IMPROVED DRYING OF HIGH MOISTURE GRAINS

ACIAR Projects PHT/1983/008, PHT/1986/008 and PHT/1990/008

Ross McLeod
eSYS Development Pty Ltd, Sydney

Somporn Isvilanonda and Sarun Wattanutchariya
Kasetsart University, Bangkok

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

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Contents

Figure

Tables

1 Summary

An economic evaluation of three ACIAR projects whose primary objective was to improve postharvest grain drying in Thailand and Australia is provided in this report.

During 1983–1996, ACIAR invested A$1.2 million in research designed to improve grain drying in these countries. Based on current adoption, the investment has resulted in a realised net present value of A$3.6 million. A benefit–cost ratio of 3:1 was estimated for the projects. In other words, for each dollar invested, three dollars of project benefits have resulted. A high proportion of realised benefits was estimated to accrue to Australian rice producers, through reduced grain drying costs, while benefits have also been captured by the Thai rice production industry through reduced postharvest losses.

Based on projected levels of future adoption, it was estimated that a project net present value of A$18.4 million could be achieved in Australia and Thailand. Several other countries such as Indonesia, the Philippines and Vietnam could also benefit from the technology developed in these projects. These benefits have not been quantified as part of this evaluation. Their inclusion would increase the value of ACIAR-supported grain drying research.

2 Introduction

The postharvest loss of agricultural produce continues to be a serious constraint to total food delivery. Within the tropics, large volumes of cereal crop produce are lost or suffer quality deterioration after harvest because of the hot humid conditions in which they are produced. In Vietnam alone, it has been estimated that 2% of the rice crop is lost during drying and cleaning. This loss has been valued at US$45 million per year (Le Doan Dien 1994).

To improve the quality of high moisture grains and reduce postharvest grain losses in Australia and Southeast Asia, ACIAR funded three projects spanning a 14-year period. The series of projects (referred to as PHT/1983/008 “Drying in Bulk Storage: Application”, PHT/1986/008 “Drying High Moisture Grains in Humid Tropical Climates” and PHT/1990/008 “Applications of In-store Drying in the Grain Industry of Southeast Asia”) were initially funded in 1983. The projects have involved collaboration between researchers at the Department of Food Science and Technology, University of New South Wales and Ricegrowers’ Co-operative Limited in Australia; the National Post Harvest Institute for Research and Extension in the Philippines; King Mongkut’s University of Technology Thonburi in Thailand; and several other Asian research and extension institutions.

In total, A$1.2 million (1996 dollar terms) has been invested in Thailand and Australia across the life of the projects. As a result of these projects, grain drying dynamics and quality characteristics have been analysed, in-store drying has been shown to be theoretically and commercially feasible in tropical cereal production areas, first-stage dryers have been commercialised, and improved in-store dryer control technology has been developed. These outputs have potential application in rice, maize, soybean and peanut industries.

This report presents a benefit–cost analysis of the above project outputs. Economic benefits are estimated for the Australian and Thai rice production industries, as these sectors are the major beneficiaries of improved drying technology. Initially, project outputs are outlined and followed by a description of Australian and Thai rice production. The nature of postharvest losses for each industry is then described and the economic impacts of improved drying technology calculated. Evaluation results and sensitivity analyses are outlined in the concluding sections of the report.

A small survey of 14 rice millers and engineers was used to provide estimates for parameters included in the evaluation. The questionnaire utilised as part of the survey is included as Appendix 1. The basis for the estimates of economic benefits are provided in text and tables throughout the report.

3 The ACIAR Projects and Their Outputs

The three projects evaluated in this report were first funded in 1983, as project PHT/1983/008 "Drying in Bulk Storage: Application". The outputs of this and the following two projects are described in this section.

3.1 Project PHT/1983/008 Drying in Bulk Storage: Application

This project involved collaboration between the University of New South Wales (UNSW), Ricegrowers' Co-operative Limited (RCL), the National Post Harvest Institute for Research and Extension (the Philippines) (NAPHIRE) (now the Bureau of Postharvest Research and Extension), King Mongkut's University of Technology Thonburi (KMUTT) and Malaysian research organisations. It commenced in 1983 and had the following major objectives:

- to study the movement of moisture and temperature profiles through bulk stored paddy when aerated and stored under differing conditions;
- to measure basic thermophysical data for paddy relevant to the design of bulk storage/drying facilities in tropical climates;
- to investigate the effect of various aeration and drying strategies on the quality of stored paddy and energy consumption; and
- to assess various energy sources as a means of improving the drying of stored paddy if required.

Investigations included the collection of ambient condition, product characteristics (related to moisture and relative humidity) and resources (energy and storage facilities) data to better understand stored grain behaviour. Research was undertaken in Australia, Thailand, Malaysia and the Philippines.

Within Australia, RCL was responsible for applying the grain storage principals developed by UNSW and collaborators. The impacts of various aeration strategies upon milling, grain cracking and breakage, grain colour, microbial build-up and cooking quality were determined using standard sampling and physico-chemical analysis methods adopted by the rice industry.

Outputs

Principal outputs relevant to Thai and Australian rice producers included the following:

- It was shown that in-store drying of paddy is feasible under hot and humid conditions. The energy consumption associated with in-store drying (low airflow rate) was half that of when grain was dried with high airflow rates.
- Where paddy is received at moisture levels of above 20%, two-stage drying was shown to be the most effective drying strategy. Two-stage drying involves fast drying in the first stage, followed by slow drying in the second phase using ambient air.
- Optimal airflow rates were derived for differing grain characteristics.

3.2 Project PHT/1986/008 Drying High Moisture Grains in Humid Tropical Climates

Following the success of PHT/1983/008, PHT/1986/008 was begun in 1987. Project objectives flowed on from those in the previous project and similar project collaborators were involved. The new project had the following objectives:

- to gather data on the relative efficiency of different drying systems—these data were used to develop pilot drying plants;
- to investigate short-term quality maintenance of wet paddy after harvest;
- to examine first-stage drying of paddy and drying of other grains such as maize and peanuts; and
- to investigate mill-level drying using rice-husk furnaces and evaluate options for first-stage drying where a two-stage drying process is needed.

Outputs

In order to achieve the above objectives, theoretical principles and models of drying were developed. Models were fitted with the data acquired by partner countries and results presented at seminars and in journal papers. Pilot drying plants were developed using outputs of the theoretical component of the project.

Importantly, researchers in Thailand and the Philippines were able to establish links with the milling sector, and commercial trials were conducted to test pilot equipment and recommendations. Following trials, a mill modified drying system which included in-store aeration was developed. The modified drying system reduced drying energy requirements and led to improved milling yields. As a result of the project it was recommended that the concept of in-store drying be adopted.

