# Impact Assessments of Forty-nine Thailand/Australia Collaborative Projects Funded by ACIAR during 1983–1995

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# Preface

There is strong evidence that agricultural research is an important source of growth in agriculture, resulting in economic and environmental benefits. ACIAR allocates its resources principally to research areas that will assist Australian agricultural scientists to use their skills to benefit developing countries while simultaneously working towards solving Australia's own agricultural problems. Given the limited funds available for research and development in agriculture, assessment of the impact of ACIAR-funded research is undertaken with a view to enhancing ACIAR performance against desired outcomes.

As part of this process, impact assessments of selected completed ACIAR projects are undertaken by economists independent of ACIAR. In December 1997, the Thai and Australian governments signed a memorandum of subsidiary arrangements relating to the ACIAR project entitled 'The Economic Evaluation of the Thailand/ Australian Collaborative Projects Funded by ACIAR – Stage 2' (IAP/1997/023). In this project, the institutional linkages were between ACIAR's Impact Assessment Program (IAP) and the Department of Agricultural and Resource Economics and the Centre for Applied Economic Research, Faculty of Economics, Kasetsart University, Bangkok. As a result of this collaboration, Associate Professor Somporn Isvilanonda and his team of economists produced 17 impact assessment papers covering 49 Thai projects funded in part by ACIAR.

In the assessment papers, it was revealed that there had been only moderate adoption of the outputs by smallholders. For example, the results of only 3 of the 49 projects have been fully adopted by the target groups, and those of only another 4 partially adopted.

One benefit of assessing the impact of the projects is the lessons that can be learnt in terms of understanding why the results of some of the apparently technically successful scientific projects were not adopted by the target groups. This information can be used in future project design to help to maximise the returns to ACIAR-funded research. A brief description of each of these reasons, and the number of projects to which they relate, follows:

- Seventeen of the 49 projects focused on basic rather than applied research and, hence, did not lead to the development of outputs that could be transferred directly to smallholders. However, the results from 13 of these projects were used in further scientific studies, some of which could ultimately result in the development of improved agricultural technologies.
- The results of five projects had not been transferred to smallholders at the time of the impact assessment because the 'development process' had not been completed. For example, the transgenic lines of papaya and cucurbits produced in the project on the ringspot virus (CS1/1992/026) still needed to be registered.
- There were four projects where a workable technology had been developed but not adopted by the smallholders because the extension effort was inadequate.
- Economic factors also limited the adoption of new technologies produced by 12 projects. For example, in a number of assessments it was revealed that the cost of the new technology prohibited its use by the very group it was targeted at. In addition, even when smallholders could afford a new technology, they did not adopt it because they believed that the returns would not be sufficient to cover the cost of their investment.
- Government policies prevented the adoption of the new technologies produced in three projects. For example, the outputs of the project on the integrated use of pesticides in grain storage (PHT/1986/009) have not been adopted because the necessary registration system for the use of chemical insecticides in grain storage does not exist in Thailand.
- The results of eight projects were not adopted because of social aspects, such as a mistrust in the scientific techniques and/or resistance to new agricultural practices by the smallholder.

Another benefit of the impact assessments undertaken by the team of economists at Kasetsart University is that they provided information on the scientific and training dimensions of each of the 49

Thai projects. While a positive economic impact is crucial to the achievement of poverty alleviation, measuring the value of a scientific research project solely on its economic performance can lead to an underestimation of the value of that project. For example, even though the impact assessments do not report many 'success stories' in terms of applied research leading to technologies of direct use to smallholders, all the ACIAR-sponsored projects contributed significantly to enhancing the scientific knowledge of the researchers and, in a large number of cases, the project outputs were used as inputs in further scientific research. In other words, assessment of this suite of projects showed significant success in increasing Thailand's scientific resource and knowledge base, the value of which should not be underestimated. As pointed out by Pinstrup-Andersen (2000)[1] 'continued public funding of basic sciences underpinning the development of improved agricultural technology is essential for continued technology development'.

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Impact Assessment Program
ACIAR

1 Pinstrup-Andersen, P. 2000. Is research a global public good? Entwicklung ländlicher Raum. Beiträge zur internationalen Zusammenarbeit, No. 2/2000, 3p.

# An Impact Assessment of ACIAR Research Projects on Biological Control in Thailand

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# 1 Introduction

The first biological control project funded by the Australian Centre for Agricultural Research (ACIAR) in Thailand began in 1985. This was followed by four more projects in the 1980s and 1990s. They provide significant benefits throughout the country. Although not easy to evaluate, an effort is made to quantify the benefits of the ACIAR projects on biological control. In this report, the benefits and costs of these projects are, where possible, quantified to estimate the returns to the funds invested in these projects in Thailand. There are five projects covered in this report, which can be classified by the types of the control method. They are: (1) using insects to control weeds (CS2/1983/039, CS2/1987/022 and CS2/1989/018); (2) using yeast protein bait to control insect pest (CS2/1989/019); and (3) using bacteria and mechanical methods to control postharvest plant disease (PHT/1993/013). The format of this paper is as follows. In section 2, a description of each of the research projects is given. Thereafter, in sections 3, 4 and 5, an impact assessment of each of the projects under review is undertaken. In each case, these sections begin with a description of the research outputs and/or impacts. Thereafter, a benefit–cost analysis is undertaken for those projects where adoption has occurred. Further, sensitivity analysis is undertaken to assess the robustness of the results. The conclusions and some recommendations are given in the final section.

# 2 Description of ACIAR research projects on biological control in Thailand

## 2.1 Control of giant sensitive plant, *Mimosa pigra*, in Thailand (CS2/1983/039)

The project CS2/1983/039 was a two-year project that started in 1985 with a budget of A$594 588. The objective of the project was to control a weedy shrub, *Mimosa pigra*, which has invaded extensive areas in northern Australia and Thailand. The method uses biological control, by searching, screening for safety, mass rearing and field releasing insects to infest the weed. The insects used in this project included: (1) seed bruchids, *Acanthoscelides puniceus* and *Acanthoscelides quadridentatus* (the most effective ones); (2) a top shoot feeder, *Chlamisus mimosae* (ineffective); (3) a top shoot borer, *Neurostrota gunniella* (rejected); (4) a stem borer, *Carmenta mimosa* (ineffective); and (5) a flower feeder, *Coelocephalapion aculeatum* (ineffective).

## 2.2 Control of giant sensitive plant, *Mimosa pigra*, in Thailand (CS2/1987/022)

Project CS2/1987/022 started in 1988 and lasted for three years. The budget for this project was A$588 011. It was an extension of project CS2/1983/039, based on the same principle but expanding its activity to monitor the effects of the released insects, especially the seed bruchids, that are the most effective agents.

## 2.3 Biological control of water hyacinth, *Eichhornia crassipes*, in Thailand (CS2/1989/018)

Project CS2/1989/018 started in 1990 for a duration of three years with a budget of A$233 223. This project has similar aims to the above two projects, except in this case water hyacinth is the target weed. Water hyacinth is one of the most serious aquatic weeds in Thailand and many other parts of the world, including Australia. The project introduced a chevroned water hyacinth weevil, *Neochetina bruchi*, from the USA into Australia and Thailand, to be released in Thailand in collaboration with the National Biological Control Research Center.

## 2.4 Biology and control of fruit flies in Thailand and Malaysia (CS2/1989/019)

Project CS2/1989/019 started in 1991. A budget of A$821 205 was allocated to the three-year term of the project. The main aim of the project was to extend the results of CS2/1983/043 to other Southeast Asian countries, such as Malaysia and Thailand. In Thailand, the objectives of the project were: to formulate a local protein bait spray from brewer's yeast waste; to control fruit fly in the central region (Bangkok and municipal areas); to collect host fruit using protein bait spray applications and trapping in the northern region (Chiang Mai and Chiang Rai province); and to collect host fruit using protein bait spray applications; and to measure infestation levels in the southern region (Songkhla province).

## 2.5 Disease control and storage-life extension in tropical fruit (PHT/1993/013)

The project started in 1994, lasted three years and had a budget of A$876 992. The objectives of the project were to develop non-chemical measures for postharvest diseases of tropical fruit and to assess their impact on fruit quality, as well as to investigate the effects of key postharvest variables, postharvest treatments and handling practices on fruit quality. The work included, for example, finding strategies for biological control for anthracnose using several methods such as biocontrol activity against the fungi causing anthracnose in tropical fruit, and studies on fruit bagging.

# 3 Impact assessment of the biological control of the giant sensitive plant (*Mimosa pigra*) (CS2/1983/039 and CS2/1987/022)

This section begins with a description of the research impacts, and the effectiveness of each project is estimated from interviews and secondary sources. Thereafter, economic valuation of benefits from the biological control projects, using mainly the market value approach, is analysed. A benefit–cost analysis is undertaken next. Finally, a sensitivity analysis is done to test the robustness of the results.

## 3.1 Description of the research outputs and impacts from biological control *M. pigra*

Before quantifying the benefits, the research outputs and impacts are listed. Estimation of the research impacts begins with identifying the commodities likely to be affected by the research, under the assumption that *M. pigra* can be found throughout the country, even if the density is not equally distributed in each province (Banpot Napompeth 1998, pers. comm.).

These two projects were an enormous success as they dealt with the control of serious exotic weeds in Thailand without the use of synthetic herbicides. In general, according to the project leader, these projects had a positive impact in terms of raising incomes and reducing poverty. An attempt is made here to value as many benefits as possible.

The research impacts that are listed here are based on an interview with the project leader, as well as on the results of Lubulwa and McMeniman (1997) and Robert (1982). The benefits from biological control of *M. pigra* in Thailand are identified under the assumption that *M. pigra* is widely disseminated throughout the country, except in the southern part of Thailand. The percentage of damaged seed of *M. pigra* and the number of *A. quadridentatus* found by the survey undertaken in some provinces in Thailand during October 1993 to May 1994 are displayed in Figures 1 and 2. The research impacts are as follows:

- *Rice.* Better control of *M. pigra* helps to increase irrigated rice yields because *M. pigra* grows along the irrigation canals to the rice fields and obstructs the water flow. Furthermore, *M. pigra* is a habitat for rats and crabs, both serious pests in rice field causing a reduction in rice yields. The areas where rice is double-cropped in Thailand are presented in Figure 3.

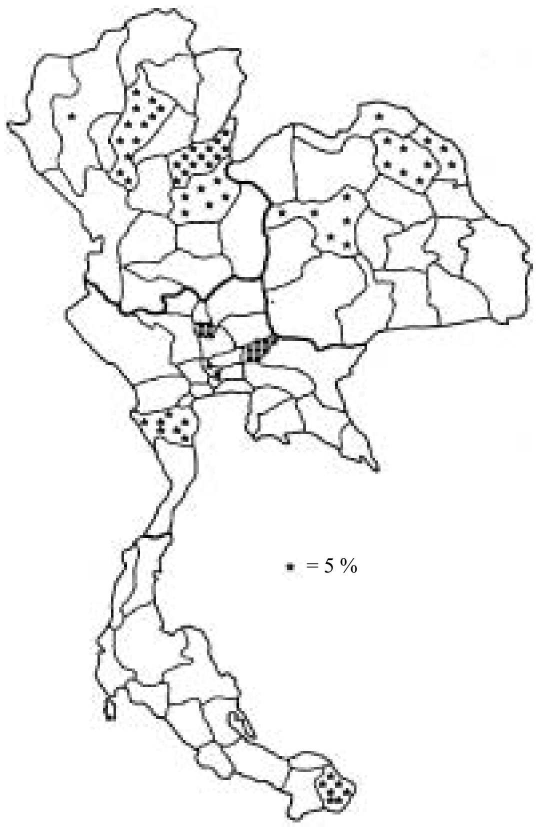


**Figure 1.** Percentage of damaged seed of *Mimosa pigra* caused by *Acanthoscelides quadridentatus*, survey 1993–94

- *Beef and buffalo meat.* Potentially, *M. pigra* could affect beef and buffalo meat production by reducing the area used for pasture and grazing and by restricting access of livestock to water. However, as buffalo and beef cattle are generally fed and watered by their owners in Thailand, rather than grazed in large paddocks, *M. pigra* has no serious impact on the production of beef and buffalo meat.

- *Palm oil. M. pigra* affects immature oil palm plantations. However, in Thailand, *M. pigra* is not an important weed in the southern part of Thailand where oil palm is extensively cultivated. So this also creates no serious problem in the Thai case.
- *Reservoirs. M. pigra* chokes waterways, irrigation ditches, changes the river flow, and accelerates the build-up of silt in reservoirs in Thailand. Therefore, better control of *M. pigra* could provide benefits. Robert (1982) stated that without *M. pigra*, a reservoir could last for about 100 years, and with *M. pigra*, the life of reservoir is reduced to 25 years only.
- *Electricity. M. pigra* grows along roads creating problems for electricity transmission lines. Better control of *M. pigra* could benefit the Electricity Generating Authority of Thailand (EGAT) by reducing the costs of electricity transmission because the cost of new utility poles and the maintenance cost of existing poles and power lines would be reduced (Robert, 1982).
- *Highways*. *M. pigra* is expanding along the national highways obstructing the aesthetic value of the countryside and causing visibility problems for transport (i.e. the vision of drivers is restricted) and increasing the potential for traffic accidents. The benefits of biological control of *M. pigra* could be a reduction of car accidents and an increase in the aesthetic value of the roadways. Due to a lack of data on aesthetic value, the preventive expenditure method is used to value the above benefits.
- *Biodiversity*. *M. pigra* is now an invasive species in the national parks. It competes with the native species causing a change in the present biodiversity resources of the national parks. Biological control would be the only feasible method to control *M. pigra* inside the

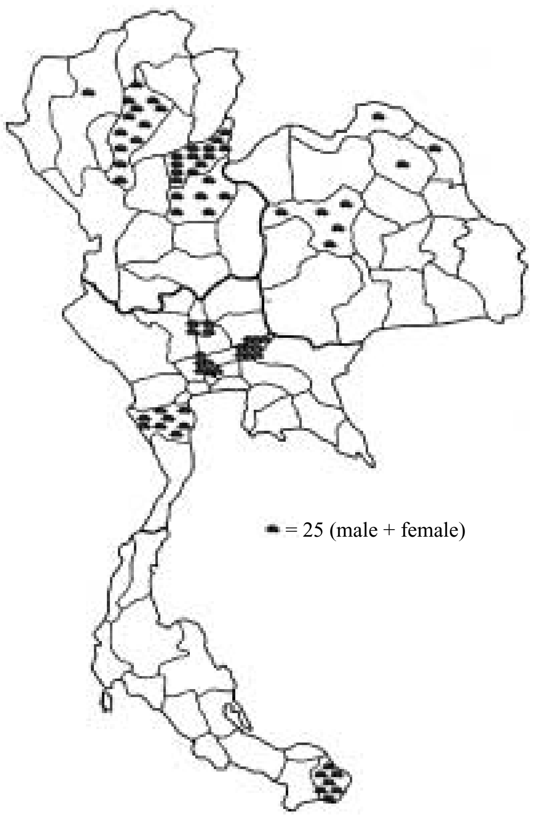


**Figure 2.** Number of *A. quadridentatus* found by the survey during October 1993–May 1994

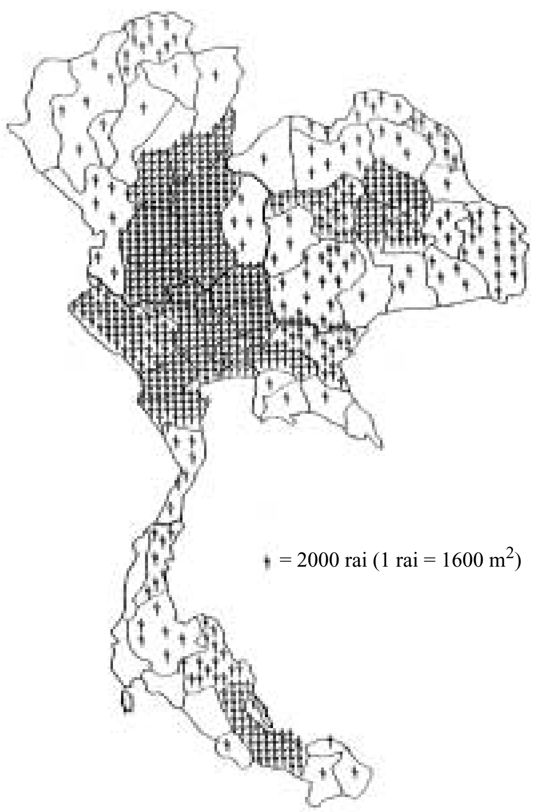


**Figure 3.** Cultivated area of second rice in Thailand, the cropping year 1996/97

forests and the national parks, where mechanical methods, such as cutting and burning mimosa plants, would be difficult to implement. Consequently, biological control of *M. pigra* is quite crucial in this case. Due to the complexity of biodiversity value, which requires more resources and time to work on, this item will not be included in the total benefit analysis. Nevertheless, some examples of earlier research on economic value of biodiversity are summarised in Table 1. Other examples of the economic value of biodiversity in tropical forests, which are based on the direct use method, are listed (Pearce and Moran, 1994):

- Medicinal/genetic value: Net present value (NPV) of $7/ha over 126,000 ha (park area) or 426,000 ha (with the additional buffer zone). This represents a minimum expected genetic value.
- Travel cost valuation of tourist trips to Costa Rica's Monteverde Cloud Forest: An average visitor valuation of $35 (1988). This gives a value in the reserve of $1,250/ha relative to the market price of local non-reserve land of $30–100/ha.
- Forest production (Malaysia): $2,455/ha compared with $217/ha from intensive agriculture.
- Tourism value from Korup: $19/ha.
- Annual value of fuelwood to Malagasy households: about $39.
- Valuation of sustainable non-timber harvest from three one-hectare plots in the Ecuadorian Amazon: average NPV for the sites of $2,306.

• *Publication*. A benefit of most ACIAR projects is the publications which accrue to these projects. From project CS2/1987/022, Control of Giant Sensitive Plant, a paper was presented at a workshop and three thesis were written (Suzuki et al., 1996) (Table 2).

**Table 1.** The economic value of biodiversity in tropical forests.

| Direct use | Indirect use | Non-use values* | Total economic value | Benefit (sustainable use)/opportunity cost ratio |
|---|---|---|---|---|
| Sustainable harvesting in 1 ha of Peruvian Amazon (timber, fruit and latex, $1987) NPV= $6820 /ha (local market value) relative to a net revenue $1000 /ha from clear-felling which risks uncertain regeneration $318 /ha plantations for timber and pulpwood or $2960 /ha from cattle ranching. | Sustained use of the Korup forest:<br>– Existence of watershed functions affording protection to Nigenan and Cameroonan fisheries NPV (£1989) £38m ($68m) or $54 ha assuming that the benefit starts to accrue in 2010 and beyond. | The existence value for the Brazilian Amazon at $30b using an arbitrary WTP figure (observed from CVM studies). | Brazilian Amazon ($199/ha)<br>Direct use 15bn<br>Indirect 46bn<br>Existence 30bn<br>Total 91bn | Implicit ratios of 6.82, 2.14 or 2.3 depending on alternative use, but subject to qualifications regarding local elasticity of demand for harvested forest products. |
| Estimated contribution of direct uses to Brazilan GNP $15b. | An imputed value of the expected loss from flooding resulting from alternative land use from 2010 onwards: NPV of expected value of loss by 2040 is £1.6m ($2.84m) or $23ha. | Value of debt-for-nature swaps may provide an approximation of a WTP reflecting a non-use value. Varying implicit valuation of different sites is reflected in the price paid by conservation bodies involved. Some swap transactions have aimed to preserve tropical forest ecosystems. | Categorized annual non-market benefits of 51.5 million hectares of Mexican forest ($m):<br>Tourism 32.2<br>Carbon 3788.3<br>watershed- protection 2.3<br>Option v 331.7<br>Existence v 60.2<br>Total 4214.8<br>Total should be a lower bound estimate. | |

* Non-use values include option, quasi-option, bequest, and existence values.
**Source:** Pearce and Moran (1994), pp. 86–87.

## 3.2 Benefit–cost analysis of the research impacts

A single sector, partial equilibrium approach is used to evaluate the benefits of the research impacts. The social benefits from the biological control methods are estimated for each sector separately, then the benefits in the separate sectors are added to give the total benefits. As shown by Just et al. (1982), the partial equilibrium approach can approximate the estimates under the general equilibrium approach[2]. They state (Just et al., 1982, p.213) that "rather comprehensive applied welfare analysis is possible. Depending on empirical conditions, all of the private social welfare effects of a proposed new or altered government policy can be measured completely, at least in an approximate sense, in a single market, which is thereby distorted or in which a distortion is altered. If the policy introduces or alters several distortions, approximate measurement of all private effects is possible by considering the changes sequentially in the respective markets they affect directly …."

### *3.2.1 Benefit value of biological control of* M. pigra

The data and underlying assumptions upon which the preliminary estimates of the annual benefits of controlling *M. pigra* are calculated are presented in Table 3. The annual benefits of biological control of *M. pigra* on rice production are obtained from several secondary data sources in Thailand but the benefits on reservoirs are obtained from Lubulwa and McMeniman (1997). The additional benefits of biological control of *M. pigra* on highways are estimated using secondary data in Thailand. Quantifying the benefit from the control of *M. pigra* on biodiversity is very complex and beyond the scope of this study. Therefore, only a description of these benefits is given. Data on national highways in Thailand is obtained from the Department of Highways (1998). The length of highway affected by *M. pigra* is estimated to be around 1% of the total highway distance (Banpot Napompeth 1998, pers. comm.). Estimated benefits in terms of reducing car accidents and increasing the highway aesthetics are valued through a market valuation technique, (i.e. preventive expenditure). The preventive expenditure is the difference in the costs of controlling *M. pigra* before and after the introduction of biological control. The annual welfare benefits from having highways clear of *M. pigra* are estimated by multiplying the preventive expenditure to the areas of highways affected by *M. pigra* (Table 4).

2. The general equilibrium approach recognises the economy-wide implications of biological control method. This approach requires a substantial amount of information. It requires a computable general equilibrium model of the whole economy.

### *3.2.2 Effective rates of damage of* M. pigra

Using insects to reduce *M. pigra* to a desirable level is an effective control method. However, it takes a long time for the insects to begin to reduce the density of *M. pigra* weeds. In Thailand, damage to *M. pigra* did not occur until the 12th year after the insects were released. This impact lag was significantly less than in the Northern Territory, where there was an 18 year lag, because the Thailand project benefited from the knowledge gained from the earlier projects (Ferrar 2000, pers. comm.). The percentage of damaged *M. pigra* seed caused by *Acanthoscelides quadridentatus* in the 23 areas surveyed in Thailand in 1993–1994 ranged from 2% to 80% (Appendix). Julien and Griffiths (1998) confirmed that that the most effective biological control agent, *Acanthoscelides quadridentatus*, resulted in up to 80% seed destruction.

**Table 2.** Summary of human capacity build-up from projects of CS2/1983/039 and CS2/1987/022

| Project no. | Project participants (Thai) | Member with enhanced skills (Thai) | Short-term training | | Other impacts |
|---|---|---|---|---|---|
| | | | No. of activities | Thai | |
| CS2/1983/039 | 7 | 7 | 1 | 3 | Research scientists linkage with international scientists |
| CS2/1987/022 | 9 | 7 | 1 | 4 | Regional linkage in biological control |

**Source:** Suzuki et al., 1996, pp.40–41

**Table 3.** Estimates of benefits from better control of *M. pigra* on rice production and on reservoirs.

| **Items and unit** | **Estimated amount** |
|---|---|
| *Rice production* | |
| Total ('000 t, average 1995–1997)[a] | 22260.00 |
| Irrigated rice ('000 t, average 1995–1997)[a] | 911.40 |
| Percentage of rice affected by *Mimosa pigra* | 1.00 |
| Quantity of rice affected by *Mimosa pigra* ('000 t) | 222.60 |
| Yield before research (t/ha, 1984)[a] | 3.69 |
| Cost of producing rice before research ($/ha)[a] | 660.50 |
| Cost of controlling *Mimosa pigra* ($/ha) before research[b] | 71.00 |
| Unit cost of producing rice before research ($/t)[a] | 179.00 |
| Cost of controlling *Mimosa pigra* ($/ha) with biological control[b] | 4.00 |
| Unit cost of producing rice after research ($/t) | 160.80 |
| Unit cost saving in the production of rice after research ($/t)[a] | 18.20 |
| Price of rice ($/t)[a] | 196.00 |
| Elasticity of supply[c] | 0.23 |
| Elasticity of demand[c] | 0.43 |
| *Reservoirs* | |
| Volume of reservoirs in a country (cubic km, 1990)[b] | 110.0000 |
| Cost of controlling *Mimosa pigra* before research ('000 $/cubic km)[b] | 0.0374 |
| Cost of controlling *Mimosa pigra* after research ('000 $/cubic km)[b] | 0.0041 |
| *Annual benefit per cubic km as a result of control* | |
| Irrigation water benefits ('000 $/cubic km)[b] | 16400.0000 |
| Aquaculture and fresh water fish culture benefits('000 $/cubic km)[b] | 0.0130 |
| Power generation benefits('000 $/cubic km)[b] | 0.5320 |
| Flood control benefits('000 $/cubic km)[b] | 0.2050 |
| Weir repair benefits('000 $/cubic km)[b] | 0.0090 |
| Annual benefit due to research freeing reservoirs of *Mimosa pigra* ('000$)[b] | 82.0000 |

**Sources:** [a] Office of Agricultural Economics (1995, 1996, and 1998); [b] Lubulwa and McMeniman (1997) p. 21; [c] Isvilanonda and Poapongsakorn (1995). The rest are from calculations.

**Table 4.** Estimates of benefit of freeing highways of *M. pigra*

| **Highways** | |
|---|---|
| Total distances of national highways in Thailand (km, 1997) | 55,321 |
| Length of highways affected by *Mimosa pigra* (km, 1997) | 553 |
| Cost of controlling *Mimosa pigra* before research ($/km) | 1,310 |
| Cost of controlling *Mimosa pigra* after research ($/km) | 40 |
| Annual benefit due to research freeing highway of *Mimosa pigra* ($/km) | 1,270 |

Based on the survey in 1998 with the project leader, the effective rate of *M. pigra* within the country is estimated at about 70% in terms of insect dissemination and dispersal and the infestation rate of *M. pigra* is estimated at about 15% in terms of target destruction (Banpot Napompeth 1998, pers. comm.). So, for the purposes of the benefit–cost analysis, the proportion of *M. pigra* damaged by the biological control is assumed to be zero damage from 1984–1995 and then 5%, 10%, and 15% in 1996, 1997 and 1998–2013, respectively (Table 5).

**Table 5.** The proportion of *M. pigra* damaged by the biological control agents.

| Year number | Year | Damage proportion |
|---|---|---|
| 1–11 | 1984–1995 | 0 |
| 12 | 1996 | 0.05 |
| 13 | 1997 | 0.10 |
| 14 | 1998–2013 | 0.15 |

### 3.2.3 *Benefit–cost analysis of the biological control of* M. pigra

The flow of the benefits and costs of biological control of *M. pigra* in Thailand is presented in Table 6. The research budget for the *M. pigra* project is equally distributed over the duration of the research. For example, the budget for the two-year project CS2/1983/039 was A$594 588, so it was assumed that the costs were equally distributed between year 1 and 2 (i.e. A$297 294 each year). Similarly, as project CS1/1987/022 was a three-year project with a budget of A$588 011, then A$196 004 was allocated to years 1, 2 and 3. In addition, it is assumed that it costs A$1500 each year for the National Biological Control Research Center in Thailand to regularly release insects into the field. The time frame for the analysis is 30 years and the discount rate is 8%. The estimated NPV of the project on the biological control of *M. pigra* is A$1.79 million, indicating positive returns to the

**Table 6.** The flow of benefits and costs ($’000) over 30 years of better control of *M. pigra* in Thailand (CS2/1983/039)

| Year no. | Year | Rice | Reservoirs | Highways | Total benefits | Total costs | Net benefit |
|---|---|---|---|---|---|---|---|
| 1 | 1984 | 0 | 0 | 0 | 0 | 297 | –297 |
| 2 | 1985 | 0 | 0 | 0 | 0 | 297 | –297 |
| 3 | 1986 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1987 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1988 | 0 | 0 | 0 | 0 | 196 | –196 |
| 6 | 1989 | 0 | 0 | 0 | 0 | 196 | –196 |
| 7 | 1990 | 0 | 0 | 0 | 0 | 196 | –196 |
| 8 | 1991 | 0 | 0 | 0 | 0 | 1.5 | –1.5 |
| 9 | 1992 | 0 | 0 | 0 | 0 | 1.5 | –1.5 |
| 10 | 1993 | 0 | 0 | 0 | 0 | 1.5 | –1.5 |
| 11 | 1994 | 0 | 0 | 0 | 0 | 1.5 | –1.5 |
| 12 | 1995 | 202.2 | 4.1 | 35 | 297.1 | 1.5 | 239.8 |
| 13 | 1996 | 404.6 | 8.2 | 70 | 612.2 | 1.5 | 481.3 |
| 14 | 1997 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 15 | 1998 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 16 | 1999 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 17 | 2000 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 18 | 2001 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 19 | 2002 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 20 | 2003 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 21 | 2004 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 22 | 2005 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 23 | 2006 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 24 | 2007 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 25 | 2008 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 26 | 2009 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 27 | 2010 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 28 | 2011 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 29 | 2012 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| 30 | 2013 | 607.2 | 12.3 | 105 | 942.3 | 1.5 | 723.0 |
| PV | (A$m) | 2266 | 460 | 392 | 2703 | 911 | 1793 |
| IRR | | | | | | | 16% |
| B/C | | | | | | | 2.97 |

funds invested (Table 6). Another measure of the value of the project is the benefit–cost ratio (B/C). In this case, it is estimated to be 2.97, again indicating the profitability of the project investment. A final indicator is the internal rate of return (IRR), which in this case was calculated to be 16%, indicating a 16% return on every dollar invested in the project.

### *Post–evaluation (1984–1998)*

The NPV of the biological control of *M. pigra* from the beginning of the project until the 1998 is estimated to be negative (–A$385 978). This indicates that long-run analysis is required to assess the 'true' value of the research.

## 3.3 Sensitivity analysis

Sensitivity analysis is essential to test whether a change in the benefit and cost data will impact on the NPV, IRR and the B/C. A set of alternative benefits and costs is used to test the robustness of the base results for the NPV and the B/C.

Lubulwa and McMeniman (1997) found that changing the proportion of rice production affected by *M. pigra* has a highly significant effect. For instance, an increase the unit cost reduction and in the area of rice affected by *M. pigra* by 100% will increase the base NPV by 70%. Conversely, decreasing the unit cost reduction and area of rice affected by *M. pigra* by 50% will reduce the base NPV by 35%. In this study, the sensitivity of the results to the base estimate of the percentage of rice affected by *M. pigra* is tested. It is found that increasing the percentage of rice affected by *M. pigra* from 1% to 5% will increase the NPV by 556%. Sensitivity analysis of the area of the highways affected by *M. pigra* was also undertaken. It was found that changing the length of highways affected by *M. pigra* has a small impact in NPV and the B/C ratio (Table 7).

**Table 7.** Sensitivity analysis of *M. pigra*

| **Items** | **NPV (A$ million)** | **B/C** |
|---|---|---|
| **Base case** | 1.79 | 2.97 |
| Increase percentage of rice affected by *M. pigra* from 1% to 5% | 11.77 | 12.92 |
| Increase highway length affected by *M. pigra* by 100% | 14 | 35 |
| Decrease highway length affected by *M. pigra* by 50 % | 1.61 | 2.77 |

Note: NPV means net present value; B/C means benefit–cost ratio.

# 4 Impact assessment of the biological control of water hyacinth (*Eichhornia crassipes)* (CS2/1989/018)

Unlike the biological control of *M. pigra,* where the benefits from the ACIAR funds are quantifiable*,* it is difficult to quantify the effectiveness of the chevroned water hyacinth weevil, *Neochetina bruchi,* in controlling *E. crassipes* at the field level. Nevertheless, a description of the research outputs and impacts and benefits is given.

## 4.1 Description of the research outputs and impacts

This project was also a great success. The primary benefits from using biological control agents to control water hyacinth can be qualitatively identified as:

- *Water evaporation*. Since the presence of *E. crassipes* increases the amount of water that is evaporated, better control o*f E. crassipes* would reduce the rate of evaporation. It was found that the evaporation from a reservoir with *E. crassipes* would be about 1.5 to 3 times higher than that of a reservoir without *E. crassipes* (Banpot Napompeth 1998, pers. comm.).
- *Water way*. *E. crassipes* presents as an obstacle in the running waterway. The mass of *E. crassipes* in the river can obstruct water transportation. In addition, too many *E. crassipes* plants in the canal network near a city, such as the Rangsit canal, will cause flooding.
- *Sedimentation in water resource*. The better control of *E. crassipes* would help to reduce the biomass, such as leaves, stems and roots, accumulated in the water resource, resulting in less sedimentation.
- *Filariasis*. The larvae of the *Mansonia* mosquito, which is the vector of filariasis in humans, thrives in *E. crassipes*. Therefore, better control of *E. crassipes* will deprive the mosquito larvae of its habitat and help reduce this disease.
- *Publications and human capacity building*. A number of publications came from project CS2/1989/018 (Suzuki et al., 1996). A summary of human capacity building is given in Table 8.

**Table 8.** Summary of human capacity build-up from project CS2/1989/018

| Project participants (Thai) | Members with enhanced skill (Thai) | Short-term training | |
|---|---|---|---|
| | | No. of activities | Thai |
| 7 | 2 | 1 | 5 |

**Source:** Suzuki et al., 1996, p. 42

## 4.2 Benefits of the biological control of *Eichhornia crassipes*

Using insects to control *E. crassipes* is a highly cost-effective control method (NBCRC, 1997). The effective damage rates of *E. crassipes* are expected to be 100% both in terms of insect distribution and target destruction (Banpot Napompeth 1998, pers. comm.). This was confirmed in the study undertaken by Pichidsuwanchai (1996), who found that the control efficiency by *N. eichhorniae*, a biocontrol agent introduced before the project CS2/1989/018, and *N. bruchi*, the biocontrol agent of the project CS2/1989/018, were not statistically different. They are considered to be equally effective and complementary in terms of their destructiveness to the water hyacinth plants. In general, the output of project CS2/1989/018 to control *E. crassipes* is successful.

The benefits derived from the biological control of *E. crassipes* have been included in the description of the research impacts. However, while project CS2/1989/018 started in 1990, with the aim of introducing a new insect to control *E. crassipes* in Thailand, *E. crassipes* had already been controlled by several effective insects since 1977. To quantify the benefits of project CS2/1989/018 alone, one must be able to differentiate between the damage to *E. crassipes* from earlier insects and the insect introduced in 1990. This cannot be done. Therefore, the benefits to Thailand from project CS2/1989/018 are not quantifiable because the damage caused by the individual insects cannot be identified at the field level.

# 5 Impact assessment of the biological control of fruit fly (CS2/1989/019)

The study on the benefits from the fruit fly projects in Thailand and Malaysia (CS2/1989/019 and CS2/1983/043) found that these two projects generated a NPV to the Australian economy of some $11m (Collins and Collins, 1998, p. 23). In contrast, the project to control fruit fly in Thailand (CS2/1989/019) has not benefited the Thai economy, because the results have not been adopted at the farm level. Nevertheless, the project did generate some benefits as listed below.

## 5.1 Description of the research outputs and impacts of the fruit fly project

Outputs of the fruit fly project were:

- *Development of a successful method to control fruit fly*. An objective of the research was to develop a method to control fruit fly, which was successfully investigated at the farm level. There was an attempt in the past to find an appropriate method to control fruit fly, but the results were not satisfactory.
- *Reducing the use of chemical insecticides.* Although the farmers abandoned the above method because of a particular constraint that is mentioned later, if the method of control were adopted, it would have resulted in a substantial reduction in chemical use.
- *Publication.* The benefits in terms of publication obtained from CS2/1989/019 are twenty published papers (Suzuki et al., 1996).
- *Scientific equipment.* A benefit cited by Suzuki et al. (1996, p. 42) is the scientific equipment for the Thai institute.
- *Human capacity build-up.* The project built-up the human capacity by enhancing the skills of the Thai researchers and through short-term training (Table 9).

## 5.2 Benefits of the fruit fly project

Even though using yeast protein bait to control fruit fly is efficient, adoption of this method at the farm level was not accomplished. The researchers stated that the lack of adoption was due to the following constraints:

- It is a time-consuming method.
- In practice, the farmer has already sprayed a multi-purposed pesticide in the field. Therefore, applying the yeast protein bait is extra work, which requires extra time and labour.

However, this does not appear to be the full story. According to Ferrar (2000, pers. comm.), the materials for yeast baits needs to be cheap for the Thai farmers to use them. While a company that produces a yeast spread, similar to Vegemite, developed a yeast bait, this was expensive compared with yeast from brewery waste. The problem was that the waste the Thais got from their brewery was far too salty and damaged the plants. Consequently, not only was the technology not adopted, but also the farmers would be reluctant to try that sort of technology again.

After the project terminated, the work also ended. Therefore, the benefits of this project were limited to human resource development (e.g. researchers) and an increased level of interest in fruit fly control. According to Ferrar (2000, pers. comm.), ACIAR should have followed the project through to its natural conclusion, as in Tonga where yeast baits are in great demand. The Royal Tongan Brewery now produces a good, cheap yeast product, which has been used very successfully there. In the case of Thailand, it is not too late to rectify this, if the Thais are interested.

**Table 9.** Summary of human capacity build-up and other impacts of CS2/1989/019

| Project Participants (Thai) | Member with enhanced skill (Thai) | Short-term training | |
|---|---|---|---|
| | | No. of activities | Thai |
| 4 | 4 | 1 | 4 |

Source:Suzuki et al., 1996, p. 42

# 6 Impact assessment of disease control and storage life extension in tropical fruit (PHT/1993/013)

It is too early to quantify the benefits of project PHT/1993/013 because its results are still at the experimental level. Nevertheless, a number of the benefits can be assessed qualitatively.

## 6.1 Description of the research outputs from the project on disease control in fruit (PHT/1993/013)

This project involves many aspects of postharvest technology. The research outputs listed here emphasise only biological control methods: microorganism and mechanism.

The research impacts from using bacteria as a biological control agent to control postharvest disease in fruits are summarised as follows.

- *Development of effective biocontrol agents*. Effective biocontrol agents were selected for the control of mango stem-end rot and anthracnose, rambutan fruit rot caused by *Greeneria* sp. and longan fruit rot (various pathogens). It was found that the past identification of the causal agents of these plant diseases was wrong. So, this finding produced huge benefits as a useful input for further study, even though it is still in the initial stage.
- *Development of a useful technique for evaluating biocontrol agents*. A leaf disk technique was developed for evaluating biocontrol agents in mango and rambutan.
- The research outputs from using a mechanical method (fruit bagging) to control fruit diseases were found to be only slightly successful. Nevertheless, they provided a certain level of new knowledge. For example:
  - A result of the postharvest treatment of mangoes using carbon dioxide showed that the decay symptoms in mango fruit exposed to high carbon dioxide levels were lower than in unexposed fruit. However, the results further showed that carbon dioxide pulsing delayed mycelial growth and spore germination temporarily. When the fruit was returned to normal air, these functions recovered very quickly (Coates et al., 1998, p.51).
  - The result of fruit bagging showed that bagging fruit while it is maturing significantly reduced the incidence and severity of anthracnose. However, it did not reduce the incidence or severity of stem-end rot (Coates, et al., 1998, p.65).

The research outputs from the project as a whole are:

- *Publication*. The benefits in term of publication obtained from PHT/1993/013 are one paper presented at a conference and another paper presented at a workshop (Suzuki et al., 1996, p. 35).
- *Human capacity building*. The project enhanced the skills of the team members and provided some short-term training (Table 10).

**Table 10.** Summary of human capacity build-up and other impacts of PHT/1993/013

| Project participants (Thai) | Members with enhanced skills (Thai) | Short-term training | |
|---|---|---|---|
| | | No. of activities | Thai |
| 3 (KU)<br>11 (CMU) | 14 | 1 | 3 |

Note: KU is Kasetsart University; CMU is Chiang Mai University.
**Source:** Suzuki et al., 1996, p. 44

## 6.2 Benefits from biological control of plant disease (PHT/1993/013)

This project provided a preliminary result for further research; that is, it contributes a substantial benefit as input for other projects. The results of this project are not as yet transferable to the farmers. Nevertheless, even though the project is terminated, the work is still continuing.

# 7 Conclusion and recommendation

The economic valuation of biological control projects in Thailand under ACIAR funding has been attempted and quantified. The results can be categorised into three different successful forms.

First, the three biological control projects (CS2/1983/039 (*M. pigra*), CS2/1987/022 (*M. pigra*) and CS2/1989/018 (*E. crassipes*), were successful and the returns to the research funding were positive. Even though the projects were terminated, the work on releasing the insects continues. In conclusion, the benefits of biological control of *M. pigra* and *E. crassipes* in Thailand are substantial, firmly rooted and sustainable.

Second, the biology and control of fruit flies (CS2/1989/019) produced a favourable output at the experimental station but there is no extension of the results at the field level. Therefore, the benefits received are mainly in terms of human resource development.

Thirdly, results from the project on disease control and storage-life extension in tropical fruits (PHT/1993/013) provide a useful input for further work. It is too early to evaluate and quantify the benefits at this stage.

Overall, ACIAR's research on biological control in Thailand has been substantially accomplished. However, there is still a room to produce more benefits from future ACIAR funding. The recommendation is to focus the future budget on extension work so the experimental results discussed above can be implemented by the target groups.

# 8 Acknowledgments

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# Appendix

The percentage of damaged seed of *Mimosa pigra* caused by *Acanthoscelides quadridentatus* survey during October 1993–May 1994

| Place of data collection* | Number of *A. quadridentatus* | | % damaged seed |
|---|---|---|---|
| | Male | Female | |
| 1. Nakorn Phanom (area 1) | 0 | 0 | 0 |
| 2. Nakorn Phanom (area 2) | 8 | 17 | 15.82 |
| 3. Khon Kaen (area 1) | 12 | 16 | 3.83 |
| 4. Khon Kaen (area 2) | 37 | 60 | 25.53 |
| 5. Sakon Nakorn (area 1) | 0 | 0 | 0 |
| 6. Sakon Nakorn (area 2) | 4 | 6 | 27.03 |
| 7. Nong Khai | 1 | 3 | 2.12 |
| 8. Lampang (area 1) | 33 | 40 | 17.68 |
| 9. Phitsanulok | 26 | 39 | 14.87 |
| 10. Lampang (area 2) | 33 | 68 | 9.28 |
| 11. Chiang Mai (area 1) | 0 | 0 | 0 |
| 12. Chiang Mai (area 2) | 7 | 10 | 4.13 |
| 13. Lampang (area 3) | 55 | 77 | 33.51 |
| 14. Uttaradit (area 1) | 36 | 48 | 19.44 |
| 15. Uttaradit (area 2) | 102 | 137 | 47.17 |
| 16. Narathiwat | 69 | 91 | 32 |
| 17. Ranong | 0 | 0 | 0 |
| 18. Ang Thong | 43 | 46 | 20.65 |
| 19. Phetchaburi | 79 | 124 | 35.86 |
| 20. Nakhon Nayok (area 1) | 204 | 177 | 79.90 |
| 21. Nakkon Nayok (area 2) | 42 | 67 | 18.69 |
| 22. Nonthaburi | 75 | 86 | 25.35 |
| 23. Phitsanulok | 32 | 37 | 12.68 |

**Source:**Napompeth, B. et al. (1994)
Note:* is listed in provincial name.

# An Impact Assessment of the Plant Virus Projects Funded by ACIAR in Thailand

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# Contents

# 1 Introduction

There are many severe virus diseases, which pose a threat to Thai agricultural products, including cereals, legumes, field crops, fruit trees, ornamentals and vegetables. Virus diseases are a major factor limiting yield and quality of these agricultural products. To solve virus disease problems, it is important for the scientists to understand viruses, plant hosts, symptoms, virus morphology, the means of natural spread and the impact on crop yield and quality. This information assists the scientists to understand the problem and to find a solution. There are several strategies for controlling plant viruses. These include: avoidance either through exclusion or minimisation; resistant cultivars; and mild strain protection.

Because of the importance of plant virus diseases in Asia, ACIAR provided funds for Thailand to study plant virus diseases. This paper, which consists of four sections, aims to assess the impact of the plant virus projects. Section I is the introduction, which is followed by a description of the projects in Section II. A description of the technology and knowledge generated by, and the economic impact of, the projects is given in Section III. The conclusions are presented in the last section.

# 2 Description of ACIAR research projects on plant virus diseases

There are three projects related to plant virus diseases that were supported by ACIAR. The first two projects are the plant virus identification and data exchange project, and the plant virus diagnostics project. The overall aim of these projects was to provide and improve basic information and facilities for plant virus identification. The success of these two projects led to the development of a further a project, which focused on transgenic resistance for controlling the papaya ringspot virus (PRSV) in papaya and cucurbits. This project used some of the scientific knowledge and facilities developed in the plant virus identification and data exchange project and the plant virus diagnostics project.

## 2.1 Plant virus identification and data exchange project

To obtain information on the occurrence of viruses in plants, suitable methods and reagents that will enable the viruses to be detected and identified need to be developed. Virus identification is a complex activity in which a range of viruses and disease characteristics are investigated, including symptom expression, virus morphology and the means of natural spread, as well as various biophysical and biochemical characteristics. The information gathered can then be compared with 'like' information, previously collected for other known viruses having similar crop affinity, then by matching characteristics, a preliminary identification can be made. The causal viruses are identified on the basis of their symptoms, host range, purification, electron microscopy, serological, and insect-vector relationships.

Project CS2/1982/002 on 'Plant Virus Identification and Data Exchange' was a three-year project that was started in 1983. Research funding was about A$162 141 (Table 1). A group of Thai scientists was recruited from the Division of Plant Pathology and Microbiology, Department of Agriculture (DOA). The aim of the project was to expand the virus identification and data exchange (VIDE) database initiated by ACIAR, to cover plant virus identification in Asia. The objectives of this project were to:

1. expand the VIDE database, and to evaluate its potential for use in developing countries as a source of information for those wanting to identify plant viruses;
2. disseminate the basic virus data and other helpful information in books, microfiche and polyclaves; and
3. investigate other possibilities for dissemination, such as on-line key programs.

