

Travel Report presented to NSW Agriculture and the Cooperative research centre for Sustainable Rice Production

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Attend international conference on "The Impact of Agricultural Research for Development in Southeast Asia" in Phnom Penh, Cambodia.
Attend ACIAR workshop on "Productivity of Lowland Rice in Southeast Asia -Overcoming Environmental Constraints" in Vientiane, Laos.
October 20th - November 5th, 2000

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1. Executive Summary

Mr Tim Farrell attended the international conference on, The Impact of Agricultural Research for Development in Southeast Asia, in Phnom Penh, Cambodia, October 24-26, 2000. Mr Farrell then participated in an ACIAR workshop on, Productivity of Lowland Rice in Southeast Asia -Overcoming Environmental Constraints, in Vientiane, Laos, from October 30th to November 1st. During this visit, Mr Farrell made contact with a number of rice scientists working in similar areas of research.

1.1. Introduction

Mr Farrell participated in all sessions of the conference and workshop. The majority of papers presented at the conference and workshop were based on rice research, and some were very relevant to the research conducted by Mr. Farrell.

1.2. Participation

Mr Farrell presented an oral paper at the ACIAR workshop. The title of the paper was "Low temperature constraints to rice production in Australia and Laos: a shared problem". His paper was well received and generated interesting discussion. Mr Farrell also contributed to the discussion throughout the conference and workshop, particularly to the workshop summary on "Low temperature lessons for Laos". Mr Farrell reviewed four papers that will be included in the workshop proceedings.

1.3. Highlights

One of the highlights of the trip was the discussion with fellow rice scientists from around the world in three distinct research areas including cold tolerance, drought tolerance and soil fertility management.

Screening for cold tolerance has produced varieties in countries with cool climates such as Korea and Japan and linkages were made with these scientists. It is planned that continued interaction between cold tolerance groups and Yanco will be possible over the next few years. This interaction has already begun, with the use of Australian varieties in cold research work in Furukawa, Japan, and the introduction of elite Japanese lines into Australia's rice breeding programs. This ACIAR project has meant that Northern Laos will begin to focus on shortening the duration of varieties and improving their level of cold tolerance. The shared experience between Australia, Japan, IRRI and Korea provides an important base for this improvement. Mr Farrell has already sent 20 varieties to Lao scientists, which have performed well in Australia's cold tolerance program. Lao varieties are soon to be sent to Mr Farrell for inclusion in field trials in the 2001/02 season. Introducing new genetic resources is crucial, and such cooperation is vital to all countries' future progress.

1.4. Acknowledgments

This trip would not have been possible without financial support from the CRC for Sustainable Rice Production and the Australian Centre for International Agricultural Research (ACIAR). The Overseas Projects section of NSW Agriculture was also of great assistance with the preparation of this trip. The support of those who willingly took on additional duties to allow me to spend some time away from Yanco is also gratefully acknowledged.

2. REPORT

2.1. Introduction

Mr Farrell attended the international conference on, "The Impact of Agricultural Research for Development in Southeast Asia", in Phnom Penh, Cambodia, October 24-26, 2000. The conference included 200 participants, with the majority coming from Cambodia, Laos, Philippines (IRRI), Thailand, Vietnam and Australia. Mr Farrell's attendance at the conference was valuable for international interaction on very relevant areas of research on cold tolerance and soil fertility.

Mr Farrell then participated in an ACIAR workshop on, "Productivity of Lowland Rice in Southeast Asia -Overcoming Environmental Constraints", in Vientiane, Laos, from October 30th to November 1st. The workshop included approximately 100 scientists primarily from Laos, Cambodia, IRRI and Australia. During this visit he made contact with a number of rice scientists working in three key areas of research including drought tolerance, cold tolerance and soil fertility.

2.2. Aims

The specific aim of attending this conference was to participate as a scientist in the CARDI conference and the ACIAR workshop.

2.3. Participation

Mr Farrell attended the conference on, "The Impact of Agricultural Research for Development in Southeast Asia" and an ACIAR workshop on, "Productivity of Lowland Rice in Southeast Asia -Overcoming Environmental Constraints" October 24- November 1, 2000.

2.4. Cambodia

2.4.1. Introduction

Cambodia has a population of approximately 12 million, with 80% of people located in rural areas. Poverty is a major problem, related to poor education levels, low incomes and landlessness. Cambodia is still in a rebuilding phase following the rule of Pol Pot and the Khmer Rouge. Agriculture has been identified as the first priority in Government policy, and this has led to the establishment of Cambodian Agricultural Research and Development Institute (CARDI) in August, 1999. CARDI is a semi-autonomous institution working with stakeholders to improve the living standards of all Cambodia's people, especially farmers, through agricultural research, training and technology transfer. Agricultural production in Cambodia contributes 40% of the GNP. However, Cambodia's economy is still weak compared to other southeast Asian countries. Cambodia was an exporter of rice until the late 60's and has been in a food deficit for the past three decades. Returns from agriculture are primarily derived from rice (3000 tonnes of rice produced in 2000) and, to a lesser extent, corn, beans, fisheries and livestock. Mem Sarom, the director of CARDI is confident that "there are opportunities for increased production in Cambodia".

Vietnam has significantly increased its rice productivity in the past 20 years and has become a model for countries such as Cambodia and Laos to follow. Two major reasons for increases in Vietnam's yield are increases in government funding and support, and collaboration with IRRI and developed countries (eg China) in the advance of hybrid rice production. Vietnamese scientists attended the international conference at Phnom Penh and offered the CARDI continued support in the drive for rice productivity and sustainability.

2.4.2. Agricultural research

Agricultural research in Cambodia is targeting:

- rice and rice-based cropping systems, eg double cropping, new varieties;
- fisheries;
- integrated animal health production;
- forestry;

- agriculture land-use suitability mapping;
- broadening food supplies for animal feed;
- pest prediction table.
-

2.4.3. Constraints to production

Constraints to rice production in Cambodia include:

- absence of clear policy framework;
- undeveloped market for rice and other food crops;
- barrier to export growth, eg low crop productivity;
- institutional problems and financial constraints;
- inadequate extension services;
- pests (rats and brown plant hopper);
- weeds;
- poor soils;
- water shortages are becoming more important than food shortages;

2.4.4. Drought and flood

Drought and flood are the key constraints to rice production in Cambodia. Depending on the region, drought or flood is the major limitation to yield. Floods can occur in the uplands as well as the lowlands, due to heavy rainfall in the mountains. There is a need to characterise the extent of both drought and flooding. Drought can occur any time during the growing season. In 1998 there was a very long drought, with 30-40% of the crops under threat, but late rains resulted in reasonable yields. Droughts generally occur every year, with early and late season drought the most common. Drought can completely damage seedlings, which may result in a delay in transplanting. Late-season drought begins in November and there has been a shift from late to medium varieties to escape from end-of-season drought.