3.3 Project PHT/1990/008 Applications of In-store Drying in the Grain Industry of Southeast Asia

A third project, PHT/1990/008, was funded. Its objectives were to:

- collect thermophysical, climatic and socioeconomic data relevant to the design of appropriate drying systems for paddy and corn in collaborating countries in Southeast Asia;
- study formation of aflatoxin in maize and ergosterol in paddy at laboratory and field levels;
- develop quality models including models for aflatoxin in maize and ergosterol in paddy;
- develop suitable designs of two-stage dryers with in-store drying as the second stage for paddy and maize;
- field test and analyse the performance of dryers developed by the project team; and
- promote the drying concepts developed to potential users and selected manufacturers interested in commercialisation of the dryers.

Outputs

Key outputs included the following:

- Thermophysical data were acquired as a result of research undertaken in the project. These data were used to model various types of drying systems and in the design of prototype dryers developed as part of the project.

- The results of mycological studies have been used to develop a model of fungal growth and aflatoxin build-up at different stages of postharvest handling.
- Prototypes were developed using design parameters synthesised in this and previous projects. Two-stage drying was promoted with in-store drying as a second stage.
- In relation to commercial outputs, the project review team concluded:

  "The most significant outcome of research activities in Thailand has been the development of a commercial fluidised bed dryer to handle first stage drying. The fluidised dryer is compact, operates at a temperature of 100–120 degrees Celsius and has a grain residence time of seven minutes. The dryer was commercialised by the Rice Engineering Supply Company. The development and commercialisation of a fluidised bed drying technology for paddy rice was not a specific goal of PN 9008, however, the development of such technology will facilitate more rapid adoption of two stage drying."

Overall, the projects have succeeded in achieving their objectives. It was proposed by the project review team that the following activities should be pursued to improve the potential for adoption of project results:

- study the optimal integration of first- and second-stage drying systems, along with appropriate tempering, cooling and re-drying practices;
- investigate other forms of fluidisation of grain for drying (e.g. spouted-bed drying) that could be more economically attractive than conventional fluidised-bed drying;
- development of biomass furnaces for fluidised-bed drying (rice husks and maize cobs);
- development of appropriate control systems for fluidised-bed dryers; and
- further promotion of two-stage drying systems.

Researchers at KMUTT have continued to investigate these aspects of mechanical drying since the end of the ACIAR projects. A biomass furnace has been commercialised and optimal spouted-bed dryer configurations are also being assessed.

4 Realised and Potential Project Outcomes

Improved drying technology has the potential to reduce postharvest grain losses and increase cereal supply in Southeast Asia and Australia. In this analysis the potential impact of this technology on the rice industries of Southeast Asia and Australia is investigated. Before outlining economic benefits of improved mechanical grain drying, the characteristics of rice production in Thailand and Australia are described.

4.1 Rice Industries of Thailand and Australia

Rice is the major crop of Southeast Asia. Globally, rice occupies about one-tenth of the arable land, but in the majority of Asian rice-producing countries, it accounts for one-third or more of the total planted area (IRRI 1993). Since the second world war, world rice area, yield and production have changed significantly. IRRI (1993) reported that the area planted has increased by almost 71% and the mean harvested yield has increased by 110%. Much of the yield increase has been attributed to the introduction of the dwarfing gene that allows for multiple cropping, along with increased use of fertiliser, irrigation water and other inputs. In Figure 1 it is evident that Thailand is a major producer of rice in Southeast Asia, while Australia represents only a small proportion of regional production.

