

The final report stated that 'the major objective of this project was to increase the productivity of the rice-based cropping systems in Laos, Cambodia and Australia, through improved efficiency of the rice breeding programs to increase yield and improve yield stability of lowland rice in these countries' (Fukai et al. 2006).

The five major areas of research were to:

- find plant breeding strategies for rainfed lowland rice
- intensify rice-based cropping systems in rainfed lowlands
- develop direct-seeding technology
- increase productivity of dry season irrigated rice
- undertake agro-ecological characterisation to help evaluate cropping system strategies.

The main outputs from the project can be summarised as follows (Fukai et al. 2006):

- Better techniques were developed with the Lao Agricultural Research Centre to select varieties, including finding ways to increase farmer participation and a establishing a database to select varieties quantitatively (this could be seen as a capacity-building outcome).
- A total of 41 lines with drought resistant characteristics were trialled with farmers in Laos (16 varieties) and Cambodia (25 varieties). Over two years, yields increased by 14% in the wet season and 18% in the dry season in Laos, and by 16% in the wet season and 26% in the dry season in Cambodia. Farmers identified 4 and 5 lines in the respective countries for further development, which was expected to lead to their release.
- Four varieties were disseminated to farmers in Savannakhet Province, through a Lao–Australia World Vision project, because they were thought to perform better than local varieties.
- Direct-seeding technologies were extended to farmers in Laos and Cambodia, with 60% (50 ha) adoption in 2 villages in the dry season by 2004–05. Direct seeding in the wet season was being investigated for Laos, but was a common practice in many parts of Cambodia.
- Progress was made in developing and extending management practices for rice-based double-cropping.
- The development of agro-climatic maps for Laos continued, and a Lao scientist began study at the University of Queensland on a water balance model.

- Low temperature screening processes were adapted for use in the rice breeding program at Yanco, New South Wales, and some of the materials developed were used in another University of Queensland program funded by the Rural Industries Research and Development Corporation. In Laos, variety TDK5 was also distributed to farmers in higher elevations, and showed a yield gain of about 16%.

3.3 *Increased productivity of rice-based cropping systems in Lao PDR* (CSE/2006/041)

This project ran from 2007 to 2011.

The final report stated that the aim of the project was 'to improve the productivity and profitability of the dominant lowland rice-based systems and to diversify (some of them) by adding non-rice crops under irrigation in the dry season' (Fukai et al. 2013).

According to Fukai et al. (2016) (somewhat more directed than the objectives described in project proposals and reports), the four objectives of the project were to:

- produce GIS maps, using a water balance simulation model that depicts the drought environment for rainfed lowland rice
- identify advanced rice breeding materials, using participatory variety selection (PVS) methods, that are well adapted and high yielding, and that are acceptable to farmers
- determine and demonstrate the most appropriate rice direct seeding methods
- determine the most appropriate crop management methods for maize and legumes.

Key sources of information on outputs from the project include the project final report (Fukai et al. 2013), and a report on adoption (Fukai et al. 2016). The project outputs identified in the 2016 report included:

- GIS maps of the rainfed lowland rice areas of Savannakhet and Champasak showing the likelihood of drought in these areas, and suggesting when crops might be planted and harvested
- the official release of three varieties—TDK13, VTE450-2 and TDK36—better adapted to drought prone areas, with 15 more drought-tolerant varieties being identified and trialled during the project
- the production, demonstration and distribution to farmers of a direct-seeding technology package
- the development of agronomic packages for maize and legumes

Further, the final report for project CSE/2006/041 listed 20 publications, comprising mainly journal and international conference papers, as well as other conference presentations, notably about the GIS work.

3.4 Likely high-impact outputs from the projects

The broad classes of outputs or contributions made by the three ACIAR-supported projects included:

- the identification and PVS trialling of high-yielding and drought-tolerant rice varieties
- the introduction and adaptation of direct-seeding technologies to lowland rice producers in Laos
- the development of management strategies for non-rice crops in the dry season
- GIS-based agro-climatic maps that enabled crop management to be better adapted to seasonal conditions
- significant capacity-building contributions, in the form of additions to scientific knowledge (publications) and to the skills of Lao scientists, through mentoring by project scientists and graduate training opportunities.

The impact of more drought-tolerant varieties and direct seeding have been assessed in a cost:benefit framework in sections 5 and 6. The adoption of non-rice crops in the dry season has been low to date, and little further attention is paid to this technology in this report.

Fukai et al. (2016) suggested that the three main reasons for the low adoption of maize and sorghum in the dry season were:

- limited markets
- limited irrigation access
- the opportunity cost of these crops.

It is difficult to value an information-based technology like the GIS agro-climatic modelling intended partly to alter farmers' perceptions of risk with respect to the coming season, and their choice of variety and fertiliser packages. We had no success in eliciting how this modelling work is presently being used.

The capacity-building contributions of the set of projects are described in Section 8.

Figure 6 shows the impact pathway for these ACIAR projects in Laos.

ACIAR PROJECT INVESTMENTS

CSI/1995/100	CIM/1999/048	CSE/2006/041

↓

TECHNOLOGIES DEVELOPED

Drought-tolerant varieties	Direct-seeding technology

↓

OUTPUTS

- Improved techniques for variety selection
- Release of three varieties TDK14, VTE450-2, TDK36
- Direct-seeding technology package
- Final reports plus scientific publications

↓

NEXT USERS

- On-farm trials
- Seed multiplication (Ag Research Centres)
- Extension agencies, PAFO

↓

HIGH-IMPACT OUTCOMES

- Home consumption of rice, farm-family welfare
- Economic impact through markets
- Social impacts, release from drudgery of transplanting
- Capacity building
  - Scientific publications
  - Informal training
  - Capacity building of farmers
  - Formal post-graduate training of scientists

Figure 6: Impact pathway for new rice varieties and direct seeding in Laos

3.5 Investment by ACIAR and partners

The most important source of data on investment by ACIAR and partners in the projects being assessed is the budget data maintained by ACIAR. In principle, these data enable the total investment by all partners, and by ACIAR, to be estimated. This can be used to estimate returns to investment.

The quality of the data in practice is sometimes deficient. The basis for estimating in-kind contributions from Australian collaborators and overseas partner institutions is usually subjective. ACIAR impact assessments typically do not have the resources to address this issue. In earlier projects, ACIAR did not collect information on the contributions from Australian and partner country institutions. Again, this issue is difficult to resolve.

Historical investment data expressed in nominal Australian dollars were converted to real terms using the Australian gross domestic product deflator based on 2017, and then compounded forward to 2017 at a 5% discount rate.[2]

Using these methods, we estimated that the total investment in the three projects to be A$14.1 million in 2017 (Table 7). No estimates were available for the contributions from Australian, Lao, Thai and Cambodian institutions for project CSI/1995/100.

Table 7: Present value (5% compound rate) in 2017 of investment by ACIAR and partners

	Total investment		
	Nominal ($)	Real ($)	Present value ($)
1997	443,001	756,824	2,008,079
1998	282,219	475,872	1,202,504
1999	184,976	310,892	748,198
2000	88,000	144,164	330,427
2001	532,583	834,273	1,821,113
2002	444,580	676,989	1,407,411
2003	436,483	644,776	1,276,613
2004	425,578	607,885	1,146,258
2005	388,178	534,582	960,033
2006	100,490	131,576	225,039
2007			
2008	401,328	478,916	742,955
2009	488,392	555,332	820,478
2010	438,660	492,839	693,473
2011	425,480	449,769	602,733
2012	84,389	87,599	111,800
Total present value (5%)			**14,097,115**

2 Net economic gains from the technologies before 2017 were similarly expressed in real terms, and compounded forward, then projected future gains (and investments to secure these gains) were discounted back to 2017.

4 Our approach to assessing economic outcomes

4.1 The welfare analysis framework

Focusing on economic outcomes (although conceptually, the same framework can be applied to all outcomes), ACIAR generally requires that impact assessments are based on traditional principles of welfare analysis, as described in Davis et al. (2008). The main principles can be distilled from a market model (Figure 7).

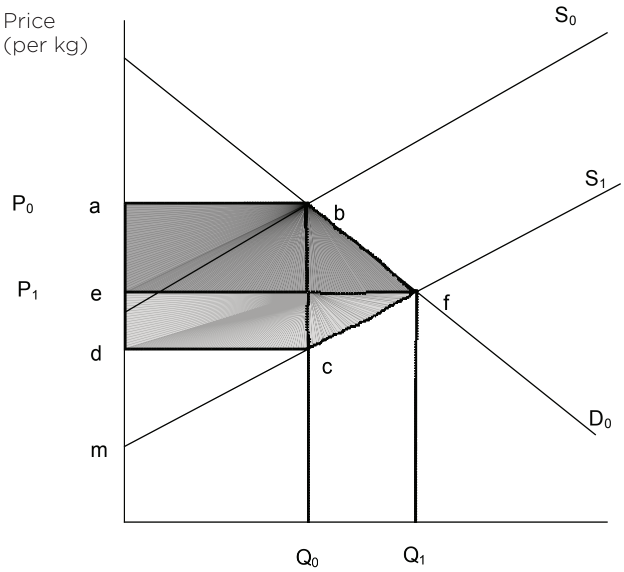

Figure 7: Approximating the impact of new technology

The change in economic welfare (or economic surplus) from a technology that lowers the unit cost of production by *bc* in Figure 7, often referred to as the k-shift, is given by the sum of the two grey shaded areas, where the darker area is the gains to consumers (CS) and the lighter area is the gain to producers (PS). The change in total economic surplus (TS) can be estimated as:

$\Delta TS = \Delta CS + \Delta PS$

$= Po*Qo*k(1 + 0.5*Z*n)$, where

$Z = ke/(e+n)$

Where:

- P_0 and Q_0 are industry price and quantity at the farm gate before the introduction of the technology
- e and n are the elasticities of demand and supply
- $k = K/P_0$
- the new technology has allowed the cost of producing Q to fall by an absolute amount of K, represented by *bc*.

The supply curve shifts to the right from S_0 to S_1, and the new industry equilibrium position is a price of P_1 and output of Q_1. An approximation of this total gain in economic surplus is given by kPQ, represented by the area *abcd*, which is total industry revenue at Q_0 times the relative change in the unit cost of production. It underestimates total welfare gain by the area *bfc*.

This is a measure of benefits accruing to all in the marketing chain from producers through to consumers, and not just a measure of return to producers.

The elasticities of demand and supply have little impact on the size of total welfare gains, but are critical to how these gains are shared. When supply is less elastic than demand, often the case in the short term, producers capture a larger share of the total benefits.

Figure 7 is a heuristic representation of the impact of research. It might represent the market for rice in Laos, say, in a typical year. In this simple model, the impact of research in terms of a supply shift is both contemporaneous, and the technology is fully adopted across the industry (or that part of the industry to which the technology pertains).

To estimate benefits through time, the lag between research activities and the availability to farmers of the new technology; and the rate and extent of adoption of the technology must be projected to enable welfare changes over the life of the technology to be estimated, and the usual techniques of financial analysis applied.[3]

3 Up to when the impact assessment was undertaken actual adoption data can be used.

The assumption that the technology causes a parallel shift in supply is a crucial one. A parallel shift means that the cost savings are bc per kg for all levels of production. It means that producers can never be worse off from adopting this technology. Even if the supply curve is flat (or the demand curve perfectly inelastic), producers can't be worse off. If there is a group of producers who don't adopt the technology, then they could be worse off because of the lower price.

The market in which the technology is modelled determines who is classed as a consumer and who is a producer. In this example, the market is for rice at the farm gate, and the technology is a farm-level technology. In this case, producer surplus accrues to the rice growers, and any input supplier they use. Consumer surplus accrues to all downstream of the farm gate, including rice wholesalers and processors, and the ultimate consumers of rice products.