2.5. Laos

2.5.1. Introduction

The population of Laos is 5 million. Rice is the most important crop in the Lao PDR, accounting for 86% of the cropped land. The rice area in Laos is 650,000 ha, producing average yields of 2.7 t/ha, with the highest yields reaching 4 t/ha. Currently 84% of all rice grown in Laos (85% of total production is glutinous) is consumed by producers. Historically, the majority of rice production in Laos has been produced during the wet season as upland and lowland crops. With the advent of irrigation, rice production in the dry season has increased from 13,600ha in 1995 to 87,000ha in 1999 (NAFRI, 2000). The wet season crop is transplanted into the field in June and harvested in October, while the dry season crop is transplanted between November and January and harvested in May. Additionally, the Lao PDR is divided into the northern, central and southern regions, each having different temperature regimes due to variations in altitude and latitude. Laos has a distinct wet and dry season. Of the rice produced in Laos in 1998, the rainfed lowlands accounted for 74%, the rainfed uplands 13% and 13% was irrigated (IRRI 1999). The total rice yield in the Lao PDR was around 2.1 million tonnes in 1999, and this has made the country self-sufficient. Over the past two decades the total harvest has doubled. Most of this increase has come from the rainy lowland environment, more than doubling from 705,000 tonnes in 1980 to 1.5 million tonnes last year. The long-term aim for Laos rice production is to reduce the area of rainfed upland rice and increase irrigated rice. Almost all of the rice in Laos is transplanted by hand and harvested by non-mechanised methods.

2.5.2. Agricultural Research

Rice is the single most important crop in Laos. The unpredictable nature of environmental conditions is the major problem for agricultural production in Laos and throughout the world. There is a wide variety of ongoing research, including:

- Varietal improvement;
- soil fertility;
- plant protection;
- agronomic studies;
- farming systems;
- nutrient studies (N input) and integrated pest management (IPM);
- studies of soil run-off and depletion of nutrients.

2.5.3. ACIAR workshop

The Lao workshop coincided with the commencement of a new ACIAR rice project, Increased production of rice-based cropping systems in Lao PDR, Cambodia, and Australia, which is being run by the University of Queensland. Other participating organisations include:

- Cooperative Research Centre for Sustainable Rice Production at Yanco, NSW
- National Agricultural and Forestry Research Institute(NAFRI), Lao PDR

- Cambodian Agricultural Research and Development Institute (CARDI)
- International Rice Research Institute (IRRI), Los Baños, Philippines.

There were approximately 100 delegates representing 10 countries. The workshop included presentations by scientists from Laos, Australia, Japan, Korea, Cambodia, Thailand and the Philippines. The workshop consisted of six sections in addition to the opening and discussion session, in which a description of the new ACIAR Rice Project in Lao PDR and Cambodia was given.

The 5 sub-projects of the ACIAR Rice Project 99-048 include:

- plant breeding strategies for rainfed lowland rice;
- intensification of rice-based cropping systems in rainfed lowlands;
- development of direct seeding technology (rainfed and irrigated);
- increasing productivity of dry season irrigated rice;
- agro-ecological characterisation.

The major goal of the ACIAR project is to increase the productivity of the rice-based cropping systems in Lao PDR, Cambodia and Australia through:

- improved efficiency of the rice breeding programs to increase yield;
- identifying appropriate strategies for agronomic improvements of rice yield and rice based cropping systems;
- agro-ecological characterisation to assist the evaluation of the potential of cropping system strategies in Lao PDR.

The objectives of the workshop include:

- understanding present production systems;
- assessment of environmental constraints:
 - drought,
 - low temperature,
 - low soil fertility;
- Current knowledge of these constraints:
 - Management options,
 - Development of adapted varieties;
- Identification of future research methods:
 - ACIAR 99-048,
 - Other new projects.

2.5.3.1. Opening section

"Alongside this research, CARDI has helped to build research capacity by teaching and training Lao personnel," said Agriculture and Forestry Minister Dr Siene Saphangthong in his opening address. The wet-season lowlands will continue to produce most rice for the foreseeable future. Higher yields and reduced year-to-year yield variability can be expected with further intensification of lowland production systems. Further production improvement will depend on higher inputs and further alleviation of production constraints. The uplands will become less important for rice as alternative, more sustainable technologies are developed to replace the "slash-and-burn" shifting cultivation.

Minister Siene Saphangthong said: "The current national socio-economic development plan stresses agro-forestry expansion and development, linking this to the processing and services industries. In this way, we are attempting to change from nature dependency production to commodity production. Nevertheless, rice remains important for Lao people. We are

striving to produce at least enough rice for domestic consumption, and if possible we hope to have a rice surplus in case of natural disaster.

"Each year, unfavourable events like drought, flood and pests damage 100,000 ha of our crops (some 20 per cent of the rice area). One solution is to switch from semi-dependency on nature to use of modern technology appropriate for Laos, switching from small and scattered production to a market commodity production approach," he added.

Dr Siene Saphangthong said that in the past five years, the Lao government has been addressing foodstuff security by expanding irrigation for agriculture. To date, some 20 per cent of farmland are irrigated, but intensive farming techniques have not been applied as much as it should have been.

"Research into and experiments on seeds are important priorities. At the same time, attention has been paid to adapting appropriate technology and mechanisation to increase the production cycles. In the past year, northern Laos experienced unusually cold weather, which affected some agricultural production and animal husbandry. If we introduce an appropriate scientific approach to farming, coupled with local expertise and support from international institutions, we believe that some time in the future, we will be able to overcome food shortages in our country," the Minister concluded.

The Lao government is set on increasing agricultural production to achieve food self-sufficiency in the short term, and to export food in the long-term. This calls for construction of hydraulic works for irrigation and drainage as soon as possible, which is why this project plays an

important role in economic development and national security not only for the Vientiane province and municipality, but for the whole country.

The ACIAR project focuses on the development of plant breeding strategies for rainfed lowland rice, but also addresses other important issues associated with productivity of rice-based cropping systems in Laos and Cambodia. These issues include the development of sound direct seeding technology, intensification of rice-based cropping systems, agroecological characterisation of environments for increased crop production, and minimising constraints for dry season irrigated rice production. The main objective of the workshop was to exchange available information that would assist development of rice-based cropping systems in Southeast Asia, particularly in the Lao PDR and Cambodia. The workshop focused on:

- characterising environmental factors that are constraints for rice production in the region and mapping the weather and soil related factors using GIS;
- understanding the impact of environmental constraints and developing methods to minimise the constraints, particularly for drought in rainfed lowland rice and low temperature in dry season irrigated rice;
- developing rice-breeding strategies for stress environments;
- a discussion of other topics related to the development of rice-based cropping systems in Southeast Asia.