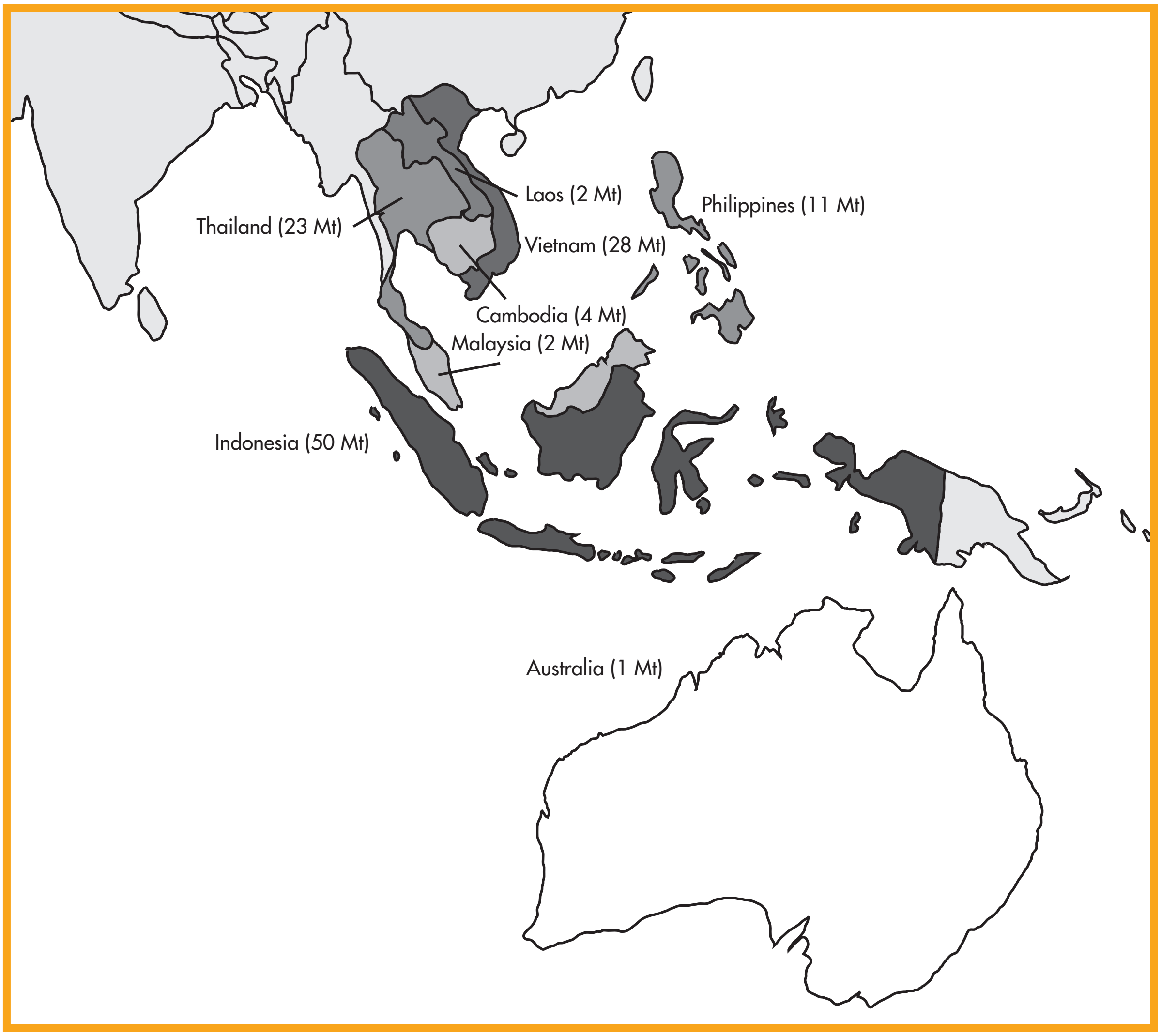
Thailand

Rice is grown throughout Thailand and is a major staple food and source of export revenue. About a third of the annual Thai crop of 23 million tonnes of paddy is exported which makes Thailand the largest exporter of rice (Isvilanonda 1997). Most of the crop is grown under rainfed conditions, particularly in the northeast region where traditional fragrant rice varieties are grown. Generally, yields are low in this region and a single crop is grown each year.

Modern varieties have not been widely adopted in Thailand. These varieties are primarily grown in the central and lower north regions where the availability of irrigation water permits multiple cropping. Rice yields in this region are above those of other production regions. Farmers in higher producing regions have adopted direct seeding and farm mechanisation in response to increases in rural labour costs.

All paddy is processed in rice mills. Larger rice mills have a capacity of 80 tonnes of paddy per day (Isvilanonda 1996). Mills of this size are primarily located on the central plain, while smaller mills (less than 10 tonnes per day) are found in the northeast. Isvilanonda (1996) indicated that mill capacity statistics are not readily available, but the Department of Industrial Control registers the number of mills by horsepower. The total number of mills in 1996 was estimated to be 66,617. Most of these mills (78%) are of small capacity, while medium (10–80 tonnes per day) and larger capacity mills accounted for 17 and 5%, respectively, of all mills. Survey participants were asked what they considered to be the major constraints on profitable rice milling in Thailand (Table 1). Opportunities to improve the financial viability of rice milling were also recorded.

Figure 1. Rice production (million tonnes of paddy, 1999) in Australia and Southeast Asia. Source: FAO (1999)



Major constraints on profitable mill production included poor quality of paddy, shortage of experienced labour and the current low capacity of milling equipment. Improvement in milling equipment and the education of farmers to adopt best farming practice are opportunities that could be pursued to enhance mill viability.

Table 1. Major constraints on rice milling in Thailand and opportunities to improve milling profitability (number of responses in brackets)

Constraints	Opportunities
• Paddy quality (11)	• Improve processing equipment (dryers) (7)
• Current milling machinery (3)	• Educate farmers to adopt best production practice (4)
• High cost of gasoline (1)	• Improve drying techniques (2)
• Shortage of experienced labour (4)	• Improve milling efficiency (4)
• Postharvest handling (1)	• Operators need to have vision (1)
• Cost of drying (1)	• Integration of drying techniques (1)
• Milling cost (2)	• Improved mill management (2)
• Fluctuation of paddy price (exchange rate movement) (1)	• Better postharvest practice (2)
• Internal management skills of rice millers (3)	• Good marketing planning (2)
• Instability of paddy price (1)	• Reduce production costs (1)
• High interest rates (1)	• Find low cost labour (1)
• Many rice mills (1)	• Government support for dryer adoption (1)

Over the last 30 years, rice production has increased by 2.8% per year, or by 10 million tonnes since 1965 (Isvilanonda 1997). During the 1960s and early 1970s, much of the observed growth was driven by increases in the cultivated area and to a lesser degree the adoption of modern varieties. Since the early 1980s, production has stagnated due to environmental degradation and shortages of irrigation water (Isvilanonda 1997).

Australia

Rice is primarily grown in irrigated areas of the Murray–Darling Basin in NSW. The industry began in 1892 when the NSW Department of Agriculture successfully produced upland rice varieties. During the 1920s Californian rice varieties were introduced and by 1930 the growing area was estimated to be 8096 ha with an average yield of 4 t/ha (IRRI 1993).

By 1997, the area under production had increased to 166,000 ha, with average yields of 8.4 t/ha (ABARE 1997). RCL coordinates much of the production, distribution and marketing of the Australian crop. In 1999, approximately 1.4 million tonnes of paddy were produced, of which 0.6 million tonnes were exported. Record production was achieved in this year, in part due to favourable seasonal conditions. A new short-season, short-grained rice variety 'Opus' was commercialised in that year (ABARE 1999). Expansion of the industry is constrained by the availability of water.

4.2 Nature of Postharvest Losses

Maintenance of grain quality is a major consideration for the postharvest handling of grain. Quality is governed by a number of factors which include variety, preharvest environment and postharvest handling. Paddy is commonly harvested at moisture contents above 18–20% (moisture content, wet basis), but needs to be stored at 14% moisture content to avoid quality deterioration.

Traditionally, a single rice crop was harvested each year in the dry season and sun dried before storage. Over the last 20 years, non-photoperiod-sensitive modern rice varieties have been introduced, facilitating the widespread adoption of multiple cropping. A large volume of rice is now harvested during periods of high rainfall and the practice of sun drying is not feasible for many producers. Modern varieties also have lower seed dormancy than traditional varieties, and will deteriorate at a rapid rate if paddy is stored at high moisture content.

Failure to reduce paddy moisture content to acceptable levels results in a number of quality problems which include (summarised from Juliano 1996):

- Delayed drying results in yellowing through stack-burning caused by heating of the wet grain (>20% moisture) as a result of grain respiration and microbial activity. Yellow grains are harder and more translucent than unaffected grains, which results in lower millable yield. Yellow grain also has a reduced lysine content.

- Aflatoxin produced by the fungus *Aspergillus flavus* is rarely a problem in paddy but affects maize because of delayed drying. Aflatoxin can cause liver disorders and cancer in poultry, pigs, and man.

4.3 Benefits Associated with Improved Grain Drying

Many millers in the Asian region have adopted mechanical dryers in order to dry paddy to acceptable levels. There are many mechanical dryers in use in Thailand. They include column dryers, fluidised-bed and in-store aeration systems. Column and fluidised-bed dryers are typically used to dry high moisture paddy by bringing paddy into contact with artificially heated air.