**Table 1** General information of the projects

| Project no. | Short title | Started | No. of years | Budget (A$) | Collaborating organisation | Interviewees |
|---|---|---|---|---|---|---|
| CS1/1982/002 | Plant Virus Identification and Data Exchange | 1983 | 3 | 162,141 | DOA | |
| CS1/1988/005 | Plant Virus Diagnostics | 1988 | 3 | 396,680 | DOA, KU | Ms Kruapan Kittipakorn<br>Ms Uraiwan Dilokkunanant |
| CS1/1992/026 | Control of Papaya Ringspot Virus in Papaya and Cucurbits through Transgenic Resistance | 1995 | 4.5 | 440,154 + 60,000 | DOA, PSU, KU | Ms Kruapan Kittipakorn<br>Dr Wanpen Srithongchai<br>Dr Ratana Sdoodee<br>Dr Suphat Attathom<br>Dr Wichai Kositratana<br>Dr Tom Burns |

*Research outcomes*

The research outcomes are summarised here (see Clark and Randles, 1986). As the virus dataset was collated, it was continually revised to improve its content, style and precision. The VIDE project used the computer-based DELTA system (DEscription Language for TAxonomy developed by M.J. Dallwitz in 1980) to store and manipulate plant virus information. In 1986, the database included information on about 200 viruses and 40 virus groups[3] (or monospecies groups).

Books and microfiche were produced using the information contained in the virus database and were distributed to scientists working in this field. While difficult to quantify, the benefits from the information distribution are expected to be considerable. For example, the 1983 book *Viruses of Legumes* provides invaluable information on many legume diseases. The researchers also gained experience in book preparation and distribution. In addition, microfiche have been produced and distributed annually, although suitable microfiche readers are not widely available in many locations. Because of the limitations of the polyclaves technique for handling logically complex information, this work was not a success. Instead, work focused on linking the VIDE database to the online interactive identification programs.

## 2.2 Plant virus diagnostics project

Project CS1/1988/005 on "Plant Virus Diagnostics Project" was a three-year project that started in 1988. The research fund for this project was A$396 680. It followed from CS1/1982/002. Thai scientists were recruited from the Division of Plant Pathology and Microbiology, DOA and from the Kasetsart University Research and Development Institute (KURDI), Kasetsart University (KU). The three sub-projects under CS1/1988/05 were:

### *2.2.1 Subproject A "Virus identification and data exchange"*

The aim of this subproject was to gather the details of all the known plant viruses and to complete the first phase of the VIDE database.

*Research outcomes*

By the end of the project, the VIDE database contained information on 920 plant virus species for 60 groups. In 1993, CAB International included all these plant virus data in a two-volume book, which has been used by plant virologists and plant pathologists.

### *2.2.2 Subproject B "Establish a bank of diagnostic antisera"*

The aim of this project was to upgrade the diagnostic antisera facilities at the DOA in Thailand. It was intended to establish a network of plant virologists throughout Asia, to enable the latest information on plant viruses be accessed, and to diagnose diseases using reliable antisera, thus optimising short- and long-term control measures.

*Research outcomes*

A large number of bulk antisera (29) has been prepared by Thai scientists to add to the store of small amounts of diagnostic antisera (175) that were collected from colleagues around the world.

Confirmation of virus identity is frequently achieved using serological techniques employing virus-specific polyclonal or monoclonal antisera. In some situations, where the incidence of a specified virus in a particular crop is to be investigated, this information may be obtained directly through the sole use of sero-diagnostic procedures such as the enzyme-linked immuno sorbent assay (ELISA) method. These antisera are now being used in a wide range of diagnostic tests and also in testing samples from field experiments in Thailand and in other Asian countries.

### *2.2.3 Subproject C "Computer laboratory"*

The aims of this subproject were to establish a computing laboratory at KURDI to prepare a Thai plant virus database, and to assess the value of the "expert system" techniques for plant virus diagnosis. A focus of this subproject was to test available software from Australian partners for storing and presenting information on plant diseases and pathogens, especially viruses, in Thai.

*Research outcomes*

As a result of this project, a computing laboratory was established and equipped at KURDI and the available computer software for storing and

3. Virus groups are collections of virus species that share most of their properties, and have probably evolved from a common ancestor (CAB International, 1990).

presenting information on plant diseases and pathogens, especially viruses, was tested. While the computer software was available to plant virologists and general pathologists, and the capacity of this software was designed for a large database (more than 2000 cases), the software was not translated into Thai and therefore the Thai plant virus database was not a success. Thai scientists asked for assistance from the Australian partner, but the problems were not overcome. This could have been because the Australian partners concentrated on developing the online plant virus information system. Therefore, the computer software for the Thai plant virus database has never been used. However, because of advanced computer technology, the plant virus database is available through the Internet.

## 2.3 Project CS1/1992/026 on "Control of papaya ringspot virus in papaya and cucurbits through transgenic resistance"

As mentioned earlier, plant viruses are a major factor limiting the production of agricultural crops. Papaya ringspot virus (PRSV) is a plant virus that affects both papaya and cucurbit crops. These two crops were originally grown for domestic consumption. Papaya is now exported from Thailand, contributing significantly to foreign exchange. For example, in 1998 Thailand exported fresh and canned papaya worth about 63.8 million baht[4] (OAE, 1999), almost double the 1987 export value, which was 33.0 million baht (Appendix Table A1).

Fresh papaya exports decreased from 4132 tonnes in 1988 to 29 tonnes in 1998 (OAE, 1999). During the same period, the amount of canned papaya increased from 416 tonnes to 2,065 tonnes (Appendix Table A1). There are several reasons why the export value and quantity of fresh papaya has fallen. First, the demand for canned papaya products has increased. Second, fresh papaya exports have been restricted to prevent plant disease contamination. (Exports in the form of canned papaya might provide a solution to this problem.) Third, the presence of a plant virus disease will result in a fall in papaya productivity and quality. Even though the area cultivated to papaya increased from 23 840 ha in 1992 to 25 920 ha in 1997, total production of papaya fell from 346 000 tonnes to 317000 tonnes during the same period. This was because papaya productivity declined from 20 t/ha in 1992 to 16.8 t/ha in 1997 (Appendix Table A2). One of the major factors affecting papaya productivity and quality is PRSV (Wang et al., 1987 cited by Dale et al., 1992). In papaya, PRSV causes mottling and distortion of leaves, stunting, reduction of fruit yield and characteristic ringspot on fruit and stem (Hollings and Brunt, 1981 cited by Dale et al., 1992).

Besides papaya, PRSV affects the productivity and quality of cucurbits by reducing yield and spoiling the fruit to such an extent that it is unmarketable. The cucurbit crops consists of cucumber, pumpkin, wax gourd, bitter gourd, loofah, watermelon, zucchini and rock melon. In Thailand, cucurbits are grown for domestic consumption and for export (Appendix Table A3). The total area cultivated for cucurbits production increased from 74 836 ha in 1994 to 99 037 ha in 1997, and the production of cucurbits rose from 902 874 tonnes in 1994 to 1 180 298 tonnes in 1997 (Appendix Table A4). Total production of cucumber, wax gourd and pumpkin in 1994 was 825 000 tonnes of which 2 009 tonnes were exported, worth US$3.38 million (Burns et al., 1996).

PRSV is now having a major impact on both domestic and export production in Thailand and there is no immediate possibility for control of either the spread of the virus or the yield loss. There are several strategies for controlling plant viruses. These include: avoidance either through exclusion or minimisation; resistant cultivars; and mild strain protection. There appears to be little scope for implementing avoidance strategies for PRSV in Thailand. Moreover, Thai scientists did research on solving PRSV problem in papaya through a mild strain protection approach (Kositratana April 1999, pers. comm.). The results of initial studies suggest that mild strain cross protection may offer some limited control. However, this characteristic cannot be transferred to the subsequent generation. Therefore, Thai scientists need to find other ways of solving PRSV problems in papaya. Of the three strategies for controlling plant viruses, using resistant cultivars seem to be the most effective. There are different methods to obtain virus resistant cultivars including selection, conventional breeding and genetic engineering. Conventional breeding requires a long time. Developing resistant varieties through the genetic engineering approach started in Thailand in the last decade.

4. Exchange rate A$ 1 = 20 Baht

The 'coat protein gene resistant' approach is the most promising new technique for breeding virus resistant plants. It has proven to be effective against a wide range of viruses in a number of different hosts (Dale et al., 1992). Thai scientists are now concentrating on transgenic plants such as chilli, tomato, papaya, long bean, cucumber and cotton. At present there are no transgenic plants in Thailand used for commercial purposes. The development of most of the transgenic plants is still at the field trial stage or earlier.

CSI/1992/026 was a three-year project that was started in 1995. Research funding was estimated to be around A$440 154. Thai scientists were recruited from: the Division of Plant Pathology and Microbiology, DOA; the Plant Genetic Engineering Unit (PGEU), KU; and the Faculty of Natural Resources, Prince of Songkhla University (PSU). In July 1998, on the advice of the project reviewer, it was decided that the project should be extended until December 1999. The additional budget for the six-month extension was around A$60 000.

Before the project, no Thai papaya or cucurbit cultivars resistant to PRSV had been identified. The aim of this project was to develop resistance via virus-derived resistance genes in Thai cultivars of papaya and cucurbits using genes from Thai strains(s) of the PRSV. This project is a direct consequence of the plant virus identification and data exchange project (CS1/1982/002) and the plant virus diagnostics project (CS1/1988/005). The research objectives of this project were:

1. the collection and identification of PRSV-P and PRSV-W isolates from the major geographic regions of Thailand;
2. cloning and sequencing of PRSV coat protein genes;
3. development of genetic constructs;
4. transformation, regeneration and screening for resistance in transgenic cucurbits; and
5. transformation, regeneration and screening for resistance in transgenic papaya.

*Research outcomes*

Surveys of papaya and cucurbit crops were conducted in the southern, central, northern and north-eastern regions of Thailand to obtain considerable information on the plant virus, which could be used in the development of genetic constructs to provide transgenic resistance. PRSV had affected almost 100% of the papaya plants surveyed in the central and north-eastern regions. In the southern region, PRSV had affected only around 10% of the papaya plants surveyed in 1996. Papaya had not been significantly affected by any other viruses. Research outcomes were collected from the review report of CS1/1992/026 (Waterhouse et al., 1998).

Intensive surveys of cucurbits showed that PRSV was a persistent and a significant problem in the four regions of Thailand. The results also showed that watermelon mosaic virus II (WMVII) and cucumber mosaic virus (CMV) were also significant problems, and identified a previously undescribed geminivirus (termed cucurbit yellow mosaic, CYMV) and an, as yet, unidentified closterovirus, as possible major pathogens of cucurbit crops.

Additionally, molecular variability was assessed at a molecular level. Each isolate was defined as either a *P* biotype (if collected from papaya) or a *W* biotype (if collected from a cucurbit and unable to infect papaya). These strains are serologically indistinguishable and classified only by host range. Regarding the molecular data results, they showed that PRSV-P biotype most likely has arisen from PRSV-W biotype by mutation.

During the second year of the project, a transformation system was established for the Thai long cucumber cultivar (Jed Bai) and plants containing the PRSV-P coat protein gene were obtained. By the end of the third year, PRSV-P coat protein transformants were obtained in the Thai short cucumber cultivar (Pollek) and in the papaya cultivar (Khak Dum).

# 3 Impact assessment of plant virus projects in Thailand

## 3.1 Technology and knowledge generation through research

### *3.1.1 Plant virus identification and data exchange project (CS1/1982/002) and Plant virus diagnostics project (CS1/1988/005)*

The technology and new knowledge generated through these projects can be classified as scientific information (database), facilities (equipment and building), collaboration and publications.

The VIDE database contains information on plant viruses from around the world, which can be used for virus identification by plant virologists and plant pathologists. A part of this database was collected under projects CS1/1982/002 and CS1/1988/005. The database information was compiled into books, microfiche, computer magnetic tape and diskette.

Without these projects, the VIDE database might not have contained plant virus information in the Asia region (tropical zone). Thai scientists are now able to obtain the information on plant viruses from books or from the Internet.

One of the successes of CS1/1988/005 was the creation of the bank of diagnostic antisera. These diagnostic antisera provide not only the facilities to stock antisera, but also an opportunity for the scientists to use the antisera for virus identification in Asia and elsewhere. As mentioned earlier, the confirmation of virus identification is achieved using serological techniques employing virus specific polychonal and monoclonal antisera.

While antisera can be bought from private companies, they are relatively costly. It is also costly, and time consuming for the scientists to produce all the antisera. Through ACIAR, the Thai scientists were able to produce and stock antisera and collect antisera from other countries in the bank. The bank now contains 29 antisera produced by Thai scientists during the project and 175 collected from outside Thailand through ACIAR cooperation with other countries.

The benefits of the bank are highlighted in the increased public availability of antisera, the increased use of antisera, and in the time and cost savings made because the antisera are readily available. With regard to the public availability of the antisera, some of the antisera has been used to produce ELISA kits. Thai farmers and private enterprise have used the distributed ELISA kits to identify viruses in orchids and potatoes. In addition, when requested, antisera are distributed to scientists within Thailand and internationally.

Antisera are used for detection and identification of viruses, especially in plant breeding programs to confirm the resistance characters, for studying epidemology of virus, and for forecasting plant virus diseases. Additionally, use of antisera to produce virus-free planting materials is helpful to control plant viruses by avoidance through exclusion or minimisation. Antisera are used widely in public and private enterprises particularly to guarantee that agricultural products meet export and import requirements.

Using antisera in ELISA can save time for the detection and identification of plant viruses. This can be done in a day. Without antisera, the detection and identification of viruses are possible by host range test, electron microscopy, molecular techniques, and so on. However, these methods are relatively costly and time-consuming. With the availability of antisera, using the ELISA method is more efficient, time saving and more reliable than the other conventional techniques.

Before having the bank of antisera, Thai scientists had to purchase antisera from overseas private companies. Costs vary, for example, from US$500 to more than US$1000 per 1 mL (Kittipakorn April 1999, pers. comm.). The price depends on the serum's titration. However, while the Thai scientists save by not purchasing antisera from the private companies, there are costs in maintaining the bank. Some difficulties have been encountered with managing the bank of diagnostic antisera, such as the time and cost requirements for producing new stock of antisera, the limited shelf life of antisera, the lack of manpower to operate and maintain the bank, and the lack of funds for maintenance. In spite of these difficulties, Thai scientists (DOA) keep running the bank of diagnostic antisera, due to its importance.

The bank operates for public interest and the antisera are distributed to other scientists. But at the same time, some new antisera are received from those scientists and kept in the bank. Unfortunately, the exchange in the number and amount of antisera has not been precisely recorded due to the lack of efficient management after the termination of the project.

Regarding all those who benefit from the bank, it might be worth it to support the bank for maintenance purposes. The scientists estimated that annual maintenance and inputs costs are about 300 000 baht, and annual personnel costs are around 220 800 baht. Other techniques that do not require antisera can also be used for virus detection and identification, such as the polymerase chain reaction (PCR) technique to detect and identify the DNA or RNA of the viruses. However, PCR techniques require more expensive equipment and more expertise, compared with the ELISA technique.

Other Thai scientists can use the facilities or equipment that were provided by ACIAR through these projects for other research work. These projects created connections among the scientists from Thailand and other institutions who have the same interests. The benefit can be identified in terms of obtaining knowledge, exchanging experiences, searching for comments, collaboration in future research and so on. There are about 23 research publications produced from CS1/1982/002 and CS1/1988/005 and six conference papers from CS1/1992/026 (Table 2).

### *3.1.2 Control of papaya ringspot virus in papaya and cucurbits through transgenic resistance*

CS1/1992/026 was extended until December 1999 and therefore, at the time of writing, it was too early to quantify economic benefits of this project. Multiple benefits have been reported for growers using transgenic crops, including more flexibility in terms of crop management, decreased dependency on conventional insecticides and herbicides, high yields and cleaner and higher grade of products (James 1998). Hence, it is recommended that when new resistant lines of papaya and cucurbits are registered and being grown by farmers or private producers, the economic benefits of the transgenic resistant approach are quantified.

At present (April 1999), the benefits are described in terms of scientific knowledge, technology transfer and collaboration. Progress of the project and possible outcomes are included. Working on this project, the scientists partly used the scientific information and facilities that were created through the projects CS1/1982/002 and CS1/1988/005. Antisera from the bank of diagnostic antisera (project CS1/1988/005) were used in project CS1/1992/026, in the virus surveys and in proving their resistant character.

Scientific knowledge provides a clear understanding of plant virus diseases in papaya and cucurbits. At present in Thailand, papaya is affected by only one virus disease, PRSV. Not only does PRSV affect cucurbits, but so also do WMVII, CMV and CYMV. This knowledge might lead to future research on other viruses of cucurbits.

The project provides for the development of expertise in Thailand in the area of advanced virus diagnostic techniques (molecular diagnostics), plant transformation and novel gene expression in plants. This technology and expertise developed during the project will be generic and, therefore, may be

**Table 2.** Research publications of the projects

| Project no. | Project Status | Book | Journal | Papers | | | Total |
|---|---|---|---|---|---|---|---|
| | | | | Conference | Workshop | Others | |
| CS1/1982/002 | Complete | 0 | 0 | 0 | 0 | 10 | 10 |
| CS1/1988/005 | Complete | 3 | 5 | 0 | 0 | 5 | 13 |
| CS1/1992/026 | Current project | 0 | 0 | 6 | 0 | 0 | 6 |

adapted to a wide range of viruses, plant species and novel genes in the future. There is not only technology transfer but also human resource development.

This project has enabled the Thai laboratory to generate its own transgenic constructs from its own virus isolates, transform its own varieties of papaya and cucumber, and do all this in its own research facilities. Thai scientists are now capable of making gene construct and generating different transgenic traits in crop plants.

Systems for regeneration and transformation of papaya have been established using Agrobacterium and biolistics (Fitch et al., 1990 cited by Dale et al., 1992). With the use of Agrobacterium, more strains of Agrobacterium and plasmids are made available, which could be readily applicable to a larger range of plants. Using biolistics, DNA is coated with gold or tungsten particles. The coated particles are then physically shot into the plant cells. Using both methods, scientists get a large number of transformed plants that are perfectly normal with no obvious differences to non-transformed plants.

Thai scientists selected "biolistics" for papaya and cucurbits transgenic resistance, largely because this technique works well and has been used in papaya and cucurbits before, while previously published research suggested that the use of Agrobacterium could not be readily applied to papaya and cucurbit. By applying biolistics, Thai scientists acquired an "embryogenic transformation" technique from their Australian partners. This technique is a very important stage required in the biolistics system.

This project created the development of a strong collaboration between the Australian and Thailand partners in an area where there is considerable overlap of interest. Moreover, facilities provided by ACIAR are useful for other research.

Thai scientists also learnt from the project the approximately time and budget requirements for doing research on transgenic plants in Thailand, which is about 5 years with a budget of 1 million baht/year. This information will guide Thai scientists in planning new proposals on transgenic plants.

*Current results*

There are about 100 putatively transformed cucumber lines (Jeb Bai), of which 6 have been shown to be resistant or immune to PRSV-P, under glasshouse conditions. However, some of these resistant lines are still affected by PRSV-W, but with much delayed symptoms compared with the non-resistance cultivars. The transgenic short cucumber lines (Pollek) were having regeneration problems, in that the seeds from the positive lines (R0) of transgenic cucumber were shrivelled. However, these seeds were planted after the 4-month dormancy period and some of these seeds germinated and developed well. Moreover, the majority of the self-pollinated seeds (R1) from these plants were normal. After the 4-month domancy period for the R1 seeds has elapsed, these seeds will be tested under the glasshouse conditions (Srithongchai 2000, pers. comm.). In addition, there are about 100 putatively transformed papaya lines of which some 30 lines are being prepared for PRSV resistance trials under glasshouse conditions.

At present, all the transformed short cucumber lines (Pollek) and most of the papaya lines remain to be tested for PRSV resistance and agronomic performance. This is done in glasshouse trials, with some non-transgenic plants to provide confidence in the results. After that, the promising lines will be tested in the field trials; however, field trials are not, at this stage, to be funded by ACIAR.

*Challenges*

There are some difficulties concerning the transgenic resistance approach. One example is the low regeneration rate; however, this is common for transgenic plants. Aborted cucumber seed from the transformed cucumber lines has also been experienced. Thai scientists (at DOA) are trying to overcome this problem. These problems generate difficulties for further tests in glasshouse and field trials, finally delaying the research outcomes. Three publications that were supposed to be written at the end of the project, were not finished by April 1999.

With regard to the difficulties with transgenic resistance, including unexpected circumstances, transformed papaya will not be ready for field trials until the end of 2000. An estimated cost of about 1 million baht/year is required for researchers and other inputs. The cucumber cultivars Jed Bai and Pollek, will not be ready for field trials until 2000 and 2001, respectively. The estimated costs of researchers and inputs per year is the same as for papaya.

Further, once the papaya and the cucumber cultivars are ready for field trails, it will take a number of years before the field tests on the control of ringspot virus are completed. The main purpose of these tests is to ensure that the results of the research are robust. Once the field tests have been completed, the results are given to the Registration Department of the DOA, which will then carry out further tests before releasing the new varieties to the Department of Extension. The Department of Extension will then test the transgenic material at different localities before notifying and distributing the transgenic material to the farmers.

*Expected benefit from the project*

When the transgenic papaya and cucumber lines are shown to be PRSV resistant and used by Thai farmers, these transgenic plants will be the first transgenic papaya and cucumber plants to be produced in Thailand by Thai scientists. The production of transgenic papaya and cucumber that have resistance to PRSV, should provide a significant economic advantage to the Thai scientists and farmers. The provision of PRSV resistant cultivars should increase the productivity of both papaya and cucurbits and provide for the revival of Thailand's domestic and export industries based on these commodities. Additionally, it should reduce inputs for papaya and cucurbit production in terms of less pesticide application. Thai farmers will benefit through an increase in productivity and a decrease in unit costs.

*Some comments*

Under CS1/1992/026, three organisations in Thailand are involved, namely, DOA, KU and PSU. There is inadequate cooperation among them. It is obvious that the scientists from one institution do not thoroughly know about the progress or outputs of the other groups of the scientists. It might be very helpful if all the scientists had had a meeting to reporting on their work.

Without ACIAR support, the ongoing research from the project CS1/1992/026 is noted. At the end of the project (December 1999), the transgenic papaya and cucumbers were ready for Thai farmers. To achieve the researchers' objectives, it is necessary for the Thai scientists to find some ongoing financial support. This will be especially difficult considering Thailand's ongoing economic problems.

# 4 Conclusions

Plant virus diseases are a major factor limiting the productivity and quality of agricultural products. To solve the virus problem, it is important to understand plant viruses in terms of plant hosts, symptoms, virus morphology, means of natural spread and impact on crop yield and quality. Plant virus projects funded by ACIAR provided basic information on plant viruses (VIDE database) through CS1/1982/002 and CS1/1985/005. This information is useful in the detection and identification of viruses by plant virologists and plant pathologists. Creation of the antisera bank at DOA makes antisera available for public use in Thailand and other countries. Additionally, the ready availability of antisera reduces research costs. The antisera are used in plant breeding programs (to confirm the resistant character), to control plant viruses by avoidance through exclusion or minimisation, for studying virus epidemiology, for forecasting of plant virus diseases, and for guaranteeing the health status of agricultural products for export and import. However, it costs money to maintain the antisera bank. Inefficient management of the bank, after the ACIAR project termination, is evident due to the lack of maintenance costs and personnel. Running the bank of antisera generates ties amongst the scientists who work on the same issues, by exchanging antisera and information on virus diagnosis and identification.

Study of the control of papaya ringspot virus (PRSV) in papaya and cucurbits through transgenic resistance provides not only basic information about PRSV in papaya and cucurbits, but also enables the transfer of technology to Thai scientists. Technology transfers include molecular biology, papaya transformation, cucurbit transformation, and gene sequence and gene expression analysis. The concentration and watchfulness of Thai scientists to achieve the project's aims was evident. As a result of some difficulties and uncontrolled circumstances, the new transgenic plants of papaya and cucumber was not fully achieved in the three years. It is strongly recommended that the benefits of the expected new resistant lines of papaya and cucurbits through transgenic resistant approach be quantified in economic terms as soon as these lines are registered and grown by farmers.

# 6 Acknowledgments

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# Appendix

**Table A1.** Quantity and value of exported papaya products in Thailand 1986–1998

| Year | Export papaya fruit | | Export papaya canned | | Total export papaya | |
|---|---|---|---|---|---|---|
| | tonne | mil. baht | tonne | mil. baht | tonne | mil. baht |
| 1986 | 4,177 | 24.35 | 269 | 5.04 | 4,446 | 29.39 |
| 1987 | 4,178 | 24.98 | 416 | 7.98 | 4,594 | 32.97 |
| 1988 | 4,132 | 25.35 | 722 | 13.82 | 4,854 | 39.17 |
| 1989 | 1,235 | 8.60 | 715 | 13.88 | 1,950 | 22.48 |
| 1990 | 247 | 2.20 | 1,344 | 28.18 | 1,591 | 30.38 |
| 1991 | 89 | 0.94 | 2,702 | 57.39 | 2,791 | 58.33 |
| 1992 | 75 | 1.47 | 1,710 | 35.98 | 1,785 | 37.45 |
| 1993 | 94 | 1.54 | 2,098 | 39.83 | 2,192 | 41.37 |
| 1994 | 355 | 2.23 | 1,890 | 36.51 | 2,245 | 38.74 |
| 1995 | 8 | 0.25 | 2,005 | 41.66 | 2,013 | 41.91 |
| 1996 | 5 | 0.21 | 2,450 | 51.77 | 2,455 | 51.98 |
| 1997 | 44 | 1.18 | 1,333 | 29.17 | 1,377 | 30.35 |
| 1998 | 29 | 1.26 | 2,065 | 62.51 | 2,094 | 63.77 |

Note: A$1 = 20 Baht
**Source:** OAE, 1999

**Table A2.** Papaya cultivated area and productivity in Thailand 1989–1997

| Year | Cultivated area (ha) | | | Production (tonne) | Yield (tonne/ha/yr) | Fruit price (baht/kg) |
|---|---|---|---|---|---|---|
| | Productive | Nonproductive | Total | | | |
| 1989 | 12,345 | 7,178 | 19,523 | 214,265 | 17.36 | 10.51 |
| 1990 | 11,733 | 7,723 | 19,456 | 206,495 | 17.60 | 12.4 |
| 1991 | 20,390 | 9,127 | 29,517 | 408,038 | 20.01 | 8.35 |
| 1992 | 17,309 | 6,567 | 23,876 | 346,305 | 20.01 | 11.06 |
| 1993 | 18,615 | 5,837 | 24,452 | 363,589 | 19.53 | 9.04 |
| 1994 | 19,776 | 6,072 | 25,848 | 367,984 | 18.61 | 7.99 |
| 1995 | 18,492 | 6,033 | 24,525 | 342,772 | 18.53 | 11.44 |
| 1996 | 19,156 | 6,483 | 25,639 | 335,433 | 17.51 | 10.75 |
| 1997 | 18,888 | 7,045 | 25,933 | 316,879 | 16.78 | 16.5 |

**Source:** OAE, 1998

**Table A3** Quantity and value of cucumber products exported from Thailand 1993–1996

| Year | Exported quantity (tonne) | Exported value (mil. baht) |
|---|---|---|
| 1993 | 4,798 | 111.9 |
| 1994 | 4,175 | 107.8 |
| 1995 | 5,226 | 140.9 |
| 1996 | 3,292 | 104.5 |

**Source:** DOAE, 1997

**Table A4** Cucurbits: cultivated area and production in Thailand 1994–1997

| Year | Cultivated area (ha) | Production (tonne) |
|---|---|---|
| 1994 | 74,836 | 902,874 |
| 1995 | 85,498 | 1,053,352 |
| 1996 | 77,994 | 1,131,919 |
| 1997 | 99,037 | 1,180,298 |

**Source:** DOAE (unpublished data)

# An Impact Assessment of the Plant Pathogenic Mycoplasma-like Organisms Project Funded by ACIAR in Thailand

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# Contents

# 1 Introduction

Although plant mycoplasma-like organisms[3] (MLOs) are associated with numerous serious crop diseases in the Asian–Pacific region and Australia, very little is known about them. Sensitive detection methods have not been developed in this part of the world to facilitate early screening programs and to enable safe movement of germplasm (Gibb et al., 1994). It is not known how many strains of MLOs are associated with these diseases. Only a limited amount of work has been done on characterising these organisms and studying the genetic relationships. MLOs can be studied on the basis of biological properties such as disease symptoms, plant host range and insect vector specificity. Recently, the study of MLOs has been hampered by a lack of research tools to culture the MLOs and to distinguish different strains.

In Thailand, investigation of plant mycoplasmas was first reported by Choopanya, indicating the detection of MLO associated with phyllody disease of sesame (Choopanya, 1973; cited by Deema and Kittipakorn, 1986). Identification of MLOs has mainly been through the detection of mycoplasma-like bodies in the diseased tissues, using electron microscopy. In Thailand, numerous MLOs have been found, such as gerbera phyllody, longan witches' broom, peanut phyllody, rice orange leaf, rice yellow dwarf, sesame phyllody, soybean phyllody, sugarcane white leaf, tomato big bud, and winged bean phyllody (Deema and Kittipakorn, 1986).

ACIAR contributed research funds for a project using molecular techniques to study relationships between MLOs, and determine the degree of relatedness between MLO diseases of sweet potato, potato, tomato and tropical legumes in Australia and what appear to be the same diseases in Asian–Pacific countries. The project aimed to promote regional awareness and expertise in the study of MLOs, to stimulate more comprehensive research and to establish appropriate quarantine procedures.

The aim of this paper is to evaluate an impact of the project on plant MLOs in Thailand funded by ACIAR. The paper consists of four sections. After the introduction, a description of the project is presented in section 2. In section 3, the impact of the research project is assessed. The conclusions are presented in the final section.

3. A mycoplasma is a pleomorphic microorganism similar to the L-form bacteria or bacteria without a cell wall.

# 2 Description of the ACIAR research project on plant mycoplasma-like organisms

Project CS2/1994/001 ("Detection and strain differentiation of plant pathogenic mycoplasma-like organisms in the Australasian and Pacific region") was a three-year project that started in 1995. The project involved scientists from the Northern Territory University (NTU) Australia, Indonesia, Thailand, Malaysia and Papua New Guinea. The total budget was A$593 507, which was distributed as follows: 19% for Australia, 23% for Indonesia, 23% for Thailand, 20% for Malaysia and 15% for Papua New Guinea. The Thai scientists were recruited from Prince of Songkhla University (PSU). The objectives of the project were to:

1. develop a routine diagnostic system for the detection of MLOs using the sweet potato little leaf MLO (SPLL) as a model system;
2. develop a system to study MLO variability;
3. characterise the MLO chromosome using SPLL and other local MLOs;
4. study the epidemiology of the disease by monitoring insect vector populations and determining the spread of disease in the field (RIRDC-funded component);
5. facilitate MLO disease management in partner countries through improved diagnostic ability leading to better understanding of the diseases and their epidemiology. The transfer of relevant technical skills, and the application of these skills for further collaborative research to understand MLOs in each country, will achieve this. Assistance will be given where necessary with equipment for MLO detection laboratories;
6. help management of MLO diseases in Papua New Guinea by helping with MLO diagnosis; and
7. identify and analyse different MLOs collected in a survey of key crops from the Australian–Asian–Pacific region with collaborators and use the results to compile a "map" of MLO strains for the region.

Most of the project's objectives have been achieved, except for objectives 4 and 6 (see Gibbs and Dale (1997) for more details). The research outcomes are summarised here.

One of the principal and most important achievements of the project has been establishing which molecular techniques are best for phytoplasmas[4] detection and identification (initial effort of the NTU). A significant number of phytoplasmas has been characterised and their variability examined. The results showed that there are at least four main groups of phytoplasmas causing significant plant diseases in the region, and pawpaw dieback in Australia and sugarcane white leaf in Southeast Asia have been identified as those requiring more detailed epidemiological studies.

Staff in all the collaborating laboratories have acquired and shared new molecular diagnostic skills and, as a result, have gathered information on both previously recorded and new phytoplasma diseases in their countries.

In Thailand, diagnostic facilities have been established at PSU. The Thai scientists were trained at NTU in polymerase chain reaction[5] (PCR) techniques and restriction fragment length polymorphism[6] (RFLP) analysis. Fifty-five plants of 14 species yielded 11 phytoplasmas, one new host (bitter gourd phyllody) record was made, and much progress was made in distinguishing different phytoplasmas. Sugarcane white leaf and green grassy shoot phytoplasmas appeared to be closely related, but were not identical. The phytoplasma found in sesame is related to Australian tomato bigbud phytoplasma (TBBP), and that from periwinkle phyllody is a member of the aster yellows group. It is interesting that no phytoplasma was detected in longans showing symptoms of witches broom disease.

4. Phytoplasmas is a new name of MLOs.
5. PCR—a method for amplifying a chosen fragment or fragments of DNA from a mixture.
6. RFLP—the pattern of fragments obtained by hydrolysing a species of DNA (e.g. the genome of an organism) using a sequence specific enzyme; the pattern is characteristic of the DNA species.

# 3 Impact evaluation of plant mycoplasma-like organisms project

The underlying benefits to the Thai scientists include an increase the scientific knowledge and practical skills of the phytoplasma researchers. This knowledge can be used for regional research and for teaching at the university level. Thus, the immediate beneficiaries of the project were the individual scientists in the collaborating countries, who are now able to screen for phytoplasmas and to undertake future phytoplasma research.

After the project ended in December 1998, there were direct and indirect benefits generated from the research. Scientific knowledge on phytoplasmas was significantly increased. Previously, scientists were not able to differentiate phytoplasmas into species level. The results of using molecular techniques for detection and differentiation of phytoplasmas in the Asian–Pacific region showed that there are at least four groups of phytoplasmas that cause plant diseases.

The Thai scientists were trained at NTU for PCR and RFLP techniques for detection and differentiation of phytoplasmas, respectively. Additionally, diagnostic facilities have been established at PSU, in Thailand.

Scientific knowledge, technology transferred and facilities supported by ACIAR provide an opportunity for Thai scientists to study phytoplasmas in Thailand. In addition, a Thai scientist has applied the PCR technique for detection of other plant pathogens. The PCR technique has been used to screen planting material for propagation before this material is distributed to growers. The PCR technique has been used successfully to detect citrus greening bacterium[7]. This is because the citrus greening bacterium and phytoplasmas have the same habitat[8]. Greening bacterium, which damages both yield and quality of the fruit produced, is considered to be one of the most important diseases of fruit crops in Thailand. Three hundred items of planting material for propagation of citrus were recently screened and distributed to farmers.

The PCR and RFLP techniques will be used to detect and to identify species of *Phytophthora* (a fungus) causing disease in durian. This is for the screening of *Phytophthora* resistance of indigenous durian in southern Thailand. In the future, the Thai scientist plans to apply the RFLP analysis to differentiate strains of citrus greening bacterium as well as to determine the cultivar of the indigenous durian.

As described above, Thai scientists have applied the technology developed to detect phytoplasmas to other plant pathogenic taxa. Hence, the Thai scientists have been able to apply the knowledge and skills learnt in CS2/1994/001 to other problems. However, without diagnostic facilities provided through the project, the Thai scientists may not have been able to continue to apply this knowledge and technology. The diagnostic facilities are not only used by phytoplasmas researchers but also by other plant pathogen researchers.

A successful outcome of this project is the transfer of the new knowledge and skills by educating and training university students. At PSU, the experience (knowledge and technology) has been transferred to the students since 1996 with three subjects on practical techniques being taught. In Thailand, the technology has also been transferred to collaborators who are going to undertake research on phytoplasmas in the future.

The use of the PCR and RFLP techniques is limited to a small group of people. This is because the users have to be highly trained and experienced. However, the beneficiaries of the project include

7. Normally, antisera are used for detecting of greening-bacteria in citrus. At the present, these antisera were not available in the world. A Thai scientist has applied the PCR technique with primer (developed by other scientists) for detecting greening-bacteria in citrus.

8. Habitat is a region where a pathogen lives in a plant. Phytoplasmas and greening bacterium both live in the phloem (food-conducting cells) of their host plant.

plant pathologists, plant breeders, agricultural extension officer, quarantine personal and farmers. Understanding of phytoplasma disease has led to improved quarantine guidelines for movement of clean germplasm and, hence, improved crop-breeding programs. The information can be used for quarantine services and for forecasting and managing the phytoplasma problems in the region.

There have been 10 research publications from the project, including one on phytoplasmas in Thailand (Sdoodee et al., 1999). In addition, a book chapter on the differentiation of white leaf from grassy shoot phytoplasma in sugarcane by RFLP analysis has been published (Sdoodee, 1999).

The project has also generated collaboration amongst the researchers in the different partner countries. They are able to exchange their experiences, knowledge and training.

Basic scientific knowledge from project CS1/1994/001 enables the Thai scientists to continue their research accurately. In addition, diagnostic facilities were established for phytoplasma screening services for the region, not just for a particular research institution. It was designed to increase awareness about phytoplasmas and to establish active study programs. The future research program will focus on phytoplasma-caused diseases, with an emphasis on practical outcomes such as protection of economically important crops from these diseases. The emphasis will be on disease control, with some basic work on the primer necessary for accurate diagnosis, and some applied work on surveys of incidence and epidemiology. One of the most important phytoplasmas in Thailand is sugarcane white leaf. To understand this phytoplasma and to control the disease in Thailand, research on the sugarcane white leaf virus will focus on epidemiology, the vector, natural spread and the life cycle.

An economic analysis has not undertaken at this stage. Currently, in Thailand, well-educated scientists only carry out the diagnostic tests. While yield reduction due to phytoplasma diseases has not been quantified previously, it is expected that increased production of important food crops will occur once the diagnostic tools are adopted as a routine part of growers’ management practices. It is recommended that the economic impacts be assessed after the study on the sugarcane white leaf disease is completed in Thailand. However, it may take another 5 years before this research is completed.

# 4 Conclusions

Project CS1/1994/001 provided important basic information on phytoplasmas, which has established a firm foundation for a new branch of plant pathology in the region. Scientific knowledge includes understanding of the distribution, variability and fundamental of nature of phytoplasmas. There are at least four main groups of phytoplasmas causing significant plant diseases in the region. Additionally, the project has enhanced expertise in detection, diagnostic and research capacity and in the diagnosis facilities in the partner countries. In Thailand, the application of the knowledge comes with screening plant material collected from agricultural experiment stations and growers' properties, not only for phytoplasma diseases but also for other plant pathogenic diseases, such as the citrus greening bacterium. The knowledge, technology and diagnostic facilities in phytoplasmas have been used to educate and train Thai students at the university level. Receiving the scientific knowledge from the project, Thai scientists have increased awareness about phytoplasmas diseases and plan to establish active study programs on the important phytoplasma diseases in the region; for example, sugarcane white leaf in Thailand.

# 5 Acknowledgments

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# An Impact Assessment of ACIAR Projects on Forest Management in Thailand

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# Contents

# 1 Introduction

A dramatic decline in forest areas in Thailand has been observed over a number of decades. Forests accounted for more than 60% of the total area of the country in 1960. This are has fallen to less than 25% by 1996. Among many attempts to solve this problem, a number of research projects on forest management were initiated under the collaboration between the Thai Government and the Australian Centre for International Agricultural Research (ACIAR). Five related research projects, which focused on different aspects on forest management (Figure 1) were financially supported by ACIAR at a cost of $A2 256 875 (Table 1). These research projects are evaluated in this report.

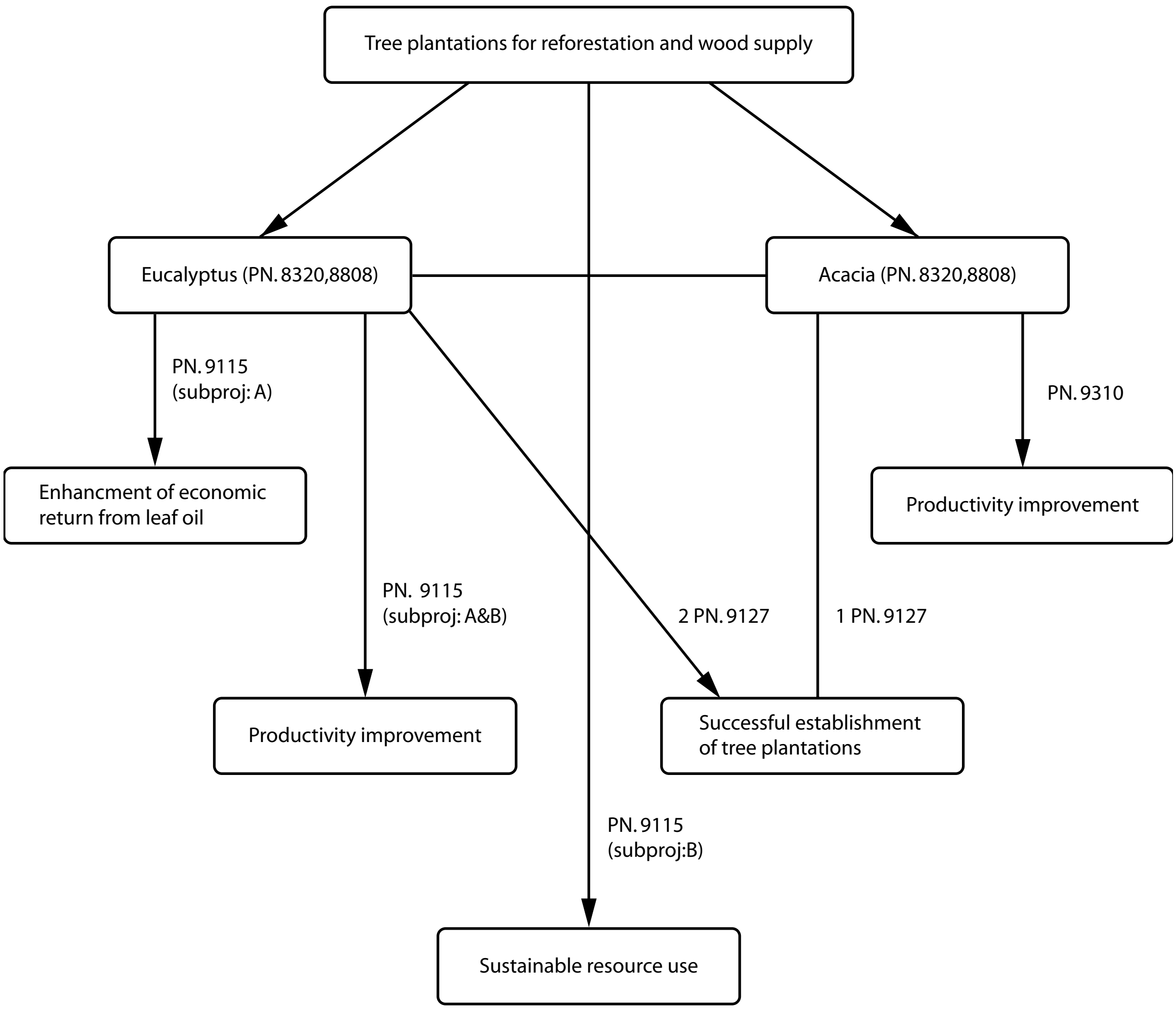


**Figure 1.** ACIAR –supported projects in forest management in Thailand

**Table 1.** ACIAR-supported projects in forest management in Thailand

| Project title/number | Project duration | Collaboration with Thai organisation | ACIAR budget ($A) |
|---|---|---|---|
| Australian Hardwoods for Fuelwood and Agroforestry (FST/1983/020, FST/1988/008) | 1985–1987<br>1988–1990 | Royal Forest Department | 440,589<br>636,453 |
| Improving and Sustaining Productivity of *Eucalyptus* in Southeast Asia (FST/1991/015)<br>• Subproject A: Breeding to improve *E. camaldulensis* plantations and improvement in Eucalyptus oil production<br>• Subproject B: Site sustainability/ *Eucalyptus-Acacia* mixture | 1992–1995 | Royal Forest Department | 796,708 |
| Predicting Tree Growth for General Regions and Specific Sites in China, Thailand and Australia (FST/1991/027) | 1992–1996 | Royal Forest Department<br>Department of Land Development | 294,125 |
| Physiology and Genetic Improvement of *Acacia auriculiformis* (FST/1993/010) | 1994–1996 | Kasetsart University<br>Royal Forest Department | 89,000 |

**Source:** Adapted from Suzuki et al., 1996

# 2 Australian hardwoods for fuelwood and agroforestry (projects FST/1983/020 and FST/1988/008)

## 2.1 Overview and objectives of the projects

Among the many problems caused by the rapid deforestation in the country, shortages of fuelwood and wood for various other purposes are the most crucial, since more than half of population lives in rural areas where wood is the main energy source for cooking and heating. As natural sources of wood supply have been destroyed, one measure to solve these problems is to establish tree plantations as substitute sources. This is complemented by attempts to reforest the deforested areas. Tree species which are fast growing, capable of surviving in various conditions, and of sustaining resource use, are required for these purposes. The collaborative research between Thailand and Australia, supported by ACIAR, was initiated under the projects on "Australian hardwoods for fuelwood and agroforestry" (FST/1983/020 and FST/1988/008). The main participating organisations are the Royal Forest Department (RFD) in Thailand and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia.

The objective of these two projects was to determine exotic Australian tree species that offer promising productivity for silviculture (for fuelwood and roundwood), industrial wood production, and reforestation. In the first period (from 1985–1987) under the project FST/1983/020, three series of field trials were established at eight sites covering different climatic and geographic conditions over the country. Five tree species, including species from the genera *Eucalyptus, Acacia, Melaleuca* and *Casuarina,* were recommended under this project. Seed for planting was supplied by ACIAR through CSIRO. It was recommended that to obtain reliable assessment information on tree species, which could help indicate which species should be promoted to the private sector and individual farmers, extension to the second phase was needed. The second phase was during 1988–1990 under the project FST/1988/008. The main activities were to continuously monitor and evaluate the trials.

## 2.2 Research findings

Among various Australian tree species planted under these research projects, assessment on growth and survival indicated that *Eucalyptus camaldulensis* was the best in terms of adaptation to all sites, while *Acacia crassicarpa* and *Acacia auriculiformis* performed well in terms of growth and height. *Melaleuca* and *Causarina* were poor in adaptability and low in mean yield. However, differences can be observed between provenances of the same species. For example, *Acacia aulacocarpa* grew better and more stable when the seed originated from Papua New Guinea than when it originated from Queensland. The researcher from RFD, Khun Vithoon, stated that it was found recently that *Acacia aulacocarp*a from Papua New Guinea is different from the tree from Queensland, and so the one from Queensland will be given a new name soon (Khun Vithoon, pers. comm. 2000). Nevertheless, site conditions, species and provenances have to be carefully matched to ensure successful establishment and yield of tree plantations. The results suggested that there is genetic diversity within the tree species and that further research in genetic improvement of each tree species is required.