There is now extensive literature describing how these welfare gains from research-induced new technologies can be estimated. In addition to the papers previously mentioned, detailed general expositions can be found in Alston (1991) and Alston et al. (1998), so will not be described in this report, except to note that minimal skills in algebra and calculus take the analyst a long way.

A key step in any impact assessment is to develop plausible scenarios about how the industry would have developed with and without ACIAR projects. It is easy to overestimate the benefits from a research project if the baseline 'without' project scenario is that the industry does not change. Yields and adoption evolve whether the project is undertaken or not.

Impact assessments have ex ante and ex post components. We have chosen to conduct the analysis from a 2017 perspective, so the ex post component extends back to the early 1990s, and the ex ante component projects a stream of net benefits forward to 2026.

This is different from much investment analysis, which only has an ex ante perspective. In this analysis, monetary values are expressed in 2017 terms. Revenue and costs accruing before 2017 are compounded forward, and those after 2017 are discounted back at a rate of 5% (the rate used in ACIAR impact assessments). This enables project performance criteria—such as net present value, benefit cost ratio, internal rate of return and modified internal rate of return—to be estimated in 2017 terms.

In this case, 1997 was the year when investment began. Criteria in 2017 terms can be expressed in 1997 terms by applying the discount factor for year 20.[4]

For the ex post component, the 'with project' scenario is represented by the historical experience of the rice industry in Laos. The challenge is to develop a plausible scenario about how the industry would likely have developed had the ACIAR projects not been undertaken. Looking forward, the impact of the technology in 2017 is the basis of projections of the 'with project' scenario, but a plausible 'without' scenario must be developed.

Some projects deliver new technologies that shift the production function (or its underlying supply function), as in Figure 8—for example, a disease resistant variety of rice. The benefits over time attributable to this new variety comprise areas A and B in Figure 8. The benefits of this technology might persist for many years, unless resistance breaks down.

Other projects might better be characterised as speeding up the rate at which technology is introduced to, and adopted by the target population. In this case, the benefits are more appropriately defined by the area B.

The projects under assessment encouraged farmers to adopt two broad technologies—higher yielding drought-resistant varieties, and direct seeding of rice. Sections 5 and 6 present 'with' and 'without' scenarios for both technologies.

4 Only the net present value changes with these different year perspectives.

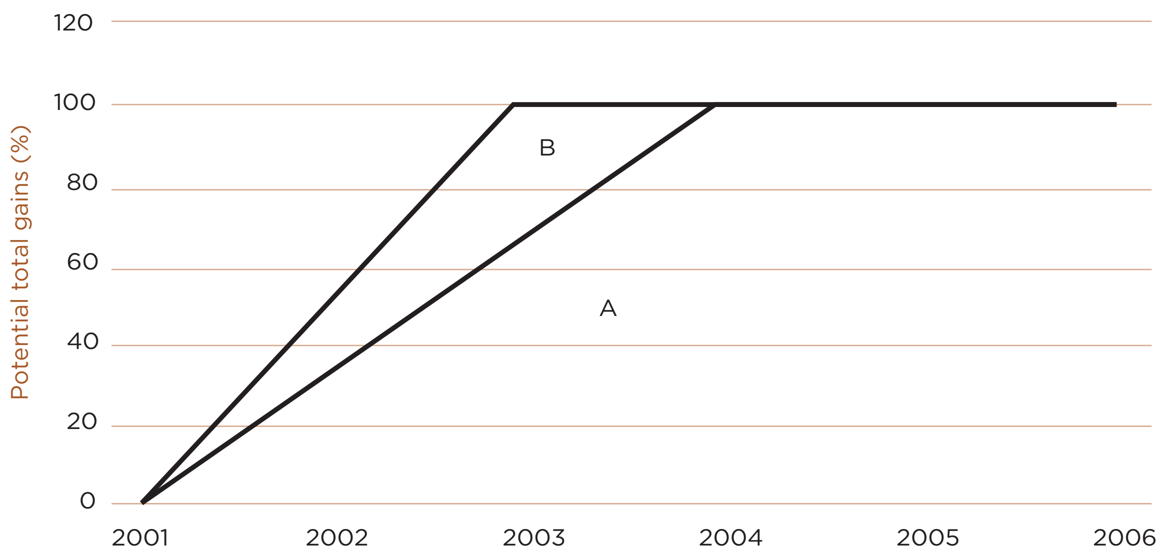

Figure 8: The impact of new technology through time

4.2 How outcomes will be measured

The information required to make assessments of possible impacts on farm household welfare came from consulting with local rice cropping experts, and the farmers with whom they work. The scientists who conducted the research also provided information. There were no published data on the areas of rice sown to different varieties for lowland Laos, or on the adoption of direct seeding. We have been transparent in our method, but our analysis is based on many judgements, rather than empirical evidence.

We have modelled the impact of the two technologies independently. The processes used to generate the benefit streams with and without the technology are described in detail in the next two sections, but in general terms, they were derived from changes in yields and costs captured in gross margin budgets.

Neither technology required major changes in overhead costs (such as from machinery investment). The parameter K was derived from changes in these budgets, and applied to the value of the rice industry at the farm level in lowland rainfed and irrigated rice in Laos. Sections 2 and 5 describe the value of rice grown in the lowland systems.

Elasticities of demand and supply are integral to estimating the welfare triangle bcf in Figure 7, and in determining how welfare gains are shared between producers and consumers.

The literature contains numerous estimates of these elasticities, but little consensus about their values. Many estimates of supply elasticity are less than 0.5, which represents a very short-run scenario where producers and the industry have limited capacity to increase production in response to new technology.

We have assumed a supply elasticity of 1.5, representing a medium- to long-run adjustment period. Rice is still a staple food for the people of Laos especially for semi-subsistence rice growers, so we have assumed a demand elasticity of 0.5.

Under these demand and supply elasticities, the largest share of the benefits from the new technologies flow through to consumers.

To arrive at a flow of net benefits, an adoption profile was developed for each technology, and a judgement made about the share of benefits attributable to the ACIAR projects, based on discussions with the Australian and Lao scientists involved in the projects.

For both technologies, we judged that the ACIAR projects advanced the time by which they became available to farmers. This assumption and those about adoption rates meant that the flow of benefits attributable to the ACIAR projects ceased by 2026, and are represented heuristically as area B in Figure 8.

5 The impact of high-yielding drought-resistant rice varieties

5.1 Why the ACIAR projects are likely to have been influential

A key outcome of the projects was identification and promotion of more drought-tolerant varieties for lowland rice farming systems in Laos. These varieties were expected to lower the risk of crop failure. In most years, some lowland areas experience dry conditions at either the start or the end of the season, so breeders look for shorter maturity of about 120 days, without sacrificing eating quality.

Section 2 described how rice yields in Laos have been growing at an annual compound rate of about 2.5%. The challenge is to assess:

- what share of this growth can be attributed to farmers adopting better varieties
- what share of the growth from better varieties can be attributed to the ACIAR projects.

The story about the adoption of better rice varieties is complex, and hampered by the unavailability of data. The variety TDK1 was the first of the improved varieties bred by the International Rice Research Institute, and released in 1993.

The World Bank (2012) reported that the adoption of improved varieties had grown from about 5% in the mid-1990s to 80% in lowland systems by 2002. By identifying the better varieties for each of the rice-growing areas in Laos yield could still be improved, and further gains are possible from ongoing breeding for characteristics such as drought tolerance and eating quality.

The ACIAR projects were timely, because support for the national breeding program from the Swiss-funded Lao International Rice Research Institute project had been reduced, especially for lowland systems (Fukai et al. 2013).

Some components of the design of the ACIAR-supported projects make it plausible that they have identified more drought-tolerant varieties, and advanced the rate at which these better varieties have been adopted by Lao farmers.

The Lao scientists were emphatic that it was not possible to take varieties bred in other countries, and expect Lao farmers to be able to grow them successfully. Genetic material suitable to Laos had to be identified and bred in Laos to suit the varying conditions throughout Laos.

Perhaps most significantly, as pointed out by the Director of the Laos Rice Research Centre, the projects brought skills in agronomy and plant physiology that neatly complemented the plant breeding skills at the Rice Research Centre.

A component of all three projects was training and assistance to scientists in the breeding program at the Rice Research Centre in how to assess and identify better varieties, using quantitative methods (a particular achievement of project CIM/1999/048). Further evidence of this is detailed in Section 8.3. The list of widely cited scientific papers (Table 18) indicates that the research into drought-tolerant varieties has been influential both in Laos and elsewhere.

A closely allied component was an expansive set of farmer participatory variety selection (PVS) trials. The PVS approach began in the CIM/1999/048 project during which Lao famers identified five lines (from 16) for further testing (Fukai et al. 2006).

The PVS method is explained in Fukai et al. (2013). Preferred varieties were selected by farmers and scientists during a sequence of mother, baby and advanced trials done over several seasons in the Vientiane, Savannakhet and Champasak Provinces.

Typically, 20 advanced lines were trialled in upper and lower toposequence positions, and 20 farmers from each village helped identify three preferred varieties for each toposequence position in each province.

Each year the mother trial was held in a different village to maximise the number of farmers involved. Over the five seasons (2007–2011), 464 farmers were involved in these mother trials. Farmers were given seed, and a recommended rate of fertiliser was also supplied.

The next year, participating farmers were given 200 g of seed of the three preferred varieties for further yield assessment. A total of 242 farmers participated in these baby trials.

Other farmers (82) who had not participated in the mother and baby trials were given seed to test in advanced variety trials. A total of 788 farmers were involved in the three provinces over the five seasons. The project team produced an extension bulletin of recommended varieties for the rice provinces in Laos for wet and dry seasons, and for three positions in the toposequence.

Fukai et al. (2016) reported that the project identified 15 rice varieties suitable for lowland rice systems, which were being used by Lao farmers. Some were better adapted to upper fields in the toposequence likely to be more drought prone. Three varieties—TDK13, VTE450-2 and TDK36—were released officially. One of the most popular varieties—TDK11—was not developed by the project team, but was one of the varieties tested and promoted in the PVS trials.

It seems highly likely that this PVS approach advanced the pace at which farmers found out about and adopted better varieties. The common practice among Lao farmers of swapping varieties with their neighbours further helped the spread of these varieties (Fukai et al. 2016). Fukai et al. (2013) stated that this method of involving farmers in PVS trials has been taken up in other research projects.

5.2 Increment in yields

Assessing rice yields in Laos is a most uncertain enterprise. The FAO data reported in Section 2 suggest that the yield of rice across all of Laos has exceeded 3 t/ha since 2000, and 4 t/ha since 2014. According to data from Provincial Agriculture and Forestry Office for 2016, the yield of lowland rainfed rice was 4.45 t/ha, and for dry season irrigated rice, it was 5.11 t/ha (Table 3). These yields far exceed those reported for the project trials, which were often less than 3 t/ha.

Some scientists interviewed suggested yields closer to those reported in the official data, although in one district, a yield of 2–2.5 t/ha was suggested.

A farmer group in Vientiane Province, with access to irrigation, reported stable yields of 4.3 t/ha in the wet season, and 4.5 t/ha in the dry season.[5] They were more concerned with price variability. We spoke with two farmer groups near Savannakhet, with one reporting yields of 2 t/ha, and the other reporting yields of 4.3 t/ha in the wet season.

We assumed an average yield for lowland rainfed rice (wet season) of 3 t/ha in the gross margin budget (Table 4), and a yield of 4 t/ha for irrigated dry season rice (Table 5).

One approach to assessing the impact of the improved varieties would have been to assess each variety separately, based on the areas sown and yield gains across lowland Laos. Data to implement this approach were unavailable.