By drying high moisture paddy, serious deterioration is avoided and milling yields can be improved. Experimental trials outlined in Soponronnarit et al. (1998) indicated that mechanical drying of paddy may increase millable yield by as much as 4.8% over paddy that is sun dried. Given the competitiveness of the milling industry and the relatively high value of milled rice, milling yield increases of this magnitude would dramatically improve the financial performance of adopting rice mills.

The greatest concentration of mechanical drying equipment is found in the central and lower northern rice-producing areas of Thailand. Mills in this area are larger than those found in the northeast, and larger volumes of high moisture paddy are more likely to be transported to mills due to the widespread adoption of modern varieties. As previously noted, these varieties are often double-cropped and harvested during wet weather. American LSU-type column dryers have been widely adopted and it is estimated that half of the region's mill capacity has mechanical drying capability (estimate derived from survey participants).

The benefits of enhanced paddy quality need to be considered against the costs of purchasing mechanical dryers, and equipment operating costs such as fuel and labour expenses. In some instances, where paddy is overheated or not tempered between passes, grain kernels can crack, and milling yields will decrease as larger amounts of broken grain are produced. Furthering the understanding of grain drying properties has been a major output of the ACIAR projects. These principles have been utilised in the development of fluidised-bed drying systems in Thailand and improved in-store aeration control systems in Australia.

The PHT/1990/008 project review team indicated that the development of the fluidised-bed dryer was the major spin-off of the project in Thailand. During that project, prototypes of this system were developed and tested in commercial milling operations. In 1995, the fluidised-bed dryer was commercialised and a large number of units is currently operating throughout Thailand. The adoption of these systems has been associated with an expansion in the use of dryers in Thailand, and for the purposes of the evaluation it is assumed that part of increased mill production resulting from the use of mechanical dryers can be attributed to the ACIAR projects.

As part of the survey associated with this project evaluation, millers and engineers were asked what they considered to be the advantages and disadvantages of fluidised-bed dryer use, and how they thought the adoption of a fluidised-bed dryer might increase mill profitability. Table 2 summarises their responses. Rapid drying capability was nominated as the greatest advantage of this type of dryer, while an inability to reduce paddy moisture below 17–18% and high labour requirements for operation were perceived to be disadvantages. A large number of participants was unaware of fluidised-bed dryers. Many respondents indicated that the adoption of fluidised-bed dryers would increase mill profitability though increases in milling efficiency.

Table 2. Advantages and disadvantages of fluidised-bed dryers in Thailand (number of responses in brackets)

Advantages	Disadvantages	How fluidised-bed dryers could increase mill profitability
• Uniform moisture content of dried grain (3) • Rapid drying capability (7) • Less expensive than LSU (2) • Requires less space than LSU (1) • Able to increase milling yield (1)	• Cannot reduce moisture level below 17–18% (2) • The machine cannot be run automatically. Requires labour input (2) • Difficult to find mechanics to repair the machine (1) • No knowledge of machine (6) • High temperature can eliminate fragrance of jasmine rice (1) • Paddy may not move on conveyer when very wet (1) • Most mills in the lower north use column dryers (1) • May reduce milling yield when low moisture grain is dried (1)	• Increase milling yield (5) • Reduce drying cost (1) • No knowledge of machine (6) • High capacity and fast rate (2)

Australian rice industry benefits have stemmed from the development of improved aeration-control technology (in-store drying) within paddy storage sheds. In-store drying involves the drying of paddy using air-ducts and mechanised fans. Typically, paddy moisture contents are reduced from 18 to 14% as a result of in-store drying. This system is particularly suited to Australia where paddy is received at 19% moisture content.

In the humid production areas of Asia, where paddy moisture contents are likely to be higher (Soponronnarit et al. 1998), paddy maybe initially dried using high energy column and fluidised-bed drying systems to about 18%

moisture content, then subsequently dried using in-store systems. Survey participants were asked what they considered to be the advantages and disadvantages of in-store drying usage in Thailand and how this drying method could increase mill profitability. The responses to these questions are summarised in Table 3.

The length of the in-store drying process was considered to be the major disadvantage of this system. Adoption of the system is also likely to involve additional capital costs associated with storage shed modifications. In-store drying was, however, perceived to be a low-cost method of drying paddy and may be suitable for mills where paddy is stored for speculative and aging premiums.

During PHT/1983/008, a great deal of information was generated about the behaviour of paddy during drying which enabled improved drying recommendations to be developed. As a result of the project, automated aeration systems were developed, and consequently the labour and energy inputs required to manage these drying systems have been reduced. These cost savings are quantified in the next section along with the capital costs associated with improved aeration-control system installation.

Table 3. Advantages and disadvantages of in-store drying in Thailand (number of responses in brackets)

Advantages	Disadvantages	How in-store drying could increase mill profitability
• This drying system is appropriate for mills that store rice and speculate on price (4) • Most paddy in lower northeast is jasmine rice. Storage for a few months will attract a price increase (1)	• Length of drying process (6) • Problem in the central region where modern varieties are grown and rice is not stored (1) • May create cash flow problem. Operators in central market hold rice for 10–15 days (1) • Many rice mills do not have a storage policy (1) • Requires modification of storage (2) • No agent to promote this dryer (1) • No knowledge (3) • Will not increase profit (1)	• Lowest cost method of drying (4) • Highest rice quality (1) • Reduce cost of rice movement every 2–3 months (1) • No knowledge (4)

5 Benefit–cost Analysis of the Projects

A standard benefit–cost approach using an economic surplus framework (Davis et al. 1987) has been used to estimate project returns. First in this section, project costs are outlined, then the assumptions surrounding the estimation of project benefits are provided. The section concludes with a presentation of benefit–cost analysis results and sensitivity analyses.

5.1 Evaluation Framework

Results are provided for two evaluation scenarios.

- The first involves an evaluation of the economic benefits and project costs that have been realised to date. Under this scenario, costs and benefits are estimated over the 1983–1999 period.
- Second, an evaluation time frame of 1983–2020 is assumed and future benefits are estimated using forecasts of future events.

Benefits and costs are discounted using a 5% discount rate for both scenarios. Internal rate of return, net present value and benefit–cost ratio investment criteria are also presented for each scenario. A benefit–cost ratio of greater than one and positive net present value indicate that project benefits are greater than project costs.

5.2 Project Costs

Costs associated with project activities in Thailand and Australia are presented in Table 4. The total costs of these activities were approximately A$1.0 million in nominal terms.