The three major areas of research included the impact of drought, the impact of low temperature, and low soil fertility. The workshop also provided information on the new ACIAR project, and the project partners encouraged feedback on the project from the workshop participants. There was an opportunity to visit ACIAR, NAFRI, and Lao-IRRI experiments following the workshop.

2.5.3.2. Rice production systems

This section included papers on the current rice production systems in Laos and Cambodia and highlighted the limitations and environmental constraints to present systems. The problem of low soil fertility and fertiliser requirements was included in this section. Examples from the neighbouring countries of Thailand and Vietnam were also included. A major objective was to determine the benefit and risks associated with various rice-based double cropping systems. Methods need to be developed to determine the probability of success of double cropping, and to estimate the water balance components in different environments. Insect pests (gall midge and brown plant hopper), rodents, weeds and disease (eg brown spot) provide major constraints to rice production. There are many constraints to rice production systems in southeast Asia that researchers are attempting to alleviate, minimise or manage (Tables 1 and 2).

Table 1.

The magnitude of constraints to rice production systems in Cambodia, Laos and Thailand

Types of constraints	Magnitude		
	Cambodia	Laos	Thailand
N	all soils	most soils	most soils
P	most low in P	most soils	most soils
K	sandy soils / not used	20-30% soils	sandy soils
S	sandy soils	20-30% soils	sandy soils
Fertiliser quality	erratic	OK	OK
Bronzing	sandy stagnant water	sandy stagnant water	?
Sandy soils	10% poor fert response	limited	extensive
Microtopography	most areas	most areas	most areas
Wetting and drying	most soils	most soils	most soils
Al toxicity	acid soils 5% of soils	?	?
Low fertiliser use	low income	low income	low income
Straw removal	most farms	most farms	most farms
Fertiliser response	variable	mod-consistent	poor

Table 2.

The management options, cultivars and future research to counter major constraints to rice production

Types of constraints	Management options	Cultivars	Future research
N	fertiliser, balanced nutrients, K fertility residue mgt, GM	breeding	long term cropping systems research on nutrient cycling
P			
K			
S			
Fertiliser quality	regulations	NA	NA
Bronzing	K, varieties	breeding	identify cause
Sandy soils	regular OM		alternative use?
Microtopography	site specific fertiliser	breeding	nutrient x water interactions
Wetting and drying	risk magt		
Al toxicity	straw, varieties	breeding	role of OM
OM available	residue, FYM	?	role of OM
Low fertiliser use	tactical use	efficient cultivars	Optimise efficiency
Straw removal	collect FYM, alt feeds		
Fertiliser response	efficient cultivars	efficient cultivars	water x nutrient interactions, roots, OM

Other management options include:

- increasing yield in low input systems;
- reduced risk with improved technologies;
- soil management for high yield;
- site-specific management;
- nutrient efficient cultivars;
- reduced labour technologies.

Some ways to develop adapted cultivars for poor soil conditions include:

- low N/P/K/S;
- other nutrients;
- Strategies:
- root depth/function,
- avoidance,
- retranslocation:
- acidity/salinity/Fe toxicity:
- tolerance.

Future research is required, including

generic:

- direct seeding,

- double cropping,
- nutrient cycling,
- root function/depth,
- chemistry of soils site specific nutrient management technologies,
- breeding strategies,
- country specific;
- adoption/ socio-economic environment,
- soil classification,
- agro-ecosystem,
- spatial information,
- training,
- fertiliser policy;
- applied:
- site specific;
- risk;
- extension;
- adaptive/participatory research.

2.5.3.3. Drought problems in rice production

2.5.3.3.1. Introduction

Fifteen papers on water and drought tolerance were presented. Genetic, physiological, agronomic and breeding approaches to combating drought in Laos, Thailand, Cambodia and Indonesia were discussed in these papers. A number of papers on statistical approaches to genotype by environment (GxE) interaction were also presented.

This section examines the drought problems and technologies available to minimise the effect of water shortages. The main emphasis in this section was to characterise the pattern of drought development in rainfed lowland rice and to consider how drought resistant cultivars may be developed.

Drought is the major environmental constraint to rice production in Laos. Variety selection and avoidance will contribute to reducing the losses related to drought. Grienggrai Pantuwan highlighted the potential successes of screening for drought tolerance in Thailand. He has found that tall varieties stress more during drought. He also discovered that a large root system is a disadvantage during a short severe drought. Greengrai is successfully screening 1200 lines each year. Leaf yellowing is highly correlated with drought tolerance and growers have had good success with drought escape.

2.5.3.3.2. Magnitude of the stress problem

Laos

In 1993, experiments were undertaken to study drought in Laos. The occurrence and timing of drought is variable, with droughts occurring during the early-season (2 in 8 years), the late-season (4 in 8 years) and sometimes no drought occurring (2 in 8 years). Early-season drought is a problem when there is not enough standing water for transplanting. Late-season drought is a problem in some provinces such as Vientiane and Savanekhet. Approximately 100,000 ha of rainfed area are affected by drought. Average yields are approximately 1 t/ha, ranging from 0 to 2 t/ha. Therefore, drought can reduce yield by more than 1 t/ha. Direct seeding in Vientiane is becoming more important because it requires less labour.

Thailand

In Northeast Thailand approximately one million hectares (56.4% of the area) is drought-prone. Bi-modal rainfall patterns exist in northeast Thailand. Early and late season drought are common. Direct seeding of rice is sometimes adopted to escape end of season drought. Less labour is required for direct seeding which also assists in improved midge resistance. Direct seeding of rice is soil and season dependent. A new breeding method for Thailand has been recently established which estimates genotype by environment interactions using multi-location trials. Environmental characterisation has enabled the use of water balance for estimation of drought patterns. Thailand breeders are successfully improving drought tolerance by wet season direct screening using yield.

2.5.3.3.3. Frequency, timing and severity of drought - a need for environmental characterisation.

Management options for combating drought have been identified and recommendations and observations include:

- The use of early season cultivars will assist the crop to escape drought conditions.
- Early, mid and late maturing varieties are sown. to overcome labour shortages during transplanting and harvesting,
- Drought-tolerant varieties, drought-escape and drought-recovery, photoperiod sensitivity are used.