Our approach, recognising that the influence of the project work on the breeding program in Laos extended beyond the four varieties identified, involved applying a small yield gain to all lowland rice.

Fukai et al. (2016) reported that the recommended trial varieties yielded 3%–7% more than the standard varieties being used in low fertility fields higher in the toposequence. The new varieties had a shorter growing season (7–10 days), making them more drought tolerant, and improving the chances of growing a second crop (where water was available). The gains in yield can be attributed to improved water use efficiency for these newer varieties.

We applied a relative yield gain from better varieties of 5% (the average of the range estimated by Fukai (2016)) to the official yield figures. The official yield series represents the 'with better varieties' scenario, while the 'without better varieties' scenario was the official yield series discounted by 5%.

The gross margin for this 'without' scenario, where yield is reduced by 5% to 2,850 kg/ha, was estimated to be 1,228,000 kip/ha (Table 8), down from 1,585,000 kip/ha for the 'with' scenario (Table 4).

5 It is hard for farmers to report yields in tonnes per hectare, because of the small fields and surrounding bunds. The amount of rice is often measured as the number of sacks, which vary in weight.

Table 8: Gross margin budget without drought-tolerant varieties for wet season lowland systems

Gross income			Rice (kip/ha)	Rice (A$/ha)
Rice	2,850 kg/ha	2,500 kip/kg (on-farm)	7,125,000	1,130
	Minus threshing	5% of revenue	356,000	57
Total income			**6,768,000**	**1,074**
Variable costs	**Quantity**	**Price**		
Rice seed	60 kg/ha	4,500 kip/kg	270,000	43
46-00-00	10 kg/ha	4,000 kip/kg	40,000	6
16-20-00	50 kg/ha	4,600 kip/kg	230,000	37
46-00-00	50 kg/ha	4,000 kip/kg	200,000	32
Fuel	30 litre/ha	10,000 kip/litre	300,000	48
Labour costs	75 days	60,000 kip/day	4,500,000	714
Total variable costs			**5,540,000**	**879**
Gross margin	TGI – TVC		**1,228,000**	**195**
Unit cost	TVC/yield	Kip/kg rice	**1,944**	**0.31**

5.3 The k-shift from drought-tolerant varieties

We converted this 5% yield gain into a k-shift of 0.0333 (3.33%), by dividing the yield gain by the elasticity of supply (1.5). It is very sensitive to the value of the supply elasticity.

The alternative approach is to derive k as the change in variable costs relative to the price of rice. This can be done by calculating the increase in unit costs in the wet season rainfed rice budget (Table 4), which represents recent technology in lowland rice production—the ‘with technology’ scenario.

The assumption, based on ACIAR trial results, is that yields would be 5% lower if older varieties were used, so unit costs would be higher, and the k-shift would be 3.9%.

The main reason for estimating the k-shift from an estimate of yield change, rather than from an estimate of a change in unit costs, is that the fertiliser regime used in the projects’ experiments was likely to be different from that used in the rice budgets we adapted from a variety of other sources. This might have implications for the yield difference.

The k-shift factor was applied to the real value of rice production in the lowland areas, where the price of rice was expressed in 2017 terms after applying the gross domestic product deflator for Laos (Table 2).

Real value of rice production is the quantity of rice produced times the real price of rice. The quantity of rice produced was derived from the area of rainfed and irrigated rice in lowland Laos times the average yield of rice as reported in FAO data (Table 9).

We have assumed that from 2016, the area sown to rice would not change, but that wet season rice yield would grow at 0.7% per year, as per the World Bank report.

Table 9: Area, yield and price data for drought-tolerant varieties

	Area of lowland rice		Yield	Real price	Real value of production
	Rainfed (ha)	Irrigated (ha)	(t/ha)	(m kip/t)	(m kip)
2008	619,950	94,072	3.78	2.920	7,880,477
2009	656,471	94,309	3.84	3.195	9,211,620
2010	664,425	109,175	3.59	3.304	9,174,561
2011	694,665	112,365	3.75	2.983	9,028,388
2012	711,134	108,037	3.74	2.427	7,435,701
2013	728,635	92,340	3.83	2.805	8,819,098
2014	753,631	102,504	4.18	2.673	9,566,872
2015	755,243	99,018	4.25	2.633	9,560,280
2016	762,960	99,300	4.26	2.556	9,389,740
2017	762,960	99,300	4.29	2.536	9,379,824
2018	762,960	99,300	4.32	2.500	9,312,082
2019	762,960	99,300	4.35	2.500	9,377,267
2020	762,960	99,300	4.38	2.500	9,442,907

5.4 Adoption of better varieties

There are two dimensions to adoption—the time profile of when adoption starts and finishes, and the level of adoption achieved.

5.4.1 Time profile of adoption

On-farm trials began during project CIM/1999/048 in the early 2000s, but the larger scale PVS mother trials in project CSE/2006/41 began in 2007, and the baby trials began in 2009. The varieties were released in different years, and, usually, adoption had started before official release. We chose 2008 as the year during which significant adoption began.

Project CSE/2006/41 finished in 2011. Later projects have focused on mechanisation. We have assumed that more recent activities by the breeders have meant the contribution to Laos yield gains by varieties to which Professor Fukai contributed started to decline from 2016 and was exhausted by 2020, so that yields with and without the ACIAR projects were 4.38 t/ha.

To reflect this, we depreciated k linearly from 2016, so that it was zero in 2020. Heuristically, the contribution of Professor Fukai and the ACIAR projects from the newer more drought-tolerant rice varieties is the area between the solid ('with' scenario) and dashed ('without' scenario) graphs of yield in Figure 9.

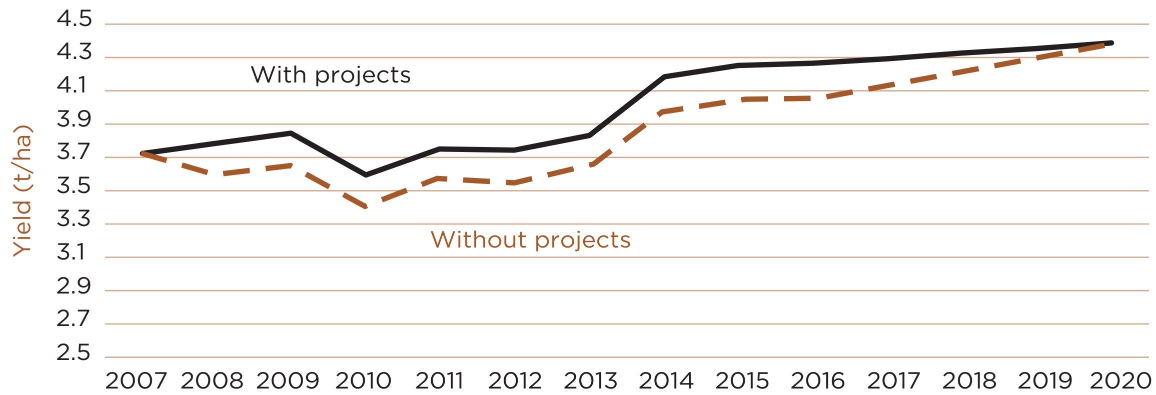

Figure 9: Rice yield with and without new varieties

5.4.2 The level of adoption

There are no published data on the plantings of rice in Laos by variety at a district or province level, but Fukai et al. (2016) conducted limited surveys of adoption by farmers participating in their trials in Vientiane and Champasak provinces.

All farmers in one village used the recommended variety, because it yielded 3.5 t/ha rather than 2.5 t/ha from the previously used variety. In another village, only 30% of fields were planted to the recommended variety.

We have been unable to assess the adoption of the four varieties extended to farmers during the ACIAR-supported projects—TDK36, TDK13, VTE405-2 and TDK11—in any consistent manner across the lowland rice areas of Laos.

The best we could do was ask the scientists and farmers we spoke with in Vientiane and Savannakhet provinces about the varieties that were being grown in their districts. Most farmers grow up to five varieties, so it is likely that in most districts no variety commands half the area sown. This means that popular varieties might only account for about 10% of sowings. Farmers grow several varieties, partly to stagger labour use, and partly because their fields vary in fertility and water-holding capacity.

On most, but not all, occasions at least one of the project varieties was identified as being grown in the area. TDK11 was mentioned most often, and is likely grown in many districts in lowland Laos. Other varieties were popular in a small number of districts, either because of particular agro-climatic conditions, or because their qualities made them attractive in particular markets. TDK11 is widely used in drought prone areas with sandy soils (often found in the higher terraces). It seems a highly versatile variety grown in wet and dry seasons throughout many areas.

TDK36, now known as Pakcheng 1, was released in 2013 (but probably grown by farmers before this), and is widely adopted (up to 70%) by farmers in four districts of Vientiane Province, replacing TDK1 and TDK2. It holds its eating quality over several cookings, is less prone to lodging, and is high yielding, but it is not suitable in upland areas.

VTE450-2, also known as Vientiane 2, is a popular variety in Vientiane Province according to scientists at the Pakcheng centre. Fukai et al. (2016) suggested it was the most popular in three provinces in central and northern Laos. In our discussions in Savannakhet it was mentioned as one of many varieties grown, but not widely. The rice breeders suggested that while TDK13 was high yielding, quality characteristics were poor, and further breeding was required.

Some Provincial Agriculture and Forestry Office staff responded to an informal survey about the proportion of crop sown to the project varieties in their provinces in 2017 (Table 10). Little can be said from such a small sample of sources, but it is consistent with the perception about the ongoing popularity of TDK11. A significant proportion of the other three varieties was sown in at least one of the provinces that responded.

Without data on production by variety, we have made a further subjective judgement that after 2008, 10% of production in lowland Laos came from the project varieties.

Table 10: Proportion of project varieties, by selected provinces, 2017

Province	Area sown to 'ACIAR' varieties (% of total area)			
	TDK11	TDK36 Pakcheng 1	VTE450-2 Vientiane 2	TDK13
Vientiane	30	20	10	20
Borikhamxai	15	0	15	0
Champasak	2	0	1.5	0
Khammouan	15	0	0	0
Salavan	30	22	0	5

5.5 The stream of benefits from the drought-tolerant varieties

Using these parameters, the gross potential stream of benefits of the drought-tolerant varieties adopted by all farmers in the lowland areas was estimated (Table 11). The stream of potential benefits is expressed in Australian dollars after applying the current exchange rate of 6,300 kip/A$ to the stream of potential benefits in 2017 kip values.

To arrive at a stream of benefits attributable to the ACIAR projects, an adoption rate of 10% was applied, and a share of gross benefits was attributed between the ACIAR-supported projects and others, such as the Rice Research Centre. We asked the parties for their view on this subjective question. We have attributed 30% of the benefits from the newer varieties to the efforts of Professor Fukai and the ACIAR projects.

Applying ACIAR's recommended discount rate of 5%, the present value in 2017 of the stream of benefits from the adoption of more drought-tolerant varieties in lowland Laos is A$18.5 million (Table 11).

We are uncertain about the level of adoption of the more drought-tolerant varieties developed during the projects. It is also unclear how long these varieties will benefit Lao farmers if used in breeding new varieties that were later widely adopted.

We have applied a flat rate of adoption of 10%, and set yield benefits to cut out in year 2020. Were the rate of adoption to reach 20% across lowland Laos, as has been the case in some provinces (Table 10), then the present value of the stream of benefits increases to A$37.1 million, and the benefit:cost ratio for the projects increases to 5.8 (from 4.4).