It is evident that ACIAR initially allocated A$0.2 million to project PHT/1983/008 (Thai and Australian activities), and followed with further contributions of A$0.3 and A$0.5 million for the follow-on projects in these countries. These costs are translated into 1996 dollar terms for the benefit–cost analysis using adjustment factors for inflation. In 1996 dollar terms, it is estimated that A$1.2 million was invested by ACIAR to develop improved drying technology in Australia and Thailand.

Table 4. Annual project costs

Year	ACIAR project costs (A$ nominal)	Other project costs (A$ nominal)	Total project costs (A$ nominal)
1983	78,800		78,800
1984	47,015		47,015
1985	36,500		36,500
1986	54,188		54,188
1987	26,441		26,441
1988	61,550		61,550
1989	97,795		97,795
1990	97,795		97,795
1991	0		0
1992	0		0
1993	76,175	28,825	105,000
1994	104,900	37,650	142,550
1995	99,400	37,650	137,050
1996	40,725	28,825	69,550

5.3 Key Assumptions

The most difficult component of any benefit–cost analysis is the estimation of project benefits, as a large number of estimates need to be factored into the benefit assessment. The magnitude of increased mill profitability as a result of drying technology adoption, the nature of industry supply and consumer demand, and the market potential for drying technology need to be quantified. Key estimates of these parameters are summarised in Table 5 for Australia and Table 6 for Thailand.

Australia

In 1999, Australia produced 1.4 million tonnes of paddy, of which 0.6 million tonnes (paddy equivalent) was exported (ABARE 1999). Australian rice exports represent only a small proportion of world rice trade, and increased production is unlikely to have a significant impact on world price.

The development of automated drying control technology has resulted in reduced power and labour requirements for in-store drying. For a typical 12,000 tonne storage shed, an annual power saving of A$21,500 and labour saving of A$3,000 has resulted from the adoption of this technology. The installation cost of an improved aeration control system is A$200,000 (R. Bowman, pers. comm.). Additionally, the system has a useful economic life of 15 years and, given a discount rate of 5%, the annualised capital cost of the system is A$18,360. The net cost saving per tonne of rice is calculated to be 0.82 (A$/t).

Table 5. Australian annual research benefits

Key parameters	Research benefits (at maximum expected adoption)
Rice produced = 1.4 (million tonnes)[a]	Change in consumer surplus = 0.0 (A$m)
Rice exported = 0.6 (million tonnes)[a]	Change in producer surplus = 0.45 (A$m)
Elasticity of demand (ed) = –0.3[b]	Total research benefits = 0.45 (A$m)
Elasticity of supply (es) = 0.3[c]	
Cost saving (k) = 0.82 (A$/t)[d]	
Maximum expected adoption = 80%[e]	
Benefits attributed = 75%[f]	

[a] *Production data from ABARE (1999) (paddy basis)*
[b,c] *Taken from McMeniman and Lubulwa (1997)*
[d, e, f] *eSYS Development Pty Limited estimates*

Table 6. Thai annual research benefits

Key parameters	Research benefits (at maximum expected adoption)
Rice produced = 23 (million tonnes)[a]	Change in consumer surplus = 0.0 (A$m)
Rice exported = 8 (million tonnes)[a]	Change in producer surplus = 1.1 (A$m)
Elasticity of demand (ed) = –0.1[b]	Total research benefits = 1.1 (A$m)
Elasticity of supply (es)= 0.3[c]	
Fluidised cost saving (k) = 0.3 (A$/t)[d]	
Fluidised expected adoption = 30%[e]	
In-store cost saving (k) = 0.3 (A$/t)[d]	
In-store expected adoption = 10%[e]	
Benefits attributed = 65%[f]	

[a] *Production data from FAO (1999) (paddy basis)*
[b, c] *Taken from McMeniman and Lubulwa (1997)*
[d, e, f] *eSYS Development Pty Limited estimates*

Project PHT/1983/008 was completed in 1987 and improved aeration control technology was first adopted in this year. Following initial adoption, it is estimated that an additional 10% of the Australian crop per year was subject to improved drying technology until approximately 60% of the Australian rice industry had adopted the technology (R. Bowman, pers. comm.). Currently, 60% of the crop is dried using improved drying technology, but this level of adoption is expected to increase. It is estimated that adoption will further increase at 5% per annum until 80% of the industry has adopted the technology.

Improved in-store aeration technology was primarily implemented in the Australian rice industry as a result of the ACIAR projects. Consequently, 75% of the benefits from the adoption of automated aeration systems have been attributed to the ACIAR projects. At the maximum expected adoption of 80%, it is estimated that the rice industry saves more than A$400,000 per year as a result of improved aeration control system adoption.

Thailand

In 1999, 23 million tonnes of paddy was produced in Thailand (FAO 1999). Approximately one third of the crop, or 8 million tonnes of paddy, is exported, making Thailand the largest international exporter of rice (Isvilanonda 1997). It is estimated that the production increase resulting from improved drying technology adoption would not be sufficient to induce a decrease in the price received by Thai rice producers and millers.

The adoption of fluidised-bed dryers will increase rice milling yields in cases where overly moist paddy is being processed. There is, however, limited information about the extent of milling yield increases as a result of mechanical dryer use under commercial operating conditions. For the purposes of the analysis, it is estimated that the average milling yield for high moisture paddy increases by 4% as a result of fluidised-bed dryer usage. The results of experimental trials outlined by Soponronnarit et al. (1998) indicated that millable yield could increase by as much as 4.8% when fluidised-bed dryers were used to dry paddy under experimental conditions. Under commercial conditions it is likely that dryer operation may not be optimal, and a millable yield increase of 4% is therefore assumed in the analysis.

It is also estimated that each dryer processes 20,000 tonnes of paddy per year (S. Soponronnarit, pers. comm.). At the assumed millable yield increase of 4%, each dryer is estimated to generate an additional 800 tonnes of milled rice per year.

Fluidised-bed dryers currently cost A$23,824 (Soponronnarit et al. 1998) and are estimated to have a useful life of 20 years. Given a discount rate of 5%, the annual cost of this capital expenditure is calculated to be A$1,820. In addition to capital cost, the adoption of fluidised-bed dryers entails additional energy and maintenance costs. These costs are examined in Soponronnarit et al. (1998) who estimate that a fluidised-bed dryer costs

A$20,000 per annum to operate. By combining these factors into a partial margin, it calculated that the average cost of producing milled rice is decreased by A$0.3 per tonne following the adoption of these dryers.

Fluidised-bed dryers were commercialised in 1995 by the Rice Engineering Supply Company in Bangkok. By late 1997, approximately 50 units had been sold in Thailand (derived from Soponronnarit et al. 1998). Corresponding to this level of adoption, nearly one million tonnes of paddy is dried using these systems. Given that 23 million tonnes of paddy are produced in Thailand, approximately 4% of the crop is dried using fluidised-bed dryers.