- Sowing time is correlated with toposequence. Early-season varieties are used in the upper toposequence, mid-season varieties are used in the mid toposequence and late-season varieties are used in the low toposequence.
- Seeding time depends on the availability of water and is not linked to escaping the end of season drought.
- Early drought results in delayed transplanting of older seedlings into dry soil.
- Staggered planting of seedbeds will provide optimum seedling size for transplanting.
- Increase the number of seedlings per hill for older seedlings to compensate for reduced tillering. Early sowing requires closer spacing, while wider spacing should be used with late sowing. An on-farm reservoir is required to supplement seedbed moisture.
- Use variety mixture for stability, such as one drought-tolerant line with one submergence-tolerant line.
- Planting methods need to be reviewed. In some regions, Thailand has a direct seeding option that can be an option for early drought.
- Soil preparation - puddling or not? Permanent bunds.
- Land levelling can be used for even establishment and water depth. Traditionally, sandy soil is cultivated but not harrowed. The number of cultivations depends on the soil type - light soils usually have a second cultivation.
- Supplementary irrigation should be established. - tube well, dig pond/canal/up terrace/on-farm reservoir, pump to high bund.
- What is the role of nutrients in combating drought? Time of application is important in relation to drought. For example, nutrients should be applied with standing water. Also, adequate nutrients are required for seedling growth, but the N rate should not be too high. There may be a relation between seedling vigour and drought resistance. Root growth is important, but excess biomass may be detrimental to yield because too much water is used.
- N and P should be applied basally.
- Farmyard manure improves the water holding capacity of the soil, and may also affect buffering capacity of soil.
- It is recommended that bedding systems are used for water management, thereby providing drainage during the wet season and water storage for dry season.
- Cropping systems can be altered to include crop rotations before and after rice.
- Catchment areas need to be restored to enhance availability of water harvesting.

2.5.3.3.4. *Ways to develop adapted cultivars*

- There are many opportunities for researchers and breeders to improve tolerance to drought:
- Available materials such as farmers' traditional varieties can be investigated. Traditional varieties contain genes for stability, but probably not for yield. The traits of traditional varieties need to be considered, as well as those offered by varieties stored in the international germplasm banks.
- Screening for drought resistance should be conducted at several levels - field, farmer's field, DS nursery, regional screening.
- Develop early, mid and late cultivars, including adaptations for escape, different toposequences, and seasons.
- by adaptation to low fertility soils and a improved fertiliser response.
- Strategies for selection should investigate traits for drought avoidance and tolerance (eg, LWP, OA, deep roots, narrow leaves, high root mean density, flowering delay, grain yield, seedling vigour, spikelet fertility, green leaf retention, drought recovery, transpiration efficiency, harvest index, leaf characteristics).
- Adequate genetic variation.
- Physiological understanding of traits.
- How do we monitor stress? Different methods can be used, including rainout shelters, drainage, checking varieties, and dry season screening.
- Breeding methods should include: site/genotypes/ reps, reference lines, heritability, and genetic correlation.
- Assess the value of traits on a range of target environments.
- Integration of traits for target environments.

2.5.3.3.5. *Future Research Required (Breeding and Agronomy for Lao, Cambodia and Thailand)*

Screening for drought tolerance in Laos (Vientiane, Savanekhat) include:

- late season drought screen with parameters including yield, spikelet fertility, green leaf retention, and flowering date;
- drain at flag leaf emergence for the mid-maturity group;
- setting up multilocation trials (eg Phrae, Umbon, and Chum Phae);

Multi-environment trials to identify genotype by environment interactions have been established involving:

- 8 locations in Cambodia;
- 3 locations in Laos with different toposequences, water balance and soil and water characterisation;
- 9 locations in NE Thailand;
- measurements of photoperiod sensitivity x seeding time;
- indirect selection of traits for direct seeding of rice (leaf water potential, flowering delay, and yield) and the evidence of their contribution to

grain yield;

- an investigation of the cost to measure leaf water potential (LWP). Is there an advantage over selecting for grain yield alone
- Drought tolerance research involves further understanding of:
- intensification of crops grown before and after drought;
- direct seeding - appropriate cultivar selection, topequence, planting time, weed control;
- characterisation of target environments - water balance, GIS, field evaluation of hydrology;
- plant density - maturity interaction versus drought, seedling age;
- tube well supplementary irrigation for early wet season rice to increase the opportunity for multiple cropping;
- the reduction of the impact of drought on yields by improving drought resistance traits or through drought escape.

2.5.3.4. *Temperature constraints in rice production*

In this section, low temperature problems in rice were examined. This included a review of the present understanding of the effect on yield of low temperature during the establishment and reproductive phases. Examples of experiences in minimising the low temperature problem were given. Genotypic variation in low temperature tolerance was also reviewed. Results of recent work in identifying low temperature problems in Laos were also presented.

There has been a 7.6-fold increase in yield from dry season lowland irrigated areas over the past decade (41 000 tonnes in 1990, 354 000 tonnes in 1999). Now there are plans for the development of further small-scale irrigation schemes to achieve a total dry season irrigated area of around 180 000 ha by 2005. Increasing productivity of dry season irrigated rice is a major objective of the ACIAR project. This can only be done by first identifying the climatic constraints and cultivar requirements of low temperature tolerance and high yield in the dry season in Laos. This includes an investigation of mechanisms for genotypic adaptation to low temperature and determining the magnitude of GxE interaction across seasons and countries.

Dr Moon He Lee, a rice physiologist, showed the success of the low temperature screening in Korea. Wind (including typhoons) is also a major problem in Korea. The expected yield is approximately 5 t/ha, but can be reduced dramatically by wind damage. In 1993, 10% of the rice area was damaged, reducing the yield to 4.2 t/ha. In 1980, the yield was nearly halved to 2.8 t/ha when 80% of the rice area was damaged by wind. However, the Korean physiologists have had good success with outstations in cooler areas. Dr Lee highlighted the impact of cooler temperatures at the vegetative stage including the inhibition of rooting, growth and tillering as well as delayed panicle initiation. He summarised the impacts of low temperature on reproductive growth including inhibited panicle development, degeneration of spikelets, disturbed meiosis and pollen formation and delayed heading. He confirmed that the critical microspore stage occurred 10 days before heading which is similar to what Mr Farrell has found in Australia. They have had success screening at 23/10oC for 10 days at reproductive development.

One of the major limitations to current rice practices in Laos is that the traditional varieties have a duration that is too long for double cropping (170 days). Currently the magnitude of low temperature stress is large affecting:

- vegetative growth (nursery, main paddy),
- seed bed (poor germination, seedling death),
- transplanting (rooting),
- tillering and development;
- reproductive growth (microspore and flowering). Sterility was not reported, but there is a potential risk as shorter duration varieties are introduced.