Table 11: Benefit stream from drought-tolerant varieties attributable to ACIAR projects

	Rice yield (t/ha)		Production (million t)	Real price (million kip/t)	Potential gross benefits	Benefits to ACIAR projects	Present value of benefits
	With	Without	Without		(million A$)	(million A$)	(million A$)
2008	3.8	3.6	2.8	2.92	42.0	1.26	2.0
2009	3.8	3.6	3.0	3.20	49.0	1.47	2.2
2010	3.6	3.4	2.9	3.30	48.8	1.47	2.1
2011	3.8	3.6	2.9	2.98	48.1	1.44	1.9
2012	3.7	3.6	3.3	2.43	39.6	1.19	1.5
2013	3.8	3.6	3.2	2.80	47.0	1.41	1.7
2014	4.2	4.0	3.8	2.67	50.9	1.53	1.8
2015	4.3	4.0	3.9	2.63	50.9	1.53	1.7
2016	4.3	4.0	3.9	2.56	50.0	1.50	1.6
2017	4.3	4.1	4.0	2.54	37.4	1.12	1.1
2018	4.3	4.2	4.1	2.50	24.7	0.74	0.7
2019	4.4	4.3	4.2	2.50	12.4	0.37	0.3
2020	4.4	4.4	4.3	2.50	0.0	0.00	0.0
Total present value of benefit stream							**18.5**

6 The impact of direct seeding of rice

6.1 Direct seeding of rice

Direct seeding of rice has emerged throughout East and South-East Asia, largely in response to the shortages of farm labour resulting from economic growth. Fitting direct-seeding methods into rice farm systems is not straightforward—solutions are specific to farmers and their systems.

The major limiting factor to more rapid and wider adoption of direct-seeding methods has been the yield-reducing and labour-increasing effects of the proliferation of weeds in rice crops that are seeded directly. Direct-seeding methods do not allow for the control of weeds by flooding, and vigorous early growth of rice plants that are achievable with transplanted rice.

While research shows that under good management, with adequate fertiliser, the risk of getting poorer yields than traditional seeding methods is low, in practice, experience has been more problematic. Overcoming the weed problems associated with direct seeding is a trial and error process. Some rice growers have tried broadcasting to establish rice, but weeds have taken over and the crops failed. When this happened, they reverted to traditional transplanting the following year.

But, with the larger economic forces at work in Laos and its near neighbour countries, the growing scarcity and higher cost of labour to transplant rice are inevitable. Direct-seeding methods offer a solution, provided the weeds can be controlled enough to allow profitable yields. Broadcasting and drum seeding are low cost direct-seeding options, and drill seeding is slightly more expensive.

The reasons for the focus of researchers on direct seeding is obvious—each of these direct-seeding methods requires 1–2 days/ha to sow a bund of rice, replacing the 30 days/ha labour required for the nursery to transplanting stages. Offsetting these savings in labour are an extra 8 days/ha to control the weed burden associated with direct seeding, and more commonly, lower yields than transplanted rice.

Less obvious, direct seeding adds flexibility and options to the annual rice planting decisions. If the rains are late in coming and delay the start of nursery operations and/or the time of transplanting, direct seeding offers the option of 'planting dry' in anticipation of the rains.

The option of direct seeding a portion of the crop and transplanting another portion—commensurate with the supply of planting labour or with the need to guarantee household rice supply for the coming year—spreads risk, and deals with production constraints of labour and early season water supply.

The net benefits of direct seeding in a farm system are:

- hand-transplanting labour costs saved minus extra labour costs for weed control in direct-seeded crops minus any yield reduction in direct-seeded crops compared with yield of transplanted crops
- plus or minus any difference in fertiliser regimes associated with the two planting methods
- plus the net benefits of the flexibility of direct seeding if the season starts dry
- including changing the mix of seeding methods from transplanting only to an opportunistic mix of direct seeding and traditional transplanting.

While some of the benefits and costs of direct seeding are easy to value, the system-wide effects and associated changes to farm and household risk are harder to value. This means the decisions to adopt the direct-seeding innovations will proceed slowly, farmer by farmer, system by system, village by village, region by region. Facing less and more costly labour supply over the medium term, rice farmers are keen to find a way to make the mechanised options work.

6.2 ACIAR projects helped develop and promote direct seeding

Each of the three ACIAR projects being reviewed had, among other aims, explicit objectives to find new information about direct seeding of rice, and to inform farmers and fellow scientists about such findings.

The brief of CSI/1995/100 included investigating the methods, effectiveness and management of direct seeding (Fukai et al. 2000). Experiments were done in Vientiane, Savannakhet and Champasak provinces.

A subsequent project was initiated in 1999 (CSI/1999/048), which was a detailed study to investigate the time of direct seeding, methods of establishment and soil conditions. The annual report for that project reported that direct seeding was becoming more popular among farmers in Southern Laos in the wet season.

A new project (CSE/2006/041) was proposed to 'expose more farmers to these options and get them to identify the most appropriate practices for their circumstances'. A farmer participatory approach was adopted, a package of information on direct-seeding technology was produced and the technology was demonstrated to farmers.

Fukai et al. (2013) reported that yields from broadcast crops, properly managed, were similar to those from transplanted crops. A survey of 76 farms found a mean reduction in direct-seeding yield of 4%, or 140 kg/ha. Fukai et al. (2013) estimated that in 2016, more than 6% of rice area in Laos (50,000 ha) was planted using direct seeding.

They considered that the total area combined for both dry and wet seasons might reach 50,000 ha in five years. It was noted that in 2009, 94,316 ha of dry season rice were planted in Laos, of which about 45% was established in the project target provinces.

Fukai et al. (2016) reported that:

> Adoption of direct seeding has taken place gradually in Laos. In Champasak Province, the direct-seeded area is about 10% in the wet season and 60–70% in the dry season. The direct-seeded area was almost zero in 2007 when the project commenced; the increase in the direct-seeded area has been more than 10,000 ha in the past eight years in the dry season alone.

Fukai et al. (2013) noted that other projects, including their previous ACIAR projects and projects by Vorlasan et al. (2016) and Clarke et al. (2016), contributed to the adoption of direct seeding, 'making it difficult to single out the contribution of any particular project'.

But a strong case can be made that the research, development and extension work done by Professor Fukai through the ACIAR-supported projects on direct seeding from 1995 to 2011 laid a foundation for the emergence of the direct-seeding technology and incorporation of this technology by farmers into their systems.

This work, the first to do direct-seeding trials in the Laos lowlands, identified the questions that had to be asked and solved, and then began to solve some of the system-related questions, such as varieties that suited direct seeding, and the critical issues of weed and fertiliser management to achieve comparable yields and gross margins to transplanting crops.

6.3 Direct seeding and transplanted gross margins

Tables 4 and 5 show transplanted rice gross margin budgets for wet and dry seasons, while Tables 12 and 13 show direct-seeded gross margin budgets for wet and dry seasons.

For these purposes, the method of direct seeding is not specified. It could be broadcasting by hand (most commonly), drill seeding, drum seeding, or, as happens often, a combination of methods. The assumptions are that:

- the farmer owns a two-wheeled tractor, and its operating costs for cultivation are included in the gross margin estimate
- the same amount of fertiliser is used with the two methods of establishing rice plants.

The differences in the costs of establishing rice using the two methods are based on direct seeding:

- requiring less labour to establish plants (1–2 days/ha regardless of method of direct seeding) than transplanting (up to 30 days/ha for nursery and transplanting), at 60,000 kip/day for labour
- resulting in a reduced seeding rate per hectare (40 kg/ha) than transplanting (60 kg/ha), with a seed cost of 4,500 kip/kg

- requiring more weeding labour per hectare (16 days) than transplanting (11 days) (Table 6).

The budgets in this section do not include costs associated with owning or contracting direct-seeding machinery, as they are likely to be small and, on any farm, various methods might be used (see the Appendix for information about these costs).

Differences in gross margins between the two methods also derive from yield differences. We have reduced the yield of direct-sown crops by 10% from transplanted crops to reflect losses from weed competition, especially as farmers learn to apply this technology to their circumstances.

Lao farmers using direct seeding commented that weed problems meant that it was not possible to direct seed the same area every year. They reverted to transplanting after some years of direct seeding.

Table 12: Direct-seeded rice gross margin budget, lowland wet season rice

Gross income			Rice (kip/ha)	Rice (A$/ha)
Rice	2,700 kg/ha	2,500 kip/kg (on farm)	6,750,000	1,071
	Minus threshing	5% of revenue	337,500	54
Total income			**6,412,500**	**1,018**
Variable costs	**Quantity**	**Price**		
Rice seed	40 kg/ha	4,500 kip/kg	180,000	29
46-00-00	10 kg/ha	4,000 kip/kg	40,000	6
16-20-00	50 kg/ha	4,600 kip/kg	230,000	37
46-00-00	50 kg/ha	4,000 kip/kg	200,000	32
Fuel	30 litre/ha	10,000 kip/litre	300,000	48
Labour costs	51 days	60,000 kip/day	3,060,000	486
Total variable costs			**4,010,000**	**637**
Gross margin	TGI – TVC		**2,402,500**	**381**
Unit cost	TVC/yield	Kip/kg rice	**1,485**	**0.24**

Table 13: Direct-seeded rice gross margin budget, lowland dry season rice

Revenue			Rice (kip/ha)	Rice (A$/ha)
Rice	3,600 kg/ha	2,500 kip/kg (on farm)	9,000,000	1,429
	Minus threshing	5% of revenue	450,000	71
Total income			**8,550,000**	**1,357**
Variable costs	**Quantity**	**Price**		
Rice seed	40 kg/ha	4,500 kip/kg	180,000	29
46-00-00	10 kg/ha	4,000 kip/kg	40,000	6
16-20-00	50 kg/ha	4,600 kip/kg	230,000	37
46-00-00	50 kg/ha	4,000 kip/kg	200,000	32
Fuel	30 litre/ha	10,000 kip/litre	300,000	48
Irrigation fee		625,000 kip/ha	625,000	99
Pumping cost		415,000 kip/ha	415,000	66
Labour costs	51 days	60,000 kip/day	3,060,000	486
Total variable costs			**5,050,000**	**833**
Gross margin	TGI – TVC		**3,500,000**	**556**
Unit cost	TVC/yield	Kip/kg rice	**1,402**	**0.22**

Table 14: Gross margins for lowland rice, by establishment method and season

Method	Wet season		Dry season	
	Kip/ha	A$/ha	Kip/ha	A$/ha
Transplanting	1,585,000	252	2,920,000	463
Direct seeding	2,402,500	381	3,500,000	556

Table 15: Unit costs and k-shift for lowland rice, by establishment method and season

Method	Wet season			Dry season		
	Kip/ha	A$/ha	%	Kip/ha	A$/ha	%
Transplant	1,847	0.29		1,645	0.26	
Direct seed	1,485	0.24		1,403	0.22	
Direct seed rotation[a]	1,639	0.26		n.a.	n.a.	
Change in unit costs	208[b]			242		
K-shift			8.31			9.69

a Three-years direct seeding, followed by two years transplanting.
b Unit cost (transplant) minus unit cost (direct seed rotation).

Table 16: Stream of benefits from direct seeding in lowland rice systems

	Projected area direct-seeded		Gross potential benefits	Attributed to ACIAR	Present value (5%)
	With ACIAR	Without ACIAR			
	ha	ha	kip	kip	A$
2014	18,700	3,740	9,295,661,769	5,577,397,061	1,024,847
2015	37,400	5,618	19,748,492,476	11,849,095,485	2,073,592
2016	56,100	8,438	29,615,545,670	17,769,327,402	2,961,555
2017	69,723	12,675	35,448,304,097	21,268,982,458	3,376,029
2018	86,655	19,038	42,015,132,727	25,209,079,636	3,810,896
2019	107,699	28,596	49,151,704,776	29,491,022,865	4,245,909
2020	133,852	42,953	56,481,787,251	33,889,072,350	4,646,771
2021	166,357	64,518	63,279,426,441	37,967,655,865	4,958,109
2022	206,756	96,911	68,254,310,922	40,952,586,553	5,093,242
2023	256,965	145,566	69,219,889,348	41,531,933,609	4,919,328
2024	319,367	218,648	62,583,075,607	37,549,845,364	4,235,869
2025	396,922	328,423	42,563,104,845	25,537,862,907	2,743,656
2026	493,311	493,312			
Total present value (5%)					**44,089,801**

In wet years, many farmers still prefer transplanting. In this analysis, a rotation hectare consists of a sequence of three years of direct seeding, followed by two years of transplanting to better represent the wet season system change, particularly in early years, until alternative weed control systems are well developed.