During the survey of Thai rice millers and engineers, participants were asked whether they considered fluidised-bed dyers would be widely adopted by medium and large rice mills in their region. Of the 14 respondents, five thought the technology would be adopted by a substantial number of mills, three by a limited number of mills and seven thought that fluidised-bed dryers would not be adopted by any mills. Corresponding to these responses, it is estimated that by 2009 approximately 30% of national production will be dried using fluidised-bed dryers. It is further estimated that adoption will increase linearly at a rate of 2% (of total crop) per year.

In-store aeration has also been researched and promoted within the Thai rice industry as a result of the ACIAR projects. This aeration system is relatively less expensive than high-energy column and fluidised-bed drying and also results in high quality paddy. Soponronnarit et al. (1993) undertook a financial analysis of in-store drying at the Chachoengsao agricultural co-operative for a 100 tonne storage facility. It was determined that the establishment of an in-store drying facility of this capacity would be A$6,189, aeration would cost A$144 per year and milling yield would increase by 5% as a result of the superior quality paddy (Soponronnarit et al. 1993).

In the absence of in-store aeration, millers would typically store paddy and manually turn stockpiles to maintain quality. Establishment of a storage facility without aeration would cost 95% of the in-store aeration facility described by Soponronnarit et al. (1993), storage sheds have an economic life of 20 years and the manual turning of 100 tonnes of paddy would cost A$125 per year. Based on these estimates, the production of rice using in-store aeration of paddy costs A$0.3/t less than traditional paddy storage.

Since completion of the ACIAR projects, between 20–30 mills have adopted in-store drying systems (S. Soponronnarit, pers. comm.). To gauge the potential for future adoption, millers and engineers participating in the survey were asked how widespread would be the adoption of in-store aeration. Of the 14 respondents, one thought the technology would be adopted by a substantial number of mills, six by a limited number of mills and seven thought that in-store drying would not be adopted by any mills. Most respondents thought that the long drying period associated with in-store aeration would curtail widespread adoption of this system. In the analysis, it is estimated that 10% of rice millers will adopt this system and adoption will increase by 1% per annum until maximum expected adoption is achieved.

At the maximum expected level of adoption, the annual benefit of the projects in Thailand has been calculated to be A$1.1 million. For evaluation purposes, it is assumed that 65% of the benefits generated from fluidised-bed and in-store dryer adoption in Thailand are directly attributable to the ACIAR projects. The project review team indicated that the development of fluidised-bed drying technology was not an original objective of the ACIAR projects. However, the introduction of the fluidised-bed dryer was a factor aiding the introduction of in-store drying.

5.4 Results

The net present value of the investment to date (1983–1999) is calculated to be A$3.6 million expressed in 1996 dollar terms and with a discount rate of 5%. The benefit–cost ratio was calculated to be 3:1 and the internal rate of return 27%. A benefit–cost ratio of this magnitude suggests that for each dollar allocated to the projects three dollars of project benefits have been generated.

The distribution of project benefits between Australian and Thai rice industries is outlined in Table 7. To date, the bulk of project benefits has been reaped by Australian rice producers. A total of A$4.2 million was estimated to have accrued to Australian producers over the 1983–1999 period. In contrast, Thai producers are estimated to have gained A$1.1 million since commercialisation of fluidised-bed dryers in 1995.

The inclusion of forecast benefits until 2020 substantially increases the aggregate value of benefits accruing to the ACIAR projects (Table 8). The present value of project benefits was estimated to increase to A$20.1 million, or an additional A$15 million. The composition of benefits also changes within this longer time perspective as Thai producers are calculated to capture 55% of total benefits. Australian producers reap a greater proportion of early project benefits because improved aeration controls were commercialised in 1987, while Thai fluidised-bed dryers were commercialised in 1995. The net present value of the projects is estimated to be A$18.4 million with the inclusion of forecast benefits.

Table 7. Present value of benefits (A$m)

Source of benefits	Present value of benefits (A$ million)	Present value of benefits (%)
Benefits to date		
Australian rice	4.2	78
Thai rice	1.1	22
Total	5.3	100
Benefits (including forecast)		
Australian rice	9.0	45
Thai rice	11.1	55
Total	20.1	100

5.5 Sensitivity Analysis

Several forecasts have been included in the analysis and estimates made in relation to the impact of drying technology. These estimates have been made using the best available information, but could change as future market potential and performance become apparent. Sensitivity analysis is undertaken in this section to determine which parameters have the more significant impacts upon the estimated economic returns of the projects.

5.5.1 Discount Rate

Future benefits are discounted to account for the time value of money. Under base assumptions, a 5% discount rate was included in the analysis. The appropriate magnitude of this parameter may vary for different investors. Consequently, the sensitivity of net present value and benefit–cost ratios is outlined in Table 9.

It is evident that a lower discount rate results in higher economic returns for the projects. In the case of the “benefits to date” scenario, the projects net present value is A$0.1 million greater when a zero percent discount rate is used. The differences in net present values are substantial when forecast benefits are incorporated. The difference between net present values at 5 and 10% discount rates is calculated to be A$6.7 million.

Table 8. Benefit–cost analysis (including forecast)