## 2.3 Impacts of the research projects

### *2.3.1 Potential economic impacts of the research findings*

The outcomes of these research projects were that some exotic Australian tree species could be introduced for tree plantations and reforestation in Thailand. The fast-growing tree species like *Eucalyptus camaldulensis* can be used at the farm level for fuelwood and for household construction, and at the industrial level as solid timber, reconstituted wood, and for pulp and paper production. Hence, planting *Eucalyptus camaldulensis* could alleviate the shortage of wood and fuelwood supply. In addition, valuable non-wood products including essential leaf oil, honey and tannins can also be obtained from this tree species. Apart from benefits to the private sector, another advantage of these tree species is that they can positively impact on the environment because they can help to reduce the salinity problem by lowering groundwater level (evaluation report phase I), and can be grown in drought areas where no other plants can survive. However, there are some adverse ecological effects associated with growing *Eucalyptus*. First, this tree species can inhibit the growth of the other plant species grown nearby, which reduces the level of biodiversity in the planted areas. Second, soil degradation can occur, particularly in soils where the soil fertility is already low, because these fast-growing tree species rapidly take up soil nutrients, leading to the depletion of the reserve of nutrients in the soil.

Apart from *Eucalyptus*, *Acacia* species were also identified by these research projects as multi-purposed tree species, which offer almost the same advantages as those of the *Eucalyptus*. However, unlike the *Eucalyptus* species, acacias have a positive impact on the environment. Soil fertility can be sustained from planting *Acacia* species as they are a nitrogen-fixing species.

### *2.3.2 Transferability of research findings*

Research outcomes in the form of identified tree species suitable for tree planting to serve reforestation purpose are quite clear. As the reforestation program is one of major task of the RFD, it was reported that these tree species, especially *Eucalyptus camaldulensis* and *Acacia auriculiformis*, are grown in reforestation areas under the responsibility of RFD. In this respect, benefits generated from these research projects accrue to the public.

The Australian tree species, including *Eucalyptus camaldulensis*, *Acacia crassicarpa*, *Acacia mangium, Acacia aulacocarpa* and *Acacia auriculiformis*, which showed their ability to adapt to various climatic and geographic conditions, were on the list of tree species for tree planting promoted to the private sector. However, the findings of the ACIAR projects have not been transferred to the end-users (private sector and individual farmers). Although it is reported that areas of *E. camaldulensis, A. auriculiformis,* and *A. mangium* have been planted in Thailand, these tree species were introduced to Thailand long before the commencement of these ACIAR projects. This is confirmed by the researcher from RFD. As for *A. aulacocapa* and *A. crassicarpa*, it is clear that these two species were introduced as a result of the ACIAR projects (FST/1983/020 and FST/1988/008), but there is no report of adoption of these species by the private sector or by individual farmers. The main reasons for the lack of adoption is that the original seed is costly and relatively difficult to obtain. Even though there has been no adoption by end-users, the research findings from these projects have been transferred to other research projects and to the ongoing activities of RFD, which is of considerable value.

These research projects are considered as the starting point of research on *Eucalyptus* and *Acacia* for agroforestry in Thailand. Three subsequent ACIAR-funded projects (including FST/1991/015, FST/1991/027, FST/1993/020) examined various aspects such as productivity improvement of the tree species, enhancement of the economic returns of the tree products (e.g. leaf oil), successful establishment of tree plantations, and sustainable resource use. The existing trials established under projects FST/1983/020 and FST/1988/008 provided an experimental and analytical basis for the subsequent three forestry projects. The linkages of these research projects are showed in Figure 1. It can be concluded that a major benefit of projects FST/1983/020 and FST/1988/008 was that they contributed enormously to the forestry projects that followed which, consequently, provided substantial benefits not only to Thailand but also to neighbouring countries. Projects FST/1991/015, FST/1991/027 and FST/1993/010 are evaluated in the following sections.

### *2.3.3 Scientific knowledge and human capacity building*

The scientific knowledge derived from these projects FST/1983/020 and FST/1988/008 is considered substantial, as a large number of publications resulted from them (see Appendix I). There were also capacity-building activities through training in field trial analysis using the "GENSTAT" software provided at the Division of Forest Research, CSIRO in Canberra, and participation in international conferences and field trips to forests in Queensland and New South Wales. In addition, equipment including meteorological and measuring instruments provided by ACIAR under these projects can continue to be used to enhance the research capability of Thai scientists.

# 3 Improving and sustaining productivity of *Eucalyptus* in Southeast asia (Project FST/1991/015)

## 3.1 Overview and objectives of the project

*Eucalyptus* species, especially *E. camaldulensis,* are known as fast-growing trees and have been a key species for reforestation in Thailand for decades. Growing demand on wood, pulp and paper products has accelerated the expansion of *Eucalyptus* plantations. The main problems with *Eucalyptus* plantations are low productivity which stems from planting with seeds of unknown origin, and decline in productivity through inbreeding. Therefore, there is a need to genetically improve seeds for *Eucalyptus* plantations. Apart from the issue of productivity, improving leaf oil production for commercial purposes is another way of enhancing the economic return from *Eucalyptus* plantations.

On the other hand, planting *Eucalyptus* in monoculture has been strongly criticised for itsnegative impacts on the environment. Soil degradation is crucial as nutrients are dramatically used up because of the fast growing characteristics of the *Eucalyptus*. A decrease in productivity of *Eucalyptus* will be a result as soil has been continuously degraded. Additionally, loss of biodiversity has been observed in *Eucalyptus* plantations as no other species can compete or even coexist with eucalypt species. Hence, developing a new management system designed to improve soil fertility is necessary for productivity enhancement while sustaining long-term land use. To introduce nitrogen-fixing trees such as *Acacia* intercropping with *Eucalyptus* would help increase the cycling of nitrogen (N) and phosphorus (P) which are key elements needed for tree productivity.

The project on "Improving and sustaining productivity of *Eucalyptus* in Southeast Asia" (FST/1991/015) was initiated under the collaboration between the RFD in Thailand and CSIRO's Division of Forestry in Australia, with the financial support of ACIAR. The aim of this project was to improve production of eucalypts (*E. camaldulensis* as a key species) while sustaining land resource use. To achieve this aim involves three main approaches: (1) to breed more productive *Eucalyptus* seeds for productivity improvement; (2) to assess potential in commercialisation of leaf oil production to enhance economic returns of *Eucalyptus* planting; and (3) to sustain land resources for long-term use by developing site management of mixed plantations of *Eucalyptus* and the nitrogen-fixing tree species, *Acacia auriculiformis*. While the project was divided into five subprojects, only the two subprojects that involved Thailand are evaluated in this paper. Descriptions of the two subprojects follow:

### *Subproject A: Breeding to improve* E. camaldulensis *plantations (establishment of progeny trials) and improvement in* Eucalyptus *oil production*

This subproject involved two main research issues: research on breeding to improve *E. camaldulensis* plantations by establishing progeny trials; and assessing *Eucalyptus* oil for commercial purposes. Four, large, open-pollinated progeny of *E. camaldulensis* were established at Ratchaburi, Chachoengsao, Kamphaengphet and Sri Sa Ket provinces. An assessment on genetic variation and determination of the relationship between growth performance and outcrossing rate in this species were the main activities.

The research on *Eucalyptus* oil attempted to determine factors affecting the quality and quantity of leaf oil. Seasonal variation in leaves and different harvesting times were tested for their effects on oil components and yields. The conditions needed for successful commercial production of *Eucalyptus* oil were identified as well. Two pilot distillation projects were conducted at the plantation in the Plangyao district of the Chacheongsao Province, and at a 6-year-old *E. camaldulensis* plantation at the Thai Plywood Plantation in the Chachoengsao Province to determine oil concentration by stream distillation and the abundance of 1,8-cineole by gas chromatograhpy from sample leaves.

*Subproject B: Site sustainability/* Eucalyptus–Acacia *mixture*

The main activity of this subproject was an assessment of the growth and nutrient accumulation of *Eucalyptus* under mixed-species plantations (*Eucalyptus camaldulensis* with *Acacia auriculiformis*) compared with a monoculture of *Eucalyptus*. Tree height and stem diameter were the parameters used for growth monitoring. The contribution of *Acacia* to soil nutrient and nutrients accumulation of *Eucalyptus* can be measured from the amount of nitrogen detected in the *Eucalyptus* stands. In addition, to assess long-term sustainable land use, soil nutrients (focusing on nitrogen and phosphorus as the main elements) of mixed-species and mono-species plantations were compared. The study sites were located at the Paktor Experimental Station of the RDF, Rachaburi Province, and at Lad Krating, Chachoengsao Province.

## 3.2 Research findings

*Subproject A: Breeding to improve* E. camaldulensis *plantations (establishment of progeny trials) and improvement in* Eucalyptus *oil production*

Results obtained from the progeny trials during the three-year period showed that there were differences in the growth of trees between regions, provenances and families. Growth was measured in terms of height, diameter and volume per tree. Growth of provenances from Queensland and Thailand was found to be better than that of provenances from the Northern Territory and Western Australia. Among provenances from Queensland, those from Petford showed promising results at all sites. This is confirmed by the fact that Petford *Eucalyptus* is widely grown in Thailand. The level of outcrossing was found to be quite high at around 96%, compared with the usual level of 75%. The provenance trials established under this project provide a good basis for breeding this tree species in Thailand. Breeding plans for *Eucalyptus* that were set up in the first stage of the research project were revised after taking into account the findings from this project. However, continuous evaluation of the trials is needed for a longer period to obtain reliable outcomes (Pinyopusarerk and Schofield, 1995).

There are many factors leading to the feasibility of commercial production of *Eucalyptus* oil. These include adequate supply of leaves, simple technology for oil distillation, cost savings as the small coppice stems from which the foliage is trimmed for distillation and extracted leaves can be used as fuel, low labour requirements and high demand for the oil product. However, commercial production seems unlikely. The main critical factor limiting potential for commercial purpose is yield of oil. The most important oil components for commercial use are characterised by high content of 1,8-cineole. Although the analysis of volatile oil found that 1,8-cineole was the major component at 51–80%, which was acceptable, variation in oil concentration was quite high, which can critically affect commercial oil production. This is influenced by various factors including time of leaf harvesting and the species. An analysis of leaf oil components showed that the best periods for leaf harvesting are January to March and May to July. In case of Thailand, where the main purpose of *Eucalyptus* plantations is for wood production, scope for harvesting the leaves is limited. Harvesting of leaves for oil production is determined by the time available for tree treatment and wood harvesting. The number of *Eucalyptus* species also contributes directly to oil composition. While hundreds of *Eucalyptus* species provide a volatile oil, only a very few species can be used for commercial oil production. As the main purpose of *Eucalyptus* plantations in Thailand is not for oil production, *Eucalyptus* species found are not considered as oil-bearing species. In addition, the generally unknown origin of eucalypts found in small-scale plantations leads to variation in quantity and quality of the essential oil. However, it is estimated that production of leaves is about 258 tonnes per hectare and with this amount of leaves, some 39kg. of oil can be produced.

*Subproject B: Site sustainability/* Eucalyptus–Acacia *mixture*

Growth improvement of *Eucalyptus* was clearly shown in mixed-species plantation of *Eucalyptus* and *Acacia*. Stem height and volume, and weight of fine roots, indicators for growth improvement of *Eucalyptus*, were found to be higher under mixed-species plantations than under monoculture. On the other hand, a decrease in growth of *Acacia,* measured from diameter at breast height (DBH), was found. Under the mixed-species plantations, the ratio of the mixture was found to influence the growth of *Eucalyptus*. A negative correlation between DBH of *Eucalyptus* and the ratio of *Acacia* mixtures was found at the Lad Krating site. The status of nutrient cycling and tree nutrition in the intercropping plantations was better than that of monocropping plantations. The status refers to nitrogen concentration in soil and foliage. However, the main researcher, Mrs Wilawan Wichiennopparat, stated that a firm conclusion still could not be made from the results obtained during the research period (approximately 3.5 years), as it was too early to observe the effects of the mixtures. An assessment of the effects of growing mixtures on productivity improvement of *Eucalyptus* and on soil characteristics will be more reliable after they have been observed for one full rotation, which is around 7–8 years (Wichiennopparat 1999, pers. comm.).

## 3.3 Impacts of the research projects

### *3.3.1 Potential economic impacts of the research findings*

*Subproject A: Breeding to improve* E. camaldulensis *plantations (establishment of progeny trials) and improvement in* Eucalyptus *oil production*

A potential economic impact of the research on breeding to improve *E. camaldulensis* plantations by the establishment of progeny trials could be expected, as tree productivity is enhanced. Although outcomes derived during the research period may not provide clear conclusion on genetic gain obtained from the progeny trials, as it is too early for evaluation, it can be expected that, after the trials, genetically improved seed would be used to establish a seed orchard. At this stage, the material in the trials could be used as the base population for further breeding programs and improvement of the genetic base in Thailand

The major economic impact of the research on leaf oil production is an enhancement of economic returns of planting *Eucalyptus*. Although achieving commercial oil production does not seem possible at this stage because of the various factors discussed above, it does shed light on commercialisation in the future, especially for large-scale plantations where appropriate species, harvesting and processing procedure can be expected. At Suan-Kiti, one of the large *Eucalyptus* plantations, there is strong interest in oil production (Khun Benjawan, August 1999, pers. comm.). Essential oil of *Eucalyptus* domestically consumed is imported mainly from China and Australia, with an average value of around 15 million baht per year according to the Thai Customs Department. In this case, import substitution could be a potential benefit generated by domestic commercial oil production. For small-scale plantations, additional benefits (in the forms of cash and non-cash income) can be generated by producing leaf oil for household consumption and for sale.

The main cost incurred in oil production is investment in a still. The 1-tonne still used in the project, which was funded by ACIAR, cost 10,000 baht, and an individual farmer may not be able to afford this. The researcher, Khun Benjawan Caruhapattana, recommended that a simple still, which is used for wine distillation, could be used for distilling *Eucalyptus* oil. She plans to develop a 0.5-tonne still for small scale farmers, and this still is expected to be used for other purposes such as lemongrass oil production (Caruhapattana August 1999, pers. comm.). Apart from investment in the still, operating expenses for oil production seem to be quite low. Fuel for distilling can be supplied by extracted leaves and small branches or stems collected after harvesting the wood, and labour which is required for transporting and harvesting of leaves can also be provided by households.

*Subproject B: Site sustainability/* Eucalyptus–Acacia *mixture*

The potential impacts of this subproject are enormous as the expected research outcomes contribute to not only an improvement in the economic return of the tree plantations, but also in sustaining long-term use of land resources. However, the potential benefits expected from the research can not be quantified at this stage. Income improvement is the main potential benefit expected from the introduction of the mixed culture of *Acacia* and *Eucalyptus*. An increase in revenue is obtained from enhanced productivity of *Eucalyptus* due to the improvement in the soil nutrient cycle induced by introducing acacias into *Eucalyptus* plantation.

Continuous depletion of land resources because of monoculture of *Eucalyptus* can be mitigated by better nutrient cycling contributed by intercropping the plantation system with *Acacia*. The improvement in soil fertility offers long term benefits of sustaining land resource use. These benefits can be simply valued as cost reductions or cost savings per year from the substitution of nitrogen-fixing species for chemical fertiliser in supplying nitrogen, the important element for tree growth. Additional income can also be generated from *Acacia*. Potential benefits of *Acacia* (especially *A. auriculiformis*) are discussed in detail in the economic evaluation of ACIAR project FST/1993/010.

### *3.3.2 Transferability of research findings*

*Subproject A: Breeding to improve* E. camaldulensis *plantations (establishment of progeny trials) and improvement in* Eucalyptus *oil production*

There are substantial spillovers from this research. These take the form of training and supervision provided by RFD researchers (Khun Vithoon and Khun Bunyarit) to Lao scientists, and study tours of Lao scientists to RFD trials in Thailand. As the research outcomes are considered to be preliminary, maintenance and evaluation of the trials to obtain significant outcomes which can be passed onto end-users, will be carried by the RFD. The researcher, Khun Vithoon, also confirmed that the collaboration between RFD and CSIRO on this issue is continuing, even though the project has finished (Vithoon, August 1999, pers. comm.).

The research outcomes of *Eucalyptus* oil production have not yet been transferred to end-users including private forestry firms or individual farmers. According to the recommendation of the researcher, there is a need for further study, especially in the case of commercial oil production, to achieve required market quality. In the case of small-scale farmers, low capital investment on oil stills under cooperative management of the farmers could be an alternative for additional revenue from *Eucalyptus* plantations. Potential transferability of research findings to small scale farmers can be foreseen as it is planned by the researcher to construct a 0.5-tonne still, which is based on the technology of the 1-tonne still provided under this project, as mentioned above. This plan would need continuous financial and technical support.

*Subproject B: Site sustainability/* Eucalyptus–Acacia *mixture*

As mentioned earlier, more time is needed before conclusions can be drawn and the research findings can be transferred to the public. However, the preliminary results found under this research have been transferred to the RFD. The RFD is continuing the research to obtain a reliable outcome which can be finally transferred to the farmers or to the private forestry sector (Wilawan 1999, pers. comm.).

### *3.3.3 Scientific knowledge and human capacity building*

*Subproject A: Breeding to improve* E. camaldulensis *plantations (establishment of progeny trials) and improvement in* Eucalyptus *oil production*

One symposium paper and one journal paper were produced as a part of this subproject (Appendix). The skills of the researchers were also enhanced in experimental design, data analysis, practical training in nursery propagation and in the establishment and measurement of field trials, and by attending a workshop (ACIAR workshop in China) and conferences (Genstat Conference in New Zealand, and CRCTHF–IUFRO Conference in Hobart, Australia).

*Subproject B: Site sustainability/* Eucalyptus–Acacia *mixture*

The main researcher from the Royal Forest Department, Mrs Wilawan, was trained in the collection of root samples, measuring water potential (i.e. the relationship between the water content of plants and soil moisture) in techniques for measuring leaf area index, and in data analysis. The knowledge obtained from the training is necessary for successfully conducting this research. Training in the techniques for measuring soil components (especially $NH_4^+$, $NO_3^-$, and P) and a study visit to CSIRO experimental sites were also undertaken by a RFD soil scientist who was one of researchers in this subproject. The research results from this subproject were presented at international conferences/workshops and were also published (Appendix).

# 4 Predicting tree growth for general regions and specific sites in China, Thailand and Australia (Project FST/1991/027)

## 4.1 Overview and objectives of the project

Under declining forest areas, tree planting plays an important role to serve a growing demand for wood and its products, and for reforestation purposes. Tree species introduced from Australia, namely *Eucalyptus camaldulensis* (Petford provenance), *Eucalyptus grandis* (Coffs Habour provenance), *Acacia mangium* (North Queensland provenance), and *Acacia auriculiformis* (Papua New Guinea provenance), are among the various tree species suitable for tree planting, mainly because of their fast growing characteristics. To successfully establish a tree plantation, there is a strong need for methods which could assist the selection of appropriate tree species under different soil and climate conditions, which contribute significantly to the growth of the trees.

The ACIAR research project on "Predicting tree growth for general regions and specific sites in China, Thailand and Australia" commenced in 1992 under collaboration among various agencies from three countries: the RFD and the Department of Land Development in Thailand, the Research Institute of Forestry in China, and the CSIRO's Division of Forestry in Australia. This project aimed at developing generic methods to help select tree species for general regions and specific sites in the three countries. The methods refer to two main programs: a climatic mapping program; and a simulation mapping program, which incorporates climatic and soil information. The climatic mapping program identifies locations which are climatically suited for selected Australian tree species. Apart from climatic conditions, soil information will be integrated into the mapping program to predict the growth of the trees. These two programs are expected to assist in selecting appropriate trees for particular areas, and also to evaluate the suitability of both climatic and soil conditions for the selected tree species.

## 4.2 Research findings

The discussion of the research findings and their impacts is limited to those that relate to Thailand.

A climatic mapping program for Thailand was generated using time series data from 1957–1989 collected by the Meteorological Department, the Royal Irrigation Department, the RFD, and the Electricity Generating Authority of Thailand. Six climatic factors—mean annual rainfall, rainfall regime, dry season length, mean maximum and minimum temperatures and mean annual temperatures—were used to characterise each location across the country, and then used for creating the 'THAI' climatic mapping program. Together with this mapping program, a zonal mapping program called 'THAIZONE' was produced by using the same set of data. Locations appropriate for the selected tree species across the country were then identified by entering into the THAI program a description of climatic requirements of the tree species and provenances produced as a part of this project.

The results obtained from the THAI climatic map are limited by the fact that only climatic conditions are evaluated. Other factors such as soil conditions, which may affect the suitability of each location for each type of tree, are not included. The Plantgro soil and climate database for Thailand, was created by the Soil Survey and Classification Division, Department of Land Development. The Plantgro model assesses plant requirements in relation to climatic and soil conditions to evaluate land suitability for selected plants. The growth of selected species at trial sites in Thailand was measured and used in an analysis of how climate and soil conditions affect tree growth. The results indicate that both these factors have an influence on rates of tree growth.

## 4.3 Impacts of the research projects

### *4.3.1 Potential economic impacts of research findings*

The results of the project offer the development of an improved database on the environment which, consequently, contributes to the long-term planning of sustainable natural resource use at the macro level. An integration of environmental conditions (such as climate) and natural resources (especially land) are very important to ensure selection of appropriate genotypes for introduction at the micro level. The information on suitable crops for specific areas is very useful for extension workers and farmers. Improvement in farm income as a result of the selection of appropriate crops can be counted as benefits generated by the project. In addition, problems in mismatching of crops and environmental conditions, which could result in crop failure and in a reduction in farm income, could also be alleviated to some extent.

### *4.3.2 Transferability of research findings*

Research findings have been transferred to scientists from difference disciplines such as forestry, agriculture, soil science, and meteorology via the workshop and publications. The spillover effect of the research is in the form of a database and programs developed by this project which have been applied and used by other areas of study (such as agriculture land evaluation and planning) and also by other countries which were not involved in the project, such as the Lao PDR, Vietnam and Cambodia.

### *4.3.3 Scientific knowledge and human capacity building*

Scientific knowledge generated, especially the computer-based program created under this project, has been publicly transferred in the form of a number of publications written as a part of the project (see Appendix), and through the workshop held Bangkok on 27–30 March 1995, and its proceedings entitled “Matching Trees and Sites” published in 1996. Capacity enhancement was obtained from training. A training course in computer-based methods for predicting plant growth which was held in Bangkok on 19–23 September 1994 to introduce the computer program generated under this project.

# 5 Physiology and genetic improvement of *Acacia auriculiformis* (Project FST/1993/010)

## 5.1 Overview and objectives of the project

Establishing tree plantations has become a popular strategy for reforestation and supporting domestic demand for timber products in Thailand. Among various tree species, *Acacia auriculiformis*, from Australia, is an attractive species for tree plantations because not only is it fast growing, but also its wood can be used for various purposes such as for timber, fuelwood and charcoal making. Also, *Acacia auriculiformis* can be used as an alternative to *Eucalyptus camaldulensis*. However, the use of these trees is still limited because of their crooked and forked stems. Thus, tree improvement research could help mitigate the limitations, which will consequently increase the economic benefits of the tree plantations.

The ACIAR project on "Physiology and genetic improvement of *Acacia auriculiformis*" was conducted from 1994 to 1996. Australia, Thailand and Vietnam collaborated in this project, which was aimed at developing genotypes of *A. auriculiformis* offering growth potential and adaptability to seasonally dry and harsh tropical environments. Three attractive attributes of *A. auriculiformis* from different provenances include the longest clear bole from the Queensland provenance (Q), the highest biomass from the Papua New Guinea provenance (P), and the greatest drought tolerance from the Northern Territory provenance (N). In Thailand, the main activities undertaken by the Faculty of Forestry, Kasetsart University, and the RDF were to:

- produce hybrid seeds by controlled pollination; and
- investigate physiological mechanisms contributing to the differential attributes among the provenances through
  - shade-house studies on the role of total leaf area in growth, and
  - the application of stable carbon isotope composition for evaluating water-use efficiency.

## 5.2 Research results

Hybrid seeds from inter-provenance and intra-provenance crosses of *A. auriculiformis* from three different provenances (Northern Territory, Queensland, and Papua New Guinea), and inter-specific crosses between *A. auriculiformis* and *A. mangium*, were produced under controlled pollination. These seeds will then be planted in Darwin and Thailand for further analysis on heterosis and physiological parameters related to growth, and for evaluation of the effects of maternal and paternal factors on the hybrids. The main problem faced during the experiment is that quite a small number of seeds was produced because of the difficulties in conducting controlled pollination under the circumstances of varying flowering intensity and time among these provenances.

The results of investigation on physiological parameters, such as leaf area, in determining growth potential showed that leaf area can be used as an indicator for growth due to the strong correlation between total leaf area and biomass production of *A. auriculiformis*. An evaluation of the determination of stable carbon isotope composition in phyllodes of *A. auriculiformis* on water-use efficiency showed insignificant effect. However, the research suggested that water-use efficiency might be under some forms of genetic control. Hence, further research is needed to provide evidence on this possibility.

## 5.3 Impacts of the research projects

### *5.3.1 Potential economic impacts of the research finding*

Potential economic impacts drawn from the research results are considered substantial since the improvement in physiological and genetic attributes of *Acacia auriculiformis* provide better quality and quantity of the tree products. This could attract the interest of the private forestry sector to adopt this leguminous tree, which offers higher value products. To the small-scale farmer, an introduction of this tree species could serve as an alternative source of fuelwood, under the growing fuelwood scarcity from deforestation, and additional income to the farm household. Apart from the expected benefits from better quality and quantity of the tree products, a potential impact on the environment is another aspect contributed by the research. *A. auriculiformis* could enhance soil fertility, as it is a nitrogen-fixing species. In addition, an ability to adapt to the drought environment can bring about revegetation of drylands or deforested lands, and ameliorate soil erosion and water viability. Although economic benefits in forms of income improvement and environmental protection of soil and water are expected, at this stage it is not possible to quantify them as the scientific research findings are still in the process of being verified.

### *5.3.2 Transferability of research findings*

The results generated by this research project are not in a form that can be transferred directly to end-users (such as private forestry sector and individual farmers), but they can be transferred to relevant organisations such as the RDF. This organisation could carry out further research to obtain complete outcomes and then the transferability of the final findings can take place. Dr Ladawan, the project leader from Kasetsart University, stated that to obtain complete and verified results will take longer than the duration of the project.

### *5.3.3 Scientific knowledge and human capacity building*

The project has delivered substantial scientific knowledge, capacity enhancement of the participating scientists, and the establishment of collaboration among scientists from partner countries. The scientific outcomes have been reported in considerable numbers of papers and reports written on different aspects of the research project (see Appendix). The human capacity of the Thai researchers was enhanced through their training in controlled pollination techniques. Although the project has finished, the research linkages among the scientists from three countries continues under the strong connection established during the research.

# 6 Summary and conclusions

Because of the sharp decrease in forest areas in Thailand, the shortage of wood and fuelwood has become a serious problem faced by the rural sector. ACIAR, in cooperation with RFD, attempted to alleviate this problem by conducting a series of research projects starting with identifying some Australian tree species suitable for fuelwood and agroforestry. *Eucalyptus* and *Acacia* were identified as being suitable for reforestation and for tree plantations as they can survive well in various conditions in Thailand. Although species of these two genera were introduced into Thailand long before the ACIAR projects started, projects FST/1983/020 and FST/1988/008 can be considered as the first attempt for in-depth research on *Eucalyptus* and *Acacia*. Subsequent research projects, including FST/1991/015, FST/1991/027, and FST/1993/010, focused on the specific issues of improving and sustaining productivity of *Eucalyptus*, physiology and genetic improvement of *Acacia auriculiformis*, and predicting tree growth for general regions and specific sites.

It can be concluded that substancial benefits are obtained from ACIAR-supported projects on forest management in Thailand, especially in the forms of producing valuable scientific outcomes, enhancing human resources, and transferring research findings in the first phase through to the subsequent research projects. Additionally, spillover effects to neighbouring countries, such as the Lao PDR, was an outstanding contribution of research project FST/1991/015 in particular. Although the potential economic impacts of the research findings can be foreseen, they are still not at the stage where they can be transferred to the private forestry sector and individual farmers as a longer time is needed for further evaluation and monitoring to derive reliable outcomes. At that stage, benefits transferred to end-users cannot be evaluated. However, in the meantime, a wide range of ongoing activities has been transferred to, and is under responsibility of, the RFD for further evaluation.

# 7 Acknowledgments

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# Impact Assessment of the ACIAR Project in Thailand on the Measurement of Nitrogen Fixation

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# Contents

# 1 Background

According to current farm management practice, nitrogen (N), phosphorus (P) and potassium (K) are the major elements required for good agricultural production, with nitrogen being the most important, along with other micronutrients. Thus, the value of nitrogen fertiliser and legumes in agricultural production has been widely promulgated. Consequently, the amount of nitrogen used in agricultural production has increased (Appendix A: Tables A1 and A2). However, nitrogen fertiliser has to be imported from abroad so the amount and the value of imported nitrogen fertiliser have increased gradually (Appendix A: Table A3).

A question that was raised during a discussion of agriculturists was ‘How could we avoid the incremental import of nitrogen fertiliser?’ This led to other questions such as, ‘How could we improve the nitrogen in soil and even recover the nitrogen from atmosphere?’ To answer these questions, many scientists and institutes in the country and abroad are studying biological nitrogen fixation instead of using chemical N-fertiliser, in order to reduce or even eliminate the imports of the costly chemical N-fertilisers.

In general, biological nitrogen fixation is a major contributor of nitrogen for agricultural production of plants, in particular grains, cereals and legumes. Levels of nitrogen in the soil are also very important in order for the soil to be suitable for legume production in terms of quantity and quality (Dr Benjavan Rerkasem, pers. comm.). To gain a better understanding of this, several projects on biological nitrogen fixation in soil for legume production have been developed and conducted under the collaboration of the ACIAR and Thai institutes such Chiang Mai University (CMU) and Khon Kaen University (KKU). The ACIAR project on nitrogen fixing is discussed in this paper.

# 2 Description of the ACIAR project on the measurement of nitrogen fixation

The ACIAR-supported activities on the measurement of nitrogen fixation consisted of three projects. The first project, PN/1983/005, was designed to develop and evaluate the procedures or methods to measure biological $N_2$ fixation, while in the second project, PN/1983/006, the ecological study of root nodule bacteria (*Rhizobium*) using legume inoculants was considered. The focus of project PN/1988/000, the successor to PN/1983/005, was on measurement methods of nitrogen fixation for selected legume production based on xylem solute and $^{15}N$ analysis.

The linkage between these ACIAR projects is shown in Figure 1.

## 2.1 ACIAR project PN/1983/005: Development and evaluation of methods to measure biological nitrogen fixation

The first project on the measurement of biological nitrogen fixation was PN/1983/005. This project involved a collaborative research program between the Faculty of Agriculture, Chiang Mai University, Thailand and the Botany Department, University of Western Australia, Australia. All participating scientists worked on this project for approximately 3 years from 1984 to 1988 and the cost of this project was A$199 770. The main activity in this research study was experiments associated with xylem sap technique, $^{15}N$ natural abundance or $^{15}N$ isotope dilution approaches to measure biological nitrogen fixation. This research procedure was demonstrated by comparing the growth with N-free nutrients with one of $^{15}N$ enrichment (concentration of mineral N). Furthermore, this research developed xylem solute methods for assessing the symbiotic dependence of ureide-exporters such as soybean, mungbean and cowpea, and an amide-exporter, peanut. This method could be done by verified $^{15}N$ natural abundance or residues under field conditions.

In Thailand, this series of experimental trials was conducted in the fields using two original target species (mungbean and soybean). The work was then extended to include other grains and forage legumes (ricebean) as well. This study was mainly initiated in order to evaluate the suitability of various reference plants besides the level of suitable of $N_2$ fixation. However, the experiments also determined the effect of moisture content, *Rhizobium* numbers, soil N levels and environmental conditions (such as temperature and moisture of soil) on $^{15}N$ of extractable mineral nitrogen (EMN) or reasonable natural abundance of $^{15}N$.

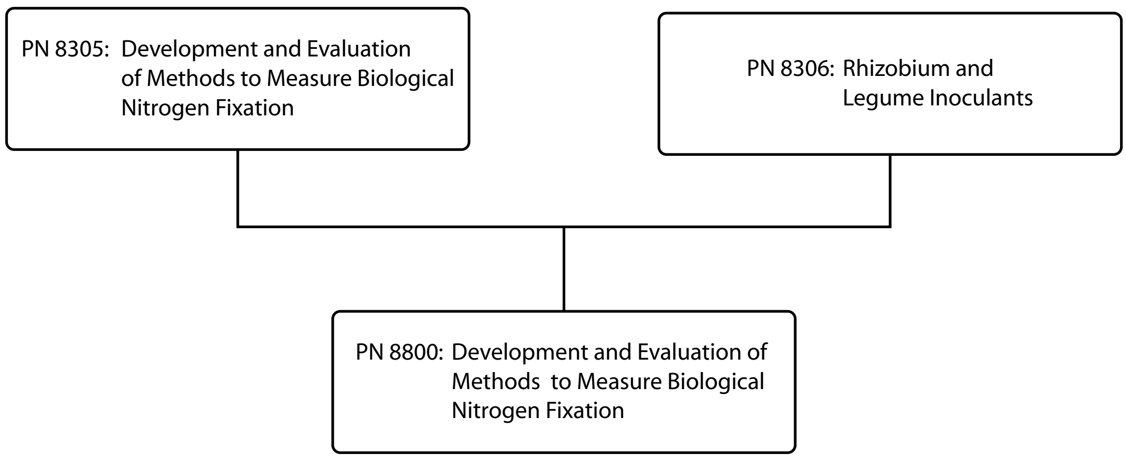


**Figure 1.**The linkage between the ACIAR project PN/1988/000 and the other ACIAR-supported legume projects

Project PN/1983/005 was very useful and the findings and results of this project could be applied to related legume production projects on improving food legumes, cereal-based cropping systems and soil fertility by using legume cropping systems. For example, this project was related or linked to various ACIAR projects such as the project on the study of *Rhizobium* ecology and inoculation (PN/1983/006), and the projects on soybean and mungbean food legume improvement (PN/1984/005), peanut improvement (PN/1984/019), and pigeon pea improvement (PN/1985/067). In addition, the method developed in this project was adapted and applied to other food legumes grown in Thailand and to other ACIAR projects such as PN/1988/000 (the $N_2$ fixation measurement project), which aimed to improve the quality and yields of these crops.

*The objective of PN/1983/005*

The objectives of this project were: (1) to develop suitable methods to measure nitrogen fixation; (2) to quantify the role of food legumes in cereal-based cropping systems (wheat and maize); (3) to identify the cereal–legume cropping sequences which require minimum N fertiliser inputs to maintain productivity; (4) to identify the possibility of constraints on $N_2$ fixation and legume production; (5) to evaluate the effect of the growing season on $N_2$ fixing capacities; (6) to evaluate and compare the capacity of local and elite US soybean germplasm to fix $N_2$ with existing indigenous or natural *Rhizobium* spp.; and (7) to evaluate symbiotic performance of food legumes in farmers' fields.

## 2.2 ACIAR project number PN/1983/006: Ecological studies of root nodule bacteria and the use of legume inoculants

This project was a collaboration of the New South Wales Department of Agriculture (NSWDA), the Chiang Mai University (CMU) and the Khon Kaen University (KKU). NSWDA implemented this project on the behalf of ACIAR while CMU and KKU conducted the same or similar project on behalf of the Royal Thai Government. This project started on 1 July 1984 and ended on 31 December 1987 and it cost A$317 990. The project was initiated to investigate the N-status of the soil by studying the suitable rhizobia in the soil and identifying the level of more suitable or highly effective rhizobia strains to legume root nodules. The growth of legumes, in general, depends on the level of N-status in the soil and the effective strains of rhizobia to nodulate their roots. However, the level of suitable rhizobia can be developed by the inoculation of the seed with the selected strains of *Rhizobium*. Therefore, this project tried to select a suitable strain of *Rhizobium* and developed the study of the ecology of *Rhizobium* by evaluating selected *Rhizobium* strains with selected hosts.

The field experiments developed in Khon Kaen were aimed at developing pasture improvement techniques by introducing the incorporation of pasture legume (*Stylosanthes* spp. and *Leucaena leucocephela*) into the agricultural systems to improve protein efficiency for ruminant animals and to maintain the fertility of soils. Moreover, the experiments were initiated to determine whether the nodules persist from season to season on both leucaena and stylosanthes species. If the nodules persisted, strain survival was estimated by measuring the new nodule population and the proportion of nodules formed by the inoculum was estimated. While the field experiments that were established in Chiang Mai concentrated on soybeans, they also tried to find out which of the *Rhizobium* strains were suitable inoculant strains. However, the strain of *Rhizobium* also depends on soil and environment conditions. Thus, the changes in the number of rhizobia were introduced into the number, type, and antibiotic resistance patterns of soil micro-flora. Consequently, the information derived from this project is suitable for providing guidelines for plant breeding and suggesting the selective strategies needed for seed inoculation to increase nitrogen fixation in the production cropping systems in Thailand as well as in other countries. Furthermore, the information from this project may be useful for suggesting how to increase $N_2$ fixation to increase soil fertility and generate high-protein products for animal and human consumption.

*The objective of PN/1983/006*

The main objectives of this project were: (1) to study *Rhizobium* in the soil and the rhizosphere of *Stylosanthes* spp. and *Leucaena leucocephela* and the effect of *Rhizobium* on both legume yields; (2) to identify the selected strains that persisted for the duration of the pasture; (3) to examine the compatibility of rhizobia that are native to Thailand; (4) to determine the need for inoculation and the desirability of selecting host germplasm for compatibility with the local *Rhizobium* population; (5) to understand the relationships of the soybean host germplasm and the rhizobia which nodulate them; (6) to improve the protein efficiency for ruminant animals; and (7) to increase the fertility of soils.

## 2.3 ACIAR project PN/1988/000: Measurement of nitrogen fixation in legume production systems

According to recent agricultural studies, the production of major food legumes grown in Thailand totals almost 1 million tons per year, with a value of production around 8000 million baht (Table 1). Among food legumes, mungbeans (green gram and black gram), soybeans and peanuts are the major food legumes grown in Thailand. The seed yield in food legume is dependent on adequate plant nutrients, especially nitrogen. Increased nitrogen leads to a better quality and quantity of legume seeds.

Food legumes contribute to human nutrition in terms of protein and, as mentioned earlier, crop protein yields of food legume can be improved by using fertiliser. However, there is a limitation to its use because of the high costs of fertiliser combined with the low per capita income of farmers and the farmers' lack of accessibility to credit facilities. Thus, in this situation, the opportunity to increase crop protein yields can only come from biological nitrogen fixation through legume $N_2$ fixing.

### *The objective of PN/1988/000*

The objectives of this project were: (1) to develop and investigate the methods for measuring $N_2$ fixation of selected food legumes based on $^{15}N$ isotope dilution and the analysis of specific N-solutes (xylem solute); (2) to apply these techniques for estimating $N_2$ fixation in various legume

**Table 1.** Food legumes: area, production, yields and farm values

| Crop year | Planted area ('000 rai) | Harvested area ('000 rai) | Production ('000 tonnes) | Yield/rai (kg/rai) | Farm value (million baht) |
|---|---|---|---|---|---|
| **(a) Total** | | | | | |
| 1993/94 | 5,350 | 4,912 | 880 | 572 | 7,451.0 |
| 1994/95 | 5,642 | 5,146 | 934 | 575 | 7,978.0 |
| 1995/96 | 4,702 | 4,404 | 767 | 579 | 7,624.0 |
| 1996/97 | 4,293 | 4,092 | 724 | 586 | 7,292.0 |
| 1997/98 | 3,890 | 3,695 | 664 | 593 | 7,441.4 |
| **(b) Mungbeans** | | | | | |
| 1993/94 | 2,147 | 1,966 | 231 | 118 | 2,180.6 |
| 1994/95 | 2,267 | 2,049 | 256 | 122 | 2,488.3 |
| 1995/96 | 2,197 | 2,080 | 234 | 113 | 2,780.0 |
| 1996/97 | 1,978 | 1,896 | 215 | 114 | 2,498.3 |
| 1997/98 | 1,804 | 1,709 | 200 | 117 | 2,252.0 |
| **(c) Soybeans** | | | | | |
| 1993/94 | 2,600 | 2,374 | 513 | 216 | 4,119.4 |
| 1994/95 | 2,724 | 2,471 | 528 | 213 | 4,129.0 |
| 1995/96 | 1,881 | 1,719 | 386 | 224 | 3,338.9 |
| 1996/97 | 1,696 | 1,597 | 359 | 225 | 3,119.7 |
| 1997/98 | 1,548 | 1,475 | 338 | 229 | 3,464.5 |
| **(d) Peanuts** | | | | | |
| 1993/94 | 603 | 572 | 136 | 238 | 1,150.6 |
| 1994/95 | 651 | 626 | 150 | 240 | 1,360.5 |
| 1995/96 | 624 | 605 | 147 | 242 | 1,505.3 |
| 1996/97 | 619 | 596 | 147 | 246 | 1,639.1 |
| 1997/98 | 538 | 511 | 126 | 247 | 1,724.9 |

**Sources:** OAE (1999)

production systems to identify the limitation of $N_2$ fixation or the reliability of nitrogen fixation; (3) to find the most effective method to maximise $N_2$ fixation to lead to more efficient management of $N_2$ fixing for the improvement of quality and quantity of food legume and developing the agricultural cropping systems; and (4) to maximise the benefit gained in high-protein food for human consumption.

From the relationships among these three projects, the impact assessment of the projects on the measurement of nitrogen fixation in legume production systems will be derived from project PN/1988/000 only. This means that the impact assessment of this project will combine the results from PN/1983/005 and PN/1983/006 with the result of PN/1988/000 and quantify the impact and benefits generated from these projects. In addition, the spillover effects of this project are quantified.

# 3 The research results and impacts

This section outlines the project results (or the new scientific knowledge generated), the impacts of research in terms of the transferability of the new information, and human capacity enhancement generated from the three nitrogen-fixation projects.

## 3.1 Description of results and impacts generated from the project

### *3.1.1 Scientific merit*

The scientific knowledge generated from project PN/1983/005 was useful in terms of developing techniques to measure biological $N_2$ fixation and applying those techniques to various field experiments to evaluate the relative merits of each of the techniques (e.g. applicable, tractable and affordable). Research results and technique development resulting from this program directly assisted various other projects such as PN/1984/005 (Soybean and mungbean improvement) and served as a model for other legume production and $N_2$ fixation work such as PN/1983/006 and PN/1988/000 in Thailand**.** The scientific information from PN/1983/006 indicated that the rhizobia generated biological nitrogen fixation in soil from the two-legume products, stylo (*Stylosanthes* spp.) and leucaena**.** The rhizosphere of nodulated legume roots will not only increase yields of legume products but it will also increase protein-levels in food for human and animal consumption. Project PN/1988/000 generated scientific knowledge about the role of food legumes to improve the productivity of legume-based cropping systems. This project also indicated the minimum N inputs needed to maintain the efficiency and productivity of food legume production.

From these three projects, a large amount of new information on legume production and management has been produced. The results also indicated that the developmental methods applied in the field to measure the biological nitrogen fixation generated from grain and forage legumes ranked highly compared with attempts of the research concerned with symbiotic nitrogen fixation. Results from these research projects also showed that grain and forage legumes make substantial contributions to the nitrogen economies of agricultural systems and can substitute for costly nitrogen fertilisers. Therefore, there is no doubt that these research projects provided very useful scientific knowledge in this area. This is also supported by the list of material articles and published papers provided in Appendix B. Because of the scientific knowledge generated in these projects, the scientists are now in a much better position to make informed judgments about the suitability of methods for quantifying biological $N_2$ fixation in different legume production systems. Moreover, the scientists have more confidence to work with the natural $^{15}N$ abundance and specific translocation techniques.

### *3.1.2 Benefits*

The project results could provide benefits in three categories: (1) in terms of the impact on productivity and efficiency of legume production; (2) the transferability of project knowledge to other related projects and other countries; and (3) enhancement of human capacity.

*Impact on productivity and the efficiency of legume production systems*

As mentioned earlier, the legumes will increase soil fertility by increasing N-input and the results of these projects ensure more efficient management of the role of legume-base cropping systems. The results of these projects generated not only agronomic benefits but also economic benefits. The biological $N_2$ fixation generates economic benefits, which can be quantified as the value of an equivalent amount of N fertiliser. In addition, results from these three research projects also indicated that grain and forage legumes can substantially contribute to the nitrogen economies of agricultural systems. The legume $N_2$ fixation could be used to generate biological nitrogen to substitute for costly nitrogen fertilisers. As mentioned earlier, N-input will increase the quantity and improve the quality of legume production. Thus, the results of these research projects will impact on more than just the productivity levels. Furthermore, the results also provide a guideline for the efficiency of $N_2$ fixation and for selecting the most effective rhizobial strains for enhanced $N_2$-fixation potential and for indicating the capacity of legume species that are capable of fixing $N_2$.

As a result of these projects, nitrogen fertiliser use can potentially be reduced and the quality and quantity of high protein food for human consumption can potentially be increased. However, the findings of this project have not been adopted directly by the farmers, because the farmers knew about the nitrogen-fixing aspects of legumes before the ACIAR project started. Furthermore, they will only grow them if the return for the legume itself is profitable. They are not concerned about the soil-fertility aspects of the legumes. Moreover, they would rather use nitrogen fertilisers and grow a more profitable crop than legumes. Therefore, there were no tangible economic benefits (Dr Benjavan Rerkasem, pers. comm. 10 March 1998). In addition, only the researchers involved have used the techniques developed from this project. Therefore, this project is very useful at the research level, while the transfer of this knowledge to the farmers and other end-users will need more attention and effort from all of the involved institutes, including the Department of Agricultural Extension (as mentioned by the project leader, Dr Benjavan Rerkasem).

Moreover, there were several other important benefits, which ultimately accrued from using the technology developed in these projects, particularly to Thailand. The projects also enable scientists to accurately assess the input of nitrogen from grain and forage legumes under a wide range of environmental and soil conditions. In addition, the programs were designed to select various species, varieties and genotypes of legumes which were efficient in $N_2$ fixation. The techniques used in this project also provided the means for $N_2$ fixation and the results of this project will reduce the need for expensive $N_2$ fertiliser as well as maintaining or even improving the protein nutrition of the population through the consumption of grain legumes with increased nitrogen fixation.

From the previous statements, it can be concluded that the research results will benefit the farmers or the consumers by providing a rich dietary source of protein, increasing farm income-generating potential by reducing cost of nitrogen fertiliser and enriching the soil with organic nitrogen (reducing the amount of N inputs).

*Scientific knowledge transferability*

The results from PN/1983/005, PN/1983/006 and PN/1988/000, such as the techniques to measure $N_2$ fixation and the effective *Rhizobium* strain for legume $N_2$ fixation, have been adequately transferred to scientists and institutes in Thailand and in the other countries through scientific literature, scientific meetings and seminars (see Appendix B). Moreover, the demonstrations and hands-on experience provided an effective and efficient way for the scientists to achieve a level of skill with the nitrogen isotope. The research results have been reported to other scientists who are working on related projects, especially those who are concerned with legume research. Furthermore, the results from this project have been promulgated through scientific meetings to scientists and extension department officers and have also been provided through a training course that uses the ACIAR techniques to measure N fixing for the technicians.