The annual gross margin for wet season direct-seeded rice is a weighted average (3:2) of the gross margins for direct-seeded and transplanted crops. The weighted average yield is 2.82 t/ha. The rotation constraint for weed control that applies to wet season direct-seeded rice is assumed to not apply to dry season irrigated direct-seeded rice. This is because irrigation offers better weed control options, negating the need for occasional transplanting.

Table 14 presents a summary of rice gross margins by establishment method and season. These data have come from tables 4, 5, 12 and 13.

The unit cost of production (total variable costs per yield unit) were derived for each system, and the change in unit cost (from transplanted rice to the direct-seeded rotation) was estimated for both the wet and dry season situations.

The k-shifts for these cost changes were estimated as the changes in unit cost relative to the price of rice per kg (that is 2,500 kip/kg). The unit costs and k-shifts are in Table 15. The k-shifts are used to estimate changes in welfare associated with the technology as described in Section 4.1.

In the economic model used to estimate the welfare effects of the adoption of direct seeding, the k factor was 8.31% for wet season crops and 9.69% for dry season crops.

6.4 Adoption of direct seeding

To scale up the economic benefits of direct seeding, the extent of direct-seeding methods used each year to grow rice in the lowland areas of Laos has to be estimated, as well as the time profile over which adoption has occurred, and will continue to occur.

6.4.1 Level of adoption

The Savannakhet Provincial Agriculture and Forestry Office 2016 (cited by Clarke et al. 2017) estimated that in Savannakhet, farmers used a drill seeder to direct seed:

- 80 ha in 2014
- 800 ha in 2015
- 17,000 ha in 2016
- 7,000 ha in 2017.

Provincial Agriculture and Forestry Office staff from five central and southern provinces reported that rates of adoption ranged from less than 1% to almost 30%.

In Khammuan Province, adoption was estimated to be 14,000 ha in 2016, about 17% of rainfed rice in that year. The following year, the area direct-seeded fell to 12,000, perhaps reflecting an earlier start to the rains.

The adoption of direct seeding varies. In one village, all the farmers were using broadcasting and an innovative method of controlling weeds. Farmers in another village had tried broadcasting, and failed, so had reverted to hand transplanting.

Farmers elsewhere were adjusting their systems, sometimes including a longer planting period, to continue with the hand transplanting, as it works and delivers their annual household rice supply with an acceptable level of reliability.

All signs were that the growing scarcity of labour for rice transplanting, and the rising cost of labour in the Laos economy will see an increased use of direct seeding, especially if more direct-seeding machinery becomes available as expected. Crop management constraints mean that in any year, a significant proportion of the crop will not be direct-seeded.

Fukai et al. (2013) estimated in 2016 that 6% of total area was sown using direct seeding, equivalent to 50,000 hectares. It seems likely that there was little direct seeding before 2014 (Professor Fukai, pers. comm., 2018).

Linearly extrapolating back from the 50,000 ha in 2016 to zero in 2013 gives assumed areas that were direct-seeded of 17,000 ha in 2014, and 34,000 ha in 2015. These numbers refer to the wet season, and we have added a further 10% for dry season irrigated crops.

Based on the information available, the area of direct-seeded lowland rice is projected to increase from the 50,000 ha in 2016 to 60% of annual rice crop area (almost 500,000 ha) by 2026.

6.4.2 Time profile of adoption

For economic analysis, we need to estimate the rate and level of adoption with and without the ACIAR projects. In our view, rising labour costs will mean strong incentives for farmers to adopt labour-saving technologies, such as direct seeding.

In Section 6.2, the path-breaking work of Professor Fukai and his colleagues was identified. Had this work not been done, it would now need to be. For these reasons, we estimate that the ACIAR projects brought forward the use of direct seeding into rice production systems by at least five years.

In our analysis, we have assumed that in the 'without projects' scenario, it would not have been until 2018 that 17,000 ha were direct-seeded. From there, the rate of adoption in response to labour costs would be even quicker than in the 'with projects' scenario, such that in 2026 both scenarios would project an area of about 500,000 ha direct sown. Figure 10 shows the 'with and without' adoption profile.

A related question is: how much can the earlier start of using direct seeding be attributed to the investment in the three ACIAR projects?

Others have also helped in demonstrating direct-seeding technologies (developed in the ACIAR projects) and encouraged their adoption. We have assumed that 60% of the benefit from the growth direct seeding to 2026 can be attributed to Professor Fukai and the ACIAR projects.

6.5 The stream of benefits from the adoption of direct seeding

We estimated that the present value (5% discount rate) of the stream of benefits attributable to ACIAR from the adoption of direct seeding is A$44.1 million (Table 16).

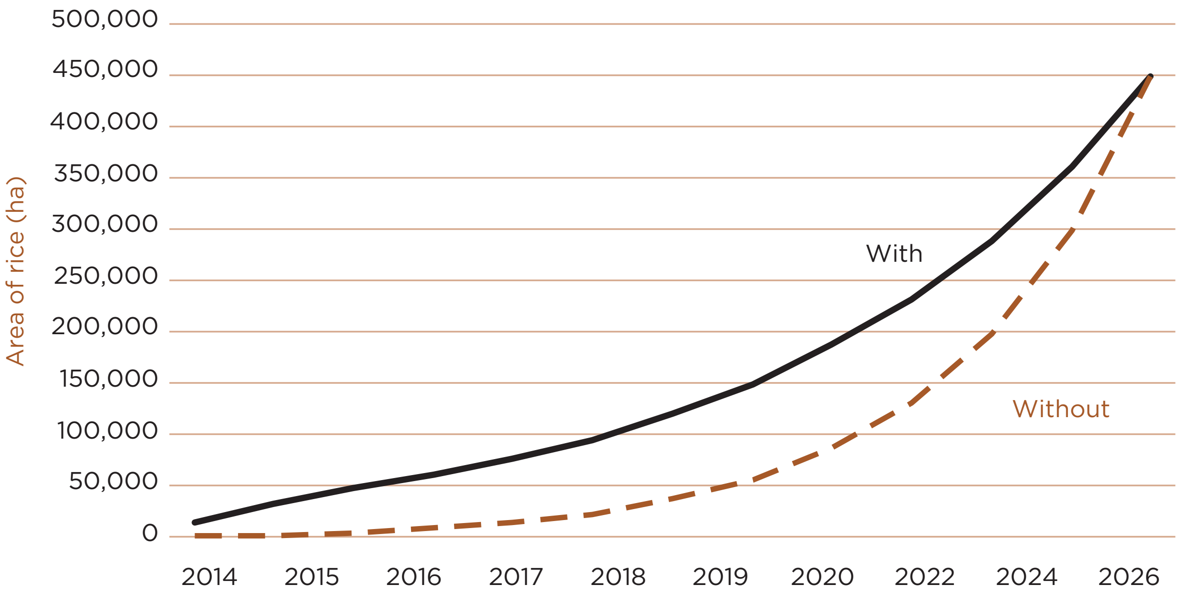

Figure 10: The adoption of direct seeding with and without the ACIAR projects

7 Economic analysis

Typically, ACIAR does impact assessments of project outcomes 30 years into the future, which would be 2047 for these projects. But in this case, the most likely contribution of the ACIAR projects to the welfare of Lao farmers has been to speed up the development and adoption of more drought-tolerant rice varieties and of direct seeding. As a result, the benefits from this 'speeding up' are exhausted by 2020 in the case of drought-tolerant varieties, and 2026 in the case of direct seeding.

The flow of benefits from the technologies introduced through the projects has been described in the previous two sections, and the flow of investment by ACIAR and its partners was described in Section 3.5. In this section, we bring these flows of benefits and costs together to estimate some of the usual measures of returns to the ACIAR investment (Table 17). All values have been expressed in 2017 dollars (as at 2017), and a discount rate of 5% has been applied to compound forward values before 2017, and discount back future benefit flows.[6]

The 2017 present value of the investment in the three projects by ACIAR and partners was A$14.1 million. The 2017 present value of the stream of benefits from the adoption of more drought-tolerant varieties and direct seeding attributable to the ACIAR projects was A$18.5 million and A$44.1 million, respectively, for a total of A$62.6 million.

So the 2017 net present value (5%) of these streams of benefits and costs was A$48.5 million. The benefit:cost ratio was 4.44:1, and the internal rate of return was 16.0%. The internal rate of return assumes that as benefits are received, they can be reinvested at the rate of 16.1%. The modified internal rate of return, assuming that net benefits are reinvested through the life of the investment at 5%, was 11.5%.

The stream of benefits from either the more drought-tolerant varieties or from the direct-seeding technology cover ACIAR's costs and opportunity costs. For drought-tolerant varieties alone, the net present value of the net benefit stream was A$4.4 million, and for direct seeding it was A$30 million.

Suppose we halved (approximately) the size of the key parameters, so that for the more drought-tolerant varieties the level of adoption was 5% rather than 10%, and the share of benefits attributed to the ACIAR projects was 15% rather than 30%.

Suppose further that for the direct-seeding technology, the level of adoptions was 13% rather than 60%, and the share of benefits attributed to the ACIAR projects was 30% rather than 60%.

In this scenario, the project investment criteria are just met, the benefit:cost ratio becomes 1 and the internal rate of return becomes 5%. This scenario seems unlikely.

Despite our uncertainty about key parameters, such as the rate and level of adoption of the technologies and the contribution the three projects made to the development and adoption of the technologies, the returns to ACIAR's investment is robust to significant changes in these parameters and has been a sound use of its funds.

In addition to these economic gains, significant gains have likely been made in scientific capacity and social gains, as household labour is released from the drudgery of transplanting rice. These issues are discussed more fully in Section 8.

6 In Section 4, we discussed this choice between 2017 and 1997 as year 0 for our analysis.

Table 17: Present value flows of benefits and costs, and rate of return criteria from the ACIAR rice projects in Laos

	Project costs	Benefits		Net flow
		Improved varieties	Direct seeding	
	A$ (2017)	A$ (2017)	A$ (2017)	
1997	2,008,079			-2,008,079
1998	1,202,504			-1,202,504
1999	748,198			-748,198
2000	330,427			-330,427
2001	1,821,113			-1,821,113
2002	1,407,411			-1,407,411
2003	1,276,613			-1,276,613
2004	1,146,258			-1,146,258
2005	960,033			-960,033
2006	225,039			-225,039
2007	–			–
2008	742,955	1,952,637		1,209,682
2009	820,478	2,173,781		1,353,302
2010	693,473	2,061,939		1,368,465
2011	602,733	1,932,464		1,329,731
2012	111,800	1,515,772		1,403,971
2013		1,712,169		1,712,169
2014		1,768,900	1,024,847	2,793,746
2015		1,683,506	2,073,592	3,757,097
2016		1,574,738	2,961,555	4,536,292
2017		1,121,880	3,376,029	4,497,909
2018		706,061	3,810,896	4,516,957
2019		338,046	4,245,909	4,583,955
2020		–	4,646,771	4,646,771
2021			4,958,109	4,958,109
2022			5,093,242	5,093,242
2023			4,919,328	4,919,328
2024			4,235,869	4,235,869
2025			2,743,656	2,743,656
Total	**14,097,115**	**18,541,890**	**44,089,801**	
			Net present value (5%)	**48,534,577**
			Benefit cost ratio	**4.44**
			Internal rate of return	**16.0%**
			Modified IRR	**11.5%**

8 Assessment of environmental, social and scientific capacity outcomes

8.1 Environmental consequences

We have been unable to identify any significant environmental consequences from the adoption of these technologies. There might be implications for water quality if farmers use more fertiliser, but decisions by farmers about fertiliser are also influenced by factors other than these technologies.