Year	Benefits						Research	Totals	
	Thai benefits A$m nominal	Adjust factor	Thai benefits A$m 1996	Aust benefits A$m nominal	Aust benefits A$m 1996	Gross benefits A$m 1996	Total costs A$m 1996	Net benefits A$m 1996	NPV A$m 1996
1983	0.00	1.87	0.00	0.00	0.00	0.00	0.15	–0.15	–0.28
1984	0.00	1.65	0.00	0.00	0.00	0.00	0.08	–0.08	–0.15
1985	0.00	1.54	0.00	0.00	0.00	0.00	0.06	–0.06	–0.10
1986	0.00	1.43	0.00	0.00	0.00	0.00	0.08	–0.08	–0.14
1987	0.00	1.34	0.00	0.06	0.07	0.07	0.04	0.04	0.06
1988	0.00	1.23	0.00	0.11	0.14	0.14	0.08	0.06	0.08
1989	0.00	1.16	0.00	0.17	0.19	0.19	0.12	0.07	0.10
1990	0.00	1.11	0.00	0.22	0.25	0.25	0.11	0.13	0.18
1991	0.00	1.09	0.00	0.28	0.30	0.30	0.00	0.30	0.39
1992	0.00	1.08	0.00	0.34	0.36	0.36	0.00	0.36	0.44
1993	0.00	1.07	0.00	0.34	0.36	0.36	0.11	0.24	0.28
1994	0.00	1.06	0.00	0.34	0.35	0.35	0.15	0.20	0.22
1995	0.08	1.03	0.08	0.34	0.34	0.43	0.14	0.28	0.30
1996	0.17	1	0.17	0.34	0.34	0.50	0.07	0.43	0.43
1997	0.25	1	0.25	0.34	0.34	0.58	0.00	0.58	0.55
1998	0.33	1	0.33	0.34	0.34	0.67	0.00	0.67	0.60
1999	0.41	1	0.41	0.34	0.34	0.75	0.00	0.75	0.65
2000	0.50	1	0.50	0.36	0.36	0.86	0.00	0.86	0.71
2001	0.58	1	0.58	0.39	0.39	0.97	0.00	0.97	0.76
2002	0.66	1	0.66	0.42	0.42	1.08	0.00	1.08	0.81
2003	0.74	1	0.74	0.45	0.45	1.19	0.00	1.19	0.85
2004	0.83	1	0.83	0.45	0.45	1.27	0.00	1.27	0.86
2005	0.87	1	0.87	0.45	0.45	1.32	0.00	1.32	0.85
2006	0.92	1	0.92	0.45	0.45	1.37	0.00	1.37	0.84
2007	0.97	1	0.97	0.45	0.45	1.42	0.00	1.42	0.83
2008	1.02	1	1.02	0.45	0.45	1.46	0.00	1.46	0.81
2009	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.80
2010	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.76
2011	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.73
2012	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.69
2013	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.66
2014	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.63
2015	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.60
2016	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.57
2017	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.54
2018	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.52
2019	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.49
2020	1.06	1	1.06	0.45	0.45	1.51	0.00	1.51	0.47
Totals	21.09		21.09	12.73	12.93	34.02	1.21	32.81	18.39

5.5.2 Expected Adoption

The expected adoption of improved drying technology in Thailand will have a significant impact upon estimated project returns. The majority of Australian paddy is already dried using improved aeration technology, but in the case of Thailand, fluidised-bed dryers have only recently been commercialised and there is considerable potential for further adoption of this technology.

Future adoption of fluidised-bed drying will be governed by the economic climate within the rice industry, seasonal conditions, changes in paddy production practices and performance of alternative mechanical drying systems. Under base assumptions, it was assumed that 30% of the Thai rice industry will adopt the technology by 2009.

The sensitivity of projected economic returns to changes in expected Thai adoption of fluidised-bed and in-store dryers is outlined in Table 10. It is evident that a reduction in the expected level of adoption by 50% reduces net present value by A$4.1 million.

Table 9. Sensitivity of investment criteria to discount rate

Discount rate	0%	5%	10%
Benefits to date			
Net present value (A$ million)	3.7	3.6	3.4
Benefit–cost ratio	4:1	3:1	2:1
Benefits (including forecast)			
Net present value (A$ million)	32.8	18.4	11.7
Benefit–cost ratio	28:1	12:1	6:1

Table 10. Sensitivity of investment criteria to expected adoption

Expected adoption	(50%) Base	Base	(150%) Base
Adoption (including forecast)			
Net present value (A$ million)	14.3	18.4	20.5
Benefit–cost ratio	9:1	12:1	13:1
Internal rate of return (%)	30	30	30

5.5.3 Milling Yield

A large component of calculated economic benefits was generated from improved milling yields as a result of fluidised-bed dryer adoption. There is a great deal of uncertainty surrounding the extent of this gain.

Empirically, fluidised-bed dried paddy has been shown to have a 4.8% greater milling yield than sun-dried paddy. The magnitude of milling gains may differ between experimental results and commercial practice. The sensitivity of economic returns to changes in the assumed milling yield gain is provided in Table 11.

Table 11. Sensitivity of investment criteria to milling yield gain (fluidised-bed)

Increased milling yield	2%	4%	6%
Benefits (including forecast)			
Net present value (A$ million)	–15.6	18.4	49.9
Benefit–cost ratio	–8:1	12:1	31:1
Internal rate of return (%)	n.a.	30	35

It is evident that the milling yield increase assumption has a great deal of importance. For the projects to generate positive economic benefits, a milling yield increase of at least 3% would be required.

6. Conclusions

Postharvest losses of rice are significant in tropical Southeast Asia and Australia. The development of improved grain-drying technology has reduced these losses.

As a result of the projects, improved in-store aeration control technology has been successfully developed in Australia and fluidised-bed dryers have been commercialised in Thailand. To date, it was estimated that the net present value of these projects has been A$3.6 million and the benefit–cost ratio 3:1.

The incorporation of forecast benefits substantially increases the economic attractiveness of the projects. At a 5% discount rate, the net present value of the projects was estimated to be A$18.4 million when the evaluation time frame was extended to 2020.

Several other benefits can be attributed to the projects. These include:

- The use of fluidised-bed drying heats paddy to a point where part gelatinisation of grain starch occurs. This process improves the eating quality of rice, as the grain tastes like 'aged' rice. This type of rice attracts a price premium in many Asian markets.

- Fluidised-bed dryers can also be used to dry maize. Maize can develop aflatoxins if it is stored at high moisture levels. These toxins can cause liver damage to livestock. Maize is commonly downgraded if high moisture has reduced product quality. To date, the use of fluidised-bed dryers to dry maize has been limited.

- Livestock production can be hindered by the presence of the trypsin inhibitor in soybeans and extruders working at high temperature are typically used to destroy the inhibitor. Fluidised-bed dryers can be used to achieve the same result at a lower cost than that associated with extrusion.

- A rice husk furnace was developed by researchers at KMUTT using findings of the ACIAR projects. The profitability of using rice husk furnaces is largely driven by the demand for rice husks from the building sector and consequent husk price. Currently, rice husks are a low cost fuel for mechanical dryers.

- A large number of researchers have been involved with the ACIAR projects. It is difficult to quantify the magnitude of economic benefits stemming from skills enhancement. Given the large number of workshops and personnel collaborating on these projects, skills enhancement is likely to have increased research efficiency.

A small extension of the projects was conducted in Vietnam with very promising results. This country produces a large volume of rice and modern varieties are extensively double cropped. Consequently, postharvest paddy losses are a major problem and researchers in this country have estimated that substantial values of rice (A$45 million) are lost each year during drying and cleaning (Le Doan Dien 1994). Intellectual property generated in the ACIAR projects could be transferred to Vietnam with substantial economic benefit.