*Enhancement of human capacity*

Through involvement in these research projects, the project leaders, the senior scientists and the young research assistants, in particular, could improve and enhance their knowledge and skills in terms of applying the mechanisms to measure nitrogen fixation. They also could identify adequate N-fixing in various species of legumes. Moreover, they benefit through participation in the short-term and long-term training programs, workshops or conferences held by the domestic and international institutes involved the research project (for example, one researcher from CMU trained for one month in Australia).

Another benefit from these projects was that one masters student got his degree by using the knowledge from project PN/1983/005, while three masters students got their degrees from applying the findings and techniques of project PN/1983/006 to their dissertations. In addition, one undergraduate student got his BSc from using part of the research results in an independent study. These three projects helped them to understand the contribution of biological $N_2$ fixation by legume production systems to agricultural community.

# 4 Conclusion and recommendation

The research undertaken in the three projects resulted in the generation of scientific information, the development of new technology and the enhancement of the research capacity of all the researchers and scientists involved in the project. In addition, the information generated from this project is likely to be used by other researchers working on related legume projects in Thailand and abroad. The management of nitrogen in agriculture includes the management of biological $N_2$ fixation and, in Thailand, an understanding of the influence of soil and crop management practices on $N_2$ fixation will enhance the development of effective food legume production systems without the unnecessary use of expensive nitrogen fertiliser.

The practice of biological $N_2$ fixation has not been adopted directly by farmers and the farmers cannot let go of the fertiliser-application approach, as they have more faith in the fertiliser companies than the advice of scientists. Thus, special efforts are required to transfer the research results to the end-users to make the research more profitable and applicable. First, the methods need to be clearly described in sufficient detail so they can be followed by the farmers. A series of pamphlets or booklets should be freely available for them. Second, demonstrations of the experimental program should be provided directly to the farmers because it is the most effective way of getting the end-users to use this technique. Third, effective extension efforts to other countries should also include a collaborative field experiment in those countries. Finally, extension to other scientists and institutes or even to the end-users or farmers within a country should be the responsibility of the research scientists and the extension-department officers in that country. Therefore, the choice of institutes and collaborating scientists, and the extension department officers is very important when considering the funding source.

Although the ultimate beneficiaries of the experimental program should be the farmers, initially it will be the researchers. Research institutions in the host countries will also benefit from the proposed research. It is likely that the knowledge, expertise and technologies developed in the collaborative project will spread within each organisation and related institutes and those researchers directly involved in the experimental program. The collaboration with other ACIAR legume projects will spread the program's expertise to many research institutes and lead to an upgrading of their research capabilities. In the long term, this will result in a more effective and widespread exploitation of the legume resource throughout the region.

# 5 Acknowledgments

In the process of finishing this paper, the author would like to express my gratitude thanks to Dr Benjavan Rerkasem, the project leader for project PN/1988/000, for her support and giving her valuable time for my interviews. Moreover, she provided and contributed the related and published documents for updating my papers. Without her help, this paper may not have been finished or even initiated. My grateful thanks are also extended to my team leader for the economic evaluation of ACIAR projects, Assoc. Prof. Somporn Isavilanonda and my colleagues, Dr Chapika Sangkapitux, Dr Suwanna Praneetvatakul, and Charuk Singhapreecha for their comments and supports during the research preparation. Grateful thanks are also extended to Australian Centre for International Agricultural Research (ACIAR) for financial support. Lastly I would like to thank my friends Dolaya Yimsaard and Ronald Banner for helping me edit this paper.

# 6 References

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# 7 Appendixes

## Appendix A. Statistics on fertiliser use in Thailand

**Table A1**. Agricultural used of chemical fertilisers, 1986–1995 (tonnes)

| Year | Total mixing chemical fertiliser | Plant nutrients | | |
|---|---|---|---|---|
| | | N | $P_2O_5$ | $K_2O$ |
| 1986 | 1,350,000 | 308,501 | 132,502 | 70,326 |
| 1987 | 1,548,765 | 342,784 | 148,344 | 96,245 |
| 1988 | 1,992,633 | 439,720 | 200,833 | 137,456 |
| 1989 | 2,297,733 | 494,923 | 188,823 | 117,793 |
| 1990 | 2,648,910 | 576,517 | 318,337 | 148,937 |
| 1991 | 2,487,082 | 525,825 | 272,318 | 164,016 |
| 1992 | 2,806,784 | 600,176 | 325,713 | 191,855 |
| 1993 | 3,195,576 | 769,095 | 430,233 | 250,147 |
| 1994 | 3,387,804 | 720,211 | 412,273 | 263,434 |
| 1995 | 3,313,313 | 663,345 | 412,159 | 288,949 |

**Source:** Bureau of Agricultural Economic Research

**Table A2**. Local mixing capacities of chemical fertiliser, 1986–1995 (tonnes)

| Year | Total mixing[a] chemical fertiliser by private manufacturers | Plant nutrients | | |
|---|---|---|---|---|
| | | N | $P_2O_5$ | $K_2O$ |
| 1986 | 287,000 | 44,828 | 32,851 | 21,776 |
| 1987 | 351,900 | 50,070 | 38,690 | 30,850 |
| 1988 | 393,722 | 61,264 | 36,676 | 35,392 |
| 1989 | 498,970 | 79,735 | 68,935 | 28,708 |
| 1990 | 439,890 | 69,080 | 47,885 | 41,760 |
| 1991 | 399,875 | 62,890 | 40,455 | 36,116 |
| 1992 | 440,085 | 64,386 | 49,790 | 42,920 |
| 1993 | 385,250 | 58,716 | 39,435 | 35,497 |
| 1994 | 422,495 | 63,953 | 47,122 | 35,043 |
| 1995 | 564,307 | 89,907 | 68,458 | 48,662 |

[a] Excludes production of crystallised foliage fertiliser and liquid fertiliser.
**Source:** Bureau of Agricultural Economic Research

**Table A3**. Quantity (tonnes) and value ('000 baht) of Fertiliser, 1994–1998

| Items | 1994 | | 1995 | | 1996 | | 1997 | | 1998 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value | Quantity | Value | Quantity | Value |
| Total | 3,017,867 | 13,549,811 | 3,160,986 | 15,812,074 | 3,439,999 | 18,242,196 | 2,990,950 | 16,933,863 | 2,873,514 | 17,851,881 |
| Nitrogen fertiliser | 947,446 | 3,285,598 | 1,104,231 | 4,600,872 | 1,170,058 | 5,486,946 | 1,234,139 | 5,796,736 | 1,497,264 | 6,891,005 |
| Phosphorus fertiliser | 10,835 | 60,356 | 6,507 | 36,666 | 556 | 4,416 | 5,059 | 30,698 | 3,936 | 30,869 |
| Potassium fertiliser | 136,068 | 507,932 | 198,491 | 737,011 | 218,270 | 841,205 | 247,093 | 1,124,567 | 247,324 | 1,494,963 |
| Nitrogen and phosphorus fertiliser | 726,683 | 3,271,665 | 499,511 | 2,699,563 | 832,639 | 4,287,731 | 438,704 | 2,436,966 | 349,103 | 2,064,127 |
| Nitrogen phosphorus and potassium fertiliser | 1,062,550 | 5,566,185 | 1,111,810 | 6,158,755 | 911,619 | 5,597,735 | 822,290 | 5,837,670 | 345,913 | 3,048,319 |
| Other fertiliser | 134,275 | 858,075 | 240,436 | 1,579,207 | 306,857 | 2,024,163 | 234,665 | 1,707,226 | 429,974 | 4,322,598 |

**Source:** Department of Customs

**Table A4.** Quantity (tonnes) and value ('000 baht) of legume exports and imports, 1994–1998

| Year | Mungbean | | Soybean | | Peanut | |
|---|---|---|---|---|---|---|
| | Quantity | Value | Quantity | Value | Quantity | Value |
| **Exports** | | | | | | |
| 1994 | 57,537 | 649,381 | 312 | 3,921 | 3,433 | 27,663 |
| 1995 | 24,922 | 386,610 | 279 | 4,152 | 3,579 | 28,112 |
| 1996 | 18,798 | 349,224 | 221 | 2,850 | 2,266 | 16,780 |
| 1997 | 15,650 | 276,764 | 329 | 5,953 | 1,447 | 11,938 |
| 1998 | 18,908 | 367,976 | 797 | 8,672 | 1,009 | 9,444 |
| **Imports** | | | | | | |
| 1994 | not available | not available | 97,998 | 703,535 | 346 | 2,560 |
| 1995 | not available | not available | 203,156 | 1,506,864 | 3,535 | 28,838 |
| 1996 | not available | not available | 418,811 | 3,421,303 | 5,922 | 44,929 |
| 1997 | not available | not available | 869,397 | 8,613,953 | 4,309 | 36,267 |
| 1998 | not available | not available | 687,255 | 7,141,997 | 2,858 | 37,459 |

**Source:** Department of Customs

# Appendix B

## Project publications

B. Rerkasem, K. Rerkasem and F. J. Bergersen (1985) Yield and nitrogen fixation advantage in corn-ricebean intercrop in Proceeding 10th North American Rhizobium Conference, University of Hawaii pp. 72.

K. Rerkasem, B. Rerkasem and S. Wongwatana (1988) Competition between legume/non-legume intercrops in ACIAR Proceeding No. 18 "Food Legume Improvement for Asian Farming System," E.S. Wallis and D.E. Byth (editors) pp. 278.

B. Rerkasem, K. Rerkasem, M.B. Peoples, D.F. Herridge and F.J. Bergersen Measurement of $N_2$ fixation in maize-ricebean intercrops in Plant and Soil.

M.B. Peoples, A.W. Faizah, B. Rerkasem and D.F. Herridge (1989) Methods for Evaluating Nitrogen Fixation by Nodulated Legumes in the Field. ACIAR Monograph No. 11. ACIAR. Canberra. 76p.

Ying Jefing, D.F. Herridage, M.B. Peoples and B. Rerkasem (1992) Effects of N fertilization on $N_2$ fixation and N balances of soybean grown after lowland rice in Plant and soil.147; p 235–242

## Activities related to PN8306

The workshop provided in the Department of Agriculture at KKU by utilising the knowledge generated from PN/1983/006.

The project on pasture improvement funded by AIDAB by applying stylo in the improvement of pasture

## PN/1983/006 publications

Homchan, Jackrit (1989), "Responses to inoculation with root nodule bacteria by *Leuceana leucocephala* in soils of northeast Thailand" Tropical Grasslands Vol. 23. No2 June 1989 p 92–97.

— (1989), "Responses to inoculation with root nodule bacteria by *Stylosanthes humilis* and *S. hamata* in soils of northeast Thailand Tropical Grasslands Vol. 23. No2, June 1989 p 98–108.

Journal: Plant and Soil in 1995 and proceeding paper in the meeting at Malaysia

## PN/1983/006 conferences and training

In 1987 there was a presentation of this project paper at the conference in Indonesia and another conference held in Malaysia

Two training courses in Khon Khan province for bankers from Agricultural and Cooperatives Bank (about 100–120 persons)

Two training courses in Khon Khan for livestock farmers about 50–70 persons and 2 seminars (in Chiang Mai and Phisanulok)

# An Economic Evaluation of an ACIAR Project on the Use of Inhibitors of Volatilisation and Nitrification to Improve Nitrogen Use by Crops in Thailand

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# Contents

# 1 Introduction and description of the project

There were many projects which have been undertaken and supported by the Australian Centre for International Agricultural Research (ACIAR) on preventing a loss in fertiliser efficiency or on the improvement of production yields. In this paper, an evaluation of a scientific project using inhibitors to improve nitrogen fertiliser efficiency is undertaken. The paper consists of three sections. This first section provides an introduction to, and description of, the project, while the second section supplies detailed information about the outcomes and impact of the project. The conclusion and some recommendations are provided in the final section.

Nitrogen is a major plant nutrient, which has a big impact on plant growth and the improvement of plant production. Since nitrogen in the soil may not sufficient for the plant's needs, a chemical or organic fertiliser should be applied to increase the fertility of the soil in and, hence, to increase the production to serve the people needs.

In the Asian region, rice is a major food and cash crop in agriculture. To increase rice production, fertiliser sources, the method of fertiliser use, rice planting and rice species need to be considered. In particular, the source of the fertiliser is a major factor that can increase the efficiency of rice production. In Asia, nitrogen fertilisers are generally used in rice production. The most common form of nitrogen fertiliser is urea because it can generate nitrogen nutrient up to 46%, and it has a lower cost per unit than other sources of nitrogen fertiliser (Stangel and Harris 1987). The amount of urea used in Asia is about 75% of the whole urea production, but the efficiency of urea fertiliser is still low particularly in rice production. By applying urea in rice fields under flooded water, it was found out that the efficiency of nitrogen fertiliser utilisation in rice was reduced and N-uptake by rice plant is only 30% to 40% of the total amount of nitrogen fertiliser applied.

There is a question about how nitrogen fertiliser can be used more efficiently to improve agricultural production, especially rice, which is a major cash crop. Dr Pornpimol Chaiwanakupt, a senior research scientist from the Department of Agriculture, Thailand, said that the efficient use of nitrogen fertiliser would have a major positive impact on rice production. Therefore, technologies that lead to a reduction in nitrogen loss through volatilisation of ammonia gas, nitrification (nitrogen oxide) and denitrification ($N_2$), including the loss of nitrogen by leaching and running water, would result in an increase in the nutrients which crops need, and, consequently, an increase in crop production. In response to this, research on ways to improve the efficiency of nitrogen fertiliser application through the use of inhibitors for reducing the nitrogen-content fertiliser loss has been conducted. This paper is concerned only about using the inhibitors to improve the efficiency of urea fertiliser in lowland rice soils.

The collaborative research project (LWR2/1989/040) on inhibitors to improve nitrogen use in Thailand started in 1991 and ended in 1995 and was undertaken by the Department of Agriculture (DOA), Thailand; Commonwealth Science and Industrial Research Organisation (CSIRO), Canberra, Australia; the University of Queensland; and the Fujian Academy of Agricultural Sciences, Fujian Province, People's Republic of China.

The main objective of this project was to study methods to increase the efficiency of urea fertiliser use in lowland rice soil by reducing nitrogen loss through nitrogen volatilisation in terms of ammonia. The method of using urease and nitrification inhibitors to prevent the nitrogen volatilisation had been studied on rice paddy fields in Thailand. There were many experiments using different kinds and different quantities of urease and nitrification inhibitors. In addition, the experiments on the other inhibitors besides the urease and nitrification inhibitors has been tested as well. However, it seems that urease and nitrification inhibitors are the most efficient inhibitors to reduce nitrogen volatilisation as ammonia gas.

Initially, a tracer technique to measure nitrogen balance was recommended by experts from the United States under an International Atomic Energy Agency (IAEA) project. This technique was used to measure nitrogen balance in soils and in plant systems in Thailand. The International Rice

Research Institute (IRRI) also networked with the International Fertilizer Development Center (IFDC) and the DOA on this subject. Then the ACIAR project introduced instruments to measure the emission of ammonia gas from flooded rice fields by a mass balance micrometeorological technique (Denmead, 1983). Stable isotope ratio mass-spectrometer was used to measure $^{15}N$-balance in this study. In this research, three experiments were established in paddy fields at the Rice Research Station at the Supanburi Province with Fluvic tropaquept soil type and Supanburi 90. In these three experiments, technological methods developed by ACIAR were used to measure ammonia volatilisation and the balance of nitrogen.

# 2 The research results and impacts

This section consists of the research outcomes of the project, starting with a description of results or new scientific knowledge generation, then outlining the impacts of research in terms of transferability of new information and human capacity enhancement generated from the project.

## 2.1 Description of results or new information generated by the project

In this scientific study, the first experiment was conducted in 1991 by using one of the urease inhibitors such as N-(n-butyl) thiophosphorictri-amide (NBPT), to prevent the process of hydrolysis of urea in terms of nitrogen volatilisation (for more information see Phongpan and Byrnes 1990). In this experiment, NBPT was used alone or mixed with other urease inhibitors. In addition, tyrbutryn algicide was used to reduce the pH level in flooded water in rice fields and to prevent the process of nitrification (or prevent $NH_3$ oxidation or nitrogen oxide) to keep ammonia in the soil for plant uptake before it is lost in the form of nitrogen gas. The results of this experiment showed that mixing urease inhibitors such as NBPT and algicide with urea significantly reduced nitrogen loss (down to 7%) and increased rice production by 31% (or 746 kg/rai[2]).

The results of the second experiment, conducted in 1992, using urease inhibitors such as phenylphosphorodiamidate (PPD) and NBPT indicated that using *both* PPD and NBPT urease inhibitors was more efficient in terms of reduced ammonia loss than using PPD *or* NBPT *alone*. The use of both PPD and NBPT urease inhibitors reduced ammonia loss from 15% to 3% of nitrogen application and increased the yield of rice on the average by 14% from 576 kg/rai to 656 kg/rai (Chaiwanakupt et al., 1996).

The results of the third experiment, which used cyclohexylphosphorictriamide (CHPT), oxygen analogue NBPT (NBPTO) and nitrification inhibitors such as phenylacetylene (PA) and algal inhibitor (using copper sulfate and terbutryn) to prevent the loss of nitrogen in the rice fields and to increase rice production, showed that CHPT has a greater impact on the reduction of nitrogen loss than does NBPTO. The use of NBPTO or CHPT with nitrification inhibitors such as phenylacetylene (PA) and an algal inhibitor such as algicide will increase N-uptake of rice plants from the fertiliser application. Consequently, the rice seeds will receive two to three times the N-uptake from the urea fertiliser and the yield of rice can increase significantly.

These experiments were carried out under various fertiliser-use scenarios, such as ‘incorporating’ by applying the fertiliser before transplanting and during panicle initiation or germination by broadcasting fertiliser in puddled soil. The results showed that, in theory, the incorporating technique was more efficient in terms of reduced nitrogen loss than was the broadcasting technique but the incorporating technique requires more workers and is more costly.

Besides the many inhibitors, such as urease inhibitors, nitrification inhibitors and algal inhibitors, there are other factors that affect the efficiency of urea fertiliser use in rice field, including the weather and the variety of rice. However, the study results indicated that the inhibitors, particularly the urease inhibitors, have the greatest impact on N-uptake by rice plants and, hence, on rice production.

The results of this study show that more efficient fertiliser use is possible and will lead to improved rice production, reduced costs of production for rice and also reduced air pollution from ammonia gas generated from nitrogen fertiliser (urea) (although the amount of the gas is relatively insignificant). In addition, the study results could be used by the fertiliser industry to produce slow-release N fertiliser by using chemical urease and nitrification inhibitors generated from the project study as components, or by using wax-coated nitrogen fertiliser etc.

2. 1 rai = 1600 $m^2$.

## 2.2 The research impacts generated from the project

This section discusses the transferability of the scientific knowledge, the enhancement of human capacity, the potential economic impacts, and other impacts of the project.

### *2.2.1 Scientific knowledge transferability*

The scientific knowledge gained from project LWR2/1989/040 is primarily of value to the scientific community because scientific expertise is required to apply the technique to capture and measure ammonia gas. The information on the research results has been reported to other scientists who are working on related projects, especially those concerned with rice research. Furthermore, the results from the project have been promoted through scientific meetings to scientists and extension officers. They have also been provided to technicians in a training course on the use of ACIAR techniques to capture and measure ammonia loss (Dr Pornpimol Chaiwanakupt, pers. comm.). In addition, the research findings have been transferred to the fertiliser industries to enable them to produce a urea-based fertiliser with a slow-release nitrogen.

Publications from project LWR2/1989/040 are enumerated in Table 1. One of the Thai papers was published in the *Journal of Biological Fertilizer Soils*, one in the *Plant and Soil* journal, two in the *Journal of Fertilizer Research*, and a further two papers in the *Thai Agricultural Research Journal*. Several papers were also published in foreign language journals: one in the *Proceedings of Plant Nutrition Colloquium*, Perth and another in the *Malaysian Society of Soil Science*, Kuala Lumpur. In addition, there were two workshop papers: one at the seminar on the 'Utilization of Nuclear Technology in Agriculture' held in Thailand and another at the 'International Plant Nutrient Colloquium' workshop held in Perth. Six conference papers were also presented including three contributed papers (unpublished) presented at a rice conference and one at a conference on efficiency improvements in food production and agriculture using nuclear technology in Thailand, while the other three conference papers were published in English and presented in Perth, Kuala Lumpur and Thailand.

### *2.2.2 Enhancement of human capacity*

The knowledge and skills of the project leader, the senior scientists, and the young research assistants in particular, have increased as a result of their involvement on this research project. The increase in the knowledge and skills has largely revolved around the mechanisms of nitrogen loss and the application of the specific techniques used in monitoring the nitrogen loss. Moreover, they benefited through their participation in the training programs, workshops or conferences held by the institutes involved in the research project, both domestically and aboard.

In addition, one Ph.D student, two masters students and one bachelors student gained valuable knowledge from the findings and techniques of the scientific project. By using part of the research findings in their dissertations or independent studies, this knowledge helped them to get their degrees. The project has also helped these students to understand and contribute to the agricultural community. In Table 2, the number of project participants and the trainees that enhanced their human capacity or skills through the research project or training programs is summarised.

**Table 1.** Summary of the publication outcomes of ACIAR Project LWR2/1989/040

| Published books | Published journal papers | | Conference papers | | Workshop papers | | Total |
|---|---|---|---|---|---|---|---|
| | Thai | Foreign | Thai | Foreign | Thai | Foreign | |
| - | 6 | 2 | 3 | 3 | 1 | 1 | 16 |

**Sources:** Suzuki, P. et al., 1996; Chaiwanakupt, P. 1999

**Table 2.** The summary of human capacity build-up

| Project participants | Members with enhanced skill | Short-term training in Australia |
|---|---|---|
| 10 | Total 4: 1 Ph.D., 2 MS and 1 BS. | 3 |

**Sources:** Suzuki, P. et al., 1996, confirmed by Chaiwanakupt, P. 1999

## 2.3 The potential economic impacts of research finding in term of production improvement

Without the research, the quantity of the rice production could remain constant or even fall and the amount of urea fertiliser might be overused or misused. Therefore, a potential economic impact exists, specifically in terms of improving rice yields and reducing fertiliser costs.

From the study, the application of urea alone caused the rice production to increase from 17.1 tonnes/rai to 22.3 tonnes/rai, while the single or multiple applications of nitrogen inhibitors, either alone or mixed with other urease inhibitors, could significantly increase rice production (see Table 3). The results of this experiment showed that the use of urea mixed with urease inhibitors, such as NBPT and algicide, compared with using urea alone can significantly reduce nitrogen loss to only 7% and increase rice production by 31% (or 746 kg/rai). This treatment appeared to be the most efficient method in terms of increased rice production and reduced nitrogen loss.

If the results of the scientific research could be applied at the farm-level, all else being equal, the farmers' income would increase and the cost of crop production would fall. However, the findings of this project have not been adopted by the farmers (as mentioned by the project leader, Dr Pornpimol Chaiwanakupt), thus the adoption rate, or the value of net benefits, could not be quantified. The reason why there was no community impact was because the finished product of slow-release nitrogen fertiliser is not on sale as it is still in the process of being tested in the field. In addition, the process of producing a compound fertiliser mixing urea with the inhibitors is too complicated for farmers. Thus, to transfer the technical knowledge to the farmers requires the fertiliser industries, especially the ones in Thailand, to produce fertiliser mixed with the inhibitors and to get the finished fertiliser product at a low cost. Then they should supply the final product of slow-release nitrogen fertiliser to the market for commercial use (Dr Pornpimol Chaiwanakupt, pers. comm. 1998).

## 2.4 Other impacts

Scientific equipment such as three Ammonia meters, one personal computer and glassware have been left at the Department of Agriculture and are presently available for related research and for bachelors and masters students to use in their studies. The results of the research on inhibitors to reduce ammonia and nitrogen oxide have been transferred to the fertiliser industries and to the IFDC, which are producing the finishing products of slow nitrogen-release fertiliser and testing in the field before supplying the final products in the market. Furthermore, a fertiliser company from France has contracted through ACIAR to produce inhibitors and slow-release nitrogen fertiliser. While there are a few domestic fertiliser companies in

**Table 3.** Effect of inhibitor treatments on nitrogen loss and grain yield of flooded rice at Suphanburi (wet season 1991)

| Treatment | Nitrogen loss (% applied N) | | Grain yield (kg./rai) | |
|---|---|---|---|---|
| | – Algicide | + Algicide | – Algicide | + Algicide |
| Control | 19.5 | 10.4 | 571.2 | 640.0 |
| NBPT | 9.3 | 7.6 | 675.2 | 619.2 |
| NBPT repeated[a] | 9.8 | – | 462.4 | – |
| Mixed inhibitors[b] | 9.1 | 7.0 | 667.2 | 745.6 |
| Calcium carbide ($CaC_2$) | 15.2 | 12.4 | 649.6 | 644.8 |
| NBPT + $CaC_2$ | 15.8 | 14.7 | 576.0 | 676.8 |
| Mixed inhibitors + $CaC_2$ | 13.8 | 13.1 | 625.6 | 628.8 |
| LSD (p = 0.05) | | 4.3 | | 97.6 |

Note: All treatments listed including control were applied 12 kg. N/rai

[a] Use NBPT more than one time

[b] Mixed inhibitor such as NBPT, PPD, DAPB, and AHA

**Source:** Chaiwanakupt, P. et al. (1996)

Thailand, they are not interested in the new product, possibly because of one or more of the following reasons:

1. The cost of testing and registration is very high.
2. The company profits may fall because they will sell less fertiliser.
3. The degree of competition is very limited in Thailand, as there are only a few domestic companies and imported fertilisers are very expensive, therefore, the incentive to adopt the latest technology is limited.
4. It is expected that the companies will develop and market the new slow-release nitrogen fertiliser but the cost of the fertiliser may be too high for the Thai farmers.

Dr Pornpimol Chaiwanakupt also mentioned that, in addition to rice production, the results of project LWR2/1989/040 have been transferred to the palm and rubber-growing industries for seedling production. Palm oil, which is grown in southern Thailand is becoming quite profitable and so is a popular crop with the Thai farmers in that region. Furthermore, a Malaysian company is paying the Thai farmers to grow the palm tree. Since the farmers who produce palm and rubber seedlings can get a higher price from selling their seedlings than from selling rice, they are more able to pay for an imported inhibitor.

The knowledge generated from this project could also be used to reduce the global emissions of nitrogen oxide, which can have a negative impact on the environment. Furthermore, the knowledge generated by this project has been transferred to other countries through the linkage between the project leader and United States Department of Agriculture (USDA) and the Asian Productivity Organization.

# 3 Conclusion and recommendation

This report deals with the evaluation of an ACIAR-supported project on use of inhibitors to improve the efficiency of nitrogen or urea fertiliser. From this project, many effective inhibitors have been identified and tested in fields with different environments and using different methods of fertiliser application in rice fields. The results showed that the effectiveness of inhibitors depends upon field condition and crop species.

There is evidence that this research generated new technology and scientific information and enhanced the research capacity of all of the involved researchers. In addition, the information generated from this project is likely to be used by other researchers in Thailand and abroad. Linkages and collaboration between the project leader and the Departments of Agriculture in the United States and Japan have formed. Despite these benefits, the results of the project are not being used by farmers or other end users (Dr Pornpimol Chaiwanakupt, pers. comm. 1999). Thus, an economic evaluation of the project LWR2/1989/040 has not been undertaken in Thailand.

To make the research more profitable and applicable, more work should be done on transferring the project results to fertiliser industries so they will produce slow-release nitrogen fertilisers for commercial use at a low cost. The process of producing urea fertiliser with inhibitors should be easily applied and the scientific knowledge generated from this project should be readily provided and introduced to the end-users or the farmers. Furthermore, the foundation of preventing nitrogen losses from urea or nitrogen fertilisers applies to other crops. These benefits should be made known so to increase the efficiency of fertiliser use and reduce environmental contamination in the future.

# 4 Acknowledgements

In the process of finishing this paper, the author would like to express gratitude to the project leaders and scientists of ACIAR projects such as Dr Pornpimol Chaiwanakupt for sharing the information and her valuable time for the preparation of this report. Without her help, this paper may not have eventuated. My special thanks also extend to Assoc. Prof. Somporn Isavilanonda, the team leader for the economic evaluation of ACIAR projects, who gave me an opportunity to handle this paper. My grateful thanks are also to my colleagues, Dr Chapika Sangkapitux, Dr Suwanana Praneetvatakul, and Charuk Singhapreecha for their comments and support during the research preparation. Grateful thanks are also extended to the Australian Centre for International Agricultural Research (ACIAR) for financial support. Last but not least I would like to thanks my friends Dolaya Yimsaard and Ronald Banner for helping me edit this paper.

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# An Assessment of the Impact of the ACIAR Project on Nutrient Management in Rainfed Cropping Systems in Thailand

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# Contents

# 1 Background

To maintain world food supply, agricultural production needs to be increased by one or more of the following ways: (1) expanding the cultivable land; (2) reducing fallow periods; (3) expansion into agricultural areas with soils which are suitable for crop production (which could not continue to happen in the long term); and/or (4) improving the quality of soil by increasing soil organic matter (SOM). To increase the content of organic matter, which provides a reservoir of plant nutrients and improves the soil's nutrients and moisture in the long term, there is a need to develop and implement appropriate management practices for crop residues on cropping systems. The significant benefits from using crop residues can be described as: (1) maintaining soil fertility; (2) improving crop production; and (3) reducing significant land degradation and soil erosion.

The appropriate systems of plant nutrient management will be applied to sustain at least the minimum nutrients and soil organic matter levels for production growth. Thus, the development of such plant nutrient management systems must consider the inputs of organic matter with or without small amounts of mineral fertiliser, the turnover of the organic matter and the potential channels for nutrient removal and residue removal, in addition to the management of soil erosion and leaching. Generally, soil fertility for agriculture depends on the amount of total organic matter (TOM) which includes labile carbon and non-labile carbon of organic matter. Hence, labile organic matter can be increased or decreased using cropping management (Swift et al., 1991) and agricultural systems cannot be sustained unless the organic matter inputs are appropriately managed to improve the organic matter breakdown (Ingram and Swift, 1989; Woomer and Ingram, 1990).

The agricultural system will be sustainable if the production is sustained at a sufficient level. Production will be sustained if the various resources are conserved. The sustainability of agriculture depends on the effect of various factors such as the use of fertiliser, the incidence of pests and diseases, environment conditions and the weather. Sanchez et al. (1989) indicated that SOM is a major resource because it is where plant nutrients are stored and it relates to soil fertility. Therefore, the higher the amount of SOM, the higher the soil fertility will be. However, the mineralisation process of organic matter will cause a loss of soil nutrients to the atmosphere, and through soil erosion and leaching. Moreover, the greater the proportion of the product that is harvested, the greater amount of plant nutrients that will be taken from the soil. When the amount of organic matter has fallen and is at an insufficient level for the plant's needs, the higher is the need for non-organic fertiliser to improve soil quality. If labile SOM and non-organic fertiliser are not sufficient for the plant needs, non-labile SOM will be used by the plant. Thus, the amount of non-labile organic matter will decrease and this will cause a reduction in the quantity of SOM, which is related to physical soil fertility. Therefore, it seems that organic matter provides an indication of soil structure. In addition, if the application of fertiliser is not possible, with the amount of uptake due to harvesting combined with the other nutrient losses, the SOM will be depleted and this will cause a reduction in total organic matter as well.

Plant nutrients generally come from two sources — soil organic matter and crop residues — and the rate of breakdown of residues can be used to evaluate the quality of soil organic matter. Soil organic matter cycling correlates with soil fertility and carbon type (Parton et. al, 1987; McCaskill and Blair, 1989; Swift et al. 1991).

The common practices of crop-residue returns and green manuring often lead to short-term pulses of plant nutrients, which frequently do not sustain crop growth to maturity, but result in long-term benefits to SOM. Therefore, to improve agricultural production, in particular in rice, by increasing the input of organic matter, ACIAR and the Ubon Rice Research Center (URRC) initiated the project LWR2/1991/002 concentrating on cropping systems for rainfed lowland rice in the northeast of Thailand. This project also concentrated on nutrient balances and the long term changes in organic matter and carbon in soil by applying crop residues and non-organic fertiliser on rice field to observe and evaluate the role of crop residues and the management of rice straw in cropping systems.

Rice is the major food crop for Thai people. From the records of the Office of Agricultural Economics, Bangkok, Thailand, during 1998 and 1999, while the largest area planted with rice was in northeast Thailand (see Table 1), rice yields in this area were below the yields in other regions (see Table 2). Therefore, the project undertook experiments to improve rice yield and soil quality in northeast Thailand, and to determine suitable and appropriate methods to improve the soil fertility. Moreover, with different management techniques, total carbon levels and nutrient dynamics were monitored and used to calculate a carbon management index (CMI), which is correlated with the chemical, physical and biological fertility of soils.

Field experiments were established in Ubon Province in northeast Thailand to investigate organic matter management and nutrient cycling, with the aim of assessing the carbon and nutrient management status of different cropping systems. In addition, field experiments were established to develop agricultural sustainability indices, which could be used to assess the sustainability of management systems in rainfed rice cropping. The purpose of this project was to examine the possibility of longer-term soil fertility rehabilitation and increasing soil organic carbon levels from the combined use of different crop residues and inorganic fertilisers and rice straw management in different rainfed cropping systems. The project was succeeded by project LWR2/1994/048, ‘Carbon Dynamics and Nutrient Cycling and the Sustainability of Cropping and Pasture Systems’, (Dr Kunnika Naklang, pers. comm. 1999).

The purpose of the experiments was to investigate the effect of different crop residues, or residue management regimes, on rice yields and on carbon and nutrient dynamics. The experiments were implemented by focusing on rice growth with or without legume residues, with or without fertiliser

**Table 1.** Planted areas in the major rice-producing regions of Thailand, 1993/94–1997/98

| Region | Planted areas (rai) | | | | |
|---|---|---|---|---|---|
| | 1993/94 | 1994/95 | 1995/96 | 1996/97 | 1997/98 |
| Northeastern | 30,734,409 | 31,040,327 | 32,024,711 | 31,688,587 | 32,144,320 |
| Northern | 12,129,172 | 12,526,986 | 12,772,740 | 12,863,685 | 12,363,686 |
| Central Plain | 10,221,356 | 9,886,193 | 9,762,606 | 9,856,922 | 9,683,472 |
| Southern | 3,068,133 | 2,919,666 | 2,846,934 | 2,881,889 | 2,766,554 |
| Whole Kingdom | 56,153,070 | 56,373,172 | 57,406,991 | 57,291,083 | 56,958,032 |

**Source:** Office of Agricultural Economics, Bangkok, Thailand, 1998 and 1999.

**Table 2.** Production and yields in the major rice-producing regions of Thailand, 1993/94–1996/97

| Region | 1993/94 | 1994/95 | 1995/96 | 1996/97 | 1997/98 |
|---|---|---|---|---|---|
| **Production (tonnes)** | | | | | |
| North-eastern | 7,125,324 | 8,009,659 | 8,435,539 | 7,977,991 | 8,633,595 |
| Northern | 4,170,424 | 4,975,721 | 4,586,988 | 4,869,251 | 4,887,740 |
| Central Plain | 4,244,548 | 4,289,886 | 3,790,644 | 4,002,138 | 4,342,743 |
| Southern | 942,367 | 885,449 | 915,446 | 932,503 | 924,710 |
| Whole Kingdom | 16,482,663 | 18,160,715 | 17,728,617 | 17,781,883 | 18,788,788 |
| **Yield per rai[a] (kg)** | | | | | |
| North-eastern | 262 | 281 | 281 | 280 | 280 |
| Northern | 389 | 444 | 453 | 435 | 403 |
| Central Plain | 450 | 456 | 460 | 440 | 467 |
| Southern | 359 | 331 | 337 | 334 | 357 |
| Whole Kingdom | 330 | 350 | 347 | 345 | 342 |

[a] 1 rai = 1600 $m^2$.

**Source:** Office of Agricultural Economics, Bangkok, Thailand, 1998 and 1999.

on soils of different management regimes, and with different amounts of fertilisers. The residues used in the project experiments were pigeon pea (*Cajanus cajan*); raintree (*Samanea saman*), *Acacia auriculiformis* and *Phyllanthus taxodifolius*, and these residues were expected to break down at different rates. The measurement of changes in the labile pool of soil carbon and measurements of breakdown rate of residues has been developed as part of the project. Furthermore, the measurements of total and labile carbon were used to calculate a carbon management index (CMI) which correlated with the chemical, physical and biological fertility of soils and, as such, related to significant aspects of sustainability for rainfed rice production in the northeastern part of Thailand.

# 2 Objectives and hypotheses

The objectives of this project were to: (1) determine the strategies to optimise the management of crop residues such as rice straw, legume leaf litter and inorganic fertilizers in rainfed cropping systems; (2) determine the suitability of nutrient and carbon (C) balances indicated as performance indicators of the sustainability of rainfed cropping systems; (3) determine the factors which affect the breakdown rate of residues; and (4) monitor how the nutrient release rates of residues correlate with their effect on crop growth and soil fertility.

The hypotheses under examination in project LWR2/1994/048 were:

1. The breakdown rates of crop residues and soil organic C levels have a negative relationship (slow breakdown rates will provide high soil organic C levels and vice versa). In addition, slow breakdown rates cause short-term nutrient immobilisation problems which can be overcome by strategic applications of inorganic fertiliser.
2. The natural variations in the isotopes of soil carbon and measurement of the labile and non-labile carbon pools of soils with CMI can be used as indices to estimate the sustainability of the current practices and the rate of rehabilitation resulting from manipulation of organic residues and inorganic fertilisers. In general, a low CMI indicates an overworked farming system and low levels of labile carbon, and vice versa.

# 3 Results of the project

An important result of the project was that pigeon pea provided higher plant nutrients in terms of nitrogen (N), phosphorus (P) and potassium (K) than raintree (*Samanea saman*), *Acacia auriculiformis*, and *Phyllanthus taxodifolius*. While rice straw contributed lower N than the other residues it provided levels of P and K similar to *Acacia auriculiformis* (Naklang et al., 1997). The breakdown rate of residues is measured by using the perfusion method developed in part by the ACIAR project LWR1/1991/002 (Konboon and Lefroy, 1995) to measure carbon dioxide levels and to calculate the percentage of the total carbon generated from residues. The breakdown rate of residues is compared with the generated carbon. From the experiments, leaf litter from pigeon pea, raintree (*Samanea saman*), rice straw, *Acacia auriculiformis*, and *Phyllanthus* had carbon levels of 17%, 11%, 10%, 8% and 7%, respectively, and the rate of breakdown is from the fastest to the slowest. The results of this project also indicated that the carbon and nutrient dynamics or cycling would maintain the chemical and physical fertility of soils. Furthermore, the use of residues with appropriate rates of breakdown, the judicious use of fertiliser and the careful management of residue and fertiliser applications have been shown to be central for the development and maintenance of sustainable cropping systems. The return of crop residues and small amounts of additional residues which breakdown at a relatively slow rate were shown to significantly affect crop yield while resulting in gradual, but significant, changes in the physical and chemical fertility of the soil, through changes in the amount of soil carbon.

In the analysis of total carbon by catalytic combustion and the analysis of labile carbon by oxidation with $KMnO_4$ to calculate CMI to indicate the sustainability of cropping systems, Blair et al. (1995) found that labile carbon increased with the application of slow breakdown residues such as raintree (*Samanea saman*), *Acacia auriculiformis*, and *Phyllanthus*. The project results also indicated that CMI increased with the application of slow breakdown residues and correlated to changes in medium- to long-term yield and measurements of chemical and physical fertility. The breakdown rate of residues is associated with the value of residues for nutrient release and long-term effects on soil carbon pools. Therefore, in the long term, the appropriate management of residues with slow breakdown rate will increase carbon and other nutrients that are useful for cropping systems.

The findings of this project are:

1. Leaf litter increases rice production.
2. Pigeon pea leaf litter increases rice production more than the other types of leaf litter in the short term.
3. The difference between rice production derived from using pigeon pea leaf litter and the other types of leaf litter decreases in the long term.
4. The application of non-organic fertiliser will increase rice production.
5. Rice straw management has no impact on rice production.
6. The level of labile carbon increases with raintree (*Samanea saman*), *Acacia auriculiformis*, and *Phyllanthus*.
7. The residues with slow breakdown rate are necessary for preservation of soil organic matter, and CMI can be used as the indicator of the changes of soil carbon.

# 4 The impact of the project results

The perfusion method and the CMI developed in project LWR2/1991/002 has created a great deal of interest in the scientific community through the papers presented at national and international conferences. This project has not only built up human capacity and enhanced the skills of six Thai project participants but has also provided project knowledge through short-term and long-term training. Three postgraduate studies (2 PhD and 1 MS) have been completed in conjunction with the project. Other postgraduate and undergraduate studies have used either the techniques developed as part of the project or analysed samples from the project experiment or both (Dr Kunnika Naklang, pers. comm. 1999).

The work carried out in LWR2/1991/002 is to be followed up in the new ACIAR funded project LWR2/1994/048. One of the aims of the new project is to further disseminate the findings of LWR2/1991/002, particularly some of the techniques developed for assessing the potential of different management systems to reduce land degradation.

# 5 Conclusion

The potential role of legume residues with slow breakdown rates in stabilising soil organic matter levels has been a key output from the project. The residues with the slow decay rates increase long-term rice yield and soil fertility, while the residues with fast breakdown rates increase rice production in the short term. These findings are contrary to the common practice of returning high quality residues which break down rapidly and which may in fact enhance denitrification.

The CMI was used to demonstrate the longer-term consequences of cultivation and residue management and to monitor the rate of change of agricultural systems relative to a stable reference system. Furthermore, the *in-vitro* perfusion apparatus has been set up in Thailand and screening has started to identify the range of legume leaf litter that may be available for farmers to use in their cropping systems.

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# An Impact Assessment of ACIAR Projects on Boron, Phosphorus and Sulfur in Thailand

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# Contents

# 1 Introduction

This report is one of series of impact assessments of scientific projects in Thailand funded by the Australian Centre for International Agricultural Research (ACIAR). This report focuses on those projects concerned with the impact of plant nutrients, such as boron, phosphorus and sulfur, on the production of Thailand's major economic crops.

The main objective of this report is to determine whether the new technology or new scientific knowledge generated from the projects is worth while and thus if the funds from ACIAR were allocated effectively and beneficially.

This paper examines four ACIAR-supported projects on the response of major economic crops, particularly food legumes and tropical crops, to plant micro- and macronutrients in Thailand. More specifically, these projects focus on the effect that the lack of micronutrients, particularly boron, phosphorus and sulfur, have on the quality and quantity of plant production. The expected impacts of the research findings generated from each project are an enhancement of the knowledge of the researchers and an increase in farmers' incomes and a reduction in the cost of production. In addition, the research findings should provide the scientists and extension officers with information that can be used to guide farmers on the appropriate use of micronutrients in the future.

The research projects on micronutrients that are examined in this report are:

1. Micronutrient requirements for growth and biological nitrogen fixation of legumes (PN/1983/029);
2. Boron and other micronutrients for food legume production (PN/1986/003);
3. Phosphorus and sulfur efficiency in tropical cropping systems (PN/1983/028); and
4. Sulfur and phosphorus management in tropical cropping systems (PN/1988/004)

This report has five sections. Following this introduction, a second section presents general information on each of the projects under review. In the third section, detailed information about the outcomes or impacts of the projects is provided. An assessment of the potential benefit of the projects is given in the fourth section. The conclusions and some recommendations are given in the final section.

# 2 An overview and objectives of the ACIAR-supported projects on soil and plant nutrients

In this section, the four completed ACIAR projects on soil and plant nutrients in Thailand are briefly summarised and general information about the timing, cost and objectives of each project is given.

## 2.1 Micronutrient requirements for growth and biological nitrogen fixation of legumes (PN/1983/029)

This project brought together scientists from Thai and Australian institutes in collaborative research that started in 1984 and lasted two years. The objectives of this project were to: (1) develop standards for the diagnosis of micronutrient deficiencies in peanuts (*Arachis hypogea* L.) and soybeans (*Glycine max* L. Mer.); (2) use these standards to identify micronutrient limitations to peanut and soybean production in Thailand on four major problem soils (Gray podzolic, Low humic gley, Rendzina, and Red-brown lateritic soils); and (3) determine the relationship of symbiotic associations and environmental conditions to micronutrient deficiency diagnosis.

This project was reviewed in February 1986 by a panel chaired by Dr Eric Craswell of ACIAR, and it was recommended that the research objectives should be redefined to focus more on boron in Thailand. Thus, this project was extended as project PN/1986/003.

## 2.2 Boron and other micronutrients for food legume production (PN/1986/003)

This project, which was based on the project PN/1983/029, started in 1986 and was completed in 1989. The objectives of this project were to: (1) determine the extent and severity of boron deficiency for the production of food legume crops such as black gram (*Vigna mungo* L. Hepper), green gram (*Vigna radiata* L. Wilezek), peanuts and soybeans in Thai soil in the four regions of Thailand; (2) develop procedures for the diagnosis, prediction and correction of boron deficiency in farmers' legume crops; and (3) identify the role of other micronutrient deficiencies in legume crop production and develop standards for their diagnosis.

These projects on micronutrient requirements for growth and biological nitrogen fixation of legumes (PN/1983/029) and boron and other micronutrient requirements for food legume production (PN/1986/003) were developed to increase seed yields and seed quality of legumes by improving soil fertility.

## 2.3 Phosphorus and sulfur efficiency in tropical cropping systems (PN/1983/028)

The objectives of project PN/1983/028 were to: (1) study phosphorus and sulfur in upland and lowland cropping systems; and (2) establish better criteria for assessing the phosphorus and sulfur status of plants and soils in Thailand. This project was conducted for 3 years from 1985, with an ACIAR budget of A$440 696. Thereafter, this project was replaced by Project PN/1988/004, which focused more on sulfur.

## 2.4 Sulfur and phosphorus management in tropical cropping systems (PN/1988/004)

This project was extended from project PN/1983/028 with the aim of comparing the impacts of different sulfur-containing fertilisers on the production of lowland and highland crops. In particular, highland crops were a primary focus in Thailand. Besides the previous objective, the other objectives of project PN/1988/004 were to:
(1) investigate the management options of sulfur fertiliser programs to increase the efficiency of sulfur in sulfur fertilisers and crop residues for upland and lowland crops and pastures;
(2) determine and monitor the level of sulfur and the other nutrients contributed to crops from crop residues (e.g. rice straw), ash (burning crop straw) or from inputs via rainfall and irrigation waters; and
(3) identify the areas of sulfur deficiency primarily in upland crops and recommend management packages for sulfur fertilisers for particular soil/crop/climate regimes.