The direct-seeding technology makes weed control more difficult. Some farmers might choose to use herbicides, but there is little evidence of this being so at present. Regardless, poor weed control, which could create environmental issues, is not compatible with the widespread adoption of direct seeding—that is, if weed control is poor, so too are yields, making the direct-seeding method an unattractive option.

8.2 Social impact

Direct-seeding technology releases some of the farm household, mostly women and children and those employed off-farm, from the drudgery of transplanting. Some rice transplanting is done by hired labour. This labour currently has a market cost/opportunity cost of 60,000 kip/day.

Some family labour also has a market opportunity cost, being able to work for other farmers as an alternative to the family operation, or working away from the farm, but returning for the times of peak labour demand, harvest and transplanting. This labour also has an opportunity cost of 60,000 kip/day.

It is likely not practical for all the released labour, especially that of the women in the household, to earn off-farm income, but that does not mean that this labour has no opportunity cost. It is likely to be put to use tending animals and other crops, such as household vegetables.

The family might also value increased leisure time. It is hard to value these non-market uses of released labour. We have valued all labour released at the market rate of 60,000 kip/day.

8.3 Capacities built

Bilateral projects sponsored by ACIAR typically fund activities across a spectrum, including human capacity building, and the development of farm-ready technologies, in pursuit of economic, social and environmental benefits.

Capacity building is likely to contribute to the successful outcomes of the project in which it was developed, but it can also add to the stocks of human and scientific capital that potentially yield a flow of services many years into the future, in the form of new technologies used by farmers.

ACIAR has funded several studies on ways to identify, report and value its capacity-building activities in a more systematic and transparent way, notably those by Gordon & Chadwick (2007) and Mullen et al. (2016). It has not been possible to review capacity building in these projects in the formal manner followed by Mullen et al. (2016).

Capacity building was a significant component of this set of projects. Capacity was developed through:

- additions to scientific knowledge in the form of scientific publications
- informal training of project scientists through mentoring, learning by doing and short courses
- building the capacity of farmers to grow rice and manage their farms through their participation in the rice variety trials
- formal postgraduate training opportunities for scientists working on the projects.

There is a lag between building capacity and its subsequent impact on the set of technologies available to farmers, so usually this impact occurs well after the conclusion of the project. This is particularly the case for postgraduate training.

8.3.1 Scientific publications

The three projects gave rise to an impressive set of publications, adding to scientific knowledge. This has a non-use value, and the potential to lead to the development in later research projects of new technologies adopted by farmers. Most publications were authored jointly by scientists from Australia, Laos and Thailand. No doubt this experience added to human scientific capacity by improving generic skills, such as scientific writing and presentation skills.

Information about publications was found in the final reports to ACIAR of the three projects. A total of 144 papers, including conference papers, were written, comprising:

- 54 from CSI/1995/100
- 70 from CIM/1999/048
- 20 from CSE/2006/041.

Professor Fukai provided a list of 11 of his most widely cited papers (Table 18). These papers have been cited more than 100, and up to 600 times.

8.3.2 Informal training

During each project, workshops and short courses were held, providing collaborating scientists with opportunities to analyse, discuss and present results, and prepare publications, which all added to capacity.

The generic skills likely to have been developed include:

- trial management, particularly on-farm participatory variety selection methods
- experimental design
- data analysis
- scientific writing
- English language presentation skills
- joining scientific networks.

The pathway to changes in farm practice is more indirect, but these skills likely increased the access of scientists to the international scientific community, and made new knowledge accessible sooner.

The opportunity to maintain and incrementally increase capacity was an important benefit of a succession of ACIAR-funded projects.

At the Rice Research Centre, one of the John Allwright Fellows commented that working on the projects led to a significant development in her project design and management skills.

Some skills acquired during capacity building were technical, and closely related to the projects' research processes and technology being developed. It is highly likely that many of these skills will prove valuable in developing new technologies in later projects.

The scientists at the Rice Research Centre found that Professor Fukai's skills in agronomy and plant physiology were complementary to their skills in breeding.

8.3.3 Capacity building through training

An important component of bilateral research projects is capacity building through mentoring, 'learning by doing', workshops and short courses. Some scientists also have had opportunity for postgraduate study, sometimes funded within the project, but usually funded either by ACIAR, through its John Allwright and John Dillon Fellowships, or by another international or Lao funding body.

Typically, during a project, a young scientist is identified and proposed for an ACIAR John Allwright Fellowship for postgraduate study at an Australian university.

Professor Fukai supervised some of the graduate students. Their field of study need not be related to a direct outcome of the project, and often their training did not conclude until well after the project ended. The three projects extended from 1997 to 2012, and it is likely that capacities built in earlier projects were of benefit to later projects, and contributed to their outcomes

From project reports, 18 people went on to undertake postgraduate degrees after first working on these projects. ACIAR funded five PhD students and one Master student. The projects funded one other Master student directly, while other external sources funded five PhD students and four Master students.

Nearly all the graduate students undertook projects with some relevance to projects. Topics of study included drought tolerance, climate modelling, non-rice crops, direct seeding and cold tolerance.

Table 18: Widely cited papers arising from the three ACIAR projects

Author	Year	Title	Citations
Fukai S. & Cooper M.	1995	Development of drought-resistant cultivars using physio-morphological traits in rice. Field Crops Research 40, 67–86	639
Boonjung H. & Fukai S.	1996.	Effects of soil water deficit at different growth stages on rice growth and yield under upland conditions: phenology, biomass production and yield. Field Crops Research 48, 47–55	215
Borrell A., Garside A., & Fukai S.	1997	Improving efficiency of water use for irrigated rice in a semi-arid tropical environment. Field Crops Research 52, 231–248	283
Fukai S., Pantuwan G., Jongdee B. & Cooper M	1999	Screening for drought resistance in rainfed lowland rice. Field Crops Research 64, 61–74	191
Wade L.J., Fukai S., Samson B.K., Ali A. & Mazid M.A.	1999	Rainfed lowland rice: physical environment and cultivar requirements. Field Crops Research 64, 3–12	140
Inthapanya P., Sipaseuth, S. P., Sihathep V., Chanphengsay M., Fukai S. & Basnayake J.	2000	Genotype differences in nutrient uptake and utilisation for grain yield production of rainfed lowland rice under fertilised and non-fertilised conditions. Field Crops Research 6, 57–68	128
Pantuwan G., Fukai S., Cooper M., Rajatasereekul S. & O'Toole J.C.	2000	Yield response of rice (Oryza sativa L.) genotypes to drought under rainfed lowland, part 3: plant factors contributing to drought resistance. Field Crops Research 73, 181–200	155
Jongdee B., Fukai S. & Cooper M.	2002	Leaf water potential and osmotic adjustment as physiological traits to improve drought tolerance in rice. Field Crops Research 76, 153–163	222
Pantuwan G., Fukai S., Cooper M., Rajatasereekul S. & O'Toole J.C.	2002	Yield response of rice (Oryza sativa L.) genotypes to different types of drought under rainfed lowlands, part 1: grain yield and yield components, Field Crops Research 73, 153–168	151
Jongdee B., Pantuwan G., Fukai S. & Fischer K.	2006	Improving drought tolerance in rainfed lowland rice: an example from Thailand. Agricultural Water Management 80, 225–240	127
Akihiko Kamoshita R., Chandra Babu N., Manikanda B & Fukai S.	2008	Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed environments. Field Crops Research 109, 1–23	273

8.3.4 Farmer capacity building

In all three projects, many of the trials were done in farmers' fields. In the last project, nearly 800 farmers took part in the PVS trials. Farmers helped select varieties that they thought would do best in their environment, and had to develop skills in comparing the performance of varieties.

Direct-seeding trials were done on farms. Direct seeding requires a new set of skills, particularly in weed, water and fertiliser management, and in preparing soil conditions necessary for rice to establish successfully.

Skills were also required to manage the trials and these are likely to have lasting benefit to the farmers.

In the last project, economic and physical data were collected during the trials, and reported back to the farmers. It is likely that they developed some skills in assessing the economic consequences of their decisions.

9 Conclusions

We have assessed the economic, social and environmental outcomes from ACIAR projects CSI/1995/100, CIM/1999/048 and CSE/2006/041, which were led by Professor Shu Fukai from the University of Queensland, and Dr Monthathip Chanphengsay from the National Agriculture and Forestry Research Institute in Laos. These projects were undertaken from 1997 to 2012, with impacts continuing far beyond that time.

ACIAR has made substantial investments over many years in research to improve the welfare of farm families in Laos (and other South-East Asian countries) dependent on growing rice.

Fukai et al. (2016) suggested that direct seeding of rice and identifying and promoting drought-tolerant varieties of rice have been the technologies developed during the projects that were most widely adopted by lowland farmers.

In assessing impact, we used project final reports, publications from the projects, and publications reporting the work of others about these technologies. We visited Vientiane and Savannakhet in Laos to discuss the technologies with scientists and farmer groups. Australian scientists who worked on the projects were most helpful.

The greatest difficulty we faced in this impact assessment was the lack of data—published or otherwise—on the area of rice plantings by variety and the area of rice that was direct-seeded.

Data were unavailable at the province level and for Laos as a whole. There is also great diversity in rice production methods across the target population for these two technologies, reflecting variations in soil type, climatic conditions, and the economic and social incentives facing farm families, most of whom operate at a semi-subsistence level.

Lindner et al. (2013) classified a set of ACIAR impact assessments as conceivable, plausible or convincing, as the level of transparency and objective support for key assumptions increased. Given our reliance on the judgement of scientists, anecdotal evidence, our own limited observations and the lack of objective data on adoption of the technologies, we self-classify this impact assessment as being plausible rather than convincing.

Our aim has been to develop a plausible story linking the resources invested in these projects by ACIAR and its partners in Laos and Australia with changes in farm practice that have improved the welfare of Lao rice growers.

We estimated that in 2017 value terms, ACIAR and its partners have invested almost A$14.1 million in the three projects.

Benefits were estimated using welfare analysis in a market model for Lao rice.

9.1 Drought-tolerant varieties

In any year, some areas of lowland rainfed rice production in Laos suffer dry conditions at some time during the production cycle. Objectives of all three projects have been the development and adoption by farmers of more drought-tolerant rice varieties. Lao farm families grow rice for their needs during the coming year, and only market what is surplus to these needs. Eating and cooking qualities of glutinous rice is as important as yield and drought tolerance in breeding programs.

We have been unable to assess the adoption of the four project varieties—TDK36, TDK13, VTE405-2 and TDK11—in any consistent manner for lowland rainfed rice in Laos, because data on plantings by variety were unavailable. We asked scientists and farmers about the popularity of these varieties. On most, but not all, occasions, at least one project variety was identified as being grown in the area.

Fukai et al. (2016) reported that the recommended trial varieties yielded 3%–7 % more than the standard varieties that were being used. We have assumed a yield gain of 5% from these drought-tolerant varieties in our analysis. This yield gain of 5% was converted to a k-shift (change in unit costs relative to the price of rice) of 3.33% (for a supply elasticity of 1.5).

Without data on production by variety, we have made subjective judgements that 10% of production of lowland rainfed rice came from project varieties bred at the Rice Research Centre, with input from Professor Fukai. Further, adoption of these varieties began in 2008, and by 2020, the ACIAR projects will no longer be influencing rice yields in Laos.