Avoiding the risk to encounter sub-optimal temperature is a shortcut some countries like Japan have used for establishing a stable cultivation system. Upon avoiding the extreme temperatures as much as possible, improving the level of tolerance needs to be considered. To avoid the risk of cold damage, selection of adequate varieties and planting time is imperative. Protecting the nursery at the seedling stage and in the main paddy from cooler conditions is the key to improved establishment and vegetative growth. For example, there were some lessons to be learned from the Japanese experience based on multi-location testing. Average air temperature requirements at transplanting varied between the different types of nurseries, such as upland nursery with vinyl cover (13.5-14oC) and semi-irrigated nursery with vinyl cover (14-15oC). Japanese researchers have also found seedlings that have a higher content of nitrogen and starch show faster rooting in the main paddy. Seedlings transplanted at 5-6th leaf stage have shown the best performance in cooler climates of Japan.

Increasing water temperatures (by using a warming pond, canal or plastic tubes) may assist growers to improve growth. Increasing water depth at the critical reproductive stage will provide warmth to the developing panicle. It is vital for researchers to get an improved understanding of the thermal conditions to identify potential risks. It is important to establish the nursery system to compare different types of protected nursery and conventional nursery. Efforts need to be made in exploring the adequate time of planting in combination with phenology of the cultivars (by means of cropping season experiments and the crop growth model). Breeding effort for suitable phenology (90-130 days) is the first priority. Screening varieties for tolerance to low temperatures at the vegetative stage is vital, and may include using cool water screening of genotypes from INGER and southeast Asia. Screening varieties for tolerance at the reproductive stage is important for some provinces (eg, Oudomxay).

Low temperature problems in rice is a shared problem throughout the world and researchers in this area from Northern Laos, Australia, Korea and Japan were represented. Cold tolerant cultivars are required for northern areas of Laos. Mr Farrell had previously sent approximately ten varieties including cold tolerant cultivars that he had identified in recent glasshouse experiments. These varieties will assist researchers and breeders to develop cultivars adapted to dry season rice production in Northern Laos. Researchers were given the opportunity to discuss best agronomic

practices.

2.5.3.5. Breeding strategies

Breeding strategies for sub-optimum conditions were examined in this section, including presentations on the description of rice breeding programs in Laos and Cambodia, as well as a description of irrigated conditions highlighting the challenges for the future. Breeding strategies in rainfed lowland rice in Thailand were also included. Experimental work to examine genotype and environment interaction in rainfed lowland rice was presented, and possible modifications to the Lao and Cambodian programs were also discussed.

2.5.3.6. Characterisation and modelling

This last presentation section examines methods of integrating information using GIS and simulation models. Experiences in Thailand and other countries were also presented as a model for Laos. The success of applying these techniques in Laos and Cambodia was also presented

On-farm level micro-ecology is important to capture the large variability in water and nutrient availability. Application of GIS technology to agroecological map development is important to assist the integration of environmental information. Collecting reliable data in Laos and in neighbouring countries is vital for the success of agroecological characterisation, which will contribute to the development of sound cultural practices and breeding program.

2.5.3.7. Discussion

The Australian Centre for International Agricultural Research (ACIAR) and the International Rice Research Institute (IRRI) presented a summary of different production systems and possible solutions for increasing rice productivity, which will contribute to addressing food shortages. The Lao Ministry has been working with ACIAR, and the results have enabled them to draw up a rice production development plan for food production in the Lao PDR.

This discussion section helped to consider the application of the knowledge, experience and skills available to us to minimise environmental constraints on production of rice based cropping systems in Laos, Cambodia and neighbouring countries. Recommendations were made to scientists in Laos and Cambodia on their future research activities.

The production systems in Laos, Cambodia and Thailand are similar in having large areas of rainfed lowland rice, low population density, subsistence agricultural and major problems relating to drought, low soil fertility and floods. However there is a unique nature of rice production in each country, with recession rice in Cambodia, irrigated rice in Laos and rice of good grain quality in Thailand

The ACIAR international workshop contributed to understanding the productions systems in Laos, specifically the rainfed lowland and irrigated dry season rice environments. Laos has many similarities to Cambodia and Thailand with extensive lowland rice, low population density and subsistence agriculture. They share common constraints to rice production (primarily drought, low soil fertility and flooding). Low temperature problems in rice are a shared problem throughout the world, including areas such as Northern Laos, Australia, Korea and Japan. Agro-ecological characterisation will contribute to an improved understanding of the environment in Laos. Breeding strategies for stress environments (eg drought, low soil fertility, and low temperature) need to be implemented to improve the productivity of rice growing in Laos and other southeast Asian countries. Improvement to production systems depends on the success of scientific research, of technology transfer and of international cooperation.

Technology transfer is vital to improvements to rice productivity throughout southeast Asia. In Laos, improved nursery protection from low temperatures is vital to superior establishment growth. Also, screening against drought in rainfed lowlands is crucial to variety development. Direct seeding technology (including land levelling) and wet seeding research needs to be delivered to growers. Germplasm transfer and evaluation is vital to reducing environmental constraints to rice production. The INGER network contributes to the ease of international germplasm exchange. Exchanging promising lines between Laos, Australia, IRRI and Cambodia is underway.

3. Acknowledgments

The financial support of the CRC for sustainable rice production and ACIAR was essential to allow this travel to occur and is greatly appreciated. The Overseas Projects section of NSW Agriculture was also of great assistance with the preparations of this trip.

The support of those who willingly took on additional duties to allow me to spend some time away from Yanco is also gratefully acknowledged.

4. Recommendations

This overseas travel was invaluable in establishing overseas contacts and colleagues in the critical areas of vegetative and mid-season low temperature damage.

4.1. Low temperature damage

Problems relating to low temperature are a shared problem throughout the world including Australia, Japan, Korea and Laos. While countries such as Laos are beginning to address problems relating to cooler conditions, countries such as Japan have a long history and good understanding of cold tolerance in rice. It is important that collaboration between the developed and developing world is encouraged to ensure worldwide food security. Interaction with scientists during this travel on the common problems relating to low temperature should continue in the future. The similarity of research objectives in participating countries means there could be great synergy by regular contact. This contact should be in 2 ways. The first is by the exchange of germplasm for low temperature tolerance testing, and the second is the exchange of scientists to compare

observation, and techniques. Lessons can be learned from countries such as Korea that have had good success in screening for cold tolerance in cooler out-stations. If a flowering test is established for determining cold tolerance then it is possible for cultivars in Australia to be tested in cooler out-stations such as Canberra or Tumut where the shorter growing season will not impede screening. Alternatively screening cultivars with deep cool water has been successful in Japan and is currently being evaluated at Yanco Agricultural Institute in the 2000/01 season. It is recommended that collaboration between researchers at Yanco Agricultural Institute and international scientists be maintained through continued involvement in this ACIAR project.