# 3 The research results and impacts

This section provides information on the research outcomes of these projects, starting with a description of the results or new scientific knowledge generated, and the impacts of research in terms of transferability of new information and human capacity enhancement generated from the project. For each topic, information is given for the projects associated with micronutrient requirements for food legume production (PN/1983/029 and PN/1986/003) and the projects associated with phosphorus and sulfur efficiency and the management of sulfur and phosphorus in tropical cropping systems (PN/1983/028 and PN/1988/004) are provided and discussed.

## 3.1 The description of results or new information generated by the project

Before an estimation of the incremental benefits or incomes generated from the project is given, the new technology or scientific knowledge generated from the projects is described.

### *3.1.1 The projects associated with Micronutrient requirements for growth and biological nitrogen fixation of legumes (PN/1983/029) and Boron and other micronutrient for food legume production (PN/1986/003)*

Both these projects were conducted to find a procedure to measure the level of micronutrients in soil and plants, and to use the findings to determine a standard level of micronutrients as a diagnostic indicator of micronutrient deficiency, particularly boron deficiency in major food legume production in Thailand.

The results of these two studies showed that boron deficiency in food legumes causes a reduction in seed yields, and lowers seed quality. For example, boron deficiency results in hollow hearts in kernels of peanuts and dimpled seeds in soybean. The experimental results also showed that the effect of boron deficiency on grain legumes might also result in poor germination and seedling establishment.

From the research study conducted by Rerkasem (1986), the results also showed that many factors influence boron response in food grain legumes, including planting season, plant species and genotype. For example, black gram that grows in the cool season was found to be more sensitive to boron deficiency than that planted in the hot or dry season. It was also found that black gram is more sensitive to boron deficiency than green gram, and that boron deficiency in peanut is indicated by hollow-heart symptom but it is relatively tolerant in terms of grain yield. In addition, soybean seemed to be more tolerant to boron deficiency than the other grain legumes (with the same level of boron that reduced seed yield of green gram, black gram and caused hollow heart in peanut). Finally, some soybean genotypes, (e.g. Nakornwawann1 (NW1)), are more sensitive to boron deficiency than the average genotype (Rerkasem, 1992).

From the experiments in the field, the results of this research showed that legume production should be improved by using the appropriate technique or by using sufficient micronutrients to create better soil fertility, or by applying the appropriate amount of micronutrients to the different grain species and genotypes.

### *3.1.2 The projects associated with Phosphorus and sulfur efficiency in tropical cropping systems (PN/1983/028) and Sulfur and phosphorus management in tropical cropping systems (PN/1988/004)*

Project PN/1983/028 demonstrated the efficiency of using sulfur in cropping systems. The results from that project were then verified in project PN/1988/004. Through a new process of Australian technology to evaluate sulfur and phosphorus, the results of the project in all the field experiments indicated that the management of crop residues (e.g. rice straw) was a significant contributor to the sulfur balance in cropping systems. In particular, the experiment conducted at Phrae in Thailand showed that plant sulfur recovery from rice straw was approximately twice that from ash, and the percentage of residue of sulfur recovered by the crop decreased (increased) as the sulfur content of the residue decreased (increased).

The studies by the Department of Agriculture (DOA) in Thailand on the determinants of the sulfur balance in the cropping systems derived from the residue component of the crop have shown that, with the absence of sulfur fertiliser, the amount of sulfur in the residues in corn and mungbean cropping systems would be reduced.

Besides crop residues, the accession of sulfur via inputs in rainfall and irrigation waters can modify sulfur fertiliser requirements and the incidental sulfur inputs in fertiliser such as ammonium sulfate, or as a component of the compound nitrogen, phosphorus and potassium fertiliser, results in a positive sulfur balance (sulfur efficiency). Therefore, sulfur supplied in rainfall and irrigation waters can also be a significant source of this element for the agriculture product. On the other hand, non-sulfur-containing fertilisers, such as urea, resulted in a negative sulfur balance (sulfur deficiency). As a result, the upland and lowland crop yields increased when sulfur-containing fertilisers were applied.

These two projects have fulfilled their aims in terms of improving the efficiency of production and reducing the cost of fertilisers used in the cropping system by: (1) developing sulfur fertiliser packages for particular soil/crop/climate regimes;
(2) mapping sulfur accessions in rainfall; and
(3) developing a soil test to identify areas where sulfur is deficient.

## 3.2 The research impacts generated by the project

The research impacts generated from the project associated with micronutrients or supplementary plant nutrients in Thailand are discussed under the following three subsections.

### *3.2.1 Scientific knowledge transferability*

Scientific knowledge specific to projects PN/1983/029 and PN/1986/003, and the transferability and adoption of the research findings of these projects by farmers, has not been identified because the knowledge from these project cannot be isolated from that derived by similar projects (Dr Benjavan Rerkasem, pers. comm. 1999). However, the information on boron deficiency in food legume crops generated from project PN/1986/003, particularly in northeast soils, has been reported widely to other scientists working in that region, ensuring that scientists and extension workers are aware of such problems. Through them, fertiliser recommendations should be accessed or suggested. However, the farmers should know about the symptoms of boron deficiency in soil or plants first, and then discuss the matter with extension workers before the latter can make suggestions or recommendations. Dr Benjavan Rerkasem (project leader) and Mr Suwapan Ratanarat (research scientist) said they could not confirm that the knowledge generated from the project has been transferred to the end-users (farmers) but they could confirm that the project did generate scientific knowledge. Moreover, the research findings were also transferred to those concerned with legume and wheat research.

While the information on sulfur fertiliser treatment generated from the projects PN/1983/028 and PN/1988/004 has not been directly adopted by the end-users, the results from these projects have been promoted through scientific meetings to scientists and extension officers and also to technicians through training courses.

A summary of the publication output from the plants nutrient projects is presented in Table 1 and the full list of the papers published as a result of the projects is presented in Appendix 2.

### *3.2.2 Enhancement of human capacity*

Through involvement in agricultural research projects, the senior scientists and young researchers, in particular, improved their agricultural research skills through participation in both short-term and long-term training programs, workshops or conferences held by the institutes involved the research projects. The numbers of project participants and trainees with enhanced human capacity (or skills) is summarised in Table 2. In addition, other scientists and students could use the techniques or knowledge generated from the projects to diagnose the level of micronutrient deficiency in other crops (Dr Benjavan Rerkasem, pers. comm. 1999).

### *3.2.3 The potential economic impacts of the research finding in term of production improvement.*

The results of the projects on boron, phosphorus and sulfur in Thailand indicate that, without the application of the research findings, the quantity and quality of crop production would be substantially reduced and the amount of fertiliser might be overused or misused. Therefore, the adoption of these findings at the farm level should result in positive economic impacts in terms of improved crop yields, better quality crops, and consequently, increased farmers' incomes and reduced crop production costs. However, the findings of these four projects have not been transferred to the end-users (as mentioned by the project scientists and the project leader), thus the adoption rate could not be quantified. Only the incremental benefit will be discussed in this paper.

The calculation of the incremental benefits can be estimated by comparing the benefits from experimental treatments with those without the experiment treatment.

*Micronutrient requirements for growth and biological nitrogen fixation of legumes (PN/1983/029) and Boron and other micronutrient for food legume production (PN/1986/003)*

The result of projects PN/1983/029 and PN/1986/003 indicated that with 0.12 mg/kg of boron in the soil (hot water soluble boron, HWSB) and 0.64 kg/rai (4 kg/ha) of borax, black gram (Requr) production increased by 39% and the production of green gram (Utong1) by 25% (Predisripipat, 1988). For the first application of 0.64 kg/rai[2] (4 kg/ha), without an additional application, the residual boron would run out by the third successive crop, while higher borax rates of 1.6 to 3.2 kg/rai (10 to 20 kg/ha) ran out after 10 crops (Rerkasem, 1992). For many lengths of planting rotations, with HWSB in soil at 0.05 mg/kg, the seed yields of soybean (Nakornsawan1) fell from 272 kg/rai to 107 kg/rai and peanut production (Tainan9) fell from 530 kg/rai to 370 kg/rai (Rerkasem and Rerkasem, 1989).

From the results given above and the Rerkasems' 1989 findings, the incremental seed yields are as given in Table 3.

*Phosphorus and sulfur efficiency in tropical cropping systems (PN/1983/028) and Sulfur and phosphorus management in tropical cropping systems (PN/1988/004)*

The results of the experiments showed that the yields of paddy rice and cowpea increased with treatments of fertilisers containing sulfur (Tables 4 and 5).

From Table 4, there were no significant differences among sulfur rates and sources and grain yields, and a significantly low yield was recorded as no S-fertiliser was applied for the years 1988 to 1990. Yield responses to sulfur uptake of 8 kg S/ha from sulfur-coated triple superphosphate (TSP) was as good as, or better than, that from gypsum. While the studies conducted in Indonesia found that gypsum (gyp.), ammonium sulfate and urea sulfur were the most efficient sources for two consecutive flooded rice crops.

2. 1 rai = 1600 $m^2$; 1 ha = 6.25 rai.

**Table 1.** Summary of the publication outcome from plants nutrient ACIAR-supported projects in Thailand

| Project number | Published books | Published journal papers | Conference papers | Workshop papers | Other papers | Total |
|---|---|---|---|---|---|---|
| PN/1983/029 and PN/1986/003 | _ | 8 | _ | _ | 6 | 14 |
| PN/1983/028 and PN/1988/004 | 2 | 2 | - | - | 8 | 12 |

**Source:** Suzuki et al. (1996)

**Table 2.** The summary of human capacity build-up

| Project number | Project participants (Thai) | Member with enhanced skills (Thai) | Short-term training (Thai) | Long-term training |
|---|---|---|---|---|
| PN/1983/029 | 4 | 4 | – | 1 |
| PN/1986/003 | 4 | 4 | 1 | – |
| PN/1983/028 | 5 | 4 | – | – |
| PN/1988/004 | 3 | 2 | – | – |

**Source:** Suzuki et al. (1996)

**Table 3.** The incremental seed yield in peanut (Tainan 9) and soybean (SJ 5) following boron application, based on treatments in northern Thailand in 1988 (for HWSB = 0.12 mg/kg and borax at 0.64 kg/rai)

| Season | Crop | Treatment | | Incremental of seed yields (kg/rai) | Percentage of increased yields (%) |
|---|---|---|---|---|---|
| | | Without boron | With boron | | |
| **Seed yield (kg/rai)** | | | | | |
| Rainy | Soybean (SJ5) | 139 | 161 | 22 | 15.82 |
| Dry | Soybean (SJ5) | 338 | 384 | 46 | 13.61 |
| Rainy | Peanut (Tainan9) | 168 | 175 | 7 | 4.17 |
| Dry | Peanut (Tainan9) | 318 | 362 | 44 | 13.84 |
| unknown | Black gram (Regue)* | – | – | – | 39 |
| unknown | Green gram (Utong1)* | – | – | – | 25 |

Note: without B = the primary nutrients the plants need, less boron; with B = the primary nutrients the plants need + boron and * based on the findings of Predisripipat (1988); soybean:% increased yield (average) = 14.26%; green gram and black gram are treated as mungbean and the percentage of increased yield (average) = 32%; peanut: increased yield (average) = 7.09%. 1 rai = 1600 $m^2$.
**Sources:** Rerkasem et al. (1988) and Predisripipat (1988)

**Table 4.** Effects of sulfur fertiliser sources on paddy rice yields (kg/ha)

| Treatment | kg S/ha | 1988 | 1989 | 1990 | Mean |
|---|---|---|---|---|---|
| Control | 0 | 1082a | 1787ab | 1276ab | 1411 |
| Gypsum | 4 | 1026a | 1925ab | 1181ab | 1377 |
| Gypsum | 8 | 1096a | 1772ab | 1276ab | 1381 |
| Gypsum | 16 | 1045a | 1807ab | 1445ab | 1432 |
| Gypsum | 32 | 100a | 1773ab | 1308b | 1360 |
| AS | 8 | 1046a | 1992ab | 1360ab | 1466 |
| Elem.S | 8 | 1067a | 1870ab | 1371ab | 1436 |
| S Bent. | 8 | 1128a | 1870ab | 1179ab | 1392 |
| Urea S | 8 | 881a | 2001ab | 1306ab | 1396 |
| SCU | 8 | 1145a | 1636b | 1276ab | 1352 |
| SCTSP | 8 | 1133a | 1798ab | 1240ab | 1390 |
| Gyp/yr. | 32 | **1192a** | **2059a** | 1212ab | 1488 |
| CK | 0 | 467b | 835c | 1016b | 773 |
| Gyp+cowpea | 16+stb | 993a | 1682ab | **1612a** | 1429 |

Note: In a column, means followed by a common letter are not significantly different at the 5% level by DMRT
**Source:** Songmuang et al. (1991)

For cowpea in 1988, all sulfur sources except sulfur-coated urea tended to increase grain yields (Table 5). Ammonium sulfate significantly increased yield while sulfur-coated urea seemed to release inadequate sulfur for cowpeas and there was no significant yield increase as the gypsum rate was increased. For 1989, the rate of gypsum (32 kg S/ha) increased cowpea yield. Cowpea yields in the third crop (1990) increased due to environmental conditions rather than because of fertiliser treatments, since with no sulfur treatment the yields still increased. The results from both tables seem to indicate that gypsum was the most efficient source for highland crops (rice and cowpea) in Thailand.

The findings from all four projects indicated that soil fertility was enhanced by using either boron or sulfur compound fertiliser, and that by using boron or sulfur content fertiliser the yields would also increase.

**Table 5** Effects of sulfur fertiliser sources on cowpea yields (kg/ha)

| Treatment | kg S/ha | 1988 | 1989 | 1990 | Total |
|---|---|---|---|---|---|
| Control | 0 | 702a | 1139ab | 1960a | 3801bcd |
| Gypsum | 4 | 651a | 1051b | 1853b | 3554def |
| Gypsum | 8 | 797a | 839b | 1710b | 3364fg |
| Gypsum | 16 | 754a | 1022b | 1774b | 3551fg |
| Gypsum | 32 | 917a | **1440a** | 1814b | **4171a** |
| Gypsum | 32* | 658a | 1194ab | **2127a** | 3980ab |
| AS | 8 | **1115a** | 1092abc | 1833b | 4040ab |
| Elem.S | 8 | 857ab | 1080abc | 1821b | 3758bcde |
| S Bent. | 8 | 762ab | 1169a | 1905b | 3836bc |
| Urea/ S | 8 | 794ab | 977abc | 1810b | 3580def |
| SCU | 8 | 559b | 861bc | 1706b | 3126g |
| TSP/S | 8 | 917a | 1006abc | 1762b | 3684cde |

Note: Values of each column followed by the same letter are not significant differences
* 32 kg S/ha as gypsum was applied every year. The bold number is the highest yield in each year.
**Source:** Pongsakul, P.and et.al, 1991

### *3.2.4 Other impacts*

The other impacts of the ACIAR-supported projects included one PhD and two masters students graduating by using some part of the projects PN/1983/029 and PN/1986/003 in their dissertations. At the end of all projects, the scientific equipment, computer and vehicles were left at the local institutions. However, from the viewpoint of the project leader or scientists, these benefits were not realised as the scientific equipment, in particular, was not used because of the expensive maintenance costs.

# 4 Economic evaluation of the micronutrient projects

The benefits of the results from these projects are limited to scientific knowledge generation because the transfer of the research findings to the end-users or the farmers had not been identified (as mentioned by the project leader and scientists). However, the research findings have been reported widely to other scientists and to extension workers. Through them, the information obtained from the research may be expected to be extended to the farmers. According to that expectation, a comparison of income with the treatment and the income without the treatment would give the change in potential incomes. The incremental incomes from micronutrient content treatment are given below.

*Projects on boron (PN/1983/029 and PN/1986/003)*

Combining the information from Table 3 with the data from Agricultural Statistics of Thailand on areas planted to crops and the price of agricultural products for crop year 1995–96 (Tables A1a–A1c and A2 in Appendix 1), and assuming that the technology has been adopted by the farmers, gives the potential incomes of each crop (Table 6).

Thereby, the incremental incomes generated from the research impacts are estimated and classified by regions or crop type or species. The incremental incomes of the fertiliser treatment is described as:

Incremental income =
Incremental seed yield (kg/rai) *
Harvested area (rai) * Farm price (baht/rai)

However, the incremental costs could not be estimated due to a lack of information on the market price of borax. Consequently, only the income increase should be imputed. In addition, to estimate the potential income change for black gram and green gram production, the market value of mungbeans will be used as a proxy for the return on these two crops.

In this paper, the potential incomes have been quantified, even though community adoption was not identified. This non-adoption could be due to a number of factors. First, the cost of boron is quite high and therefore the farmers may not be able to afford it. Second, the farmers may not be aware that the problems that they are experiencing with crop yields and quality are a result of boron deficiency. While extension officers may suggest a fertiliser that is high in boron to the farmers, they may not explain the reasons behind their suggestion. This could be because using boron can be quite difficult. It is easy to apply too much, resulting in boron toxicity. However, mixing borax with normal fertiliser is not too difficult, although the extension officers would still need to be involved to pass on the results of the study and methods for correct use to the farmers (T. Fischer, pers. comm. 2000). Third, the results of the incremental change in seed yields vary according to many factors such as the amount of boron in the soil and seed, the soil type, the planting season, crop species, and genotype.

As can be seen in Table 6, the increase in income was not large for one year, even though full adoption (100%) was assumed, while the increments in seed yields are quite significant (Table 3). This result may be because the planting areas of these crops are not large. Therefore, the incremental income was not large. Consequently, from the estimation, it is quite hard to tell if these projects were profitable.

*Projects on sulfur (PN/1983/028 and PN/1988/004)*

The benefits from the results of these two projects were mostly in the form of scientific knowledge about how to use the fertiliser package to improve the outputs. Most of the research was done in field experiments. The knowledge had not been extended to the farmers or the end-users (Dr Pichit Pongsakul and Mr Suwapan Ratanarat, pers. comm.1999). The main reason for this is that the experimental research did not provide consistent results about incremental production from adding more sulfur (see Tables 4 and 5). This may be because the appropriate application rate for sulfur fertiliser packages depends on soil type, crop species and climate regimes. More research needs to be undertaken to obtain consistent and verifiable results. Because of the inconsistency in the results, an economic evaluation of these projects was not undertaken.

**Table 6.** The estimation of incremental incomes from food legume production under the adoption of research technology, based on regions, crop species, soil types or texture and planting season; crop year 1994–95 (baht/rai/year)

| Region/adoption rate (%) | Soybean* | Peanut* | Green gram and black grams (mungbean) | Total incremental income if research technology were adopted |
|---|---|---|---|---|
| **Northeastern** | | | | |
| 1 | 3,544.51 | 1,532.26 | 5,702.55 | 10779.32 |
| 5 | 17,722.55 | 7661.3 | 28512.75 | 53896.60 |
| 20 | 70890.2 | 30645.2 | 114051 | 132180.60 |
| 50 | 177225.5 | 76613.00 | 285127.5 | 538966.00 |
| 80 | 283560.8 | 122580.8 | 456204.00 | 862345.60 |
| 100 | 354451.00 | 153226.00 | 570255.00 | 1077932.00 |
| **Northern** | | | | |
| 1 | 14,814.70 | 2,061.46 | 63,245.58 | 80121.74 |
| 5 | 74073.5 | 10307.3 | 316227.9 | 400608.70 |
| 20 | 296294 | 41229.2 | 1264911.6 | 1602434.80 |
| 50 | 740735 | 103073 | 3162279 | 4006087.00 |
| 80 | 1185176 | 164916.8 | 5059646.4 | 6409739.20 |
| 100 | 1481470 | 206146 | 6324558 | 8012174.00 |
| **Central** | | | | |
| 1 | 2,845.81 | 579.738 | 9,439.98 | 12865.53 |
| 5 | 14229.05 | 28998.69 | 47199.9 | 64327.64 |
| 20 | 56916.2 | 11594.76 | 188799.6 | 257310.56 |
| 50 | 142290.5 | 28986.9 | 471999 | 643276.40 |
| 80 | 227664.8 | 46379.04 | 755198.4 | 1029242.24 |
| 100 | 284581 | 57973.8 | 943998 | 1286552.80 |
| **Southern** | | | | |
| 1 | N/A | 220.317 | 678.63 | 898.95 |
| 5 | N/A | 1101.59 | 3393.15 | 4494.74 |
| 20 | N/A | 4406.34 | 13572.6 | 17978.94 |
| 50 | N/A | 11015.85 | 33931.5 | 44947.35 |
| 80 | N/A | 17625.36 | 54290.4 | 71915.76 |
| 100 | N/A | 22031.7 | 67863 | 89894.70 |
| **Whole Kingdom** | | | | |
| 1 | 21,205.01 | 4,393.78 | 79,066.74 | 104665.53 |
| 5 | 106025.1 | 21968.9 | 395333.7 | 523327.65 |
| 20 | 424100.2 | 87875.6 | 1581334.8 | 2093310.60 |
| 50 | 1060251 | 219689 | 3953337 | 5233277.00 |
| 80 | 1696401 | 351502.4 | 6325339.2 | 8373242.40 |
| 100 | 2120501 | 4393788 | 7906674 | 10466553.00 |

Note: N/A = not available
**Source:** from calculation

# 5 Conclusion and recommendation

This report deals with the impact assessment of ACIAR-supported projects on plant nutrients. There is evidence that this research was very useful in terms of generating new technology or scientific information and enhancing the skills of the involved researchers and scientists involved (Dr Benjavan Rerkasem, D. Pichit Pongsakul and Mr Suwapan Ratanarat, pers. comm. 1999). In addition, while the information generated from the projects is likely to be used by the other researchers in related fields, the extension of the project results to the farmers is either unknown or known to be limited (Dr Benjavan Rerkasem, Dr Pichit Pongsakul, Mr Suwapan Ratanarat and Mr Kukiat Soitong, pers. comm. 1999). Even though the research findings have no community impact, an economic evaluation of the Thai plant nutrient projects PN/1983/029 and PN/1986/004 was undertaken to see whether the projects could potentially generate increased incremental income for the end-users when full adoption is assumed.

From the interview with the project leaders and scientists (Dr Benjavan Rerkasem, Dr Pichit Pongsakul, and Mr Suwapan Ratanarat), it was surmised that the project findings have not been transferred to the end-users because the technique to identify the level of micronutrient deficiency requires scientific knowledge. Furthermore, it is quite hard for the end-users to make their own compound fertiliser as it is very complicated.

To make the research more profitable, more work should be done on the issues of extending the findings to the end-users or the farmers through researchers or extension officers. There should be collaboration between the project scientists and the extension officers to get the project findings to the end-users. From the interviews with the project leaders and scientists, it appears that the project scientists provide the results of their findings only to those who are interested in similar projects, as they have no obligation to extend their finding to the end-users. It is the duty of the extension office to transfer the knowledge generated from the projects to the end-users. Furthermore, the project technology or knowledge should be more precisely defined and monitored.

# 7 Acknowledgments

In the process of finishing this paper, the author would like to express thanks to the project leaders and scientists of ACIAR projects, such as Dr Benjavan Rerkasem, Suwapan Ratanarat, Dr Pichit Pongsakul and Kukiat Soitong, for sharing information and their valuable time for the preparation of this report. Without their helps, this paper might not have eventuated. My special thanks also extend to Assoc. Prof. Somporn Isavilanonda, the team leader for the economic evaluation of ACIAR projects, who gives me an opportunity to handle this paper. My grateful thanks are also to my colleagues Dr Chapika Sangkapitux, Dr Suwanana Praneetvatakul, and Charuk Singhapreecha for their comments and support during the research preparation. Grateful thanks are also extended to Australian Centre for International Agricultural Research (ACIAR) for financial support. Last but not least I would like to thank my friends Dolaya Yimsaard and Ronald Banner for helping me edit this paper.

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# Appendix 1 Production statistics

**Table A1a.** Mungbean: planted and harvested areas, production yield by region, crop year 1995–96

| Region | Planted area (rai) | Harvested area (rai) | Production (ton) | Yield (kg) per rai |
|---|---|---|---|---|
| North-eastern | 157,204 | 150,004 | 16,733 | 112 |
| Northern | 1,758,246 | 1,663,657 | 189,352 | 115 |
| Central | 261,836 | 248,316 | 26,359 | 106 |
| Southern | 19,591 | 17,851 | 1,907 | 107 |
| Whole Kingdom | 2,196,877 | 2,079,828 | 234,351 | 113 |

Farm price = 9.72 (1994/1995) and 11.88 (1995/1996). 1 rai = 1600 $m^2$.

**Table A1b.** Soybean: planted and harvested areas, production yield by region, crop year 1995–96

| Region | Planted area (rai) | Harvested area (rai) | Production (ton) | Yield (kg) per rai |
|---|---|---|---|---|
| North-eastern | 217,435 | 211,051 | 48,936 | 232 |
| Northern | 291,416 | 283,941 | 71,227 | 251 |
| Central | 82,288 | 79,852 | 20,379 | 255 |
| Southern | 32,896 | 30,346 | 6,213 | 205 |
| Whole Kingdom | 624,035 | 605,190 | 146,755 | 242 |

Farm price (1995/1996) = 7.52 (1994/1995) and 8.65 (1995/1996)

**Table A1c.** Peanut: Planted and harvested areas, production yield by region, crop year 1995/96

| Region | Planted area (rai) | Harvested area (rai) | Production (ton) | Yield (kg) per rai |
|---|---|---|---|---|
| North-eastern | 302,176 | 287,356 | 62,676 | 218 |
| Northern | 1,313,005 | 1,201,039 | 267,282 | 223 |
| Central | 265,667 | 230,712 | 55,602 | 241 |
| Southern | - | - | - | - |
| Whole Kingdom | 1,880,848 | 1,719,107 | 385,560 | 224 |

Farm price = 9.07 (1994/95) and 10.24 (1995/1996)
**Source:** Thailand, Office of Agricultural Economics, 1996

**Table A2.** Production cost by crop and region, crop year 1994–95

| Crops and Items | Northern | Central | Northeastern | South | Whole Kingdom |
|---|---|---|---|---|---|
| **Mungbean** | | | | | |
| Total cost (baht/rai) | 800.11 | 734.15 | 732.87 | 699.56 | 786.10 (815.54) |
| Variable cost | 639.61 | 569.51 | 571.43 | 559.22 | 625.23 (654.67) |
| Fixed cost | 160.50 | 164.64 | 161.44 | 140.34 | 160.87 (160.87) |
| Average cost(baht/kg) | 6.96 | 6.74 | 7.63 | 7.69 | 6.97 (7.65) |
| **Soybean** | | | | | |
| Total cost (baht/rai) | 1,296.33 | 1,234.34 | 1,271.87 | - | 1,287.54 (1,453.29) |
| Variable cost | 1,136.22 | 1,076.51 | 1,116.33 | - | 1,128.23 (1,293.97) |
| Fixed cost | 160.11 | 157.83 | 155.54 | - | 159.32 (159.32 |
| Average cost (baht/kg) | 6.90 | 5.41 | 6.20 | - | 6.64 (7.09) |
| **Peanut** | | | | | |
| Total cost (baht/rai) | 1,635.81 | 1,662.22 | 1,561.47 | 1,700.86 | 1,617.00 (1,822.35) |
| Variable cost | 1,507.75 | 1,529.60 | 1,434.91 | 1,558.93 | 1,488.91 (1,693.54) |
| Fixed cost | 128.06 | 132.62 | 126.56 | 141.93 | 128.81 (128.81) |
| Average cost (baht/kg) | 6.96 | 6.52 | 7.03 | 9.40 | 7.00 (7.75) |

Note: numbers in brackets are the cost for crop year 1995–96
**Source:** Thailand, Office of Agricultural Economics, 1996

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# An Assessment of the Realised Impacts of Long-Term Storage of Grains Under Plastic Covers Project Funded by ACIAR in Thailand

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# Contents

# 1 Introduction

In Thailand, milled rice is usually bagged, stacked, and stored uncovered in a warehouse. The warehouses are usually of the horizontal type, ventilated to permit cooling of the grain through natural convection. In this type of storage, grains are prone to insect attack unless precautions are taken. The main insect control procedure for bag storage in Thailand is fumigation under gas-proof sheets. At present, methyl bromide and phosphine are widely used to fumigate bag stacks of milled rice (DOA, 1998). When grain remains in storage for a substantial period, insects can reinfest grains once the sheets are removed after fumigation. Fumigants (phosphine and methyl bromide) are used to disinfest grain, but cannot protect grain for long periods unless the fumigant is sealed inside the storage structure. Similarly, gas-tight storage is required if grain is to be protected by controlled atmospheres (e.g. carbon dioxide or nitrogen) (Daglish et al., 1993). There is, therefore, a need to develop a storage technique to guard against reinfestation. Apart from preventing losses during storage, there is also a need to develop a method to preserve the quality of grain for longer storage periods, to meet the nutritional requirement of consumers. Projects funded by ACIAR may help provide some of these benefits.

The aim of this paper is to assess the impact of the "Long-term storage of grains under plastic covers" project in Thailand funded by ACIAR. The description of the project is presented in section 2. The scientific outcomes of the project are described in section 3. Information on the adoption of this technology in Thailand is presented in section 4, while an evaluation of the project's economic benefits for Thailand is undertaken in section 5. The conclusion is presented in the final section.

# 2 Description of ACIAR research project on the long-term storage of grains under plastic covers

Project PHT/1983/007 was conducted in Australia (CSIRO Division of Entomology), Indonesia, Malaysia, Singapore, the Philippines and Thailand. It was a three-year project that started in June 1984 and finished in December 1987 in Thailand. Research funding was about A$230 877 for Thailand. A group of Thai scientists was recruited from the Entomology and Zoology Division, DOA. In addition, two grain-handling authorities, namely Mah Boonkrong Rice Mill Co. Ltd.[3], Bangkok and Tep Tip Mills, Bangkok cooperated in this study.

The project tested a "controlled atmosphere storage technique" (CAST) based on initial fumigation of bagged grain (paddy rice, milled rice, maize) with carbon dioxide ($CO_2$), followed by storage within custom-made plastic enclosures sealed to a specified high level of gas-tightness. The main objective of the project was to test the technique as a method for preserving grain quality during long-term storage. The project simulated a wide range of commercial concentration levels, and degrees of gas-tightness.

The project had two parts. Part A was a field assessment of grain storage in sealed plastic enclosures. Part B assessed the protection against infestation offered by relatively low (less than, or equal to 40 percent) $CO_2$ atmospheres.

The specific objectives of Part A [field assessment of grain storage in sealed plastic enclosures] were to:

1. determine the reliability of the sealed stack method of storage, in terms of protection from reinfestation by insects and maintenance of the quality of rice and other commodities; and
2. monitor gas concentrations and humidity within the stacks during the storage period as a means of detecting adverse changes within the atmosphere contained in the enclosure.

The specific objectives of Part B [protection against infestation offered by relatively low (less than, or equal to 40 percent) $CO_2$ atmospheres] were to:

1. quantify the response of various insect pests to relatively low $CO_2$ concentrations;
2. confirm laboratory results in parallel with field assessment of mortality in the stacks used in Part A of this project;
3. integrate these data with those being obtained for high $CO_2$ contents and thus contribute to the development of an overall quantitative model for the toxic response of insects to $CO_2$; and
4. produce an optimal dosage regime for use of $CO_2$ as a "fumigant" and thus determine the degree of sealing required maintaining this regime.

In Thailand, bagged grains were treated by standard sheet fumigation using phosphine for disinfestation. In general, the fumigations seen outside the quarantine system were of a low standard, well below that required for a high level of insect killing. Later, instead of using phosphine, $CO_2$ was used as the gas for the initial disinfestation of the grain. $CO_2$ is a fumigant that produces no harmful residues and is relatively safe to use (Annis and Graver, 1985, cited by Sukprakarn et al., 1988). It is effective in killing insects at all stages of their life cycles and could be used for long-term storage of milled rice (Annis et al., 1984; Suharno et al., 1984, cited by Sukprakarn et al., 1988). Field tests were conducted at commercial grain storage plants in Thailand.

3. Mah Boonkrong Mill Trader has changed name to Pathum Rice Mill and Granary Co. Ltd.

# 3 Impact of the project on long-term storage of grains under plastic covers

The main conclusions of part A of the project were that (Annis and Graver, 1992):

1. sealed storage of bag-stacks is technically and operationally feasible;
2. it is possible to set out a defined procedure to make sealed storage of bag-stacks a reliable process;
3. either $CO_2$ or phosphine can be used successfully for the initial fumigation of sealed bag-stacks;
4. at present $CO_2$, while providing a highly efficient and safe method of fumigation, tends to be too expensive for routine use in most parts of the ASEAN region. However, it has economic advantages under certain circumstances; and
5. phosphine treatments in sealed bag-stacks are much cheaper and may have a substantial role to play in long-term storage of bagged commodities.

The main conclusions of part B were that (Annis and Graver, 1992):

1. $CO_2$ concentrations of less than 35 percent in air are not generally useful for commodity disinfestation. But $CO_2$ concentrations down to 20 percent in air are likely to be protective by halting population growth; and
2. the dosage regime most suited to sealed bag-stack storage is an initial $CO_2$ concentration of above 70 percent in air, declining to not less than 35 percent after 15 days or longer.

With regards to Thailand, results from the field assessment proved that phosphine fumigation is an effective measure for long-term storage of milled rice. It was tested for 30, 60, 170 and 200 days of storage. Not only was no insect infestation recorded but also the rice quality was acceptable.

The efficacy of $CO_2$ in controlling insects in milled rice stored for periods of 2, 4, 6, 8 and 12 months was tested. $CO_2$ was effective in controlling insects in the stacks opened at 2, 4, 6 and 8 months, but not in the stack sealed for 12 months. Grain quality showed a slight decrease with increased storage time. Trial 1 was unsuccessful because of leakage of $CO_2$ from the enclosures, which resulted in increasing numbers of the major insect population.

The benefits accruing to Thailand from the project include scientific knowledge, technology transfer (used by the rice handlers), training and publications. The technology for using $CO_2$ for long-term storage of milled rice in sealed bag-stacks has not been adopted for the bulk storage of grain. Some disadvantages[4] are as follows:

1. The technique of sealing plastic sheets with adhesive tape was not efficient, as it does not prevent leakage of fumigant gases (phosphine and $CO_2$).
2. Adhesive tape was used to seal the floor and cover sheets. The cover sheet had to be cut every time to open it. This means that new material is required at a high cost. This is not convenient and leads to high input costs. However, Thai users have applied another material from Israel in which a zip is used for sealing, instead of adhesive tape. It is more convenient and the sheet can be used for longer periods, but the zips are much more expensive than the adhesive tape (van Graver, pers. comm. 2000).
3. Compared with the conventional fumigation method (using methyl bromide and phosphine), there was no significantly different in terms of seed quality. Moreover, the input cost for applying $CO_2$ is higher than the conventional ones. This is a reason why this technique was not adopted in the macro level (bulk storage).

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4. Information is retrieved from interviewing the scientists and rice mill producers.

Although six machines for $CO_2$ fumigation of the consumer-size packs of grain were available at the Department of Agriculture, only two of them were ever used at the Lop Buri Agricultural Co-operation Center, and now these machines are not in use at all. The reasons are:

1. there is no significant difference in rice quality compared with the conventional system;
2. the high cost of $CO_2$; and
3. the low productivity of the machine.

# 4 Adoption in Thailand

Nitrogen and $CO_2$ are beginning to replace the toxic fumigants, particularly in storage facilities that are gas-tight or can economically be made so, and the length of the exposure period is not a limiting factor (Reichmuth, 1990). The future potential of these gases as Controlled Atmospheres (CA) is strongly dependent on the level of gas-tightness of the treated premises (Reichmuth, 1990). The use of controlled atmospheres (CA) for insect control in the bulk storage of grains can have the added benefit of controlling mould growth and mycotoxin production (Hocking, 1990). $CO_2$ has generally had little effect on grain quality, while an increase in oxygen concentration does have a small deleterious effect (Gras and Bason, 1990).

In case of Thailand, $CO_2$ has been used to preserve the quality and to extend the shelf life of consumer-sized (2 kg) plastic packs of cargo rice[5] as used by the Phathum Rice Mill and Granary Co. Ltd. As this is a much smaller scale of operation, it appears to be commercially viable.

Adoption of the technology began after the experiment with DOA (funded by ACIAR) finished in 1987. However, it was applied to the consumer-size packs of 2 kg cargo rice and not to rice that is held in bulk storage. This technique was found to be very suitable for the cargo rice. This is because cargo rice contains some fat and readily acquires a rancid smell after it has been left untreated for a few days. In the first year, about 7000 packs per month were distributed to the market. The growth rate is approximately 10–20 percent per year. In 1998 and 1999, there were about 20,000 and 30,000 packs per month distributed to the market.

Some disadvantages described by the users are summarised below:

1. Applying $CO_2$ has a negative impact on the health of workers (lack of $O_2$).
2. The techniques has some requirements, such as use at the correct temperature.
3. After $CO_2$ fumigation, it takes 24 hours to make sure that the packing is intact before delivering to the market. This constraint creates difficulties during periods of high market demand.
4. About 20 percent of the product was lost because of inefficient packaging.
5. The machine has a low productivity — therefore, a more efficient machine or some other technique is needed (see below).
6. There is high input cost because the technique needs special plastic bags (3.50 baht/bag) and $CO_2$ input (0.25 baht/pack).

At present the number of traders in milled rice in consumer-size packs is 45. The price of milled rice consumer-size pack in 1999 fell by about 20–30 percent compared with the price in 1998. High competition among the traders for milled rice consumer-size packs was predicted for the year 2000, which could lead to lower prices for the milled rice consumer-size pack (Neaw Nha Newspaper, 3.01.2000). On the other hand, the demand of cargo rice consumer-size pack will increase in the future, because of increasing consumer awareness about the quality of food products. The value of the consumer-size packs of rice milled was about 10,000 million baht in 1999.

Because of the disadvantages of the $CO_2$ fumigation technique experienced by the Phathum Rice Mill and Granary Co. Ltd., the company has considered other techniques, such as vacuum packing. This technique can be used to store grain for long periods while maintaining acceptable grain quality. In addition, the productivity of the machinery is relatively high, the input cost are relatively low as $CO_2$[6] and special plastic bags[7] are not required, but the vacuum machine is quite costly, ranging from A$10,000 to A$25,000.

5. Cargo rice is milled but unpolished rice.

6. Cost of $CO_2$ input is approximately 0.25 baht/pack of 2 kg cargo rice (price at 1999).
7. Plastic bag for packaging using $CO_2$ should be thick (3.50 baht/bag price at 1999), but for vacuum technique the lower grade of the plastic bag can be used.

# 5 Economic evaluation

Ryland (1991) did an economic assessment of the project PHT/1983/007 in 1991. The impact of the project on stock management practices in the ASEAN countries was considered in terms of the economic benefits and reduced risks arising from investment in the CAST system as a component of national storage policies. Implementation of CAST requires modest technology inputs readily available in ASEAN. With regard to the social impacts, it was assessed that the adoption of CAST methods by the ASEAN grain storage economy has generally had a neutral impact on labour requirements. There may, however, be opportunities for increased employment of women for testing and monitoring the sealed bag-stacks. There are opportunities for an overall increase in productivity of labour and for a stable, better-paid workforce involved in the improved technology. As a future impact, it was mentioned that this development would most likely come from private sector traders and farmer groups as government intervention in the grain industries is reduced, and controls on prices and distribution are liberalised.

Ryland concluded that the CAST system would become the standard form of treatment of grain in central storage in ASEAN over the next 10 years with grain volumes treated increasing from around 174,000 tons in 1989 to more than 2.12 million tons. In line with this projected level of adoption by the grain industry in ASEAN, it was estimated that the net present value (NPV) of the project will increase from around $A3.27 million at adoption levels in 1989 to an expected $A9.2 million at 1990 in 1990 dollars.

Project PHT/1983/007 was appraised in terms of the incremental costs and benefits of the improved technology. The methodology used was to obtain technical parameters for labour usage, $CO_2$ requirements and material needs in terms of thick plastic bags and other materials. These requirements were costed in terms of a 2 kg pack of cargo rice using 1999 values.

Postharvest loss assessment, a critical parameter in evaluating benefits from postharvest research, is the extent to which derived improvement in storage practice reduces dry matter or weight losses in the stored commodity. Weight loss in central storage system in Thailand ranged from 1.5 to 3.5 percent with an average of 2.5 percent[8] (Greeley, 1987, cited by Ryland, 1991).

In the economic appraisal of the technology, the price of rice and cost of $CO_2$ were adjusted to reflect their traded values. The analysis was based on the estimates provided by the rice mill trader and the scientists. Information needed for the evaluation includes the starting point for applying this technique, the change in costs, labour requirements, product prices and adoption rate.

Using the ACIAR economic impact model developed by Lubulwa and McMeniman (1998), the benefits from this technique were estimated. The purpose is to determine whether the investment in doing research does provides a benefit. Producer and consumer surplus is then estimated.

The research budget for the postharvest project is used as the cost for analysis by assuming that the budget is equally distributed over the duration of research. The paddy products affected is assumed to be one percent of the total paddy supply in Thailand. It is primarily used for cargo rice packaging. The benefit of the new packaging technique is calculated from the cost and benefit before and after using this technique. It is assumed that postharvest losses fell from 2.5 percent to 1.5 percent using this technique. The cost of packaging is increased due to the extra cost of $CO_2$ and the better grade of plastic bag needed (see Table 1).

An ex-post analysis was made. Estimating economic surplus, the time frame is 30 years (1984 to 2012) and the discount rate applies at 8 percent. Assuming that the maximum adoption rate is 10% of the target group, 15 years after the project started the NPV of this technique over 30 years is greater than zero (Table 2). Even though the NPV result showed the positive impact under the current assumption, there is some indication that, if it proves to be cost effective, vacuum technology may replace the $CO_2$ fumigation technique in the near future.

8. This information was taken from the study of FAO (1977).

**Table 1.** Estimate of annual benefit of the $CO_2$ fumigation technique for milled rice in Thailand

| Items | Unit | Estimated amount |
|---|---|---|
| Paddy production of Thailand[a] | '000 tonnes | 23 580 |
| Milled rice production in Thailand | '000 tonnes | 13 800 |
| Value of product wasted before research | A$/tonne | 8.12 |
| Value of product wasted after research | A$/tonne | 4.1 |
| Additional packing costs – materials | A$/tonne | 0.01 |
| Additional fumigation costs – chemical | A$/tonne | 0.06 |
| Elasticity of supply[b] | | 0.23 |
| Elasticity of demand[b] | | 0.43 |

a. Paddy production in 1997–98 (OAE 1999)
b. Elasticity of supply and demand is after Isvilanonda and Poapongsakorn (1995)

**Table 2.** Economic impact of the $CO_2$ fumigation technique for milled rice in Thailand from 1984 to 2012

| Overall | Unit | (A$) |
|---|---|---|
| Total discounted producer surplus | A$ | 460 270 |
| Total discounted consumer surplus | A$ | 87 431 |
| Total discounted economic surplus | A$ | 547 701 |
| Total discounted research costs | A$ | 18 794 |
| Net present value | A$ | 359 757 |
| Internal rate of return | % | 15.6 |

**Source:** Calculations using ACIAR economic impact model

# 6 Conclusions

Thailand has received some benefits from the project PHT/1983/007, namely scientific knowledge, technology transfer (used by the rice handlers), training and publications. The technology, using $CO_2$ for long-term storage of milled rice in sealed bag-stacks, has not been adopted for the bulk storage, but it has been used to preserve quality and extend the shelf life of consumer-size plastic packs of cargo rice. This is a much smaller scale of operation, which appears to be commercially viable. This technique is found to be very suitable for cargo rice. This is because cargo rice contains some fat and has a rancid smell if left untreated for a few days.

Ex-post economic evaluation was done for the project to determine the returns to the investment. The research budget spent on the project in Thailand is used as the cost for analysis. The benefit of the technology is calculated from the changes in the cost of inputs and changes in the product price between this technique and the conventional one. The time frame for estimating the economic surplus is 30 years (1984 to 2012) and the discount rate is 8 percent. The net present value of this technique over 30 years was estimated to be A$359 757. This suggests that the investment in the project PHT/1983/007 was worthwhile.

On the other hand, because of the disadvantages of the $CO_2$ fumigation technique experienced by the users, other techniques, such as vacuum packing, could be used for the cargo rice market if they proved to be economically feasible.

# 7 Acknowledgments

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# An Assessment of the Research Benefits of Integrated Use of Pesticides in Grain Storage (ACIAR Funded Project PHT/1986/009) in Thailand

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# Contents

# 1 Introduction

Insects and mites are a major cause of grain loss between harvesting and consumption in many countries of Southeast Asia, including Thailand. They cause losses in stored grains and seeds by not only consuming the commodity but also by contaminating it with insect fragments, faeces, webbing, ill-smelling metabolic products and with a variety of microflora. Insects therefore constitute a major sanitation and quality control problem (Snelson 1987). The impacts of these insects and mites on postharvest grain include damage to stored grain by feeding on it, lowering germination, spoiling its appearance, lowering its milling quality, producing off-odours, causing it to heat and creating conditions favourable to the growth of moulds (Snelson 1987). The application of pesticides is a means of helping to achieve desirable levels of loss prevention. Australia is a world leader in the development of grain protectant chemicals, such as pesticides incorporated directly into the grain mass to protect it from insect and mite attack (Davis, 1995). In the project on the integrated use of pesticides in grain storage in the humid tropics that was implemented in Thailand (PHT/1986/009), the techniques of pesticide application in grain storage were transferred from Australia and tested. If the technology provided a better control of insects and mites in stored grains in Thailand, it would help to eliminate insect problems in grain storage. In this paper, an attempt is made to assess the outcomes of project PHT/1986/009, to describe the benefits derived from that project, and to provide a description of the project constraints, which resulted in non-adoption of the techniques developed.

# 2 Description of the project

The project on integrated use of pesticides in grain storage in the humid tropics (PHT/1986/009) began in 1987 and lasted 3 years with a budget of A$97 500 for Thailand. This project complements the research undertaken in project PHT/1983/009 (not undertaken in Thailand) in which effective pesticide treatments for the storage of maize and rice were sought. Therefore, project PHT/1986/009 continues the research of project PHT/1983/009 extending the coverage to legume crops, and also to include Thailand and China. The countries under project PHT/1983/009 included Australia, Philippines, Malaysia and Thailand. The main objective of project PHT/1986/009 in Thailand was to develop an effective pesticide treatment for stored grains, covered rice, maize, mungbeans, soybeans, wheat and groundnuts. However, while a number of commodities were covered in this project, as shown in Table 1, there main emphasis was on rice and maize (Sukprakarn, 1985).

The research activities included: (i) comparing the effects of a range of cereal species on the biological activity of grain protectants, including insect growth regulators; (ii) examining the effects of synergists on the activity of synthetic pyrethroids; (iii) monitoring the effect of phosphine fumigation on germination of seeds fumigated at high moisture levels; (iv) setting up field trials in Thailand to evaluate fabric and grain protectant treatments developed in the project and integrated, where necessary, with fumigation and other control measures; and (v) participation in the ACIAR Grain Storage Research Program macro- and micro-economic studies to optimise the technology and expedite its appropriate placement in the grain industries.