Some components of the design of the ACIAR-supported projects make it plausible that they have identified varieties of rice that are more tolerant to drought, and advanced the rate at which these varieties have been adopted by Lao farmers.

The Lao scientists were emphatic that it was not possible to take varieties bred for use in other countries and expect Lao farmers to grow them successfully. Professor Fukai brought skills in agronomy and plant physiology that complemented the plant breeding skills at the Rice Research Centre, and helped build capacity in Lao scientists through mentoring, short courses and 'learning by doing'.

A closely allied component was an expansive set of farmer PVS trials. Preferred varieties were selected by farmers and scientists during a sequence of mother, baby and advanced trials done over several seasons in the Vientiane, Savannakhet and Champasak provinces. A total of 788 farmers were involved in the three provinces over the five seasons.

We have assumed that 30% of the benefits from the breeding and adoption by farmers of more drought-tolerant varieties can be attributed to Professor Fukai and this set of ACIAR projects.

These assumptions yielded a benefit stream from 2008 to 2020 of A$18.5 million in 2017 present value terms.

9.2 Direct seeding

The ACIAR projects aimed to develop and extend methods of direct seeding of rice. The supply of farm labour in Laos was becoming scarcer and more expensive, because of economic growth increasing job opportunities and real wages in the economy. There was a need to find ways of planting rice using less labour.

The research, development and extension into direct seeding of the three ACIAR projects from 1995 to 2011 developed a direct-seeding technology suitable for the lowlands of Laos.

The projects found that well-managed direct-seeded crops can produce yields and crop gross margins that were comparable with the performance of transplanted crops. This information is invaluable to farmers weighing up the decision to adopt the innovation under conditions of much uncertainty about its likely performance.

The management of weeds in direct-seeded crops remains challenging for farmers. It seems that direct-seeded and transplanted crops will have to be grown in rotation until better weed management strategies evolve. Soil moisture conditions also influence the choice between direct seeding and transplanting in any year and subsequent crop yields.

If the research underlying the direct-seeding technology done during the ACIAR projects from 1997 to 2011 had not been done, this work would now need to be done.

Our judgement is that the ACIAR projects most probably brought forward the use of direct seeding by at least five years, and, having done this, the three ACIAR projects can claim 60% of the benefits likely to come from adoption of direct seeding by lowland rice farmers between 2014 and 2026. Without the projects, these benefits would not have been achieved for a further five years.

Under both 'with' and 'without' the ACIAR projects scenarios, we have assumed that by 2026, 60% of the area of lowland rice will be direct sown.

9.3 Returns to ACIAR projects

The present value in 2017 of the investment in the three projects by ACIAR and partners, estimated using a 5% discount rate, was almost A$14.1 million. The present value in 2017 of the stream of benefits from the adoption of more drought-tolerant varieties and direct seeding attributable to the ACIAR projects was A$18.5 million and A$44.1 million, respectively, for a total of A$62.6 million, at 5% discount rate.

The net present value of these streams of benefits and costs was A$48.5 million. The benefit:cost ratio was 4.44:1, and the internal rate of return was 16.0%. The internal rate of return assumes that interim net benefits are reinvested at the rate of 16.0%. The modified internal rate of return, assuming that net benefits are reinvested at a rate of 5%, was 11.5%.

Investment by ACIAR and its partners in the three projects has been a good use of its funds. This finding is quite robust, given our assumptions about key parameters for which there is great uncertainty. If the level of adoption and the share of benefits attributable to both components of the projects are halved, the investment still earns the required rate of return.

9.4 Capacity building

In addition to measured economic benefits, capacity building was a most significant component of this set of projects. Capacity was developed through:

- additions to scientific knowledge in the form of scientific publications
- informal training of project scientists through mentoring, learning by doing and short courses
- building the capacity of farmers to grow rice and manage their farms through their participation in the rice variety trials
- formal postgraduate training opportunities for scientists working on the projects.

There is a lag between building capacity and its subsequent impact on the set of technologies available to farmers, so usually this impact occurs well after the conclusion of the conclusion of the project. This set of projects extended from 1997 to 2012, so it is likely that capacities built in earlier projects were of benefit to later projects, and contributed to their outcomes.

The three projects produced 144 scientific and conference publications—substantial additions to the stock of scientific knowledge. Most publications were jointly authored by scientists from Australia, Laos and Thailand. Successful collaborative work increases the capacity of researchers by improving generic skills, such as scientific writing and presentation skills. The 11 most widely cited papers by Professor Fukai and co-authors were cited between 128 and 639 times.

Workshops and short courses were held as part of each project. Collaborating scientists had opportunities to analyse, discuss and present results and prepare publications, which all added to capacity. The opportunity to maintain and incrementally increase capacity was an important benefit of a succession of ACIAR-funded projects.

After working on the projects, 18 people completed postgraduate degrees. ACIAR funded five PhD students and one Master student. The projects funded one Master student directly, while other external sources funded five PhD students and four Master students. The students studied drought tolerance, climate modelling, non-rice crops, direct seeding and cold tolerance.

In all three projects, many trials were done in the fields of rice farmers. Nearly 800 farmers participated in the plant variety selection trials of the final project, developing skills in selecting varieties best suited to their environment, and in understanding and weighing-up the economic consequences of their decisions.

Direct-seeding trials were also done in farmer's fields. Direct seeding is a system change with various implications, which requires new skills, particularly in weed management and the soil conditions needed for the plants to establish successfully.

9.5 Social impacts

Fukai et al. 2016 argued that the direct-seeding technology had positive social impacts, because it released some of the farm household, especially women, from the hard manual labour of transplanting.

Some people released by direct seeding might find employment off-farm, while some freed up from transplanting would likely use their time to manage other minor crops and animals, manage the household, and have leisure time.

It is hard to value the opportunity cost of these activities. We valued all labour released at the current market rate of 60,000 kip/day.

9.6 Summary

Despite uncertainties around the key parameters, such as adoption and attribution, this set of projects has been a good use of ACIAR funds. Lao rice growers in lowland areas have earned higher incomes from the two technologies—more drought-tolerant rice varieties and the direct-seeding technology—and the flow of net benefits to rice farming families is likely to increase as adoption spreads.

The rate of return on capital to ACIAR and its partners has been satisfactory. Significant scientific capacity was also built in new knowledge, as evidenced by a strong publications record, and in human scientific capacity, through informal means, such as mentoring and 'learning by doing'.

The direct-seeding technology enables farm families to reduce their time on the onerous task of transplanting rice, providing opportunities for other off-farm and on-farm activities, including employment, growing vegetables, tending livestock, managing the household and having more leisure time.

Appendix
Costs of owning or acquiring direct-seeding equipment

The question of farmer ownership of the direct-seeding equipment relates to the cost of acquiring the services of direct-seeding equipment. This cost, whether owned or contracted, is not included.

The annual cost of acquiring machinery services, whether owned or contracted, is part of a comparison between the costs of the alternative methods of establishing rice.

To own a small drill would cost about A$500. Depending on design and quality, the drill could be used to plant 10–30 ha/year, and have a life of more than 20 years with zero salvage value.

This would give an annual depreciation cost of (A$500–0)/20=$25. Average annual interest cost of owning the equipment would be ($500+0)/2*0.05=$12.50. Annual repair and maintenance of the drill would be 3% of new price, or about $15. So the total annual costs of owning the drill would be about $50.

If the drill was used to plant 10 ha of neighbouring rice farmers' land, the cost per hectare before labour cost would be $5, or about 30,000 kip.

If a drum seeder was used, the annual cost of using this low-cost implement would be very low. As a mix of methods of direct seeding are used, in varying proportions for each farm system in any year, the cost of acquiring machinery services for direct seeding of rice has not been explicitly included.

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Impact assessment series

No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics 1998	Control of Newcastle disease in village chickens	AS1/1983/034, AS1/1987/017, AS1/1993/222
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6	Ryan J.G. 1998	Pigeonpea improvement	CS1/1982/001, CS1/1985/067
7	Centre for International Economics 1998	Reducing fish losses due to epizootic ulcerative syndrome—an ex ante evaluation	FIS/1991/030
8	McKenney D.W. 1998	Australian tree species selection in China	FST/1984/057, FST/1988/048
9	ACIL Consulting 1998	Sulfur test KCL–40 and growth of the Australian canola industry	PN/1983/028, PN/1988/004
10	AACM International 1998	Conservation tillage and controlled traffic	LWR2/1992/009
11	Chudleigh P. 1998	Postharvest R&D concerning tropical fruits	PHT/1983/056, PHT/1988/044
12	Waterhouse D., Dillon B. and Vincent D. 1999	Biological control of the banana skipper in Papua New Guinea	CS2/1988/002-C
13	Chudleigh P. 1999	Breeding and quality analysis of rapeseed	CS1/1984/069, CS1/1988/039
14	McLeod R., Isvilanonda S. and Wattanutchariya S. 1999	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008, PHT/1990/008
15	Chudleigh P. 1999	Use and management of grain protectants in China and Australia	PHT/1990/035
16	McLeod R. 2001	Control of footrot in small ruminants of Nepal	AS2/1991/017, AS2/1996/021
17	Tisdell C. and Wilson C. 2001	Breeding and feeding pigs in Australia and Vietnam	AS2/1994/023
18	Vincent D. and Quirke D. 2002	Controlling *Phalaris minor* in the Indian rice-wheat belt	CS1/1996/013
19	Pearce D. 2002	Measuring the poverty impact of ACIAR projects — a broad framework	
20	Warner R. and Bauer M. 2002	*Mama Lus Frut* scheme: an assessment of poverty reduction	ASEM/1999/084
21	McLeod R. 2003	Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in Southeast Asia	AS1/1983/067, AS1/1988/035, AS1/1992/004, AS1/1994/038

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22	Bauer M., Pearce D. and Vincent D. 2003	Saving a staple crop: impact of biological control of the banana skipper on poverty reduction in Papua New Guinea	CS2/1988/002-C
23	McLeod R. 2003	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011, AS2/1993/001
24	Palis F.G., Sumalde Z.M. and Hossain M. 2004	Assessment of the rodent control projects in Vietnam funded by ACIAR and AusAID: adoption and impact	AS1/1998/036
25	Brennan J.P. and Quade K.J. 2004	Genetics of and breeding for rust resistance in wheat in India and Pakistan	CS1/1983/037, CS1/1988/014
26	Mullen J.D. 2004	Impact assessment of ACIAR-funded projects on grain-market reform in China	ADP/1997/021, ANRE1/1992/028
27	van Bueren M. 2004	Acacia hybrids in Vietnam	FST/1986/030
28	Harris D. 2004	Water and nitrogen management in wheat-maize production on the North China Plain	LWR1/1996/164
29	Lindner R. 2004	Impact assessment of research on the biology and management of coconut crabs on Vanuatu	FIS/1983/081
30	van Bueren M. 2004	Eucalypt tree improvement in China	FST/1984/057, FST/1987/036, FST/1988/048, FST/1990/044, FST/1994/025, FST/1996/125, FST/1997/077
31	Pearce D. 2005	Review of ACIAR's research on agricultural policy	
32	Tingsong Jiang and Pearce D. 2005	Shelf-life extension of leafy vegetables —evaluating the impacts	PHT/1994/016
33	Vere D. 2005	Research into conservation tillage for dryland cropping in Australia and China	LWR2/1992/009, LWR2/1996/143
34	Pearce D. 2005	Identifying the sex pheromone of the sugarcane borer moth	CS2/1991/680
35	Raitzer D.A. and Lindner R. 2005	Review of the returns to ACIAR's bilateral R&D investments	
36	Lindner R. 2005	Impacts of mud crab hatchery technology in Vietnam	FIS/1992/017, FIS/1999/076
37	McLeod R. 2005	Management of fruit flies in the Pacific	CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225
38	ACIAR 2006	Future directions for ACIAR's animal health research	