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- Mr Darryl Hill – Ricegrowers Co-operative Limited
- Dr Suwanna Praneetvatakul – Kasetsart University
- Dr George Srzednicki – University of New South Wales

Survey participants:

- Mr Yingyod Yingyuenyong – Director, Rice Engineering Supply Co. Limited
- Dr Somchart Soponronnarit – King Mongkut's University of Technology
- Mr Udhis Vanichanont – Chaivanich Rice Mill, Suphan Buri Province
- Manager, Benchapued Rice Mill, Phitsanulok Province
- Dr Maitri Naewphanit, Division of Agricultural Engineering, Department of Agriculture
- Manager, Sin Rung Ruang Rice Mill, Ubon Racha Thanee Province
- Mr Yongyudh Sri Chomquant, rice broker and mill owner, Pichit Province
- Mrs Virinda Srilachareon, Suchit Rice Mill, Suphan Buri Province
- Mr Pratum Phunsanguan, Manoroam Agricultural Co-op, Chainart Province
- Mr Yee Sae-Tieng, Benjapued Rice Mill, Pitsanulok Province
- Mr Sarnti Keittikun-kungwan, Chareon Panich Rice Mill, Pitsanulok Province
- Manager, Pattara Phun Rice Mill, Pitsanulok Province
- Mr Buntao Mutsuwan, Sinha Wattana Rice Mill, Pitsanulok Province
- Manager, Kung Lee Jun Rice Mill, Ayudthaya Province

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9 Appendix

Questionnaire

The Impact of Improved Paddy Drying Technology

All information will be treated in strict confidence

This questionnaire forms part of a project designed to estimate the economic impact of improved drying technology in Thailand and Australia. A summary of results will be made available to any interested parties.

It can be answered from a regional or national viewpoint

1. In your opinion, what percentage of regional/national paddy is dried using mechanical dryers?

Please specify (whether regional or national)

....

Percentage (%)

....

2. Currently, what are the major types of mechanical dryers used to dry paddy in your region/country (i.e. LSU, fluidised-bed, in-store…..)? In order of decreasing importance

1..

2..

3..

4..

3. Do you think the use of mechanical drying of paddy will increase or decrease in the future? Why/why not?

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4. What do think are the advantages and disadvantages of fluidised-bed dryers over other mechanical paddy drying systems?

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5. How could fluidised-bed dryers increase rice mill profitability?

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6. How widely do you think fluidised-bed dryers will be adopted by medium and large rice mills in your region/Thailand?

1 Most medium and large rice mills

2 A substantial number of medium and large rice mills

3 A limited number of medium and large rice mills

4 No medium and large rice mills

Why?

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7. How could in-store paddy drying systems improve mill profitability?

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8. What do you think are the major constraints and opportunities for the adoption of in-store paddy drying systems in Thailand?

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9. How widely do you think in-store paddy drying systems will be adopted by medium and large rice mills in your region/Thailand?

1 Most medium and large rice mills

2 A substantial number of medium and large rice mills

3 A limited number of medium and large rice mills

4 No medium and large rice mills

Why?

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....

GENERAL

10. In your opinion what are the three most important constraints on profitable rice milling in your region/Thailand? Please list in decreasing importance and explain

1...

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2...

....

3...

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11. In your opinion, what are the three most beneficial and feasible strategies to improve the profitability of rice milling in your region/Thailand? Please list in decreasing importance and explain

1...

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2...

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3...

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Thank you very much for your assistance.

If you would like a summary of the survey please include your contact details

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IMPACT ASSESSMENT SERIES

No.	Author and year of publication	Title	ACIAR project numbers
1	Centre for International Economics (1998)	Control of Newcastle disease in village chickens	8334, 8717 and 93/222
2	George, P.S. (1998)	Increased efficiency of straw utilisation by cattle and buffalo	8203, 8601 and 8817
3	Centre for International Economics (1998)	Establishment of a protected area in Vanuatu	9020
4	Watson, A.S. (1998)	Raw wool production and marketing in China	8811
5	Collins, D.J. and Collins, B.A (1998)	Fruit fly in Malaysia and Thailand 1985–1993	8343 and 8919
6	Ryan, J.G. (1998)	Pigeon pea improvement	8201 and 8567
7	Centre for International Economics (1998)	Reducing fish losses due to epizootic ulcerative syndrome — an ex ante evaluation	9130
8	McKenney, D.W. (1998)	Australian tree species selection in China	8457 and 8848
9	ACIL Consulting (1998)	Sulfur test KCL–40 and growth of the Australian canola industry	8328 and 8804
10	AACM International (1998)	Conservation tillage and controlled traffic	9209
11	Chudleigh, P. (1998)	Post-harvest R&D concerning tropical fruits	8356 and 8844
12	Centre for International Economics (1998)	Biological control of the banana skipper in Papua New Guinea	8802-C
13	Chudleigh, P. (1999)	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039

ECONOMIC ASSESSMENT SERIES (DISCONTINUED)

No.	Author and year of publication	Title	ACIAR project numbers
1	Doeleman, J.A. (1990a)	Biological Control of Salvinia	8340
2	Tobin, J. (1990)	Fruit Fly Control	8343
3	Fleming, E. (1991)	Improving the Feed Value of Straw Fed to Cattle and Buffalo	8203 and 8601
4	Doeleman, J.A.,(1990b)	Benefits and Costs of Entomopathogenic Nematodes: Two Biological Control Applications in China	8451 and 8929
5	Chudleigh, P.D. (1991a)	Tick-borne Disease Control in Cattle	8321
6	Chudleigh, P.D. (1991b)	Breeding and Quality Analysis of Canola (Rapeseed)	8469 and 8839
7	Johnston, J. and Cummings, R. (1991)	Control of Newcastle Disease in Village Chickens with Oral V4 Vaccine	8334 and 8717
8	Ryland, G.J. (1991)	Long Term Storage of Grain Under Plastic Covers	8307
9	Chudleigh, P.D. (1991c)	Integrated Use of Insecticides in Grain Storage in the Humid Tropics	8309, 8609 and 8311
10	Chamala, S., Karan, V., Raman, K.V and Gadewar, A.U. (1991)	An Evaluation of the Use and Impact of the ACIAR Book *Nutritional Disorders of Grain Sorghum*	8207
11	Tisdell, C. (1991)	Culture of Giant Clams for Food and for Restocking Tropical Reefs	8332 and 8733
12	McKenney, D.W., Davis, J.S., Turnbull, J.W. and Searle, S.D. (1991)	The Impact of Australian Tree Species Research in China	8457 and 8848
	Menz, K.M. (1991)	Overview of Economic Assessments 1–12	