4.2. Genetic exchange

Germplasm transfer and evaluation is important to overcome environmental constraints in rice growing areas throughout the world. The INGER network provides a good framework for exchange of genetic material between rice growing nations. There has been exchange of promising lines amongst Cambodia, Laos and Australia. In the 2000 rice season 10 promising cold tolerant varieties were sent by Mr Farrell and sown in the field trials at Laos. Mr Farrell is looking forward to seeing the results of cultivars grown under environmental conditions in Laos. Mr Farrell is expecting 20 varieties to be sent from Laos for testing in the 2001/02 rice season. It is recommended that the exchange of material with other countries be continued to build Australia's genetic resources.

5. Travel Itinerary

October 20 Narrandera-Sydney-Bangkok

October 22-23 Discussions with Phd supervisor (workshop organiser) and visit to CARDI lab.

October 24-26 Attend CARDI Conference in Phnom Penh, *"The Impact of Agricultural Research for Development in Southeast Asia"*

October 27-28 Visit CARDI trial sites

October 29 Travel to Vientiane, Laos

October 30-Nov 1 Attend workshop in Vientiane, *"Productivity of Lowland Rice in Southeast Asia -Overcoming Environmental Constraints"*

November 2-3 Visit the ACIAR, NAFRI and Lao-IRRI trial sites.

November 4 Vientiane-Sydney

November 5 Sydney - Narrandera

6. Appendix

6.1. Interesting facts

- Laos has dealt with the rodent problem by eating them!
- Cambodian National Golf course is the only one in the world where women walk in front of the men (I am unsure if this is related to the rule of Pol Pot and Khmer Rouge who riddled Cambodia with land mines).
- 85% of rice produced is glutinous (they love sticky rice. I bought 8 sticky rice cane baskets home and have now realised that glutinous rice is not available in the Riverina).
- Since 1990 there have been 6 serious floods in Laos. Rather than develop submergence tolerance they prefer to take them out of production. In 1995, floods damaged 29% of the Lao rice area . When I flew into Phnom Penh I asked the local person sitting next to me what ocean was that and they replied "That's Cambodia". Looking more closely I could see some roofs.
- Currently the population of Laos is 5 million and is projected to be 8 million by 2020.
- The majority of funding for agricultural research in Laos and Cambodia is derived from international donors (eg ACIAR, AUSAID) and government funding.
- Common land preparation for rice is 3 cultivations, 2 ploughs, 1 harrow, flood and then transplant.
- Extension staff in Cambodia said that farmers would tell the truth and assist them, in exchange for food.
- A successful way to randomly select farms for research has been to throw a grain of rice on a map.
- Women in the field who were processing rice plants were earning US\$1.2 each day.
- When we drove down the driveway into CARDI, they were reconstructing the roads in front of us following floods.
- From my experience people in Southeast Asia are amongst the happiest people in the world I have seen despite poverty and famine.

6.2. Paper presented at ACIAR workshop

Temperature constraints to rice production in Australia and Laos: a shared problem

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Abstract

With the transition to dry season rice production, Laos now faces many new challenges relating to extreme temperature problems. The temperature conditions throughout Laos are highly variable which relate to the differences in altitude and elevation. Provinces in the northern region of Laos suffer from low temperature problems during the vegetative and reproductive phase. These problems are shared by temperate rice growing countries including Australia. Provinces in southern Laos are faced with problems relating to high temperatures during anthesis.

With the establishment of the Cooperative Research Centre (CRC) for sustainable rice production, Australia has focused on improving the level of cold tolerance of commercial varieties at the establishment and reproductive stages. Progress has been made in identifying cultivars, which have superior seedling vigour and cold tolerance and have been incorporated into the Australian breeding program. Collaborative research between Australia and Laos will prove beneficial to manage extreme temperature variability, which reduces rice yield.

Key words:

low temperature, rice, Australia, Laos, cold tolerance

Introduction

Seasonal temperature variation is common throughout the world, and can cause severe food shortages. Such extreme temperatures throughout the rice season dramatically reduce yield, changing key yield components. Cooperative research into the effect of temperature on rice can contribute to food security worldwide. Vegetative development (emergence to panicle initiation), reproductive development (panicle initiation to heading) and the grain formation and ripening stages are important for grain yield potential (Boerema 1974). Although the dynamics of rice production in Australia and Laos are at different extremes of production and mechanisation, significant yield losses due to temperature variability has been experienced in both countries (Table 1). With the development of the Cooperative Research Centre for Sustainable Rice Production (Rice CRC) in

Australia, a multi-faceted approach to the research on low temperature has begun. Good progress has been made by a team of researchers in understanding the low temperature problems at the protein, cell, organ and plant level. The Rice CRC and Australian Centre for International Agricultural Research (ACIAR) project (Increased crop production for lowland rice in south east Asia), have initiated collaborative research which will contribute to solving the problems relating to the impact of extreme temperatures on rice production in Australia and Laos.

Rice Practices

Australia

Rice growing in Australia is confined to the Riverina region of New South Wales (NSW) centred at 35oS, 146oE. There is very little variation in altitude (120m) across the rice producing areas. Approximately 140,000ha are sown each year, producing industry-wide average yields up to 9.4t/ha, with the highest yielding crops exceeding 13t/ha. Although rice growing areas to the south are 1-2oC cooler than the north, there is generally little temperature variability across the rice growing area. The average rainfall during the growing season is 200mm with the crop requiring full irrigation. The growing season is characterised by long days with high levels of solar radiation. Low temperatures during establishment and a cool grain-filling period restrict the length of the growth season, while low night temperatures during reproductive development can cause catastrophic yield loss.

There is a single crop grown each year, which is planted in spring, grows through the summer and is harvested in autumn. Rice planting starts in late September, as soon as the risk of frost is negligible. Full season cultivars and short season cultivars are sown in early October and November respectively to ensure that reproductive development coincides with greatest chance of warm night temperatures (late January-early February). Grain filling occurs in February-March when the cooler temperatures extend the duration of grain filling producing grains of high quality. Rice crops are drained and harvested in March -April, prior to the first frosts, when the moisture content is between 16-22%.

Over 90% of Australian rice crops are sown aerially. The majority of nitrogen is applied prior to permanent flood and if required top-dressed at panicle initiation. Average N application rates are 80-100 kg N/ha.