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39	Pearce D., Monck M., Chadwick K. and Corbishley J. 2006	Benefits to Australia from ACIAR-funded research	AS2/1990/028, AS2/1994/017, AS2/1994/018, AS2/1999/060, CS1/1990/012, CS1/1994/968, FST/1993/016, PHT/1990/051
40	Corbishley J. and Pearce D. 2006.	Zero tillage for weed control in India: the contribution to poverty alleviation	CS1/1996/013
41	ACIAR 2006	ACIAR and public funding of R&D. Submission to Productivity Commission study on public support for science and innovation	
42	Pearce D. and Monck M. 2006	Benefits to Australia of selected CABI products	
43	Harris D.N. 2006	Water management in public irrigation schemes in Vietnam	LWR1/1998/034, LWR2/1994/004
44	Gordon J. and Chadwick K. 2007	Impact assessment of capacity building and training: assessment framework and two case studies	CS1/1982/001, CS1/1985/067, LWR2/1994/004, LWR2/1998/034
45	Turnbull J.W. 2007	Development of sustainable forestry plantations in China: a review	
46	Monck M. and Pearce D. 2007	Mite pests of honey bees in the Asia–Pacific region	AS2/1990/028, AS2/1994/017, AS2/1994/018, AS2/1999/060
47	Fisher H. and Gordon J. 2007	Improved Australian tree species for Vietnam	FST/1993/118 and FST/1998/096
48	Longmore C., Gordon J. and Bantilan M.C. 2007	Assessment of capacity building: overcoming production constraints to sorghum in rainfed environments in India and Australia	CS1/1994/968
49	Fisher H. and Gordon J. 2007	Minimising impacts of fungal disease of eucalypts in South-East Asia	FST/1994/041
50	Monck M. and Pearce D. 2007	Monck M. and Pearce D. 2007. Improved trade in mangoes from the Philippines, Thailand and Australia	CS1/1990/012, PHT/1990/051
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52	Fisher H. and Gordon J. 2008	Breeding and feeding pigs in Vietnam: assessment of capacity building and an update on impacts	AS2/1994/023
53	Monck M. and Pearce D. 2008	The impact of increasing efficiency and productivity of ruminants in India by the use of protected nutrient technology	AH/1997/115
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No.	Author(s) and year of publication	Title	ACIAR project numbers
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56	Lindner B. and McLeod P. 2008	A review and impact assessment of ACIAR's fruitfly research partnerships—1984–2007	CP/1997/079, CP/2001/027, CP/2002/086, CP/2007/002, CP/2007/187, CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225, CS2/1997/101, CS2/1998/005, CS2/2003/036, PHT/1990/051, PHT/1993/87, PHT/1994/133
57	Montes N.D., Zapata Jr N.R., Alo A.M.P. and Mullen J.D. 2008	Management of internal parasites in goats in the Philippines	AS1/1997/133
58	Davis J., Gordon J., Pearce D. and Templeton D. 2008	Guidelines for assessing the impacts of ACIAR's research activities	
59	Chupungco A., Dumayas E. and Mullen J. 2008	Two-stage grain drying in the Philippines	PHT/1983/008, PHT/1986/008, PHT/1990/008
60	Centre for International Economics 2009	ACIAR Database for Impact Assessments (ADIA): an outline of the database structure and a guide to its operation	
61	Fisher H. and Pearce D. 2009	Salinity reduction in tannery effluents in India and Australia	AS1/2001/005
62	Francisco S.R., Mangabat M.C., Mataia A.B., Acda M.A., Kagaoan C.V., Laguna J.P., Ramos M., Garabiag K.A., Paguia F.L. and Mullen J.D. 2009	Integrated management of insect pests of stored grain in the Philippines	PHT/1983/009, PHT/1983/011, PHT/1986/009, PHT/1990/009
63	Harding M., Tingsong Jiang and Pearce D. 2009	Analysis of ACIAR's returns on investment: appropriateness, efficiency and effectiveness	
64	Mullen J.D. 2010	Reform of domestic grain markets in China: a reassessment of the contribution of ACIAR-funded economic policy research	ADP/1997/021 and ANRE1/1992/028
65	Martin G. 2010	ACIAR investment in research on forages in Indonesia	AS2/2000/103, AS2/2000/124, AS2/2001/125, LPS/2004/005, SMAR/2006/061, SMAR/2006/096
66	Harris D.N. 2010	Extending low-cost fish farming in Thailand: an ACIAR–World Vision collaborative program	PLIA/2000/165
67	Fisher H. 2010	The biology, socioeconomics and management of the barramundi fishery in Papua New Guinea's Western Province	FIS/1998/024
68	McClintock A. and Griffith G. 2010	Benefit–cost meta-analysis of investment in the International Agricultural Research Centres	

No.	Author(s) and year of publication	Title	ACIAR project numbers
69	Pearce D. 2010	Lessons learned from past ACIAR impact assessments, adoption studies and experience	
70	Harris D.N. 2011	Extending low-chill fruit in northern Thailand: an ACIAR–World Vision collaborative project	PLIA/2000/165
71	Lindner R. 2011	The economic impact in Indonesia and Australia from ACIAR's investment in plantation forestry research, 1987–2009	FST/1986/013, FST/1990/043, FST/1993/118, FST/1995/110, FST/1995/124, FST/1996/182, FST/1997/035, FST/1998/096, FST/2000/122, FST/2000/123, FST/2003/048, FST/2004/058
72	Lindner R. 2011	Frameworks for assessing policy research and ACIAR's investment in policy-oriented projects in Indonesia	ADP/1994/049, ADP/2000/100, ADP/2000/126, AGB/2000/072, AGB/2004/028, ANRE1/1990/038, ANRE1/1993/023, ANRE1/1993/705, EFS/1983/062, EFS/1988/022
73	Fisher H. 2011	Forestry in Papua New Guinea: a review of ACIAR's program	FST/1994/033, FST/1995/123, FST/1998/118, FST/2002/010, FST/2004/050, FST/2004/055, FST/2004/061, FST/2006/048, FST/2006/088, FST/2006/120, FST/2007/078, FST/2009/012
74	Brennan J.P. and Malabayabas A. 2011	International Rice Research Institute's contribution to rice varietal yield improvement in South-East Asia	
75	Harris D.N. 2011	Extending rice crop yield improvements in Lao PDR: an ACIAR–World Vision collaborative project	CIM/1999/048, CS1/1995/100, PLIA/2000/165
76	Grewal B., Grunfeld H. and Sheehan P. 2011	The contribution of agricultural growth to poverty reduction	
77	Saunders C., Davis L. and Pearce D. 2012	Rice–wheat cropping systems in India and Australia, and development of the 'Happy Seeder'	LWR/2000/089, LWR/2006/132, CSE/2006/124
78	Carpenter D. and McGillivray M. 2012	A methodology for assessing the poverty-reducing impacts of Australia's international agricultural research	
79	Dugdale A., Sadleir C., Tennant-Wood R. and Turner M. 2012	Developing and testing a tool for measuring capacity building	
80	Fisher H., Sar L. and Winzenried C. 2012	Oil palm pathways: an analysis of ACIAR's oil palm projects in Papua New Guinea	ASEM/1999/084, ASEM/2002/014, ASEM/2006/127, CP/1996/091, CP/2007/098, PC/2004/064, PC/2006/063
81	Pearce D. and White L. 2012	Including natural resource management and environmental impacts within impact assessment studies: methodological issues	

No.	Author(s) and year of publication	Title	ACIAR project numbers
82	Fisher H. and Hohnen L. 2012	ACIAR's activities in Africa: a review	AS1/1983/003, AS1/1995/040, AS1/1995/111, AS1/1996/096, AS1/1998/010, AS2/1990/047, AS2/1991/018, AS2/1993/724, AS2/1996/014, AS2/1999/063, AS2/1996/090, AS2/1996/149, AS2/1996/203, AS2/1997/098, CP/1994/126, CS2/1990/007, EFS/1983/026, FST/1983/020, FST/1983/031, FST/1983/057, FST/1988/008, FST/1988/009, FST/1991/026, FST/1995/107, FST/1996/124, FST/1996/206, FST/2003/002, IAP/1996/181, LPS/1999/036, LPS/2002/081, LPS/2004/022, LPS/2008/013, LWR/2011/015, LWR1/1994/046, LWR2/1987/035, LWR2/1996/049, LWR2/1996/163, LWRS/1996/215, LWR2/1997/038, SMCN/1999/003, SMCN/1999/004, SMCN/2000/173, SMCN/2001/028
83	Palis F.G., Sumalde Z.M., Torres C.S., Contreras A.P. and Datar F.A. 2013	Impact pathway analysis of ACIAR's investment in rodent control in Vietnam, Lao PDR and Cambodia	ADP/2000/007, ADP/2003/060, ADP/2004/016, AS1/1994/020, AS1/1996/079, AS1/1998/036, CARD 2000/024, PLIA/2000/165
84	Mayne J. and Stern E. 2013	Impact evaluation of natural resource management research programs: a broader view	
85	Jilani A., Pearce D. and Bailo F. 2013	ACIAR wheat and maize projects in Afghanistan	SMCN/2002/028, CIM/2004/002, CIM/2007/065
86	Lindner B., McLeod P. and Mullen J. 2013	Returns to ACIAR's investment in bilateral agricultural research	
87	Fisher H. 2014	Newcastle disease control in Africa	AS1/1995/040, AS1/1996/096
88	Clarke M. 2015	ACIAR-funded crop–livestock projects, Tibet Autonomous Region, People's Republic of China	LPS/2002/104, CIM/2002/093, LPS/2005/018, LPS/2005/129, LPS/2006/119, LPS/2008/048, LPS/2010/028, C2012/228, C2013/017
89	Pearce D. 2016	Sustaining cocoa production: impact evaluation of cocoa projects in Indonesia and Papua New Guinea	SMAR/2005/074, HORT/2010/011, ASEM/2003/015, ASEM/2006/127, PC/2006/114
90	Pearce D. 2016	Impact of private sector involvement in ACIAR projects: a framework and cocoa case studies	PC/2006/114, ASEM/2006/127, SMAR/2005/074, HORT/2010/011
91	Brown P. R., Nidumolu U. B., Kuehne G., Llewellyn R., Mungai O., Brown B. and Ouzman J. 2016	Development of the public release version of Smallholder ADOPT for developing countries	
92	Davila F., Sloan T. and van Kerkhoff L. 2016	Knowledge systems and RAPID framework for impact assessments	CP/1997/017

No.	Author(s) and year of publication	Title	ACIAR project numbers
93	Mullen, J.D., de Meyer, J., Gray, D. and Morris, G. 2016	Recognising the contribution of capacity building in ACIAR bilateral projects: Case studies from three IAS reports.	FST/1986/030, FST/1993/118, FST/1998/096, FIS/2005/114
94	Davila F., Sloan T., Milne M., and van Kerkhoff L., 2017	Impact assessment of giant clam research in the Indo-Pacific region	FIS/1982/032, FIS/1987/033, EFS/1988/023, FIS/1995/042
95	Ackerman J.L. and Sayaka B. 2018	Impact assessment of ACIAR's Aceh aquaculture rehabilitation projects	FIS/2005/009, FIS/2006/002
96	Clarke, M. and Mikhailovich, K. 2018	Impact assessment of investment in aquaculture-based livelihoods in the Pacific islands region and tropical Australia	FIS/2001/075, FIS/2006/138
97	Mullen J.D., Malcolm B. and Farquharson R.J. 2019	Impact assessment of ACIAR-supported research in lowland rice systems in Lao PDR	CSI/1995/100, CIM/1999/048, CSE/2006/041
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