**Table 1** The proportion of the research undertaken on each commodity in project PHT/1986/009

| Rice | Maize | Groundnut | Mungbean | Soybean | Wheat | Total |
|---|---|---|---|---|---|---|
| 65 | 15 | 5 | 5 | 5 | 5 | 100 |

**Source:** Calculated from ACIAR (1990)

# 3 The research impacts

## 3.1 Background

Rice is the main crop cultivated in Thailand. Besides rice, maize is also another important crop. Most farmers in Thailand do not store grains for long periods, except to keep as seed for replanting purpose. Thai farmers normally sell rice or maize products immediately before harvesting or after threshing, because of money requirements. Nearly all grains are kept in the mills or silos ready to be exported or distributed to the local markets. Therefore, grain-protectant activity has been undertaken mainly by the distributors or traders rather than by farmers. This is why little research work on stored grain insects has been done during recent years; most of the research was concentrated on insect pest attack in the field rather than on insects of stored grains (Sukprakarn, 1986). Therefore, project PHT/1986/009 could be considered as important research on the integrated use of pesticides in grain storage at the small-scale level in Thailand.

## 3.2 Research benefits

Davis (1995, p.12) summarised the benefits of the project. He considered that it had a significant effect throughout the world in reducing food losses, as well as producing an effective pesticide treatment relevant to the storage of rice and maize in the humid tropics. In addition, these new initiatives can apply to the storage of other crops such as legumes. The benefits to Australia, the Philippines and Malaysia was estimated to be significant. In Thailand, paddy rice is stored off-farm in processing mills or in specialised storage areas, as well as in bags. A significant amount of milled rice is stored in bags, and therefore needs to be fumigated (Sukprakarn, 1986). However, insecticides have not been commonly used in admixture or on bag stacks. Estimates of losses due to insect infestation vary from 1% to 25%, with commercial storage estimates at 4–5% (ACIAR, 1990). This implies that if these losses can be prevented, it would provide benefits to Thailand by increasing the amount of grain available for sale, particularly rice and maize for local consumption and export. Because Thailand is an exporter of grain, not only are potential weight losses important but also quality downgrading caused by insect infestation and problems of residual insecticides are potential constraints to trade. In summary, the potential benefit of the project could be a significant increase in rice exports.

In practice, however, the potential benefits were not realised, because there was no adoption of the technology from PHT/1986/009. The reason for this is that there is in Thailand no registration system for chemical insecticide used in grain storage (Sukprakarn 1999, pers. comm.). Most grain storage activities in Thailand are undertaken by small and medium enterprises. As the control of chemical residues in grain after spraying is rather complicated, the Thai authorities may have decided that registering the chemicals could have led to overuse, resulting in a serious health threat or a loss of valuable export markets. In contrast, grain storage activities in Australia involve larger enterprises, and so the system of chemical residue control in Australia is more effective.

While there are no realised economic benefits, other benefits derived from project PHT/1986/009 to Thailand include:

- the enhancement of human (researchers and farmers) capacity building (Table 2);

**Table 2.** Human capacity build-up and other impacts of PHT/1986/009

| Published papers | Member with enhanced skill Thai | Giving lectures | | Training | |
|---|---|---|---|---|---|
| | | Rice miller | Department of Agricultural Extension and universities | Short-course | International |
| 2 | 4 | 10 | 15 | 1 | 3 |

**Source:** Sukprakarn 1999, (pers. comm.)

- providing an appropriate technology on the proper use of chemical insecticide in grain, including the scientific equipment; and
- providing a reference point for other research projects.

The published papers are:

- Sukprakarn, C. and Visarathanonth, P. 1989. *Insecticide Control for Stored Maize*, In: Naewbanij, O. (Ed.), Grain Postharvest Research and Development: Priorities for the Nineties. Proceedings of the Twelfth Asian Seminar on Grain Postharvest Technology, ASEAN Grain Postharvest Programme, Bangkok, Thailand.
- Department of Agriculture, *Research and Development Activities on Grain Storage Pests and Their Control*, a paper presented at the workshop on Current Trends in Integrated Pest Management in Grain Storage, 26–29 June 1989, Singapore.

# 4 Conclusion

The technique of chemical insecticide application in grain storage (PHT/1986/009) was transferred from Australia for testing in Thailand. The technology performs well in improving control of insects and mites in stored grains in Thailand at the research station (on-farm trial). That is to say, project PHT/1986/009 could be considered as important research on the integrated use of pesticides in grain storage at the small-scale level in Thailand. The potential benefits of the project are an increase in grain availability (mainly rice and maize) for both local consumption and especially for export. Nevertheless, at present there is no adoption of the technology to farmers from the project PHT/1986/009 in Thailand because of the absence of a registration system for chemical use in grain storage and the lack of an effective control system to measure chemical residue in grains. The existing substances used in Thailand to prevent the loss in grain storage are $CO_2$, methyl bromide and phosphine. In conclusion, the only benefits derived from PHT/1986/009 are enhancements to researcher and farmer knowledge (human capacity building) of the appropriate and proper use of chemical insecticide application in grain, and also as a reference for other research projects.

# 5 Acknowledgments

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# An Assessment of the Realised Impacts of Fungi and Aflatoxin Projects Funded by ACIAR in Thailand

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# Contents

# 1 Introduction

Fungi and mycotoxins have caused serious problems in food and feed stuffs in Asia in recent years because of their high toxicity and carcinogenicity. Lubulwa and Davis (1994) present the potential impacts of fungi and aflatoxin (one of the most important mycotoxins) as follows: (a) fungi are well known spoilage agents in stored foods, where their growth can cause a downgrading of the commodity and, in severe cases, total loss; (b) they have mutagenic and carcinogenic effects on humans who consume aflatoxin-contaminated food over a long period; (c) reductions in livestock health and productivity are caused from the use of aflatoxin-contaminated fodder; and d) there is the loss of export markets because of regulations restricting international trade in aflatoxin-contaminated grains.

In the case of Thailand, agricultural products are important in terms of domestic consumption and exports. Because of the aflatoxin content in agricultural products, some products, peanuts and maize for example, cannot be exported to Western countries, Moreover, there is no regulatory or monitoring system in place to guarantee that the peanuts or maize are low in aflatoxins. If the aflatoxin problem can be overcome or alleviated, peanuts and maize could become very valuable export commodities.

ACIAR contributed research funds for a comprehensive study on fungi and aflatoxin. Phase one was to undertake a comprehensive and extensive survey of the mycological status (both the fungal flora and mycotoxins) of durable food commodities in Asia. Phase two was to study the development of aflatoxins in peanuts, a major crop in Asia that has severe aflatoxin problems.

This paper aims to evaluate an economic impact of the fungi and aflatoxin projects in Thailand funded by ACIAR. There are four sections. After this introduction, a description of the projects is presented in section 2. The technology generated through the projects is described and evaluated in section 3. The conclusions are presented in the last section.

# 2 Description of ACIAR research projects on fungi and aflatoxin

A summary of each of the projects is given in Table 1, while a more detailed description of the tables is given in the following two subsections.

## 2.1 Project PHT/1988/006 on "Fungi and mycotoxins in food and feed stuffs"

Project PHT/1988/006 was a three-year project that was started in 1988. Besides Thailand, the project was also conducted in Philippines and Indonesia. For Thailand, the research funding was about 95% of the total budget (A$988 155). A group of Thai scientists were recruited from the Division of Plant Pathology and Microbiology, Department of Agriculture (DOA) to work on this project. The overall objective was to undertake a comprehensive and extensive survey of the mycological status of durable commodities, with respect to both the fungal flora and mycotoxins. Particular attention was given to rapid methods for identifying toxin-producing fungi. The specific objectives were to:

1. isolate and identify fungi growing in specific commodities and determine the mycotoxins they are capable of producing;
2. assess the significance of each species as a spoilage fungus or mycotoxin producer on the basis of its relative prevalence;
3. develop a computer database of fungi significant in Asian commodities, including incidence, mycotoxins, and factors influencing toxin production;
4. assess the mycotoxin status of each commodity by assaying the samples for specific mycotoxins, samples of major commodities being assayed throughout their postharvest history.
5. attempt correlated fungal invasion with visual deterioration i.e. to develop simple techniques for quality monitoring;
6. train Asian microbiologists and chemists in the standard methods being used, so that mycological and mycotoxin quality can be assessed locally but be comparable throughout the region;
7. explore techniques for simplified or quicker identification of important mycotoxigenic fungi, including development of computer-assisted keys;
8. assess, where appropriate, and within the constraints of the project, the impact of improved handling, drying, and storage procedures on the incidence of both fungi and mycotoxins;
9. where identifiable problems can be pinpointed, seek solutions in collaborations with local authorities and other ACIAR postharvest projects in terms of agricultural practice, handling, drying and storage; and
10. undertake fundamental studies on the influence of environmental factors, especially water activity and temperature, on the growth of, and toxin production by, the more significant fungi encountered. Such data will be of great value in assessing the efficacy of drying and storage treatments designed to inhibit fungal growth and toxin production.

**Table 1.** General information of the projects

| Project no. | Short title | Started | No. of years | Budget (A$) | Organisation involved | Interviewed Person |
|---|---|---|---|---|---|---|
| PHT/1988/006 | Fungi & Mycotoxins in Food and Feed Stuffs | 1988 | 3 | 1,040,163 | DOA | Ms Kanjana Bhudhasamai |
| PHT/1991/004 | Aflatoxin Formation in Asian Peanuts | 1991 | 3 | 379,106 | DOA | Ms Kanjana Bhudhasamai<br>Dr Woothisak Butranu |

In Thailand, 600 commodity samples have been collected to assess their mycological status. Some 367 samples of various crops including maize, sorghum, peanuts, cashews, soybeans, copra, paddy rice, mungbeans, cassava and wheat have been collected from farms, traders and from silo storage. In addition, 233 retail samples were purchased over the same period, comprising black beans, mungbeans, soybeans, red beans, black rice, white rice, cashews, peanuts and sesame seeds.

From these samples, an estimated 14,000 fungal isolates have been cultured and identified, mostly to species level. The results showed that the commodities carrying the highest number of potentially mycotoxigenic fungi were maize and peanuts. Samples taken from further down the distribution chain tended to have higher counts of fungi, and a greater diversity of species than samples taken at the farm and trader levels (see King, 1991).

Two important fungal species commonly produce aflatoxins: *Aspergillus flavus* and *A. parasiticus*. A third, less common species, *A. nomius*, is also capable of producing aflatoxins. In Thailand, *A. flavus*, which was common in most samples of peanuts and maize, produces B aflatoxins and sometimes cyclopiazonic acid, while *A. parasiticus* produces B and G aflatoxins, but was not detected in any maize samples. *A. nomius* can produce both B and G aflatoxins, but appears to be relatively uncommon. *A. nomius* was detected occasionally.

A second potentially important species is *Fusarium moniliforme*, which occurred frequently in maize samples. *F. moniliforme* can produce fusarins and, probably more importantly, fumonisin mycotoxins. *F. moniliforme* toxins have been shown to cause diseases in humans.

Regarding the mycotoxin status of commodities, aflatoxin was detected in a number of maize samples and in retail peanut samples and in occasional samples of sorghum and soybeans. Concentrations of aflatoxins detected in these commodities were relatively high.

In conclusion, there were aflatoxin problems with two of the 18 crops surveyed. For example, *A. flavus* and aflatoxin at high concentrations were present in many of the peanut and maize samples from Thailand. Levels of aflatoxin in retail peanut samples ranged up to 550 µg/kg and in maize up to more than 4000 µg/kg. The acceptable limit for total aflatoxin in peanuts in Australia is 15 µg/kg.

## 2.2 Project PHT/1991/004 on "Factors affecting invasion by *Aspergillus flavus and Aflatoxin formation in Asian peanuts*"

Project PHT/1991/004 was a two-year project that started in 1991. Research funding was about A$379,106. A group of Thai scientists from the DOA worked on the project. The overall objective of this project was to clearly define the time of entry of *A. flavus* into Asian peanut plants and developing nuts, and the relationship of that time of entry to aflatoxin production. This issue is important because vastly different processes for the control of aflatoxin production in grain are required depending on whether invasion and production of aflatoxin occur before or after harvest. As a consequence of this information, a program will be designed to test ways to reduce such invasion, with the ultimate aim of reducing levels of aflatoxins in these commodities. The specific objectives of project PHT/1991/004 are as follows:

1. In collaboration with the DOA in Thailand, to monitor peanut crops for the presence of *A. flavus* from the time of planting, through nut development, to harvest and storage. In other words, to clearly establish the main times of *A. flavus* entry into peanut plants and nuts.
2. At the same time, to assess the development of aflatoxins in the nuts, again over the whole time span of nut development, harvest and storage.
3. To positively identify *A. flavus* and *A. parasiticus*, together with the related species *A. nomius*, and hence to determine the comparative distribution of these species in Thai peanuts and soils used for peanuts.
4. Using this information, to assess the efficacy of techniques, currently under development at the Food Research Laboratory (FRL) in Australia, for reducing *A. flavus* invasion under Asian field conditions.
5. If such experiments are successful, to plan field trials of one or more promising techniques.
6. In glasshouse studies at FRL, to carry out preliminary studies on *A. flavus* and *A. parasiticus* invasion in maize.

Objectives 1–3 were the responsibility of the Thai scientists. The Australian partners took responsibility for objectives 4 and 6. With regards to objective 5, there was no promising technique developed through the research. Research outcomes are summarised below.

For representative results, the study of *A. flavus* infection in peanuts covered a range of climatic and cultural conditions. Therefore, studies were carried out at three districts of Chiang Mai, Khon Kaen and Suphan Buri provinces. Two, and then later three, farms were studied throughout each growing season to assess the levels of *A. flavus* in peanut seed, the developing plants, and the nuts before and after harvest, including the soils before and after planting. The farmers used the normal technology and cultural practices for peanut cultivation at each location.

Growing peanut plants and developing nuts were sampled every two weeks throughout the growing season of 12–16 weeks. Where feasible, samples were also taken from kernels after harvesting, on farms or in trader storages and at retail outlets. Plant parts and kernels were surface disinfected in chlorine (10% household bleach, 2 minutes) then plated on Aspergillus Flavus and Parasiticus Agar (AFPA) (Pitt and Hocking, 1991). After 3 days incubation, particles infected with *A. flavus* (plus *A. parasiticus* and *A. nomius*[3]) were counted, recorded on data sheets and forwarded to the Division of Food Science and Technology (DFST), CSIRO for collation. Percentage infection rates were calculated. Two soil samples were also taken from each site before and after planting, dried, frozen for two weeks and forwarded to DFST via the Australian quarantine system.

Results indicated that levels of infection in developing plants and peanuts under Thai field conditions are usually low. Invasion of fungi in peanuts increases after harvest, during drying on both farms and in trader storages. *A. flavus* infection became higher at harvest and during storage and distribution of rainy season crops than dry season in three locations. However, these results were based on one trial only. In reality, an unacceptable level of aflatoxins can occur pre-harvest if the plant is stressed (Johnson, pers. comm. 2000)

Other results indicated that if a significant level of *A. flavus* invasion occurs before peanuts are harvested, this would provide encouragement that competitive nontoxigenic *A. flavus* may be an effective method for reducing aflatoxin (see Miller, 1993; Pitt et al., 1994) by inhibiting growth of toxigenic *A. flavus*. Since project PHT/1991/004 began, interesting results using a nontoxigenic mutant of *A. parasiticus* in this manner at the National Peanut Research Laboratory in Dawson Georgia, USA, have been report (Dorner et al., 1992; Kinzel, 1992 cited by Pitt et al., 1994). Nontoxigenic *A. flavus* introduced into peanuts preharvest may compete effectively against toxigenic *A. flavus* during drying and storage. There is a real possibility that the infection of peanuts by competitive nontoxigenic *A. flavus* can reduce final aflatoxin levels without any major change to harvesting, drying or marketing practices.

3. *A. parasiticus* and *A. nomius* are rare in Thai field conditions.

# 3 Economic impact of fungi and aflatoxin projects

## 3.1 Technology and scientific knowledge generation through research

So far, these ACIAR-funded projects on fungi and aflatoxin have not developed a new technology for solving the problem of fungi and aflatoxin in agricultural products at field level. However, the basic scientific knowledge that was discovered through the projects has been used as input for further studies. In this section, the benefits in terms of scientific knowledge, technology transfer (used by the scientists) and publications are described.

### *3.1.1 Project PHT/1988/006 on "Fungi and mycotoxins in food and feed stuffs"*

*Scientific knowledge*

This research has comprehensively defined the fungal flora and associated mycotoxins in major durable commodities in Thailand. It acts as an indicator of the status of commodities in Southeast Asia. This has never been done before, and is a significant achievement, adding greatly to the world knowledge of fungal spoilage of tropical stored commodities, and the consequent potential for mycotoxin formation (King 1991). This information provides an increasing of awareness of a serious public health problem in Thai foods and feed stuffs from mould spoilage and mycotoxins. The scientific knowledge from this project is defined as a primary step in improvement of the long-term health of human and animal consumers of those commodities.

A database of food commodities, and the fungi and mycotoxins that they may carry, was developed and installed in the five locations of the project. It is being used to collect data for ultimate summarisation. There are about 20 research publications from project PHT/1988/006 (Table 2).

Benefits have already flowed to participating countries in terms of training. Two researchers from Thailand have received training in standard methods for isolation and identification of fungi and mycotoxins in foods. These skills are rare and are particularly needed in tropical climates where fungal food spoilage is a constant problem.

FRL has developed a standard technique (Pitt and Hocking, 1991) for mycological examination. This technique was introduced to Thai scientists through PHT/1988/006. The technique of direct planting after surface disinfection generally limits growth to those fungi which have been present inside the kernels or particles at the time of planting, so the figures represent true fungal growth, not surface contamination. Originally, potato dextrose agar (PDA) was used for mycological examination in Thailand. It takes about one week for incubation, then the fungi is isolated and cultured for another one week (purification). After two weeks, the scientists are able to identify whether it is *A. flavus* or not. PDA is simply not suited to the growth of storage fungi (Pitt and Hocking, 1991). Working with this project, Thai scientists used standard technique to identify storage fungi (*A. flavus and A. parasiticus*) by using Aspergillus Flavus and Parasiticus Agar (AFPA). AFPA is recommended for the detection and enumeration of *A. flavus* and other potentially aflatoxigenic fungi (Hocking, 1982, cited by Pitt and Hocking, 1991). When incubated at 30°C for 48 to 60 hours, bright orange yellow reverse colours distinguish colonies of

**Table 2** Research publications from the projects

| Project No. | Book | Journal | Papers | | Total |
|---|---|---|---|---|---|
| | | | Workshop | Other | |
| PHT/1988/006 | 1 | 1 | 8 | 10 | 20 |
| PHT/1991/004 | 1 | 0 | 6 | 7 | 14 |

*A. flavus* and *A. paraciticus*. The advantages of AFPA for routine use include rapidity, as a 48 hours incubation period is usually sufficient; specificity, and simplicity as little skill is required in interpreting results. As a consequence, it can be a simple, routine guide to possible aflatoxin contamination (Pitt, 1984, cited by Pitt and Hocking, 1991). On the other hand, the cost of preparing AFPA is relatively high compared with PDA, but it is more efficient in terms of results and time saving.

Additionally, Thai scientists have applied the technology package for the systematic identification in fungi and mycotoxins in foods and feed stuffs that they learned (knowledge and facilities) from doing research on fungi and mycotoxin with different partners from, for example, Japan, the USA and Australia.

Technology or knowledge on "taxonomy" from this project has been distributed to government and private company officers who work in the same field. This can be thought of a technology transfer that provides high benefits. So far, eight training workshops have taken place with 30 participants per workshop. Additionally, the workshops are conducted for practical purposes to students from Thai universities 2 or 3 times a year. This can be classified as human resources development. As a result of training activities associated with the project, the pool of personnel with the skills needed to identify moulds and mycotoxins has increased. Training has been identified as a primary factor in addressing fungi and mycotoxin problems in the developing countries of the region.

#### *3.1.2 Project PHT/1991/004 on "Factors affecting invasion by* Aspergillus flavus *and aflatoxin formation in Asian peanuts"*

Under this project, Thai scientists acted as collaborators doing field experiments, fungi and mycotoxin identification and data collection. Thai scientists used the technique that they were trained in at the FRL to identify *A. flavus* in the peanut crops. An understanding of *A. flavus* invasion in susceptible crops, such as peanuts, is a prerequisite to projects designed to actually reduce and eliminate aflatoxins from foods and feed stuffs. For example, it is now know that, when the soil moisture content is consistent during the growing period, *A. flavus* infection does not produce aflatoxins until after the peanuts are harvested. However, when the soil moisture content fluctuates, this induces high level of *A. flavus* during the growing period (Butranu et al., 1994). As a result, suggestions were drawn from this scientific knowledge to reduce or even eliminate the incidence of aflatoxins in peanuts. The suggestions included drying after harvesting, storing peanuts for no more than four weeks, rapid movement of peanuts to processing, planting peanuts in the wet season and so on. Hence, the scientific knowledge is useful not only for the scientists, but also for the farmers, food processors and consumers.

There are about 14 research publications from PHT/1991/004 (Table 1).

The underlying objective of PHT/1991/004 was to learn the extent of the existing problem of aflatoxins in peanuts, rather than to solve the problem itself. Consequently, PHT/1991/004 has minimal impact on Thai communities. Thai scientists benefit from the training in research methods, mycology and toxicological assay techniques. Australian scientists might benefit from this project by obtaining valuable data for the Australia project on aflatoxin formation in peanuts (Pitt et al., 1994).

## 3.2 Economic impact of technology generated through research

Since the projects have not developed any new technology for solving this problem, the economic impact of the technology cannot be assessed. Nevertheless, this section summarises the economic impacts of the fungi and aflatoxins projects collected from other relevant reports.

The economic impact of aflatoxins in Asian foods and feeds is largely unknown, but is probably higher than suspected. Aflatoxins are insidious poisons, with the highest impact on those who eat the poorest food and who, because of weaker defence mechanisms, are most susceptible to aflatoxicoses. Aflatoxins also increase the difficulties involved in the small-scale commercial production of domestic animals and birds. Young animals, and especially poultry, are highly sensitive to aflatoxins, and starter rations free of aflatoxins can be very difficult to obtain on a continuing basis in Asia.

There are two aspects to significance of the aflatoxin problem: economic losses and medical issues. When the Thai authorities eventually adopt a regulatory system for checking commodities for aflatoxins and removing unsatisfactory lots from human food supplies, the cost will be substantial. In Australia, the cost of aflatoxin removal from the peanut crop has been conservatively estimated as 3% of total value. Similar figures in Thailand would suggest a cost of A$2.46 million for the 1996–97 financial year. Much of this cost is associated with chemical testing for aflatoxins, and the cost of materials for the tests is such that savings due to lower labour costs would be minimal. The possibility of developing an export market for Thai peanuts would be a bonus.

The medical cost of aflatoxins in Thailand and other Southeast Asian countries is very difficult to quantify, but is unacceptably high. Deaths in Asia from liver cancer, associated with aflatoxins from the consumption of peanuts and maize, are believed to be much higher than that in Western countries, both because of the high levels of aflatoxins currently being consumed, and the co-carcinogenicity of the hepatitis B virus, which is endemic in Asia.

If the project can develop any method or technology to reduce the aflatoxin problem in agricultural products, especially peanuts and maize, the main beneficiaries of the results of these projects will ultimately be consumers of staple foodstuffs in developing countries in Southeast Asia and elsewhere. Benefits will take the form of higher quality, more nutritious food, free from contamination by mould toxins. Other benefits will flow to the grain industries of these countries through the reduction of monetary losses caused by downgrading or loss of commodity because of fungal damage.

Even though these projects have not developed new technology to solve the problem of fungi and aflatoxin in agricultural products, especially peanuts and maize, the welfare impact, presented by Lubulwa and Davis (1996), indicated the potential benefits if the technologies were developed and adopted.

Lubulwa and Davis (1996) presented economic assessment of the cost and potential benefits from PHT/1988/006 and PHT/1991/006. The focus of their assessment was on aflatoxin-contamination of peanuts and maize, and its impact on human health and animal production. It was estimated that substantial benefits will accrue from technological advances in the pre- and postharvest practices likely to be stimulated by the research. While a new technology has not been developed from the work carried out in PHT/1988/006 and PHT/1991/006, the projects do provide the scientific basis and the justification for the development of a technology that could lead to the benefit. Therefore, in the Lubulwa and Davis (1996) study, it was assumed that the technologies, which use the information generated under PHT/1988/006 and PHT/1991/006, were developed in 6 years after the completion of the projects. There was no cost for the technology and no cost occurred at the farm level. Possible technologies included in the analysis by using information to change decision-making or resource-use practices as follows: (a) aflatoxin regulations to limit exposure of human and livestock populations to aflatoxins in grains; (b) improved grain-pricing regimes which reward production of aflatoxin-free grains; (c) selection of cultivars of maize and peanuts that are aflatoxin resistant; (d) use of non-toxicogenic fungi to competitively exclude the toxicogenic fungi; (e) better drying methods for grains; and (f) chemical methods to detoxify or decontaminate aflatoxin-contaminated grains. There were two scenarios, namely an optimistic ‘free lunch’ scenario and a scenario involving a farm-level aflatoxin control method that leads to an increase in farm-level costs (equal to 10% of the farm-gate price). Commodities included in this analysis were maize, peanuts, pork, poultry meat, and hen eggs. The economic assessment results showed that benefits were distributed as follows: Indonesia by A$542 million, Philippines by A$177 million, Thailand by A$133 million and rest of the world by A$85million. The net present value (NPV) was A$936 million and internal rate of return was 69%. With an increase in farm-level costs, it would reduce the NPV of benefits from A$936 to A$901 million and the internal rate of return would drop slightly from 69% to 68%.

# 4 Conclusions

Project PHT/1988/006 on fungi and mycotoxins in food and feed stuffs generated important scientific information, which increased awareness of a serious public health risk in Thai food and feed stuffs because of mould spoilage and mycotoxins. The levels of aflatoxins in Thai peanuts and maize are high and are undoubtedly the major source of aflatoxins in human and animal diets. One of the important benefits of the project is the transfer of standard technology for isolation and identification of fungi in food and feed stuffs to government officials, private companies, and university students. These skills are needed in Thailand not only in research work but also in controlling agricultural products (quarantine service).

However, there has been limited follow-up among scientists from the project. Even though one of the project's objective was to develop a computer database of fungi significant in Asian commodities, including incidence, mycotoxins, and factors influencing toxin production, Thai scientists have not received any information on fungi and aflatoxin in food and feed stuffs in Indonesia and Philippines. It would be useful if a collaboration developed among these scientists.

Knowledge on high aflatoxins in peanuts led to the study on factors affecting *A. flavus* invasion and aflatoxin formation in Asian peanuts (PHT/1991/004). Thai scientists acted as collaborators, doing field experiments, identifying fungi and mycotoxins and collecting data. The experience of the Thai scientists was that after forwarding data from the field experiments to the Australian partners, the Thai scientists have not received any contribution. This is perhaps due to the fact that the project has been discontinued.

An understanding of *A. flavus* invasion in peanuts is essential for projects designed to reduce or eliminate aflatoxins from foods and feed stuffs. The aim of this project was to learn the basis of the existing problem of aflatoxin in peanuts, rather than to solve the problem itself. However, the experience obtained from the projects, including previous knowledge, were used to frame some suggestions for eliminating aflatoxins and distribute to the farmers, food processors and consumers. Nevertheless, the problems of aflatoxins in foods and feed stuffs in Thailand remain in urgent need of attention, on both economic and medical grounds.

# 5 Acknowledgments

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# An Impact Assessment of ACIAR Project on Replacing Fishmeal in Aquaculture Diets in Thailand

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# Contents

# 1 Introduction

Fish are the most important source of animal protein for people in every part of Thailand. The Office of Agricultural Economics (OAE) estimated that domestic demand during 1989–1997 increased almost 15% annually. OAE also estimated that the current annual growth rate of farm value rose significantly each year (OAE). As the population continues to grow, demand for fish was expected to escalate by about 1 million tonnes by the year 2000. As a result, expanding fish consumption may extend into fishmeal products.

In Thailand, the demand for fishmeal has increased sharply with the rapid expansion in animal farming (including aquaculture), resulting in an increase in the price for fishmeal (sse Jantrarotai, 1995; Jantrarotai et al., 1995, 1996). During 1988, prices for fishmeal increased 27.8% as supplies of "trash fish" decreased . In 1957, 48% of the total fisheries catch was consumed fresh while 52% was consumed as processed fish. By the early 1990s, this balance had changed, with only 16% of total fisheries catch consumed fresh, 42% consumed processed, and 41% used for fishmeal production. This increase in fish for fishmeal has created problems in the supply of fish for human consumption.

During 1994, ACIAR provided financial support for a study of the feed formula to improve quality and shorten the production period of catfish. This project is designated FIS/1992/007, "Replacing fishmeal in aquaculture". As fishmeal supply is critical for the fast-growing aquaculture industry in South and Southeast Asia, the industry needs to reduce its reliance on low quality fish from capture fisheries as a source of fishmeal, which severely impacts on the supply of fish for low-income families. Project FIS/1992/002 examined alternative non-fish feed ingredients and evaluated their digestibility and food value. The scientists tested promising new ingredients in gradual amounts as substitutes for fishmeal, striving to provide an optimum balance of protein, fats and carbohydrates. The project linked into a diversity of scientific disciplines including aquaculture nutrition, terrestrial animal nutrition, biochemistry, biotechnology and food processing.

The main objectives of project FIS/1992/007 were to:

- review available ingredients, which have potential in combination with other ingredients, to replace fishmeal or trash fish in acquaculture diets;
- determine the digestibility of alternative protein source of fishmeal;
- formulate, using digestibility diets, nutritionally balanced diets, using alternative ingredients to trash fish fishmeal and compare performance of fish on these diets with that of fish on fishmeal diets;
- determine optimum protein requirements and the potential for replacing sparing amounts of protein using fat or carbohydrate; and
- determine the potential use of commercially available, synthetic amino acid supplements in fish diets.

Therefore, the advantages of the project are:

1. the development of cost-effective diets, based on alternative protein sources for fish;
2. an increase in aquaculture production of fish protein result in lower price for these products;
3. an increase in the use of alternative protein sources to fishmeal;
4. a reduction in the dependence on fish and fishmeal for aquaculture feeds;
5. a reduction in the pressure on capture fisheries; and
6. an increase in the marketing opportunities for agricultural products.

This paper attempts to draw inferences about the impact of ACIAR project FIS/1992/007 on farmer welfare, by using data and information collected in the field survey. In this section, the background to the project has been presented. In section 2, a summary of the available data and of the characteristics of the project that are used in the preliminary assessment is given. The analytical framework for the study is given in section 3, while a description of the statistical methods and results is presented in section 4. The conclusions are contained in section 5.

# 2 General characteristics of the projects in the preliminary assessment

## 2.1 Overview and expected benefits of project FIS/1992/007

The need to replace fishmeal in aquaculture diets has been accepted as a major research priority in the international community. A large number of studies has already been done but most of these have not been well coordinated and often have not assessed the digestibility or availability of alternatives to fishmeal as protein sources for the target species. This flaw has often prevented this work being transferred to industry. Therefore, the research conducted by ACIAR project FIS/1992/007 differed from most previous work on replacing fishmeal in that a systematic approach was undertaken. A wide range of alternative feed ingredients was critically evaluated and the digestibility of these ingredients to target aquaculture species was determined. On the basis of digestibility results, new ingredients were used in the experiments where graded amounts of these ingredients were used to replace “trash fish” or fishmeal. Data on locally available ingredients with potential for use in feeds prepared on-site for hybrid catfish were used in linear least-cost computer programs to formulate nutritionally-balanced feed mixes. Farmers were provided with a selection of recipes, which took into account variability in the cost and availability of ingredients in the different regions and allow them to mix the most nutritionally balanced feed possible. This was expected to benefit catfish farmers in Thailand.

In addition to the expected major economic benefits to Thailand there is another lesser known benefit. This is that a substantial proportion of the “trash fish” and fishmeal currently used in aquaculture diets can be replaced with a cheaper substitute. Therefore, the cheaper diets and lower production costs will lead to greater production and profits for low-income fish farmers. On the other hand, lower prices for farmed fish will also increase the availability of fish protein for human consumption.

## 2.2 Expected impacts

### *2.2.1 Environmental impacts*

It was expected that this project would address the environmental issue of feed composition. Research into determining optimum protein and energy requirements would lead to diets that produce less wastage. Minimising total protein content in diets would also minimise total nitrogen output in effluent water.

### *2.2.2 Gender impacts*

It was expected that this project would benefit rural men and women, lead to increased incomes, better nutrition and improved family life.

## 2.3 Research inputs

The overall objective of the project was to develop cost-effective diets for catfish in Thailand. This project was conducted for a three-year period. However, to effectively transfer the technology during this period to low-income fish farmers throughout Thailand and to develop cost-effective feeds on a commercial basis requires additional time.

To achieve the objective, ACIAR provided research input is shown in Table 1. The table summarises the average inputs to the project, such as money, time and personnel. The average budget of the project was A$277 696 and the length of the project was three years. Some 30 Thai researchers and research assistants worked on the project.

**Table 1.** Research inputs of project

| Research input | |
|---|---|
| ACIAR’s budget | A$277 696 |
| Length of project | 3 years |
| Number of Thai research participants | 30 |

## 2.4 Catfish production in Thailand

As shown in Table 2, catfish production has increased over the past twelve years ending 1995, while catfish prices were quite stable during that time. This implies that the catfish farmers expanded their production to meet the market demand for catfish. This lead to an increase in the quality of the catfish supplied to market at the same time.

There were estimated to be about 20,919 catfish farms in Thailand in 1995 (OAE). The largest number of catfish farms are located in the southern part of the country, while the main production of catfish comes from the central plain with an area 6092 million rai (975 million ha [1 rai = 1600 $m^2$]) (see Table 3.) However, interviewing the catfish farmers revealed that there is an imbalance in the consumption and production of catfish within the region. Almost 50% of the catfish farm production in the central plain was exported to other regions.

**Table 2.** Catfish production in Thailand

| Year | Area of catfish cultivated (rai) | Price (baht/kg) |
|---|---|---|
| 1984 | 2206 | 29.58 |
| 1985 | 3397 | 30.80 |
| 1986 | 3883 | 22.64 |
| 1987 | 3314 | 28.44 |
| 1988 | 3895 | 31.52 |
| 1989 | 5478 | 30.32 |
| 1990 | 7060 | 26.87 |
| 1991 | 9415 | 25.32 |
| 1992 | 13326 | 24.85 |
| 1993 | 15220 | 25.06 |
| 1994 | 19189 | 23.90 |
| 1995 | 23562 | 25.68 |

**Source:** Office of Agricultural Economic

**Table 3.** Number of catfish farms and area in catfish cultivation

| Region | No. of farmers | Area (rai) |
|---|---|---|
| Country | 20919 | 23562 |
| Northern | 3618 | 4035 |
| Central plain | 1639 | 6092 |
| Eastern | 1454 | 4168 |
| Western | 755 | 2785 |
| Southern | 11040 | 3958 |
| North Eastern | 2350 | 2543 |

**Source:** Office of Agricultural Economics

**Table 4.** Catfish feed and wholesale prices: 1980–1998

| Year | Unit/kg | Baht/kg | Wholesale price (baht) |
|---|---|---|---|
| 1980 | 20 | 6.00 | 120.0 |
| 1981 | 20 | 6.72 | 134.4 |
| 1982 | 20 | 7.44 | 148.8 |
| 1983 | 20 | 8.16 | 163.2 |
| 1984 | 20 | 8.88 | 177.6 |
| 1985 | 20 | 9.60 | 192.0 |
| 1986 | 20 | 10.32 | 206.4 |
| 1987 | 20 | 11.04 | 220.8 |
| 1988 | 20 | 11.76 | 235.2 |
| 1989 | 20 | 12.48 | 249.6 |
| 1990 | 20 | 13.20 | 264.0 |
| 1991 | 20 | 13.92 | 278.4 |
| 1992 | 20 | 14.64 | 292.8 |
| 1993 | 20 | 15.36 | 307.2 |
| 1994 | 20 | 16.08 | 321.6 |
| 1995 | 20 | 16.80 | 336.0 |
| 1996 | 20 | 17.52 | 350.4 |
| 1997 | 20 | 18.24 | 364.8 |
| 1998 | 20 | 19.00 | 380.0 |

# 3 Research evaluation framework and zones of adoption

The expected outputs of research project FIS/1992/007 can be separated into two parts. First, it has produced publications that are used at the academic level. The number of publications can be seen in Table 5. The table indicates that about 40% of the completed research papers have been published in journals. Other papers include conference and workshop papers and a chapter in a book.

**Table 5.** Number of publications

| Type of publication | No. of publications |
|---|---|
| Book/chapters in books (at least one) | 2 |
| Journal papers (at least one) | 6 |
| Conference/workshop papers (at least one) | 2 |
| Other (booklets, video tapes, theses, etc.) | 7 |

**Sources:** Project FIS/1992/007

Second, the project's major effect on the catfish farmers will be to improve their net profitability. To measure this effect, the concept of economic surplus will be employed.

The effects of research output on production costs are hypothesised by using a simple non-traded goods framework. The two tasks that comprise the economic surplus model are the target zone of adoption and the benefit–cost analysis.

The return on research investment depends on extending the calculations by the target zone of adoption, while benefits in the zones of diffusion were calculated as net additional incomes over the base level of investment.

## 3.1 Potential adoption

To estimate adoption rate, the central plain was chosen as the sample area for collecting the data. The survey result shows that 7–10% of farmers would adopt this technology, especially farmers who lived near the experimental site, while the farmers who lived in other regions, such as people in southern, northeastern, western, and eastern regions, cannot adopt this technology. The main reasons for the adoption was that the farmers who live close to the experimental site could get information quite easily. However, there are some farmers who refused to use the technology. The reasons are that they are familiar with traditional production and the new technology is too complicated for them. The major complication is that they have to buy a machine for mixing the ingredients of fishmeal. Therefore, the technology will benefits the farmers who are sharing or integrating their production.

## 3.1 Barriers to adoption

The basic farm cost structure, which was estimated by the field survey, shows that almost 70% of total costs come from feed meal. This indicates that the benefits from new technology will result in improved farmer income by reducing unit cost. Moreover, the survey data imply that the expansion of catfish farms is dependent on catfish market price, which is different between regions. The reason for the market price difference is that the major costs of production are also different by region. There is a variety of different technologies that farmers can use to mix catfish feed. Most of the farmers are familiar with the traditional way but there are some using new technology.

The effect of the research on farmer welfare will be calculated based on all the above-mentioned information. However, it is not easy to do because the incremental benefit after the project implementation could not be calculated because of the limitation of the information about the demand for catfish between regions which is used to estimate elasticity of demand by region. In addition, some information about the cost of catfish production was not available during the collection of the data.

# 4 Conclusion and recommendation

This paper has discussed the impact of ACIAR project on replacing fishmeal in aquaculture diet. This study suggests that this research could be very beneficial to catfish farmers who accept and incorporate the new technology. However, a major problem is how to increase the adoption rate of the new technology. To make the research more profitable and applicable, it is recommended that government should budget to extend this information to the farmer.

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# An Impact Assessment of the Livestock Research Projects in Thailand Funded by ACIAR

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# Contents

# 1 Introduction

Livestock research plays an important role for the development of many developing countries such as Thailand, where agriculture is still a mainstay of the country. Besides crop production, livestock are raised on almost every farm in Thailand. In rural areas, native chickens are commonly found around the house as the main source of protein for home consumption. Buffaloes and cattle are commonly raised for both draught and meat. Seventy percent of buffaloes in Thailand are raised in the north-eastern region mainly for draught in areas where machinery is rather difficult to use. Swine are also normally raised for both home consumption and for sale. As livestock production is widespread throughout the country, sanitary management, especially disease control, is very important. Hence, research related to the control of livestock diseases is crucial. ACIAR has funded several livestock research projects in Thailand. Five important ACIAR livestock research projects are evaluated in this paper. This evaluation starts by describing each project. The impact analysis is done next by summarising the research activity, defining the main research findings, and finally, where possible, assessing the benefits derived from the project.

# 2 Description of ACIAR research projects on livestock in Thailand

## 2.1 Research and development of foot-and-mouth disease diagnostic methods in Thailand (AS1/1983/067)

This project started in 1985 with a duration of 4 years and a budget of A$583 028. The objectives were: (i) to develop and implement improved foot-and-mouth (FMD) virus typing method; (ii) to develop and apply appropriate FMD virus isolation procedures; (iii) to determine the antigenic variation of FMD virus types in Thailand; (iv) to improve procedures for antibody measurement and application to vaccine evaluation and epidemiological investigations; and (v) to accurately estimate 140s antigen in FMD vaccine batches (ACIAR, 1985).

## 2.2 Diagnosis and control of foot-and-mouth disease in Thailand (AS1/1988/035)

Project AS1/1988/035 started in 1989 with a duration of 3 years and a budget of A$681 093. This project followed on from AS1/1983/067 and was based on similar principles. The objectives of project AS1/1988/035 were: (i) to develop improvements to diagnostic procedures required for field studies of FMD; (ii) to develop improved FMD strain differentiation procedures; (iii) to monitor the distribution of virus types and antigenic variation of field isolates of FMD virus; (iv) to monitor the efficacy of vaccination procedures by assessing the serological responses and investigating the disease in livestock; and (v) to assess benefits and costs of FMD control in Thailand. Also, the economic analysis has been done in more detail under the ACIAR project AS1/1992/004, entitled "Improved methods in diagnosis, epidemiology, economic and information mangement in Australia and Thailand".

## 2.3 Evaluation of different buffalo genotypes (AS2/1985/015)

Project AS2/1985/015 started in 1985, lasted 3 years and had a budget of A$85 618. The objectives of the project were: (i) to research comparative studies of growth and physiological characteristics of swamp, murrah, and crossbred buffaloes by on-station research; and (ii) to study variations in draught power by on-farm research (ACIAR, 1989).

## 2.4 Genetic identification of strains and genotypes of buffaloes and goats in Southeast Asia (AS1/1983/064)

This project started in 1986, lasted 3 years and had a budget of A$407 092. The main objectives of the project were: (i) to estimate gene frequencies at biochemical loci in populations of buffaloes in Australia, Indonesia, Malaysia, the Philippines, Thailand and Sri Lanka; and goats in Indonesia, Malaysia, the Philippines, Thailand and Sri Lanka; (ii) to estimate the genetic similarity of populations using the data generated from the first objective; (iii) to analyse the pattern of inheritance of biochemical markers and chromosomal segregation in F1 and F2 generations, and backcross river to swamp crossbred buffaloes; and (iv) to correlate the presence of biochemical alleles and chromosome composition with performance in terms of economic traits such as draught power, reproduction, milk production or feed utilisation, using research results of project (AS2/1985/015) for both biochemical and chromosomal analyses (ACIAR, 1986, 1990).

## 2.5 Newcastle disease in village chickens (AS1/1987/017)

The project started in 1988, lasted 4 years and had a budget of A$228 738. The main objective, which involved laboratory research, was to look at the question of how well the virus, when used as a vaccine, survives when applied to different feed vehicles, and to study aspects of the immune reaction within and between birds. In Thailand, the mains focus of the trials was on a comparison of the HRV4 vaccine administered orally through various feed carriers and drinking water, with conventional vaccination (ACIAR, 1998). Furthermore, efficacy and challenge trials were done, and laboratory style trials were undertaken to improve the vaccine with respect to conferring protection and being safe to use. In addition, the pilot trials with this laboratory work were set up in selected villages. The data were collected by household interviews and estimation of the health, productivity and economic response of chickens (Johnston and Cumming, 1991).

# 3 Impact assessment of the control of foot-and-mouth disease in Thailand (AS1/1983/067 and AS1/1988/035)

Foot-and.mouth disease (FMD) is an important disease that affects small and large ruminants in many countries in Southeast Asia, such as Thailand, Laos, Myanmar, Cambodia, and the Philippines (ACIAR 1988, p.8). In general, FMD appears as a highly contagious disease of cattle, buffalo, pigs, sheep, goats and wild ruminants. It can cause fever, vesicles on the feet, mouth and udder, and death in young animals (OIE 1996, cited by Harrison and Tisdall, 1997, p.1). In Thailand, FMD is a major cause of death in young piglets, and of lost production in intensive rearing areas. In addition, infection of FMD on cattle and buffalo results in the reduction of draught capacity and milk production. The presence of FMD in Thailand affects the amount of pig and cattle meats exports and the potential for export markets in Singapore, Japan and Europe (ACIAR, 1988). Hence, the control of FMD is crucial. In addition, the research of types and subtypes of the present FMD virus is essential in choosing the appropriate vaccine. Development of laboratory tests for the diagnosis and typing of FMD is a high priority.

## 3.1 Research findings of the control of foot-and-mouth disease (FMD)

The first phase of the control of FMD was done through AS1/1983/067 by researching and developing FMD diagnostic methods. In general, there are seven serotypes of FMD virus of which three exist in Thailand (serotype A, O and Asia 1). Vaccination against one type does not offer protection against other types. In addition, within each type there are several subtypes, which may or may not provide cross immunisation. The requirements for a successful control of FMD include appropriate type and subtype of vaccines; sufficient vaccine production capacity; facilities for the distribution and storage of vaccine (a cold chain); adequate personnel to deliver vaccine to the target species on a regular basis; and restrictions of the movement of animals to prevent the spread of the disease. The highest priority of AS1/1983/067 was to improve isolation and typing methods.

Antigenic variation of FMD serotypes, especially type A and to a lesser extent Asia 1 and O, has been investigated by virus isolation and ELISA procedures to replace the neutralisation test, a standard method. However, a technical problem in obtaining correlations between 146 antigens measured by the ELISA method compared with the standard method was encountered. Hence, further development and investigation was still required (ACIAR, 1988).

Later, AS1/1988/035 was continued. The constraint the ELISA technique faced in the first phase was eliminated. The major achievement of the second phase was the successful development and verification of the modified liquid phase ELISA test for measuring antibodies to FMD. The ELISA technique was found to provide comparable results to serum neutralisation tests, but had an advantage in terms of a rapid method for early warning of a potential major antigenic shift of outbreak virus strains. Additional research findings were (ACIAR 1994, pp.15–17):

- *Calfhood vaccination*. A primary immunisation course of two vaccine doses one month apart, commencing at 6 months of age, and then followed by a twice annual booster dose, provides substantially better immunity than a single dose of vaccine at 6 months of age followed by twice annual booster doses.
- *Herd immunity in response to mass vaccination campaigns*. A computer model was developed to predict herd immunity levels in cattle populations after vaccination. The model was used to determine the serological responses for a large group of cattle (272) vaccinated under village conditions in northern Thailand.
- *Three high risk factors for FMD in villages of northern Thailand*. The three high risk factors were found to be: (i) when new cattle and buffaloes are purchased and introduced to the villages; (ii) when there are co-mingling of cattle with those of neighboring villages at common watering and grazing points; and (iii)

where the villagers pay less attention to their cattle.