Laos

The Lao People's Democratic Republic (Lao PDR) is located in the tropics, between the latitudes 14oN and 22oN and longitudes 100oE and 108oE. The rice area in Laos is 650,000ha, producing average yields of 2.7t/ha, with the highest yields reaching 4t/ha. The Lao PDR is divided into the northern, central and southern regions, each having different temperature regimes due to variations in altitude and latitude. Laos has a distinct wet and dry season. Historically, the majority of rice production in Laos has been produced during the wet season as upland and lowland crops. With the advent of irrigation, rice production in the dry season has increased from 13,600ha in 1995 to 87,000ha in 1999 (NAFRI, 2000). The wet season crop is transplanted into the field in June and harvested in October, while the dry season crop is transplanted between November and January and harvested in May. Of the rice produced in Laos in 1998, the rainfed lowlands accounted for 74%, the rainfed uplands 13% and 13% was irrigated (IRRI 1999). The long-term aim for Laos rice production is to reduce the area of rainfed upland rice and increase irrigated rice. Almost all of the rice in Laos is transplanted by hand and harvested by non-mechanised methods. The impact of low temperature on rice production relates specifically to the dry -season crop at both the establishment and reproductive stages. Elevation and latitude principally determine temperature variation between provinces within Laos. Champassak, a southern province (15oN), has an elevation of 120 metres, and high temperatures during flowering in April (Figure 1-F) sometimes limit dry season yields. In comparison, Xieng Khouang has an elevation of 1050 metres and is located at latitude of 19.5oN. It suffers from low temperature at establishment and microspore stages in the dry season (Figure 1-D). The temperature patterns in all six provinces show that the average minimum temperatures slowly decrease from November through to December throughout the early establishment phase (Figure 1).

Low Temperature at the Vegetative Stage

Background

The vegetative stage refers to a period from germination to panicle initiation and is characterised by active tillering, gradual increase in height, and leaf emergence at regular intervals. Germination starts when seed dormancy has been broken, the seed absorbs adequate water, and is exposed to a temperature ranging from about 10oC to 40oC. Temperature has a profound influence on germination by affecting the activation stage and post-germination growth. There are clear varietal differences in seed germination at low temperatures (Yoshida 1981). Low temperature can affect the developmental processes of rice plants. Low temperatures impair photosynthesis, which reduces growth and results in indirect yield loss due to less carbohydrate availability for grain production (Smillie et al. 1988). Low temperatures causing poor establishment and vegetative growth in rice is a common problem in countries such as Australia and Laos.

Temperature variability

The average minimum temperature during establishment (November) in Yanco, NSW, Australia is 12.3oC, with the variation being higher within, rather than across, years. For the corresponding period in Laos (December), the minimum temperatures in Xieng Khouang and Champassak were 8.3°C and 18.5oC respectively. Variation for temperature within and across years was calculated based on daily maximum and minimum temperature data. The coefficient of variation (cv) of temperature across years was calculated from the standard deviation of the mean temperature for each year divided by mean temperature across all years. The cv of temperature within years was calculated as the mean of the cv of daily data for each year. All cv's are shown as a percentage (Table 2). Establishment of dry-season rice crops in provinces such as Xieng Khouang is difficult, because 10oC may be considered as the critical minimum temperature for elongation of shoots and roots (Yoshida 1981). The temperature variability was higher within years than across years in all six provinces. The extent of low temperature appears to be related to the altitude of provinces in Laos with Vientiane (171m) and Champassak (120 m) provinces not affected by low temperature during establishment.

Seedling vigour

Seedling vigour is an important foundation for efficient crop production. Vegetative vigour, the rapid attainment of plant biomass, depends on the initial size of seedlings and the rate at which they grow. A controlled-environment experiment was conducted at Yanco to explore differences in seedling vigour among 38 direct-sown cultivars from the International Cold Tolerance Nursery. Seedlings were grown at 25/15°C for two weeks prior to the imposition of temperature treatments. Seedling size at two weeks was considered the initial size. The temperature treatments (7/22°C, 10/25°C and 13/28°C minimum/maximum temperatures respectively), reflected the range of conditions likely to occur during establishment in Australia and Laos. There was a five-fold difference in average seedling biomass between the low and high temperature treatments. Cultivars exposed to the highest temperatures had the greatest biomass, averaging 600mg per seedling. Average biomass of seedlings at the intermediate and low temperature treatments were significantly lower, at 290mg and 120mg respectively. A selection of four cultivars is shown, which include those with the greatest and least response to temperature (Figure 2). The tropical cultivar IR36 had the smallest response to increasing temperature. Surprisingly, a temperate cultivar from California, L202, showed a modest response to temperature. HSC 55, a cultivar from Hungary (a temperate region) showed the greatest positive response to increasing temperature. There were significant differences between cultivars at each of the temperature treatments, with differences greater at the highest temperature. The NSW cultivars Amaroo (shown in Figure 2), Jarrah, Millin and Illabong (not shown) performed similarly and were intermediate in their response to temperature. At the lowest temperature treatment, there were no cultivars that had higher biomass than Amaroo, but at higher temperatures there was significant genotypic variation. In Laos, temperature conditions during establishment resemble the 10/25°C and 13/28°C temperature treatments. There are potential benefits available from increased biomass production, if the early vigour of cultivars such as HSC 55 could be incorporated into commercial cultivars.

N-Uptake

Nitrogen uptake by the rice plant at panicle initiation (PI) is recognised as a key determinant of yield potential in the NSW rice industry. The amount of nitrogen in the above-ground tissue of the crop at PI is driven by temperature conditions during the establishment phase. The mean air temperature from November 1 to December 31 was calculated from 1989-1999 at Yanco Agricultural Institute. For each year the average nitrogen uptake for all Amaroo crops sown between October 1-7 was calculated across all rice growing areas. There was a significant correlation ($r^2=0.44$) between average air temperature and nitrogen uptake at panicle initiation (Figure 3-A). The average temperature in 1994 was 20°C and the nitrogen uptake was 87kgN/ha. In 1995 the average temperature was 23°C and the nitrogen uptake was 125 kgN/ha. A significant correlation exists between nitrogen uptake and yield ($r^2=0.45$), which suggests that good early growth resulting in higher PI nitrogen uptake is an important factor contributing to higher yields (Figure 3-B). A strong correlation between average temperature during establishment and grain yield ($r^2=0.73$) highlights the importance of early growth in contributing to Australia's high yields (Figure 3-C).

Low Temperature at the Reproductive Stage

Background

Low temperature during reproductive development (panicle initiation to maturity) is one of the major factors limiting productivity in the NSW rice industry. Low temperatures during late January to early February disturb normal development of the pollen grains, causing spikelet sterility. The risk of yield reduction in a low temperature year is greatly enhanced by increased nitrogen status of the crop (Heenan 1984, Satake et al. 1987). Hayase et al. (1969) concluded that the young microspore stage, which is related to male sterility, is the most sensitive stage to low temperatures for rice plants. Low temperatures during reproductive development reduce the number of engorged pollen grains and fertilised spikelets in rice (Ito 1971). Deep irrigation water (20cm) during the reproductive period can help protect the young panicles from low air temperatures. It provides a buffer and increases the panicle temperature by up to 7°C on a cool night (Williams and Angus 1994).