- *FMD outbreak studies*. These studies showed that: (i) FMD outbreaks commonly lasted a maximum 4 weeks; (ii) the attack rates vary from 1–50%; (iii) beef cattle were at more risk than buffaloes; (iv) adult animals were at more risk than young animals; and (v) draught animals had the lowest risk of infection.

## 3.2 Research impact evaluation of the control of foot-and-mouth disease

Benefits generated from AS1/1983/067 are:

- the provision of a laboratory service, especially the establishment of a FMD diagnostic laboratory at Hang Chat in Thailand;
- the development of rapid techniques for the detection and typing of FMD virus; and
- laboratory training in ELISA techniques.

Benefits generated from AS1/1988/035 are:

- an understanding of, and training in, modern epidemiological techniques;
- the weight gain in cattle through the avoidance of clinical disease; and
- the successful development of international cooperation among the countries; institutions and individuals.

Following a study of the benefits of the animal health programs[2] in Thailand, Harrison and Tisdell (1997) summarised them as follows:

1. Private benefits to producers and traders:
   - increased meat and milk production;
   - improved reproduction;
   - higher draught, transport and dung;
   - less restrictions on stock sales;
   - higher sale prices for livestock;
   - reduced animal health costs;
   - trade gains to producers and traders; and
   - increased export opportunities for non-livestock products.
2. Consumer benefits:
   - reduced meat prices due to supply increases.
3. Public and social benefits:
   - livestock quality (genetic) improvements;
   - more efficient production from industry modernisation and intensification;
   - enhanced industry and national development;
   - public health improvement;
   - income distribution benefits and social welfare costs avoided; and
   - animal welfare gains.

However, based on the interviews, the above benefits are still only partly realised. In practice, a number of constraints exist. These are (P. Chamnanpood, pers. comm. 1999):

- The current quality of vaccine is uncertain i.e. delivery chains of vaccines to animals are quite long (Figure 1). If there is any break in the cold chain during transportation, the quality of vaccine drops.
- There is still a lack of quality control.
- The operational procedures in the control program of FMD are not effective. For an effective control of FMD in a village, about 80% of the animal herd needs to be vaccinated. The second vaccination requires that 10% must have been vaccinated from the first vaccination. This condition has not yet been achieved in practice.

Therefore, only a certain level of FMD control has been reached in Thailand. A genuine cooperation between farmers and government officers in the control of FMD is required. In addition, the efficiency of the government control program needs to be consolidated.

Nevertheless, based on the interviews with the project leaders of both projects as well as the review documents (ACIAR, 1988), the research benefits generated from the control of FMD projects can be summarised as follows:

2. Animal health programs is concerned with prevention, reduction, outbreak control or eradication of livestock diseases. Disease usually includes internal parasites or parasitic diseases and nutrient deficiencies (non-infectious diseases (Harrison and Tisdell 1997).

- Scientific achievement has been attained in terms of the development of rapid methods for the diagnosis and typing of FMD.
- Human capacity building is a major benefit from the project. The training of Thai scientists in detection methods for the virus, and the establishment of a new FMD diagnostic laboratory, are important longer-term benefits for the country (Table 1).
- Some control of FMD in Thailand.

In addition, Thailand now acts as a regional reference laboratory for FMD by diagnosing and typing of samples sent from other countries in the region. The Australian teams have also benefited of obtaining experience in laboratory diagnosis of FMD.

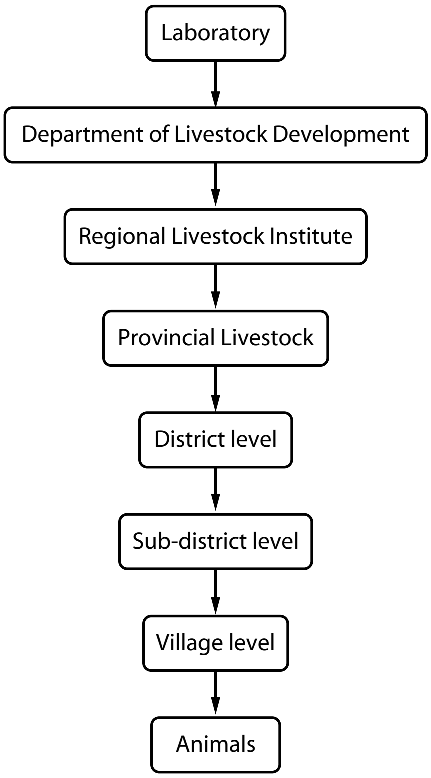


**Figure 1.** Channel of vaccines from the laboratory to animals

**Table 1** Summary of human capacity building and other impacts of AS1/1983/067 and AS1/1988/035

| Project No. | Project Participants (Thai) | Member enhanced skill (Thai) | Short-term training | | Long-term training | | Other impacts |
|---|---|---|---|---|---|---|---|
| | | | No. of activities | Thai | No. of activities | Thai | |
| AS1/1983/067 | 8 | 5 | 1 | 2 | 1 (M.Sc.) | 1 | Simple equipments |
| AS1/1988/035 | 11 | 8 | 1 | 2 | 1 (M.Sc.) | 1 | |

**Source:** Suzuki et al (1996), pp. 40 and 42

# 4 Impact analysis of the identification of genotypes of buffaloes (AS2/1985/015 and AS1/1983/064)

Swamp buffaloes are the main type of buffalo in Thailand, which are mainly raised for draught and meat purposes. Murrah buffalo is an exotic type of buffalo in Thailand, originating from India, which is primarily raised for milk. Due to the government's policy to enhance the nutritional level of rural people, murrah buffaloes have been introduced into Thailand since 1972 (P. Sakunmun, pers. comm. 1999). The project AS2/1985/015 started in 1985 and was mainly concerning with comparisons of swamp, F1 murrah x swamp crossbred and murrah buffaloes. The research was done at research stations and on smallholder farms.

## 4.1 Research findings of the identification of genotypes of buffaloes

In general, reproductive capacity, growth rate, and productivity of the crossbreds F1 (murrah x swamp) are better than those of the swamp buffaloes. Crossbreds have their first calf when they are a year younger than swamp buffaloes and the calving interval is also shorter in the cossbreds. Crossbreds produce more milk than swamp buffaloes. Both genotypes responded with better reproductive performance when supplementary feeds were given but they do not differ in terms of digestion efficiency (ACIAR, 1989).

Based on interviews, an important finding is that the F2 crossbreds (F1 x swamp or F1 x murrah) were worse than the F1 crossbred (murrah x swamp) in many aspects, such as growth rate and reproductive rate, while the crossbred F2 (F1 x F1) gave variable results. When crossbred F1 (murrah x swamp) is introduced to smallholder farms, the genotype of F2 will be very hard to control. In the field, it is rather difficult to control cross-breeding among them. The solution would be to keep only F1 on the farm but this is usually not possible in reality. It implies, therefore, that the productivity of buffaloes in the next generation might decline if the above crossbred F2 is widely raised. In addition, another important finding is that some male hybrid F1 were sub-fertile (P. Sakunmun, pers. comm. 1999; M. Kamonpatana, pers. comm. 1999). Further research is still required before the crossbred F1 can be generally introduced to farmers. Furthermore, it is confirmed that the swamp buffalo is overall the most suitable type of buffalo for Thailand. Since, rural Thai people are not accustomed to drinking buffalo milk[3] or eating buffalo milk products, the raising of buffaloes for milking is rare.

Nevertheless, the crossbred F1 (murrah x swamp) will be more useful to raise in large-scale enterprises, where breeding can be controlled, than on smallholder farms.

## 4.2 Evaluation of the impacts of research on the identification of genotypes of buffaloes

The benefits generated from the projects can be summarised as follows:

- It was the first research on buffalo from which data have been systematically collected.
- It provided very useful information to the policy-makers, agricultural extension workers and related persons on the buffalo development program and planning. However, the crossbred F1 was not broadly promoted by the Thai Government to smallholder farms for two main reasons. First. further research is required to confirm the earlier findings (Skummun, pers. comm. 2000). Second, there is a real concern that if farmers do not fully understand the consequences of cross-breeding, they will end up with a high proportion of F2 and F3 buffalo. This would have a negative impact on meat production and reproduction. Nevertheless, the crossbred F1 is available for sale and could be used by large-scale producers (Skummun, pers. comm. 2000).

3. Buffalo milk has a high fat content (about 7–8%).

- Even though the project was terminated, research on the crossbred F1 was continued by the Department of Livestock Development (DLD) in Thailand. However, as the number of native buffalo has fallen significantly over the last 10 years (from 4.7 million to less than 1 million), ensuring that these animals do not become extinct is now of greater concern to the DLD than is the cross-breeding program (Skummun, pers. comm. 2000).
- The project enhanced human capacity (Table 2).

**Table 2.** Summary of human capacity build-up and other impacts of AS1/1983/064 and AS2/1985/015

| Project participants (Thai) | Member with enhanced skill (Thai) | Short-term training | |
|---|---|---|---|
| | | No. of activities | Thai |
| 9 | 8 | 1 | 1 |

**Sources:** Suzuki and et al 1996; Sakunmun, pers. comm. 1999 and M. Kamonpatana, pers. comm. 1999

- Several publications in Thai were published using the results of the project. About four internal publications were produced from AS2/1985/015 (P. Sakunmun, pers. comm. 1999) and about 10 publications from AS1/1983/064 (Kamonpatana, pers. comm. 1999). Some of the publications produced from the projects are:

1. Bunyavejchewin, P. et al. 1989. Comparison of growth and physiological characteristics of swamp, murrah, and crossbred buffaloes. In: Breeding Research. The Key to the Survival of the Earth, Proceedings I of the 6th International Congress of the Society for the Advancement of Breeding Researchers in Asia and Oceania, S. Iyama and G. Takeda (eds). Tsukuba, Japan.
2. Bunyavejchewin, P. et al. 1989. Comparison of growth and physiological characteristics of swamp, murrah, and crossbred buffaloes. In: Proceedings of Seminar on Buffalo Genotypes for Small Farms in Asia, M.K. Vidyadaran, T.I. Azmi, P.K. Basrur (eds.). Serdang, Malaysia.
3. Bunyavejchewin, P., B. Tantagnai and S. Konanta. 1989. Poll measurement of crossbred buffalo (Swamp × Murrah). Buffalo Bulletin Vol 8(3): 63–66
4. Bunyavejchewin, P. 1989. Crossbred buffalo for academic purpose. Cattle and Buffalo Journal. Year 2. Iss. 2: 27–32 (in Thai language)

# 5 Impact analysis of the control of Newcastle disease in village chickens (AS1/1987/017)

Newcastle disease was an important disease of village chickens in Thailand, but Thailand now achieves a level of protection against the disease using conventional vaccines. Conventional vaccination can be managed in several ways such as intranasal, eyedrops, spray, intramuscular, or mixing into drinking water. These methods reduce chicken confinement and facilitate husbandry control. However, village and wild chickens are scattered over wide areas, with multi-aged populations and are under minimum control. The application of conventional Newcastle disease vaccines is rather difficult under these conditions. In addition, the vaccines used to control Newcastle disease in Thailand are not heat-tolerant. Therefore, it would be very helpful, especially in remote areas, if a heat-resistant vaccine could be developed to control Newcastle disease in village chickens. An Australian private company developed a heat-resistant V4 strain of Newcastle disease virus (HRV4) to control Newcastle disease and needed to test its efficiency in several tropical countries including Thailand. Hence, the project was aimed at testing the effectiveness of HRV4 in Thailand by comparing the HRV4 vaccine administered orally through various feed carriers and drinking water.

The information used for evaluating the impact of the work was obtained from the project leader. The impact analysis was done by first summarising the research findings and then drawing conclusions regarding the impacts generated by the project.

## 5.1 Research findings of the control of Newcastle disease in village chickens

There are two sources of research findings from AS1/1987/017: laboratory and pilot village field trials. The laboratory efficacy trials showed that HRV4 is able to induce immunity effectively when administered either intranasally or orally after mixing with paddy rice, cooked white rice or drinking water. However, the results of field trials differed from the laboratory trials due to uncontrolled conditions such as: (i) household cooperation — a good farmer who conscientiously cooperated in the vaccination program gave better results than a poor one; (ii) husbandry — resistance was higher in chickens which were well cared for; (iii) parasitic infection — coccidiosis infection reduced the level of immunity; (iv) vaccine dosage — the dose of vaccine received by chickens varied and some doses were inadequate to induce immunity (Tantaswasdi et al., 1992). In summary, the results of field trials varied from 28 per cent to 85 per cent for oral vaccine (ACIAR, 1998).

After the completion of field trials, there was still an attempt to develop heat resistant vaccine from a local isolate since HRV4 vaccine belonged to a private company. It would not be possible to locally develop HRV4 in Thailand. HRV4 might be appropriated for wild birds which are rather difficult to gather. The possibility of future use of HRV4 is not foreseen, for several reasons (Tantaswasdi, pers. comm. 1999). These are:

- intranasal is the most effective of controlling Newcastle disease, even for the HRV4;
- local vaccine is still applicable. LaSota vaccine is locally produced in Thailand for the control of Newcastle disease; and
- since Newcastle disease is a trade barrier issue, the government program on the control of Newcastle disease is considered to be effective (Tantaswadi, pers. comm. 2000).

**Table 3** Summary of human capacity building and other impacts of PN 8717

| Project Participants (Thai) | Personnel with Enhanced skill (Thai) | Short-term training | |
|---|---|---|---|
| | | No. of activities | Thai |
| 13 | 13 | 1 | 1 |

**Source:** Suzuki et al 1996, p. 41

## 5.2 Research impact evaluation of the control of Newcastle disease in village chickens

The main research impact generated from AS1/1987/017 is the idea and technology of mixing vaccine in feed (Tantaswasdi, pers. comm. 1999). In addition, there were about 13 members of the project with enhanced scientific skills (Table 3) and two publications generated from the project as follows:

1. Tantaswasdi, U. et al. 1992. Control of Newcastle Disease in Village Chickens with Oral V4 Vaccine in Thailand. ACIAR Proceedings 39.
2. Tantaswasdi, U. et al. 1992. Evaluation of an oral Newcastle disease vaccine in Thailand. In: *Preventive Veterinary Medicine*, 12, 87–94

# 6 Conclusion and recommendation

The benefits of five important livestock research projects in Thailand funded by ACIAR were evaluated in this paper. The paper attempted to evaluate the research impact at the research level, and to the end-users. In general, although there was little adoption of the technology to the end-users, all the projects contributed significantly in enhancing the scientific knowledge of the researchers in terms of human capacity building. Some specific issues can be concluded as follows.

- The control of foot-and-mouth disease seems to be one of the most successful livestock projects in Thailand funded by ACIAR. Unfortunately, due to the local environmental and political constraints, some of the technology generated from the project has not yet be applied in the field.
- The study of the buffalo genotype generates a very high benefit to the Thai society by convincing policy-makers not to implement a flawed policy at the macro level. That is to say more research is still required before the conclusion of the crossbred swamp and murrah buffaloes will be extensively introduced to farmers.

In summary, the adoption of all technologies generated from ACIAR funded projects requires a continuation of the research i.e. sufficient budgets and long-term research. In addition, developing interdisciplinary teams by including extension workers and economists could be useful for future ACIAR research. Particular attention should be paid to improving farm-level adoption of research results.

# 7 Acknowledgments

The author would like to thank all project leaders and researchers who provide their valuable time for the author to interview, and gave comments and recommendations in evaluating the project benefits. Special thanks to Assoc. Prof. Somporn Isavilanonda, team leader for the impact assessment of ACIAR projects, who provided an opportunity for the author to carry out and complete this paper. Thanks also are extended to Dr Acharee Sattarasart for valuable discussion during the research mission and to Dr Wyne Ellis and Mrs Sansanee Ellis for their kind help in editing the English.

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# An Impact Assessment of ACIAR Projects on Soil Management for Sustainable Agriculture in Thailand

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# Contents

# 1 Introduction

The collaboration between the Thai Government and the Australian Centre for International Agricultural Research (ACIAR) in conducting research has been established over the past decades. Among various research issues, soil management for sustainable agriculture is prominent, and a number of projects focusing on this issue were undertaken with the support of ACIAR. The aim of this report is to assess the impact of those ACIAR research projects dealing with the issues of managing soil acidity, soil salinity and soil erosion in Thailand. There are seven research projects evaluated in this report:

## 1.1 Soil acidity

- Project SWL/1989/004: Management of acid soils for sustainable food crop production in the humid tropics of Asia.

## 1.2 Soil salinity

- Project SWL/1984/031: Landscape salinity in the Khorat Plateau, northeast Thailand.
- Project FST/1986/033: Australian woody species for saline sites in Asia.
- Project FST/1992/022: Groundwater control for salinity management and agriculture in the Khon Kaen area, northeast Thailand.
- Project FST/1993/016: Tree growing on salt-affected land in Pakistan, Thailand and Australia.

## 1.3 Soil erosion

- Project SWL/1985/051: Management of soil erosion for sustained crop production
- Project LWR1/1992/001: Sustainable cropping systems for tropical steeplands

The total budget provided by ACIAR for these research projects was $A1 558 634 (Table 1).

This paper is organised into four main sections. After this introduction, the following three sections focus on the issues of soil acidity (project SWL/1989/004), soil salinity (projects SWL/1984/031, FST/1992/022, FST/1986/033 and FST/1993/016) and soil erosion (projects SWL/1985/051 and LWR1/1992/001), respectively. The format for each of the three sections is the same. Each section starts with an overview of the project, including a description of the objectives of the research projects. The project findings are presented next, and the impacts of the findings are intensively evaluated afterwards. Impacts generated by each research project are classified into three items including potential economic impacts of the research findings, transferability of research findings, and scientific knowledge and human capacity enhancement. The concluding remarks are made in the last section.

**Table 1.** ACIAR budgets ($A) for the soil management projects in Thailand

| Year started | Soil acidity | Soil salinity | | | | Soil erosion | |
|---|---|---|---|---|---|---|---|
| | SWL/1989/004 | SWL/1984/031 | FST/1986/033 | FST/1992/022 | FST/1993/016 | SWL/1985/051 | LWR1/1992/001 |
| 1985 | – | 379,814 | – | – | – | – | – |
| 1988 | – | – | 191,442 | – | – | – | – |
| 1989 | – | – | – | – | – | 206,817 | – |
| 1991 | 117,009 | – | – | – | – | – | – |
| 1992 | – | – | – | 393,528 | – | – | 261,024 |
| 1994 | – | – | – | – | 9,000 | – | – |

Note: it is assumed that each project was financed in the first year.

# 2 Soil acidity

Soil acidity is considered a threat to agricultural areas by causing low productivity. In Southeast Asia, it is estimated that 197 million hectares or 50% of the land area comprises acid tropical soils. From the characteristics of these soils, only tolerant crops can be grown, such as rubber and palm trees. Other food crops do not grow well under these soil conditions, unless the soils receive appropriate treatment so they can be more effectively used. This issue was researched under the project SWL/1989/004 funded by ACIAR.

## 2.1 Overview and objectives of project SWL/1989/004

The ACIAR Project SWL/1989/004, “Management of acid soils for sustainable food crop production in the humid tropics of Asia”, commenced in 1990 under the collaboration of various countries including Australia, Indonesia, the Philippines, Malaysia and Thailand.

Focusing on the Thai case, an acid upland area in southern Thailand was selected as the site for the experimental research. In the south of Thailand, 3.5 million ha of land is categorised as acid upland soils with high exchangeable Al concentration, low concentrations of exchangeable Ca, Mg, and K, low available P and low organic matter. These characteristics have been considered as constraining food crop production. According to such constraints, the soils are mainly used for rubber and oil palm plantations, which can tolerate soil acidity. As the majority of rubber producers are smallholders, effective food crop production before canopy closure of the rubber trees could provide them with supplementary income and foods. However, the sustainable food crop production would need appropriate acid soil management. Hence, the main objective of this project was to identify a strategy for food crop production by intercropping such crops with young rubber trees, together with the determination of an effective means for acid soil management to help sustain the intercrop production.

## 2.2 Research findings

The research findings are separated in two steps. First, it was found that the fertility of acid upland soil could be improved by the use of fertiliser. Inorganic fertilisers did provide a substantial fertility improvement, while addition of organic matter did not yield a significant improvement in soil fertility. Second, supersweet corn and upland rice were selected for further experiments on intercropping in rubber plantations before canopy closure. These two crops were grown under different levels of fertiliser inputs. The experimental results showed that high fertiliser input provided the highest yield for both crops, and the lowest yield was from farmers’ traditional practices (referred mainly to non–fertiliser application). Nevertheless, the net income from supersweet corn under fertiliser treatment was found to be less than that of farmers’ practice and for upland rice, net negative income was obtained. A rotational cropping package of mungbean with low input treatment, supersweet corn with low input treatment, and groundnut with high input treatment is recommended by the research.

## 2.3 Impacts of the research project SWL/1989/004

The research project SWL/1989/004 provides substantial benefits which can be classified into three main items. These are:

### *2.3.1 Potential economic impacts of the research findings*

The main potential economic impact of this research is an increase in income of small rubber growers from food crop production. This impact can be estimated by comparing the net benefits of technologies recommended by the project with those of current farmers’ practices. From the information on net income of crops grown as intercrops with young rubber trees under different input treatments shown in Table 2, an incremental net income from a change in cropping practices is estimated to be 21,004 baht/ha (Table 3). The estimation is made under the assumption that the flow of incremental net benefit is possible only in the first three years after the rubber trees are planted as this is the time before canopy closure, and the package of rotational food crops, mungbean/ supersweet corn/groundnut grown under rainfed conditions is the same for both practices, and upland rice is not included in this package. Apart from the benefit in the form of increased net income, the technology recommended by this research also has a positive impact on the growth of rubber trees. The increase in the girth of the rubber trees is considered as another source of improvement in farmers' incomes. Nilnond et al. (1995) indicated that while an effect of input treatments on rubber tree growth is observed, it's quite small. This may be because it is too early to monitor the growth effect. Hence, the benefit of this research on rubber tree growth will not be quantified in this paper.

**Table 2.** Net income of various crops grown as intercrops with young rubber trees under three different input treatments

| Crop | Input treatment (baht/ha) | | |
|---|---|---|---|
| | Farmers' practice | High fertiliser input | Low fertiliser input |
| Groundnut | 2,218 | 10,680 | 4,724 |
| Mungbean | –102 | 2,153 | 3,890 |
| Supersweet corn | 17,760 | 21,930 | 26,310 |
| Upland rice | –210 | –9,500 | –3,340 |

**Source:** Nilnond et al., 1995

### *Transferability of research findings*

Information obtained in December 1998 from the researcher, Dr Chairatna, indicated that the project did not directly aim to extend the findings to the farmers, which would need another step. Dr Chairatna estimated that ultimately 20% to 50% of farmers would adopt this technology, especially those farmers who live near the experimental site (interviewing Dr Chairatna via e-mail, December 1998). The main reasons for the adoption was that the farmers could get higher yield and higher net profit compared with their normal practices. Although the highest level of adoption is estimated to be 50%, there are many factors which could act as barriers for adoption (discussed later), which would mean that the ultimate level of adoption could be well below 50%. As mentioned in Nilnond et al. (1995) rubber trees are being replanted at the rate of 50 000 ha per year. These replanted areas could be considered as the target areas for application of intercropping of food crops. It is estimated that 50% of rubber plantation could be intercropped with food crops for the first three years of rubber-tree growth (Dr Chairatna1, pers. comm. 1999).

On the other hand, the potential constraints to the adoption of the research results by smallholders include the high costs of soil treatment using fertiliser, labour shortages and marketing problems. In addition, the types of crops recommended by the project may not fit with the farmers' preferences. For example, upland rice, which is considered to be an important crop for food security, is not recommended because of its low profitability compared to other crops. Detailed information on the cost of, and return to, each crop under different input treatments is shown in Table 4. Other barriers to adoption may result from the risk caused by the high investment in fertiliser for crops grown under rainfed conditions. Net negative income was obtained from food crops when facing drought during the growing season. As intercropping is allowed only in a short period (just three years before the canopy closure), this would make the sustainability of food crop production not technically feasible. A final possible barrier to adoption is the fact that the area planted to rubber trees has declined because of a fall in the price of rubber (Willett, pers. comm. 2000).

### *2.3.2 Scientific knowledge and human capacity building*

Scientific knowledge was an item of benefits generated by the research project. This project also led to two publications (see Appendix). Capacity enhancement was obtained from training through the training workshops and conferences were organised in cooperation with the International Bureau for Soils Research and Management**,** a coordinator and sponsor of this project.

**Table 3.** Net income of crop grown under farmers' practice and recommended practice

| Year | Crop | Net Income (baht/ha) | | Estimated incremental net income (baht/ha) |
|---|---|---|---|---|
| | | Farmers' practice | Recommended practice | |
| 1 | Mungbean | –102 | 3,890 | 3,992 |
| 2 | Supersweet corn | 17,760 | 26,310 | 8,550 |
| 3 | Groundnut | 2,218 | 10,680 | 8,462 |
| | | | Total | 21,004 |

**Source:** adapted from Nilnond et al., 1995

**Table 4.** Estimated income and expenditure of mungbeans, supersweet corn, and upland rice (unit: baht/ha)

| Item | Mungbean | | | Supersweet Corn | | | Upland Rice | | |
|---|---|---|---|---|---|---|---|---|---|
| | **F** | **H** | **L** | **F** | **H** | **L** | **F** | **H** | **L** |
| Expenditure | | | | | | | | | |
| 1. land preparation | 938 | 938 | 938 | 1,860 | 1,860 | 1,860 | 1,860 | 1,860 | 1,860 |
| 2. planting | 1,360 | 1,360 | 1,360 | 1,190 | 1,190 | 1,190 | 1,360 | 1,390 | 1,360 |
| 3. fertilizer, lime, seed | 860 | 5,657 | 3,090 | 1,030 | 4,770 | 3,080 | 310 | 8,240 | 2,260 |
| 4. pest and disease control | 1,500 | 3,012 | 2,162 | 2,220 | 4,400 | 3,310 | 3,080 | 5,270 | 4,180 |
| 5. harvest | 1,000 | 2,000 | 1,700 | 300 | 850 | 500 | 700 | 1,170 | |
| Total cost | 5,658 | 12,967 | 9,250 | 6,590 | 13,070 | 9,940 | 7,310 | 17,900 | 709,940 |
| Yield | 0.463 t/ha | 1.237 t/ha | 1.095 t/ha | 48,700 cob /ha | 70,000 cob/ha | 72,500 cob/ha | 1.42 ton/ha | 1.68 t/ha | 1.32 t/ha |
| Price | 12 baht./kg | 12 baht./kg | 12 baht./kg | 0.50 baht/cob | 0.50 baht/cob | 0.50 baht/cob | 5,000 baht./t | 5,000 baht/t | 5,000 baht/t |
| Income | 5,556 | 14,850 | 13,140 | 24,350 | 35,000 | 36,250 | 7,100 | 84,000 | 6,600 |
| Net income | –102 | 2,153 | 3,890 | 17,760 | 21,930 | 26,310 | –210 | –9,5000 | –3,340 |

Note: F = farmers' traditional practice, H = high fertilizer input, L = low fertilizer input
**Source:** Nilnond et al., 1995

# 3 Soil salinity

Soil salinity is one of the nation's main problems, especially in the Northeast where 2.85 million hectares (or about 17.8 million rais) are classified as salt-affected areas. The seriousness of this problem can be clearly seen from the growing areas of abandoned land where agriculture activities are no longer profitable. To tackle this issue, a series of research projects funded by ACIAR was conducted, including projects SWL/1984/031, FST/1986/033, FST/1992/022 and FST/1993/016.

## 3.1 Overview and objectives of project SWL/1984/031, FST/1986/033, FST/1992/022 and FST/1993/016

Project SWL/1984/031, "Landscape salinity in the Khorat Plateau, North-East Thailand", started in 1985 and was completed in 1988 under the collaboration of the Department of Land Development, Thailand and CSIRO, Australia. The objective of this project was to develop methods for identifying physical causes of soil salinity, with the aim of reducing salinity and increasing crop yields.

In 1988, a related project on Australian woody species for saline sites in Asia (project FST/1986/033) was initiated, aimed at extending research findings from project SWL/1984/031 a step further. Hence, the main counterpart from Thailand was still the Department of Land Development. The objectives of this project were to evaluate and select the most promising salt-tolerant germplasm of Australian woody tree and shrub species, and to identify conditions for the establishment of trees in saline sites in Thailand.

Project FST/1992/022, "Groundwater control for salinity management and agriculture in the Khon Kaen area, Northeast Thailand", was conducted from 1993 until 1997 under the collaboration of the Khon Kaen University and the Department of Mineral Resources in Thailand and the University of Technology in Sydney, Australia. The areas of Huai Yai Basin including Khon Kaen city and the districts of Muang, Phra Yun and Bang Fang were selected as study sites. This project focused on examining and modelling the salt load transported through groundwater systems to identify recharge and discharge areas. It also aimed at developing methods to forecast land salinisation as a result of different land use patterns, and examining management strategies to reduce recharge on salinisation in discharge areas.

In 1994, ACIAR funded another related research project under the topic of "Tree growing on salt-affected land" (project FST/1993/016), and the Department of Land Development and Royal Forest Department were the principal investigators from Thailand. This project intended to predict growth opportunities of the selected tree species identified by the project FST/1986/033 focusing on the water-use issue. Some scientific results obtained from project FST/1992/022 were used as basic information for this project.

## 3.2 Research findings

The main finding of the project SWL/1984/031 was that the deforestation resulting from the expansion of agriculture lands into the upland (recharge) areas caused problems of salinity in the lowland (discharge) areas via the mobilisation of halite through the groundwater system (Williamson et al., 1989). In addition, the area under Mahasarakham Formation was identified by this project as the primary salt source. These findings were obtained by the methods developed in this project.

Following from the research results of the project SWL/1984/031 in which the discharge and recharge areas were identified, in project FST/1986/033 it was concluded that *Acacia ampliceps* and *Eucalyptus camaldulensis*, native Australian woody species, could grow in saline soils. Given the various levels of salinity in the discharge areas, the research found that *Acacia ampliceps* provided the most promising ability to grow under highly saline conditions. However, the successful establishment of the selected species required special treatments as a means to overcome some constraints such as water-logging and poor soil conditions. Applying mulch with the straw and hulls from rice and gypsum to the soil, and pre-conditioning the seedlings to salt and water-logging were the means recommended by the projects (Dissataporn et al., 1992).

Under project FST/1992/022, the flow of underground water between recharge and discharge areas was mapped and identified by using the groundwater model developed by this research, together with some technological knowledge transferred from project SWL/1984/031. The research indicated that redistributing salt to the ground surface in discharge areas stemmed from the local and regional groundwater flow systems in the recharge areas. The solution was that growing trees in recharge areas would delimit the problem of salinity, since the excess water which was replenishing the groundwater would be used by the trees. For discharge areas, salt-tolerant trees could also help lower the level of saline groundwater. It is suggested by this research that information was needed on the water used by trees, the number of trees and the plantation areas for tree growing strategies to solve soil salinity in recharge and discharge areas (Lertsirivorakul, 1944). This issue was examined in a related ACIAR project, FST/1993/016.

Project FST/1993/016 focused on monitoring the levels of water use by *Eucalyptus camaldulensis* on moderately and strongly saline soils in discharge areas. It was found that level of water use by *E. camaldulensis* grown in strongly saline soil was higher than that in moderately saline soil (Luangjame et al., 1995). However, the rate of survival of *E. camaldulensis* in highly saline conditions was very low and, under such conditions, *Acacia ampliceps* was more appropriate (Mr Manop Tandatemiya, pers. comm. 1999). This was also confirmed by the results of project FST/1986/033 (Mr Chaiyanam Dissataporn, pers. comm. 1999).

It can be concluded that the series of ACIAR research projects generated valuable results concerning the salinity problem in Thailand. Apart from the methods/technologies developed to identify the causes of salinity problem and the flow of groundwater between recharge and discharge areas, the main outcome was the strategy to solve this problem by planting trees in these areas. However, different tree species are required for the areas with different saline conditions. For the highly saline condition, *Acacia ampliceps* is recommended. *Eucalyptus camaldulensis* can be used in the recharge areas and in moderately and slightly saline soils in the discharge areas.

## 3.3 Impacts of the research projects

The research projects provided substantial benefits which can be categorized into three items:

### *3.3.1 Potential economic impacts of the research findings*

The negative externality is the main concern of the soil salinity problem. It was found by the research that changes in land use from forest to commercial crop production in the recharge areas increased levels of salinity in discharge areas. The effects of soil salinity are decreased crop yields in the short-run, and for the long-run, soil degradation could be so severe as to make agricultural activity physically and economically unfeasible. From the total study site area of 108 500 hectares, conversion of forest to field crops can be seen, as forest areas account for only 13% of the total areas, while 87% is farmland with sugarcane, kenaf, maize and cassava as the main crops in the uplands, and paddy rice and vegetables in the lowlands (Williamson et al., 1989). Under this situation, if the knowledge obtained from the research is not applied, rice and vegetable production in the lowland discharge areas could be substantially reduced and finally terminated by the increase in soil salinity from the changes of land use in the highland recharge areas.

Hence, application of the research findings provides potential economic impacts in the form of improving the yield of crops grown in the potentially salt-affected discharge areas, and soil fertility improvement in the moderately and highly saline discharge areas where no agricultural activity is feasible. In this paper, the impacts mentioned will mainly be qualitatively discussed, although some attempt will be made to quantify the potential economic impacts derived as results of the research projects.

*A. Crop yield improvement.* Improvement in crop yields grown in the salt-affected areas is expected to be achieved via the change in the land-use pattern for agricultural activities in the upland recharge areas. The yield improvement will consequently increase farmers' incomes and quality of life. It is reported by the Department of Land Development (1997), that 76% of low salt-affected area (2 million hectares, or 12.6 million rai[2]) in the lowland is feasible for rice production, and the yields are about

2. 1 rai = 1600 $m^2$.

100–150 kg/rai (average 125 kg/rai). The reduction of salinity expansion from reforestation in the upland recharge areas would help to increase rice yields to 300–500 kg/rai (or an average rice yield of 400 kg/rai). Then net increase in rice production (ONQ) is 277 kg/rai (i.e. 400 – 125 kg/rai). The net return to rice production in the Northeast of Thailand (NR) reported by the Office of Agricultural Economics in 1997 was about 0.407 baht per kg. From this, the estimated potential increase in the net benefit of rice yield improvements in the lowland discharge areas (ONB), as a result of the change in land use in the upland recharge areas (if the research findings are carried out by the end-users) is:

ONB = NR × ONQ

= 0.407 × 275

= 111.93 baht/ rai.

From the potential incremental net benefit at 111.93 baht/rai, the total incremental net benefit of the low salt-affected areas (12.6 million rais) for rice production is estimated to be about 1,410.26 million baht per year.

*B. Land degradation reduction.* Information on salt-affected area identification provided by the research projects can be used for finding options for land-use management to reduce soil degradation from salinisation in the lowland discharge areas. In the Northeast, salt-affected areas account for 17% of the total areas, or about 17.8 million rai, with 1.5 million rai subject to high salt levels, 3.7 million rai subject to moderate salt levels, and 12.6 million rai subject to low salt levels (DLD, 1997). The areas where there are moderate and high salt levels can hardly be used for agriculture activities because of the very low quality and quantity of production as a result of degraded soil. Salt-tolerant trees is a strategy suggested by the research for reducing soil degradation and to improve farmers' income by enabling them to use the degraded soil. Assuming that the high and moderate salt-affected areas contribute no economic benefits to the farmers, planting *A. ampliceps*, as recommended by project FST/1986/033, could gradually improve the physical and chemical condition of the soil through nitrogen fixation. Hence, the potential benefit of the research would be an improvement in soil fertility in these areas in the long run. Also, in a comparatively short time, farmers could earn additional income from planting this salt-tolerant tree species because it can be used for pulpwood, fuelwood, and fodder (Dissataporn et al., 1992). Given that the highly and moderately salt-affected areas are hardly used for agriculture, then the potential benefit of planting salt-tolerant *A. ampliceps* trees is to convert 5.2 million rai of unusable land to usable land which could bring about sustainability in the land-use system, which consequently provides a long-term improvement in the farmers' incomes.

### *3.3.2 Transferability of research findings*

While the economic benefits from the research findings are potentially substantial, for these benefits to be realised they need to be transferred to the end-users. In practice, there are difficulties in transferring these findings to the end-users. For the upland recharge areas, which account for 3.1 million hectares (19.4 millions rai), the solution to mitigate the salinity problem in the lowland discharge areas requires that the land-use pattern in the recharge areas should be changed from field crops, which are currently being cultivated, to forests or trees. However, this change in farming practices may not be accepted by farmers for two main reasons. First, while farmers' income from field crops may not be that high, the turnover is fast compared with tree growing, which would not generate income in a short period of time. This is the most crucial factor hindering a solution to the salinity problem. Second, even though the tree species suggested by the project, *Eucalyptus camaldulensis*, is fast growing and so can generate income in a relatively short time (about 5 years), there are still doubts about its effects on other nearby plants. The farmers negative perceptions about growing eucalypts needs to be addressed before they will decide to adopt *E. camaldulensis* for tree plantation in the recharge areas.

In the case of lowland discharge areas, where *Acacia ampliceps* is recommended for tree planting, there is also no evidence of farmers adopting *A. ampliceps* in the highly salt-affected areas (Mr Chaiyanam Dissataporn and Mr Manop Tandatemiya, pers. comm. 1999). The reason for non-adoption may stem from the fact that no significant economic benefit can been seen from planting *A. ampliceps*. In Australia, where this tree species originated, it is mainly used as fodder for sheep, but in the case of Thailand, especially in the Northeast, sheep raising does not exist. In addition, as this species is not native to this areas, the farmers find it hard to accept. Hence, it can be argued that the failure to practically apply the research results stems from the social and economic conditions not being properly addressed. In this case, non-adoption is a result of introducing a “non-appropriate tree” to the farmers (Mr Chaiyanam Dissataporn, pers. comm. 1999). However, if the information that *A. ampliceps* can also be used for pulp production is passed on to farmers and firms, then this could help to promote the adoption of planting *A. ampliceps* in the highly salt-affected discharge areas in the future.

Although transferability of the research results to the end-users is quite limited for various reasons discussed above, the findings are still considered to provide “valuable scientific knowledge” on salinity, which can be transferred to collaborating and other relevant agencies, including land-use planning agencies, extension agencies (such as the Department of Agriculture Extension) and to the Royal Forest Department under the Ministry of Agriculture and Cooperatives. The outcomes of project SWL/1984/031 were used not only in related ACIAR projects (FST/1986/033 and FST/1992/022), but also in non-ACIAR research projects, especially projects conducted under the Department of Land Development (Mr Chaiyanam pers. comm. 1998). The research results of FST/1992/022 were subsequently transferred to project FST/1993/016 and, as IBSRAM was a counterpart in that project, it also benefited in terms of knowledge advancement. The Japan International Cooperation Agency (JICA) also obtained information from this research which was used to support the Reforestation Project in the Northeast of Thailand to establish seeding nurseries to develop community forest management. The information transferred from projects FST/1986/33 and FST/1992/022 was the main input into project FST/1993/016, and the results of this project have been passed on to a Department of Land Development project. This is four year (1996–1999) pilot project aimed at transferring the results of FST/1986/033 and FST/1993/016 to the end-users by providing a cash incentive to the farmers to plant the trees as recommended by these two projects (Mr Manop Tandatemiya, pers. comm. 1999). In conclusion, the series of ACIAR projects on salinity issue provided substantial scientific knowledge which can be used by various agencies to tackle the problem of soil salinity, but the transfer of this knowledge to the end-users has been limited.

### *3.3.3 Scientific knowledge and human capability enhancement*

Benefits in the form of scientific knowledge can be seen from the publications produced under these four projects (see Appendix). The projects also enhanced human capacity through training and study-visit programs. Under project SWL/1984/031, enhancing human capacity especially for the scientists and researchers from the Department of Land Development was through training and a study visits to Australia. In addition, technologies used in this project have been perfectly transferred to the researchers. Workshops and training courses in Australia, Thailand and Pakistan were also provided as a part of project FST/1986/033. For the project FST/1992/022, two academic staff from Khon Kaen University and a hydrologist from the Department of Mineral Resources attended the short training course and a study tour in Australia. In addition, a PhD thesis and several students’ project and reports (see Appendix) were written as parts of this research project. Thai researchers who were involved in project FST/1993/016 attended the intensive training course on water use at Rushworth, Victoria.

# 4 Soil erosion

Soil erosion has become a serious problem in Thailand especially in the North and Northeast where steep slope areas have been used for agriculture without appropriate concern for soil conservation. There are two related research projects that were funded by ACIAR, which dealt with the soil erosion issue. These are the project on the 'Management of soil erosion for sustained crop production' (SWL/1985/051) and the project on 'Sustainable cropping systems for tropical steeplands' (LWR1/1992/001).

## 4.1 Overview and objectives of ACIAR project SWL/1985/051 and LWR1/1992/001

The ACIAR project SWL/1985/051, 'Management of soil erosion for sustained crop production', aimed at studying soil erosion and sustainable cropping practices on the sloping lands of Australia and Southeast Asia, including Malaysia, the Philippines, and Thailand. The focus of this paper is on Thailand. The project was conducted during 1989–1991 under cooperation between the Department of Land Development as the representative from Thailand and Griffith University from Australia. An area in Khon Kaen, where soil was characterised as loamy sand with a 3.6% slope and classified under the Chumpuang series, was selected as an experimental site for this project. Rozelle, the main crop in this area, was grown in experimental plots under four different cultivation practices including up-and-down slope cultivation, contour cultivation, subsoiling and contour cultivation, and no tillage. The objectives of project were to:

- investigate and measure the loss of soil, water and nutrient from the range of cropping practices;
- use information gathered to validate the soil erosion model, called the GUESS model developed by Griffith University; and
- identify the effectiveness of the cropping practices in minimising soil, water and nutrient losses in the steeplands.

In the second phase, the research project LWR1/1992/001 'Sustainable cropping systems for tropical steeplands', was conducted to investigate soil loss in the steeplands by using the technology developed in project SWL/1985/051, and also to evaluate the sustainability of cropping systems that could potentially be adopted by farmers. The study area was moved to the northern part of Thailand. Ban Thum Wiang Kae, Tambon Narailuang, Amphur Song Kwae, Nan Province was selected as a research site. Soil type in this area is of the Ban Chong soil series: a clayey, kaolinitic, isohyperthermic, Oxic Paleustults. Experimental plots with corn as the main crop were conducted under different treatments including grass strip hedge using *Vetiver*, alley cropping using *Tephrosia*, hillside ditch, and current farming practice (no conservation measure).

## 4.2 Research findings

A data base for the soil erosion model was successfully produced under these two research projects and it was used in the erosion model. Contour cultivation was found to be the most effective option in terms of a reduction in soil, water and nutrient losses, and also optimising yield, while alley cropping with *Tephrosia* was recommended in project LWR1/1992/001 for erosion control in the steeplands.

## 4.3 Impacts of the research projects

These two projects provide substantial benefits which will be evaluated below. Information supporting this evaluation was obtained from interviewing researchers and farmers living close to the research site.

### *4.3.1 Potential economic impacts of the research findings*

These two projects provide benefits in the form of scientific information on soil conservation practices. Under project SWL/1985/051, the benefit in the form of reduced soil and nutrient loss is substantial under the contour cultivation compared with the farmers' practice, though the yield improvement is not so marked (see Table 5). Among various valuation approaches, the replacement cost approach is applied in this paper to value the benefit from a reduction in soil erosion at the farm level. Selecting nutrient loss reduction as the benefit from applying contour cultivation instead of continuing with the current farmers' practice, the potential benefit is estimated as:

- Average reduction in nutrient loss = 2.59 kg/ha.
- Average price of fertiliser (N+P+K) = 8 baht/kg.
- Estimated benefit from reduction in nutrient loss = 20.72 baht/ha.

The results of project LWR1/1992/001 indicated that soil conservation practices under grass strip hedge using *Vetiver*, and under alley cropping using *Tephrosia,* offer a reduction in soil loss compared with farmers' practice, but the change in crop yield was not so marked (see Table 6). It was too early to draw a conclusion from the experiment because the impact of soil conservation may take a longer time to provide significant benefit in both soil loss reduction and yield improvement (project researcher, pers. comm. 1998).

Apart from the 'on-site' benefits mentioned above, a reduction in soil erosion also provides flow-on benefits in terms of decreasing the off-site impacts, such as improving water quality in the natural waterways, reducing sedimentation, and so on. Hence, the total potential benefits of reduction in soil erosion could be quite substantial when taking both on-site and off-site impacts into consideration.

### *4.3.2 Transferability of research findings*

The new electronic equipment (called 'Logging') used for measuring soil and nutrient losses in project SWL/1985/051, together with the findings from this research project were transferred to project LWR1/1992/001.

In contrast, adoption of the research findings by the end-users, such as farmers, was very limited. Both projects did produced scientific data which can be used for modelling soil erosion. For the project SWL/1985/051, the main output was data collected from various soil management systems, which indicated that contour cultivation is the best option for soil, water and nutrient management. However, contour cultivation is not a new technology. The farmers have known about contour cultivation for a long time, but do not practise it. The reason is that farmer find cultivation against the slope to be difficult and dangerous.

Similarly there is no transfer of the research results from project LWR1/1992/001 to the farmers. Non-adoption was confirmed by interviewing with a few villagers living near by the research site (October 1998). The main reason for non-adoption is that even though the farmers recognise the seriousness of the erosion, the small size of agricultural land mitigates against the alley cropping. In addition, as the experimental results shows, crop yield under alley cropping with *Tephrosia* is not that high. This

**Table 5** Soil loss and dry matter yield of rozelle under (A) farmers' practice and (B) contour cultivation

| Year | Soil loss (kg/ha) | | Dry matter (kg/ha) | | Nutrient (N+P+K) loss (kg/ha) | |
|---|---|---|---|---|---|---|
| | (A) | (B) | (A) | (B) | (A) | (B) |
| 1989 | 2,309 | 372 | 13,310 | 13,080 | 3.57 | 1.21 |
| 1990 | 2,095 | 905 | 15,040 | 15,450 | 5.65 | 3.76 |
| 1991 | 3,938 | 1,724 | 12,090 | 12,390 | 10.64 | 7.12 |

**Source:** Sombatpanit et al. (1995)

**Table 6** Soil loss and yield of corn under farmers' practice, grass strip, and alley cropping

| Year | Farmers' practice | | Grass strip | | Alley cropping | |
|---|---|---|---|---|---|---|
| | Soil loss (kg/rai) | Yield of corn (kg/rai) | Soil loss (kg/rai) | Yield of corn (kg/rai) | Soil loss (kg/rai) | Yyield of corn (kg/rai) |
| 1993 | na. | 294 | na. | 308 | na. | 295 |
| 1994 | 98.99 | 389 | 56.71 | 373 | 56.95 | 404 |
| 1995 | na. | 467 | na. | 415 | na. | 440 |
| 1996 | 93.95 | 549 | 41.75 | 465 | 49.74 | 458 |

Note: 1 ha = 6.25 rai
**Source:** unpublished data obtained from the researcher

would be another barrier for transferring such practice to farmers.

#### *4.3.3 Scientific knowledge and human capacity building*

Contribution of scientific knowledge generated by the research projects is in the form of academic papers. There were two papers written as a part of the project that were published in Soil Technology, Vol. 8, No. 3 (see Appendix for details). Another form of benefit contributed by the research is human capability enhancement through technical and practical training offered in this research project.

# 5 Concluding remarks

This paper has discussed the impacts of seven ACIAR research projects dealing with the issues of soil management for sustainable agriculture in Thailand. These projects are considered very successful in providing substantial benefits in forms of scientific knowledge and human capacity enhancement, and also in the transfer of the research findings to other researchers (as shown in table 7). However, the benefit in terms of transferring the research results to the end-users are quite limited for all of the projects evaluated in this paper. This limitation may come from the nature of each research project which most likely focused more on producing scientific information than on those social and economic conditions that significantly influence adoption. Although generating technology is important, it is of little value if the technology is not adopted by the end-users. Hence, it is recommended that to successfully transfer the research results to the end-users, integrating personnel from other disciplines, such as economists and extension workers into the research teams could be a solution.

**Table 7** Impacts of ACIAR research projects on soil management

| Project no. | Transferability to other ACIAR projects/non-ACIAR projects/agencies | Adoption by end users | Scientific knowledge/human capacity enhancement |
|---|---|---|---|
| SWL/1989/004 | IBSRAM | – | M |
| SWL/1984/031 | FST/1986/033, FST/1992/022, DLD, IBSRAM | – | M |
| FST/1986/033 | FST/1993/016, DLD | – | M |
| FST/1992/022 | FST/1993/016, JICA | – | M |
| FST/1993/016 | DLD | – | M |
| SWL/1985/051 | LWR1/1992/001 | – | M |
| LWR1/1992/001 | DLD, IBSRAM | – | M |

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# Appendix: Project publications


## Publications of project SWL/1989/004

Nilnond, C., Suthipradit, S., Sophanodora, P., Masae, A., Kamnalrut, A., Jatupote, W., Nualsri, L., Limchitti, Y. and Kungpisdan, N., 1995. Management of acid soil for sustainable food crop production in southern Thailand – ACIAR Project 8904, in *Progress in network research on the management of acid soils (IBSRAM/ASIALAND)*, IBSRAM Network Document no. 16, Bangkok: IBSRAM, pp.81–108.

Nilnond, C., Suthipradit, S. and Nualsri, L., 1996. Management of upland acid soils for sustainable food-crop production in southern Thailand, in *The Management of Acid Soils in Southeast Asia (IBSRAM/ASIALAND),* IBSRAM Network Document no. 18, Bangkok: IBSRAM, pp.53 –58.

## Publications of project SWL/1984/031

Williamson, D.R., Turner, J.V., Peck, A.J. and Arunin, S., 1989. Groundwater hydrology and salinity in a valley in northeast Thailand, in Abriola, L.M. (ed.), *Groundwater Contamination*, IAHS Publication No. 185, pp. 147–154.

## Publication of project FST/1986/033

Marcar, N.E., Hussain, R.W., Arunin, S., and Beetson, T., 1991, Trails with Australian and other *Acacia* species on salt-affected land in Pakistan, Thailand, and Australia, in Turnbull J.W. (ed.), *ACIAR Proceedings No. 35*, pp.229–232

## Publications of project FST/1992/022

Lertsirivorakul, R., 1994. Tree water use management for tree growing strategy to lower the shallow saline water level in Khon Kaen area, Northeast Thailand. *Proc. Conf. on Technology and Development in Northeast Thailand, Faculty of Technology, Khon Kaen University, August 1994, p22.*

Lertsirivorakul, R., Milne-Home, W. A. and Knight, M. J., 1995. Occurrence and origin of nitrate in groundwater within the Khon Kaen region, Northeast Thailand, *Proc. Conf. on Geology, Geotechnology and Mineral resources of Indochina (Geo-Indo' 95), 22–25 Nov., Khon Kaen, pp665–670.*

## Students' projects and reports under project FST/1992/022

Chalyapetr, K., 1997. *Application of GIS for hydrogeological mapping, Husi Yai Basin, Khon Kaen Province, Northeast Thailand,* Special project, Department of Geotechnology, Faculty of Technology, Khon Kaen University.

Khamsarn, P. and Passada, N., 1995. *Relationship between soil moisture condition and tree water use at recharge and discharge areas*, Khon Kaen University campus, Special problem for 4th year Soil science students, Faculty of Agriculture, Khon Kaen University.

Natee, R., 1995. *Resistivity survey for delineating salt layer and saline aquifer in the Khon Kaen areas*, Special project, Department of Geotechnology, Faculty of Technology, Khon Kaen University.

Phusongsi, W., 1996. *Hydrogeochemistry and groundwater flow in Phyra Yun-Ban Fang catchment, Khon Kaen Province, Northeast Thailand,* Special project, Department of Geotechnology, Faculty of Technology, Khon Kaen University.

Sriwong, S., 1995. *Remote sensing analysis for hydrogeological study and land use classification in the Khon kaen areas*, Special project, Department of Geothechnology, Faculty of Technology, Khon Kaen University.

## Publications of project FST/1993/016:

Luangjame, J., Tandatemiya, M. and Lertsirivorakul, R., 1995. Water use of *Eucalyptus camaldulensis* on salt affected soil at Ban Dong Bung in Yang Talad district, Kalasin province, NE Thailand, in Boontawee, B., (ed.), *Proceedings of the National Forestry Conference 1995*, Royal Forest Department, Thailand, pp.33–47 (in Thai).

Tandatemiya, M., 1996, Management of slightly and moderately salt-affected soils, poster session handout for 4th National Conference and Workshop on 'The productive use and rehabilitation of saline lands', Albany, Western Australia.

## Publications of project SWL/1985/051

Ciesiolka, C., Coughlan, K., Rose, C., Escalante, M., Hashim, G., Paningbatan, E. and Sombatpanit, S., 1995, Methodology for a multi-country study of soil erosion management, *Soil Technology*, vol.8 No. 3, pp. 179–192.

Sombatpanit, S., Rose, C., Ciesiolka, C. and Coughlan, K., 1995, Soil and nutrient loss under rozelle (*Hibiscus subdariffa* L. var. *altissima*) at Khon Kaen, Thailand, *Soil Technology*, vol. 8 No. 3, pp. 235–242.

# An Assessment of the Realised Impacts of Projects Funded by ACIAR in Thailand on Flowering Behaviour and Subsequent Productivity of Mango

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# Contents

# 1 Introduction

Mango (*Mangifera indica*) ranks among the top five fruits grown in Thailand. It is one of the most important fruits of the tropics and subtropics in terms of domestic consumption and increasing exports. Three important export markets are Malaysia, Singapore and Hong Kong, with 90 percent of the total exports. However, among the major tree fruits of the world, mangoes exhibit one of the lowest orchard efficiency, with sustainable yields of less than 8 tonnes/ha. Productivity of mangoes in Thailand is about 6 tonnes/ha (Table 1).

Planting area increased from 0.20 million hectares in 1990 to 0.30 million hectares in 1996, with total fruit production of 1.21 million tonnes (t). The most important cultivars for both the fresh fruit domestic market and for the export market are Nam Dokmai and Khieo Sawoei. In 1996, the planted areas of Nam Dokmai and Khieo Sawoei were 14 and 24 percent of the total area, the productivity is about 5.39 and 5.11 t/ha and the price is 19.6 and 24.4 baht/kg, respectively (Tables 2 and 3). Prices of mango cultivars vary because of quality differences. Some cultivars are consumed when they are unripe, while others are consumed when they are ripe. Based on economic theory, prices differ due to supply and demand conditions in the regions. In the case of mangoes, the harvesting period is during March to May. Consequently, the price of mangoes in May is the lowest (see Annex). If mangoes can be

**Table 1.** Mango production in Thailand, 1996

| Regions | Planted area (ha) | | Total | Yield (t/ha) | Total production (t) | Price | |
|---|---|---|---|---|---|---|---|
| | Bearing | Not bearing | | | | (baht/kg) | (A$/t) |
| North | 53,460 | 26,535 | 79,995 | 5.43 | 290,036 | 11.82 | 591 |
| Northeast | 65,635 | 37,847 | 103,483 | 5.26 | 345,340 | 15.00 | 750 |
| Central | 16,838 | 8,200 | 25,038 | 6.30 | 106,089 | 17.27 | 864 |
| East | 36,843 | 14,232 | 51,076 | 7.39 | 272,417 | 18.07 | 904 |
| West | 25,979 | 12,448 | 38,428 | 6.83 | 177,473 | 16.44 | 822 |
| South | 2,555 | 1,373 | 3,928 | 6.34 | 16,213 | 18.70 | 935 |
| Whole Kingdom | 201,311 | 100,636 | 301,947 | 6.00 | 1,207,567 | 15.03 | 752 |

Note: A$1 = 20 baht
Source: DOAE 1998

**Table 2.** Khieo Sawoei cultivar production in Thailand, 1996

| Regions | Planted area (ha) | | Total | Yield (t/ha) | Total production (t) | Price | |
|---|---|---|---|---|---|---|---|
| | Bearing | Not bearing | | | | (baht/kg) | (A$/t) |
| North | 12,075 | 8,656 | 20,731 | 3.08 | 37,239 | 17.71 | 886 |
| Northeast | 10,850 | 10,248 | 21,098 | 5.24 | 56,839 | 22.11 | 1106 |
| Central | 5,070 | 3,319 | 8,389 | 6.47 | 32,798 | 30.48 | 1524 |
| East | 6,771 | 4,094 | 10,865 | 6.56 | 44,387 | 36.38 | 1819 |
| West | 6,861 | 4,326 | 11,187 | 6.07 | 41,616 | 30.46 | 1523 |
| South | 76 | 93 | 169 | 5.58 | 423 | 33.68 | 1684 |
| Whole Kingdom | 41,703 | 30,736 | 72,439 | 5.11 | 213,302 | 24.38 | 1219 |

Note: A$1 = 20 baht
Source: DOAE 1998

harvested earlier or later, the mango producers might benefit from higher prices.

Only a small portion of the mango crop was exported in 1998, with about 10 209 t sold as fresh mangoes for 201 million baht and 5526 t sold as processed mango for 206 million baht (Table 4).

Low productivity of mangoes is associated with irregular bearing (Beal and Newman, 1996, cited in ACIAR 1997), which is largely a result of flowering and excessive fruit drop occurring during the early stages of fruit development (Chacko, 1984, 1990, cited in ACIAR 1997). Understanding the various exogenous and endogenous factors associated with floral initiation and fruit set and retention in mangoes is critical for developing suitable orchard management practices to achieve higher and more regular yields. Improved and sustainable yields will enhance market development and consequently the economic viability of Thai mango producers.

The aim of this paper is to assess the impact of the project on flowering behaviour and subsequent productivity of mango in Thailand funded by ACIAR. After this introduction, a description of the project is given in section 2. In section 3, the outcomes generated through the project are described and evaluated. In the last section, the conclusions are presented.

**Table 3.** Nam Dokmai production in Thailand, 1996

| Regions | Planted area (ha) | | Total | Yield (t/ha) | Total production (t) | Price | |
|---|---|---|---|---|---|---|---|
| | Bearing | Not bearing | | | | (baht/kg) | (A$/t) |
| North | 4,812 | 3,370 | 8,182 | 3.71 | 17,877 | 14.84 | 742 |
| Northeast | 6,165 | 4,541 | 10,706 | 5.05 | 31,115 | 19.23 | 962 |
| Central | 3,342 | 2,615 | 5,957 | 6.21 | 20,754 | 24.23 | 1212 |
| East | 6,424 | 2,440 | 8,864 | 5.92 | 38,021 | 26.39 | 1320 |
| West | 4,264 | 2,299 | 6,562 | 6.35 | 27,057 | 19.91 | 996 |
| South | 144 | 375 | 519 | 4.65 | 669 | 25.00 | 1250 |
| Whole Kingdom | 25,150 | 15,639 | 40,789 | 5.39 | 135,494 | 19.58 | 979 |

Note: A1$ = 20 baht
Source: DOAE 1998

**Table 4.** Mango exports for Thailand, 1987–1998

| Year | Mangoes fresh exports (t) | Value ('000 baht) | Processing mangoes exports (t) | Value ('000 baht) |
|---|---|---|---|---|
| 1987 | 3,736 | 28,309 | 1,332 | 32,710 |
| 1988 | 6,713 | 49,727 | 2,256 | 51,145 |
| 1989 | 4,205 | 30,171 | 2,939 | 67,982 |
| 1990 | 5,724 | 37,358 | 4,254 | 95,220 |
| 1991 | 3,236 | 26,132 | 6,270 | 143,797 |
| 1992 | 3,947 | 31,616 | 6,716 | 147,124 |
| 1993 | 2,940 | 26,110 | 4,707 | 102,078 |
| 1994 | 3,411 | 48,459 | 6,397 | 138,557 |
| 1995 | 3,658 | 42,174 | 5,914 | 136,379 |
| 1996 | 8,250 | 120,135 | 6,937 | 175,430 |
| 1997 | 8,522 | 148,939 | 5,993 | 182,271 |
| 1998 | 10,209 | 201,489 | 5,526 | 206,064 |

**Source:** Agricultural Statistics of Thailand, OAE

# 2 Description of ACIAR research projects on the flowering behaviour and subsequent productivity of mangoes

Project CS1/1990/012 was a three-year project that started in July 1994. Research funding was about A$764 712, but only A$565 495 had been expended by the end of the three years (June 1997). A group of Thai scientists was recruited from the Horticultural Research Institute, Department of Agriculture (DOA). After reviewing the projects in May 1997, it was suggested that the project should be extended for another 12 months to complete the work. The project terminated in September 1999.

The overall objective of project CS1/1990/012 was to improve sustainable crop production in mango cultivars growing in the subtropical and tropical environments of Thailand and Australia so that domestic and export markets can be reliably supplied with quality fruit, yielding higher financial returns to growers. The specific objectives were to:

1. define the genotype by environment phenology pattern for significant commercial cultivars grown in Australia and Thailand;
2. study the physiological and flowering response of erratic bearing and regular bearing mango cultivars grown in containers and in the field to seasonal changes in temperature, atmospheric vapour pressure deficit (VPD) and soil moisture;
3. study the effect of chemical cincturing on leaf gas exchange, carbohydrate accumulation, 14C-assimilate distribution and flowering in the cultivar Kensington;
4. study the seasonal variation in temperature, atmospheric vapour pressure deficit (VPD) and soil moisture and their effect on leaf gas exchange and flowering in two commercial mango cultivars grown in the tropical regions of Thailand;
5. study the comparative efficiency of the chemical cincturing technique with that of paclobutrazol treatment, a growth retardant currently under development, for flower induction in mango cultivars commercially grown in Thailand and determine the impact of such treatments on leaf gas exchange and carbohydrate accumulation;
6. study leaf gas exchange and 14C-assimilate distribution in grafted plants of Kensington, Irwin and Nam Dokmai grown under inductive and non-inductive temperature regimes in controlled environmental chambers;
7. evaluate major Thai and Australian cultivars for adaptation to cold temperatures and establish correlation between cold adaptation and yield performance in subtropical environments;
8. study floral development, pollen germination and ovule fertilisation of major Thai and Australian cultivars under cool, subtropical conditions;
9. define minimum critical threshold temperatures for successful pollination and ovule fertilisation for a range of Thai and Australian cultivars;
10. improve the capabilities of horticultural field staff in Thailand with respect to tree fruit phenology and physiology research techniques through liaison and training; and
11. determine potential management strategies that will enhance the sustainable productivity of Thai and Australian mango cultivars.

In Thailand, three different locations were selected, namely Phichit Horticulture Research Centre (HRC), Sisaket HRC and Chiang Rai HRC. Phichit and Sisaket are classified as tropical zones, while Chiang Rai is grouped in the subtropical zone. Experiments in Thailand were conducted to complete objectives 1, 4, 5, 7, 10 and 11.

# 3 Impact of the project

The benefits from the project can be classified into different groups. It provides a basis for joint research, exchange of technology and the development of ongoing scientific relationships between the three organisations within the two countries, namely the DOA in Thailand, and ACIAR and CSIRO in Australia. At the time of writing, this ACIAR-funded project on flowering behaviour and subsequent productivity of mangoes had not released any new technology for improving the sustainable crop production in mango cultivars growing in subtropical and tropical environments. Therefore, the economic impact of the technology was not assessed.

Nevertheless, the researchers and scientists have obtained scientific information that can be used for further research. Research on the technique developed from this project has continued at the experimental level and the mechanical cincturing technique has been tested in farmers' orchards on two varieties of mangoes. The results from these tests indicated that the technique had no influence on out-of-season flowering, but it appeared to have a positive effect on in-season flowering. However, the low response rate for inducing out-of-season flowering could have been caused by abnormal climatic conditions (low temperatures over a long period) and therefore it would be necessary to repeat the tests a few more times before any reliable conclusions can be drawn (Pongsomboon, pers. comm. 2000).

Given that the economic assessment was not undertaken, only benefits in terms of scientific knowledge, technology transfer (used by the scientists) and publications are given in this section.

*Objective 1*: To define the genotype by environment phenology for significant commercial cultivars grown in Thailand (Chiang Rai, Phichit and Sisaket HRCs)

The systematic collection of phenological information was conducted successfully at all sites and it provides a detailed description of the annual cycles of mango growth and cropping in Thailand. In most cases, this information has covered three years (1995–97). Some problems were experienced in Thailand where fruit were harvested or experimental trees removed by growers before all data had been collected. This had most impact at Chiang Rai, where the substitute trees were in poor condition when experiments commenced in 1995. Inspection during the review indicated that these trees had not all recovered to full health by May 1997. Much of the problem may relate to boron deficiency.

After being reviewed in May 1997, the project was extended for another 18 months. The pheno-physiological models were presented with one-year cycle data (1997–98) for significant commercial cultivars such as Khieo Sawoei and Nam Dokmai in all the three sites.

In the scientists' opinion, the data obtained from the one year study may not be sufficient for developing a representative descriptive model of mango tree performance in the tropical and subtropical regions. Improper functioning of some scientific equipment and errors in its application also happened occasionally. The inconsistent health of the experimental trees presented another restriction. The investigation should be followed for at least another annual cycle.

The research did develop detailed information on the environmental interactions on crop phenology and physiology, providing data that were not available previously. This assists in the development of managerial strategies to enhance sustainable production.

*Objective 4*: Study the seasonal variation in temperature, VPD and soil moisture and their effect on leaf gas exchange and flowering in two commercial mango cultivars growing in the tropical and subtropical regions of Thailand (Phichit and Chiang Rai HRCs, respectively)

There was one-year cycle data (1997–98) for leaf gas exchange, vegetative flush growth, and flowering for two mango cultivars, namely Khieo Sawoei and Nam Dokmai at the Phichit HRC and the Chiang Rai HRC. Such physiological aspects were determined in association with the seasonal variation in temperature. During the implementation in the first three-year phase, there were some problems with the management of the scientific equipment for the study, such as the CIRAS system for the leaf gas exchange measurement. Initially, its electrical control system malfunctioned when it came to Thailand and before it was used. The restriction existed for some time because the equipment had to be sent back to the product company in the UK for a special check-up and service. The logistical problem of transporting equipment among the three experimental sites was also difficult to solve. The magnitude of this problem decreased when, during the extension phase, the measurements were required for only two of the research sites. Moreover, VPD and soil moisture measurements could not be made as no specific equipment was allocated. However, in the case of the tree water stress study, another reasonable physiological parameter was monitored instead: PEA chlorophyll fluorescence measurement. The equipment for this was provided with support from ACIAR. The chlorophyll fluorescence data, coupled with tree growth and cropping data, were collected for the three sites by moving the equipment from one site to the next. The results were present with the one-year cycle pattern similar to the other parameter studies.

*Objective 5*: Study the comparative efficiency of the chemical cincturing technique with paclobutrazol treatment, a growth retardant currently under development, for flower induction in mango cultivars commercially grown in Thailand and determine the impact of such treatments on leaf gas exchange and carbohydrate accumulation (Phichit HRC)

The parclobutrazol soil application is the current technology for inducing an out-of-season crop for mangoes in Thailand (Eamsap, 1992; Suppakitjaruk, 1990; Tong-Umpai, 1986). One of the main constraints to using parclobutrazol is a long-term residue of the chemical in mango leaf and soil, for about 6 months (Eamsap, 1992). By the way, a chemical cincturing technique developed by Dr E.K. Chacko (CSIRO) in Darwin was reported to be highly effective for the floral induction of mangoes in the tropical environment in Australia. This provided an opportunity for Thai mango growers in the tropical region to control out-of-season cropping by using this new procedure. An efficiency comparison between these two techniques was made for the control of out-of-season flowering in the two commercial mango cultivars, namely Khieo Sawoei and Nam Dokmai in mango orchards at Phichit and the mango-growing block at Sisaket HRC. It was evident that both the paclobutrazol application and the chemical cincturing were generally effective floral inductants producing an out-of-season crop for the two mango cultivars at Phichit. Nevertheless, at Sisaket, low responsiveness for flowering promotion of both cultivars was expressed when applied with the chemical cincturing technique compared with the paclobutrazol effect.

Unfortunately, the study of the active ingredient of the chemical used with the cincturing procedure became a constraint, because at present no chemical company appears to be continuing manufacturing the necessary ingredient. Therefore, as suggested by the project review team in May 1997, the effectiveness of simple mechanical cincturing technique without any chemical was also examined during the project extension phase. With the two-year data, both the new mechanical cincturing and the paclobutrazol application were similarly effective for controlling out-of-season cropping in both the Khieo Sawoei and Nam Dokmai cultivars for the Phichit orchards. Meanwhile, at Sisaket only the paclobutrazol application enhanced out-of-season flowering of both cultivars.

The scientists recommended that, to assess the effectiveness of the new mechanical cincturing technique for inducing out-of-season flowering in mangoes, the technology trial should be conducted continuously for many growing areas in tropical climate regions of Thailand. It would be designed to generate both early and late season crops for an extension of the production seasons year round.

So far, Thai farmers have experienced unsatisfactory results from using hormones and chemicals for inducing out-of-season crop for mangoes due to a lack of knowledge (Khamlerd, 1984). This could be because early production is not only affected by the application of hormones and chemicals for inducing out-of-season cropping, but also by other factors such as mango variety, mango condition, type of chemical used, pests, environmental conditions and plant hormones. If this new technique is to be useful for Thai mango producers, it is very important to transfer both this technique and the knowledge of all relevant factors to the farmers.

*Objective 7*: To evaluate major Thai cultivars for adaptation to cold temperatures and establish correlation between cold adaptation and yield performance in a subtropical environment (Chiang Rai HRC)

The effect of ambient temperature on floral sex expression was studied over three years and provides evidence that the number of hermaphrodite flowers does vary with cultivars across years. However, low temperatures did not always correlate with low numbers of hermaphrodite flowers and there was no convincing evidence that hermaphrodite flower numbers ever limited fruit set or yields.

*Objective 10*: To improve the capabilities of horticultural field staff in Thailand with respect to tree fruit phenology and physiology research techniques through liaison and training.

Benefits have already flowed to participating countries in terms of training. Five Thailand DOA staff members visited Australia for training during different periods from October 1994 to October 1995. Dr Wasan Pongsomboon (Phichit HRC) and Dr Suwit Chaikiattiyos (Sisaket HRC) spent 8 weeks at both Darwin, CSIRO Division of Horticulture and Maroochy Horticultural Research Station, Queensland Department of Primary Industries for both tropical and subtropical research-training courses. Mrs Sumaree Suwanbutr (Phichit HRC) had 4 weeks of training on starch analysis technique at Queensland Department of Primary Industries, Brisbane. Mr Montri Dasanond (Chiang Rai HRC) and Mr Rakcha Kurubunjerdjit (Sisaket HRC) received 12 weeks training in pollen study of mango flowers at Maroochy Horticultural Research Station, Queensland. A major impact for the Thailand DOA is the raising of the skill and experience levels for many of the project staff members following visits to Thailand by Australian project staff to enhance the implementation of research work program.

*Objective 11*: To determine potential management strategies that will enhance the sustainable productivity of Thai mango cultivars (Chiang Rai, Phichit and Sisaket HRCs)

The problems of erratic flowering and low productivity have not been completely solved, although a better understanding of the contributing factors has undoubtedly been generated. Nowadays, having substantial main season production, probably close to saturation point for each domestic fresh fruit market, a future replacement project should focus on extending production seasons, both early and late. It is expected that the new mechanical cincturing technique will continue to be tested. Modification of this technique includes application combined with low dosage of paclobutrazol compared with the unique procedures of cincturing, parclobutrazol and other chemical applications.

*An additional objective*: To access the extent of boron deficiency in Thailand mango orchards, to develop remedial strategies and to quantity the impact of deficiency symptoms on parameters measured in this project (Chiang Rai, Phichit and Sisaket HRCs)

Other aspects of mineral nutrition are also important. For example, interestingly, boron and calcium have positive effects on fruit set/bearing capacity and quality. Knowledge of the importance of these mineral nutrients would enable appropriate strategies for mango orchard management to be developed.

It is understood that the boron deficiency problem is widespread in various soil types in many plantation areas throughout Thailand. Therefore, a true picture of flowering and fruit set limitations in Thailand may not emerge until the nutritional problems have been solved. Boron addition trials were designed at all the three experimental sites commencing in late 1996.

The data on flowering and fruit set of the two commercial mango cultivars were monitored over two annual cropping cycles. The results expressed a trend of positive effects of boron application, both soil and leaf, on fruiting capacity. However, it has not been clear whether the diagnosed symptoms of boron deficiency have been substantially corrected by the boron application at the three test sites. This solution might be a long-term effect and is probably based on the mango cultivars in association with the environment conditions. Moreover, the overall standard of tree management varied among the research and commercial sites. Other physiological or nutritional problems may, therefore, be revealed once the boron deficit is corrected. Even though, as the results from the present boron trials show, preliminary recommendations could not be made for growers, at least they provide a guide on the amount and formulation of boron, the application time and the appropriate application methods. Such information will benefit tree health and cropping performance. Further studies should follow, including a study on rootstock selection for boron uptake and delivery.

# 4 Conclusions

Benefits from the projects can be summarised as follows. Basic information in plant protection, postharvest management, etc. can be derived from the projects and applied in further research. Understanding of mango physiology might be useful for the physiology of other crops that have the same character. For example, the project developed detailed information on the environmental interactions on crop phenology and physiology, providing data that were previously not available. This assists in the development of managerial strategies to enhance sustainable production.

Researchers and scientists can use this information as intermediate inputs for further research work. Moreover, exchange and update of information from the scientists, including comments and suggestions among the three institutes involved, namely the DOA, the Queensland Department of Primary Industries and CSIRO (Darwin), takes place. A new technique, called mechanical cincturing, is used for inducing out-of-season flowering of mangoes. The scientists plan to assess the effectiveness of the new mechanical cincturing technique for inducing out-of-season flowering in mangoes. This assessment should be conducted continuously for many growing areas in the tropical climate of Thailand. It would be designed to generate both early and late season crops for an extension of the production season through the year. Interviews with Thai mango producers indicate that they are going to test this technique at the end of 1999. Further, another three years is needed to test this technique for many growing areas in tropical climate of Thailand. In addition, the scientists from the project presented the results of the work to the public, as publications, posters and lectures.

Thai researchers and scientists have gained experience from training supported by the projects such as physiological, chemical analysis, nutrition, starch analysis technique and pollen study of mango flowers, etc. Equipment installed from the project can be used for other works. One Thai researcher received a scholarship in 1996 for PhD study at the University of Queensland.

As the problems regarding mango productivity have not been solved, further research is required before recommendations on sustainable mango production in Thailand can be made.

# 5 Acknowledgments

The authors gratefully thank Dr Wasan Pongsomboon, Dr Suwit Chaikiattyos and Khun Montri Dasanonda, Horticulture Research Centres, Department of Agriculture for giving their valuable time to make comments and recommendations on the valuation of project benefits.

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Tong-Umpai, P. 1986. Plant growth regulators in mangoes. Unpublished paper.

# 7 List of project publications

## Publications

Chaikiattiyos, S., W. Pongsomboon, M. Dasanonda, and P. Anunpunt. 1996. Floral expression and Khieo Sawoei and Nam Dokmai mangoes grown in tropical and subtropical climates in Thailand. Acta Horticulturae

Dasanonda, M., W. Pongsomboon, S. Chaikiattiyos, S. Vorapitrirangsi and P. Anupunt. 1997. Floral sex expression of Khieo Sawoei and Nam Dokmai mangoes grown in tropical and subtropical climates in Thailand. Proceedings of the 5$^{th}$ International Mango Symposium. Tel Aviv, Israel, September 1997

## Poster

Pheno-Physiological Modelling for cvs. Khieo Sawoei and Nam Dokmai mangoes grown in Tropical and Subtropical Climates of Thailand. Poster presented at “The Sixth International Mango Symposium” on 6–9 April 1999, Chonburi Thailand

# Annex

Farm gate price of mangoes in baht/kg, 1991–98

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Khieo Sawoei cultivar** | | | | | | | | | | | | | |
| 1991 | 73.0 | 76.9 | 53.4 | 27.6 | 29.6 | | | | | | | | 32.3 |
| 1992 | | | 34.2 | 33.2 | 17.4 | 12.0 | | | | | | | 25.8 |
| 1993 | 70.0 | 55.6 | 38.7 | 22.7 | 14.0 | | | | | | | | 22.2 |
| 1994 | | 40.9 | 43.8 | 37.5 | 20.6 | | | | | | | | 35.7 |
| 1995 | 65.0 | 41.3 | 30.0 | 31.7 | 16.8 | | | | | | | | 36.9 |
| 1996 | | | 39.3 | 24.5 | 10.0 | | | | | | | | 24.6 |
| 1997 | | 40.0 | 39.0 | 26.0 | 16.9 | | | | | | | | 30.5 |
| 1998 | | 40.0 | 41.5 | 31.6 | 40.0 | | | | 53.3 | 35.5 | 23.6 | 31.7 | 37.2 |
| **Nam Dokmai cultivar** | | | | | | | | | | | | | |
| 1991 | | 58.3 | 38.8 | 25.0 | 30.0 | | | | | | | | 27.7 |
| 1992 | | | 26.0 | 21.3 | | | | | | | | | 22.0 |
| 1993 | 25.0 | 34.4 | 32.5 | 26.0 | 8.7 | | | | | | | | 23.4 |
| 1994 | | 29.5 | 43.8 | 29.1 | 12.5 | | | | | | | | 28.7 |
| 1995 | | 25.0 | 29.3 | 34.0 | 20.0 | | | | | | | | 27.1 |
| 1996 | | | 32.5 | 23.9 | 22.0 | | | | | | | | 26.1 |
| 1997 | | 30.0 | 32.6 | 18.2 | 11.4 | | | | | | | | 22.9 |
| 1998 | | 32.5 | 43.7 | 23.5 | 30.0 | | | | 21.7 | 15.0 | 22.6 | 26.5 | 26.9 |

Note: Average price is weighted by amount of mangoes sold for the whole year.
**Source:** OAE 1999

# An Impact Assessment of ACIAR-funded Projects on Rainfed Lowland and Flood-prone Rice Plant Improvement in Thailand

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# Contents

# 1 Introduction

Rice is Thailand's staple food crop. In addition, Thailand is a major exporter in the world rice market. Of the 20 million tons of rice produced in 1997, two-third was used for domestic consumption and the surplus was exported. Despite the importance of rice in the Thai economy, rice yields in Thailand are relatively low, resulting in low farm incomes. Attempts to increase the rice yield through varietal improvement have been made but most varietal developments so far are better suited for irrigated environments. Rice research for rainfed and flood-prone environments is very rare, despite the fact that the majority of rice is grown in unfavourable production environments.

Over the past decade, the Thai Government, in collaboration with the Australian Centre for International Agricultural Research (ACIAR), has conducted research on rice plant improvements in unfavourable production environments with the aim to improve a physiology of rice for a better yield. The purpose of this paper is to investigate the impacts of these projects. After this introduction, the background of ACIAR-supported projects on rice plant improvements is summarised in section 2. In section 3, scientific information and technology generation is discussed. An impact assessment of the research is made in section 4. In the last section, the conclusions and suggestions are presented.

# 2 Description of four ACIAR-supported research projects on rice plant improvement

The area planted to rice in Thailand is around 9.17 million ha (OAE, 1998). This area comprises four rice production environments, namely rainfed lowland, irrigated lowland, upland, and deepwater rice. Among these four production cultures, rainfed lowland and deepwater cultures share nearly 75% of the total production area. The inherent characteristic of the rainfed lowland is the erratic rainfall pattern, which creates water stress for growing rice. Furthermore, in many major rainfed areas, particularly in the Northeast, production of rice is made in even more difficult because of the sandy soils, which have a very low water-holding capacity and low soil fertility. In contrast, the deepwater rice-growing areas in the Central Plain and some of the Lower North, have the opposite situation. This area is flooded for long periods under an erratic water-level during the rainy season. Floating rice varieties are commonly grown in this production area with a very low yield.

To enhance rice yields in unfavourable environments, four ACIAR–supported research projects on rice plant improvement were developed in collaboration with the Thai Government. Two of these projects (CS1/1983/025 and CS1/1987/030) were in relation to deep water rice improvement, while the other two (CS1/1990/045 and CS1/1995/100) involved rainfed lowland rice improvement. A summary of the four projects is given in Table 1.

## 2.1 Project on "Flooding tolerance of rice" (CS1/1983/025 and CS1/1987/030)

The critical problems of the farmers in deepwater areas are the inherently low productivity of traditional rice cultivars and the risk of crop loss or damage due to the submergence of plants by unpredictable, abnormally deep floods. The project CS1/1983/025 was developed to investigate the adverse effects of complete submergence on the growth of rice cultivars. The project started in 1983 and lasted three years. It had four lines of inquiry (ACIAR, 1986): (1) environmental measurements of flood waters; (2) crop physiology in the field in Thailand and whole plant physiological studies under controlled conditions in Australia; (3) physiological experiments on the biophysical and biochemical mechanisms which are responsible for tolerance to flooding; and (4) tissue culture for physiological studies and plant improvement. The field surveys were conducted to measure concentrations of carbon dioxide, oxygen, and ethylene in floodwaters at different locations throughout Thailand. Controlled field experiments for a comparative response of submergence tolerant and submergence-intolerant cultivars were undertaken at the Huntra Deep Water Rice Research Station. The tissue culture techniques in developing new varieties for deepwater areas were undertaken at the University of Western Australia and Murdoch

**Table 1** A Summary of ACIAR's Funded Research on Rice Plant Improvement in Thailand and Laos

| Project number. | Title | Year started | Duration | Budget funded by ACIAR (A$) | Thai organisation involved |
|---|---|---|---|---|---|
| CS1/1983/025 | Flooding tolerance of rice | 1983 | 3 | 545,887 | DOA |
| CS1/1987/030 | Rice flooding tolerance | 1987 | 1 | 65,000 | DOA |
| CS1/1990/045 | Plant improvement of rainfed lowland rice in drought prone areas | 1992 | 3 | 722,764 | DOA |
| CS1/1995/100 | Plant breeding strategies for rainfed lowland rice in Northeast Thailand and Laos | 1995 | 3 | 306,818 | DOA |

**Source:** ACIAR's project details, Economic Evaluation Unit, Australian Centre for International Agricultural Research.

University. After ending this project, it was extended for another year under project CS1/1987/030 to complete the unfinished scientific experiments from project CS1/1983/025 (ACIAR, 1986).

## 2.2 Project on "Plant improvement of rainfed lowland rice in drought prone areas" (CS1/1990/045) and Project on "Plant breeding strategies for rainfed lowland rice in Northeast Thailand and Laos" (CS1/1995/100)

Project CS1/1990/045 was a three-year project with the research conducted in Thailand, Laos, and Australia. The project was conducted in Thailand during 1992–1994 and in Laos during 1993–1995. The project aimed to develop rice cultivars that would produce in dry environments yields higher than those of the existing cultivars. The specific research objectives included: (1) characterisation of drought environments and genotypic variation in response to drought; (2) evaluation of current screening methods for drought tolerance and genetic analysis of drought resistant components; and (3) evaluation of rice cultivars for saturated soil culture. Experiments were conducted at 10 research stations in the North and Northeast Thailand and at two research stations in Laos (ACIAR, 1991).

Project CS1/1995/100 followed on from CS1/1990/045. It was a three-year project starting started in 1996. The project aimed is to develop breeding strategies to improve the efficiency of the rice improvement programs in both Thailand and Laos. Five specific objectives can be listed: (1) to evaluate the existing and alternative breeding methods, particularly selection strategies for rainfed lowland rice in Northeast Thailand; (2) to develop a screening method against late-season drought and to identify physiological and morphological traits which confer drought resistance; (3) to examine whether or not screening under high fertiliser inputs is appropriate for selection of genotypes and to identify reasons for the superiority of some genotypes under different soil fertility conditions; (4) to evaluate the genotypic requirement for direct seeding to minimise adverse effects of drought; and (5) to quantify the effect of various environmental factors on phenological development of different rice cultivars, and to examine whether different phenology groups are required at different locations in Northeast Thailand and Laos. There were six rice research stations in Thailand and three rice research stations in Laos involved in testing the breeding lines.

# 3 Research findings

## 3.1 Scientific information and outputs generated by the research

Scientific research is a production process for acquiring scientific information and technology generation. These two outputs are importantly different in a further production process. The scientific knowledge is itself basic information for new technology generation. On the other hand, the new technology generation from the research is an important input for productivity improvement.

The research outputs generated so far by ACIAR's plant improvement projects for deep water rice in flooding areas and rainfed lowland rice in drought prone areas are mostly in terms of basic scientific knowledge for alternative genetic and agronomic improvements of rice yield in those areas.

### *3.1.1 CS1/1983/025 and CS1/1987/030*

The research work of these projects included: (1) field surveys on carbon dioxide, oxygen, and ethylene concentrations in floodwater and plant organs of deepwater and floating rice cultivar; (2) controlled field experiments on traditional deepwater and floating rice cultivars exposed to increasing water levels; (3) controlled field experiments on complete submergence; and (4) phytotron experiments on the importance of carbon dioxide, oxygen, and ethylene in floodwater during submergence of rice. The main research finding indicated that physiological implications for rice plants submerged in deep-water situation have been found to be linked with light climate, pH, temperature and dissolved gases (carbon dioxide, oxygen, and ethylene). Particularly, high ethylene concentrations were observed to be the primary factor for instigating internode elongation, which is an adverse factor of increasing water levels (Greenway and Setter, 1986).

### *3.1.2 CS1/1990/045 and CS1/1995/100*

The research work of project CS1/1990/045 involved: (1) multi-location trials to determine the pattern of drought development under rainfed conditions and the genotypic variation in grain yield under different growing conditions; (2) seeding screening methods for drought resistance; (3) genotypic differences in response to drought and crop management; (4) physiology of drought resistance; (5) development of recombinant inbred lines; (6) rice simulation model for estimating yield reduction due to drought and other factors. The project has generated a large volume of scientific information from many experiments conducted in North and Northeast Thailand and in Laos, as well as from a computer simulation model that was specifically developed for the project (Fukai et al. 1996). The main conclusions were:

- Both early and late season droughts are common in rainfed lowland rice areas in Thailand and Laos, but the severity of the problem differs in the various regions. Early-season drought affects mainly transplanting whereas late-season drought affects yield directly. A late-season drought alone affects the yield of a standard cultivar (KDML 105) by 30% on average, although the loss varies greatly among locations in Thailand. The effects of the drought on grain yield is irregular. The late season drought did not affect crop yield all the time, except for late–maturing cultivars. The large yield loss due to late seeding under standard puddling conditions can be alleviated greatly by soil compaction. Improved soil fertility can also result in increased yield even in drought situation.
- The most important factor determining yield of rainfed lowland rice in Thailand and Laos is phenology, particularly flowering time. Different regions differ in water availability and hence require different phenology types, but early-medium flowering types that flower in early-mid October are generally most suited to the environment. Incorporating this finding into breeding programs will enhance the chance of producing high yielding cultivars.

Project CS1/1990/045 was intended to provide future directions for plant improvement programs rather than for direct technology development. Thus, after CS1/1990/045 was ended, it was replaced by CS1/1995/100. The replacement project incorporated the research outcomes obtained from CS1/1990/045 for further testing of the ideas developed from the results of the previous project.

The research work of CS1/1995/100 involved: (1) a comparison of the present and alternative breeding methods by employing 463 lines for testing under varying environmental condition in the region; (2) screening against late-season drought in both wet and dry seasons; (3) genotype and soil fertility interaction to identify the variety responses to different levels of fertiliser under rainfed lowland conditions; (4) genotype requirement for direct seeding; and (5) effects of genotype-by-environment interactions for phenology (Fukai et al, 1998). The scientific information derived from the projects included the following:

- The analysis of multi-environment trials (MET) indicated that there is a larger variance for yield due to genetic and environment interactions than due to genotype alone. These interactions clearly complicate selection for broad adaptation but highlight possible opportunities for selection for specific adaptation when repeatable genetic and environment interactions are identified.
- The impact of late season drought can be reduced by selection of appropriate phenology types for the target environment. One possibility is to use the delay in flowering under drought as a selection criterion. Furthermore, genotypes which can maintain high leaf water potential at flowering when drought stress develops are likely to have low spikelet sterility and hence minimise the adverse effects of drought on yield.
- Genotypes differ in their response to variation in soil fertility. In addition, the efficiency of nutrient use appears to be genotype specific and consistent across environments. In addition, the rainfed lowland rice crop simulation model was successfully developed to evaluate variation in soil fertility, particularly under water stress conditions.
- Direct seeding can produce yields that are comparable to transplanting, if establishment is good and weeds are controlled. There is a large genotype variation in response to weed competition and this variation can be explained in a breeding program.
- Low temperature during panicle development and high nitrogen fertiliser application reduce pollen grain number per anther and induces spikelet sterility. Genotypes differ in pollen number and also in response to low temperature stress during pollen development stage.

Given the strong evidence for genetic and environment interactions for yield in rainfed lowland area of North and Northeast Thailand, the line IR57514-PMI-5-B-1-2, which was identified as consistently high yielding, is now considered as one of the most promising lines for new varietal development.

## 3.2 Research publications

Research information can be distributed to the public through research publications in scientific journals, conferences or workshop proceedings and others. The public availability of this research information may be beneficial to other scientists. Some 60 publications were produced from the four projects on rice plant improvements. About 14 research papers were published in scientific journals. Others were presented in scientific conferences or workshops or as memos in circulation papers (Table 2).

**Table 2.** Types of research publications generated by the projects.

| Project no. | Book | Journal | Papers | | | Total |
|---|---|---|---|---|---|---|
| | | | Conference | Workshop | Other | |
| 1. CS1/1983/025[a] | none | none | - | 4 | 10 | 14 |
| 2. CS1/1987/030 | na | na | Na | Na | na | na |
| 2. CS1/1990/045[b] | none | 8 | 7 | 10 | - | 25 |
| 3. CS1/1995/100[c] | none | 6 | 3 | 9 | 3 | 21 |

**Source:**

a. Derived from ACIAR's Review Report for Project CS1/1983/025 "Rice Flooding Tolerance" and Proceedings of the 1987 International Deepwater Rice Workshop, Bangkok, Thailand. International Rice Research Institute, Manila, Philippines.
b. Derived from Fukai et al. (1996)
c. Derived from Fukai et al. (1998)

# 4 Impact assessment of the research projects

Development of cultivars of rice plants that are suited to unfavourable production environments takes some time before a new variety can be generated. It also requires a large amount of scientific effort and research investment. So far, the rice plant improvement projects funded by ACIAR have produced new scientific outputs that are useful for further scientific research for new varietal improvement. It was accepted that both the projects on deepwater rice and the projects on rainfed lowland rice plant improvements have disseminated advanced plant breeding methods to Thai scientists who worked in the projects. Their enhanced research skills have resulted in changes necessary for the development of more efficient plant breeding programs for the production environments in Thailand and Laos. This also would contribute to a gain in efficiency of the plant breeding program. However, the financial gains due to adoption of scientific methods by scientists is beyond the scope of this paper. So far, the development of new rice variety, particularly for rainfed lowland rice farmers, is continuing.

In terms of human capacity development in the Department of Agriculture (DOA), Suzuki et al. (1996) reported that eight Thai researchers from CS1/1983/025 attended a short training course in Australia. Fukai et al. (1998) reported that two researchers under CS1/1990/045 and CS1/1995/100 have gone onto further study by enrolling in a PhD degree at the University of Queensland. In addition, several Thai scientists stayed for 6–8 weeks in Australia for training.

In addition, some scientific outputs derived from projects CS1/1983/025 and CS1/1987/030 were used in “the International Training Course in Rice Cultivation Technique and Extension” under the collaboration between the Thai and Japanese governments from 1986 to 1993. About a hundred rice scientists from Southeast and West Asia were trained under this program. Also, it is found that the book on “Rice in Deep Water”, which was written by David Catling (1992), has referenced at least 8 scientific papers that were generated by project CS1/1983/025. The list of those referenced papers is attached in Annex I. In a recent interview, Dr Kupkanchanakul (a former researcher in project CS1/1983/025) said that the experiences obtained from participation in project CS1/1983/025 led him and some other researchers to engage in other rice research projects including: (1) rice for life; (2) the deep water rice improvement program managed by the Department of Agriculture; and (3) a mega-project on rice production managed by the Kasetsart University and the Ministry of Agriculture.

In summary, while there were no confirmed reports by Thai scientists that the scientific finding have been transferred to the farmers in the form of new technology development up until the end of 1999, the research outputs are still very useful as scientific inputs for agronomists or other scientists in the development of rice breeding programs.

# 5 Conclusion

Scientific collaboration between Thai and Australian scientists has significantly developed the Thailand rice breeding program in unfavourable production environments. The transferability of advanced research methods on rice physiology and environmental interactions, particularly in rainfed lowland areas, has enhanced and strengthened research skills of Thai scientists as well as research management of plant improvement programs in the Department of Agriculture. The research outputs generated from the projects provide useful information for future new varietal development, particularly the promising lines obtained from rainfed lowland rice projects.

# 6 Acknowledgments

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# Annex: Project publications

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