A recent glasshouse experiment at the University of Queensland found a significant positive correlation between total number of engorged pollen grains produced in an anther and the number of pollen grains intercepted by the stigma ($r^2= 0.81$). This correlation suggests that 600 engorged pollen grains per anther would result in greater than 40 intercepted on the stigma (Figure 4-A). There was a significant negative correlation between number of engorged pollen grains and spikelet sterility ($r^2= 0.59$). The relationship suggests that 600 engorged pollen grains will result in less than 30% sterility (Figure 4-B). These correlations indicate that a large number of engorged pollen per anther is the key to successful fertilisation.

Temperature variability

The critical temperature for inducing sterility varies amongst cultivars. The unpredictability of low temperature during the microspore stage of rice has caused severe yield losses throughout the world. Low temperatures throughout Japan in 1993 led to the opening up of their markets for the importation of rice. An extended low temperature event in Australia during the reproductive stage in 1996 reduced yields across the rice industry by 25%. In Laos the 1999/2000 season was the coolest since 1974, causing major shortfalls in rice production. Satake (1969) estimated the critical temperatures were 15°C to 17°C in a tolerant cultivar and 17°C to 19°C in a susceptible one. Australian rice crops are exposed to reproductive low temperature damage from late-January through to early-February. Long term data show that this period is usually the warmest with an average minimum temperature of 17°C. However, in the dry season crops in Laos the time of reproductive development is more variable, occurring from early-March through to mid-April. The average minimum temperature across five Laos provinces increased by 3.5°C from early March to early April (Figure 5). The average minimum temperature in Oudonxay in Northern Laos was increased from 12°C in early March to 16.4°C in early April. Delaying reproductive development by sowing later may reduce the extent of low temperature damage in Laos.

Genotypic variability

Glasshouse

A series of two experiments investigating genotypic variation for low temperature tolerance (36 and 18 cultivars respectively) was recently completed in temperature controlled facilities at Yanco Agricultural Institute. Three day/night temperature regimes (32/25, 25/15 and 27/13oC) were imposed on cultivars from after panicle initiation through to head emergence. A combined analysis identified seven international cultivars that consistently performed better than all the Australian cultivars. The cultivars include Liman and Pavlovsky (from Russia), Plovdiv 22 (Bulgaria), Akihikari and Haenuki (Japan), HSC55 (Hungary) and M103 (California). Low temperatures reduced harvest index (grain/total biomass) of these tolerant cultivars by only 20% compared to 50% for the major Australian cultivars.

Field

Field trials at Yanco Agricultural Institute during the 1998/99 and 1999/2000 seasons aimed to confirm the tolerance of cultivars in the field. The 1998/99 season consisted of nine sowing dates from early October to late December with each sowing date including a replicated trial of 30 genotypes. However attempts to confirm cold tolerance in the field was thwarted by the occurrence of above average temperatures. The 1999/2000 field trial comprised six sowing dates from October 5 to December 30, 1999. Deep (22 cm) and shallow (5 cm) water depth treatments were imposed through the critical young microspore stage. Twenty-eight cultivars from different origins, with varying susceptibility to low temperatures, were replicated in each of the 12 bays. Low night temperatures during the late December-early January and late January periods caused significant levels of sterility in most cultivars in the shallow water treatments. Liman (Russia), M103 (America) and Hitomebore (Japan) had a low level of sterility despite experiencing low temperatures during critical stages in late January. Sprint (Russia), Doongara (Australia) and Leng Kwang (China) had high levels of sterility in the shallow water treatments and appear to be susceptible to mid-season low temperatures.

Screening for Low Temperature Tolerance at the Reproductive Stage

Background

With over 100,000 rice cultivars worldwide, screening for low temperature tolerance at the establishment and the microspore stage in rice has been targeted. Australia's researchers have had success using temperature controlled facilities and serial field trials while Japan's researchers have developed field screening using cool water from bores.

Genetic Material

The International Rice Cold Tolerance Nursery (IRCTN) is a selection of cultivars from different origins evaluated at different locations for cold tolerance. Australia has sourced cold tolerant cultivars a result of their performance in the IRCTN, reports in the literature or recommendations by international scientists. One hundred and five international cultivars from 1991 and 1992 (IRCTN) were introduced to Australia and grown in small plots at Yanco Agricultural Institute in 1995. In recent temperature controlled experiments, seven cultivars from this nursery were more cold tolerant than Millin, Australia's most cold tolerant cultivar. Australia has successfully exchanged cold tolerant material and continues to do so with many countries such as Japan. Australia's plant physiologists and breeders are working closely together to improve the level of cold tolerance in commercial rice cultivars.

Deep cool water screening

Rapid screening of genotypes for cold tolerance at the reproductive stage of rice has been a success in experimental stations throughout Japan. Many research stations have established small experimental bays dedicated to screening for cold tolerant cultivars. Rice is transplanted into these bays and then cool bore water (19oC) is introduced following panicle initiation. Following panicle initiation of the first cultivar to flowering of the last cultivar the water depth is maintained at 20cm for approximately 40 days. The rice breeder from Myagi Prefecture Agriculture Experiment Station, Furukawa, has successfully released cold tolerant cultivars such as Jyoudeki using this deep cold water screening facility (Nagano 1998). The water temperature from a spearhead bore at Yanco, Australia is approximately 20oC, which is approximately 5oC warmer than bore water in Japan and may not be suitable for cool water screening.

High Temperature at Flowering

Temperature variability

When high temperature conditions occur during flowering, spikelet sterility can sometimes be seen on the windward side of Australian rice crops. Evaporative cooling can reduce canopy temperature by 7oC on hot windy days protecting spikelets from high temperatures at anthesis. Historically, high temperature induced sterility has not been a major problem in South East Asia because most rice is grown in the wet season. However, high temperatures and high humidity during flowering are becoming a constraint to rice production in the lowlands particularly in southern Laos. A recent report confirms that spikelet sterility under high temperature is increased with humidity (Matsui et al. 1997). The average maximum temperatures during March and April in the Champassak province, is 35.3°C and 35.8oC respectively (Figure 1-F). In the Sekong province the average maximum temperature was greater than 35oC from January through to May, 1998. The breeding program that produces cultivars for southern Laos should target improving the heat tolerance and attempting to induce earlier flowering.

Mechanisms

The rice plant is most sensitive to high temperatures during flowering, causing impaired pollen germination and a reduced number of pollen on the stigma leading to spikelet sterility (Yoshida et al. 1981). IRRRI (1979) confirmed genotypic variation existed by identifying 13 of 291 selections

that were tolerant for high temperature damage at flowering. High temperatures disturb reproductive processes occurring within an hour after anthesis. This includes dehiscence of anther, pollen shedding, germination of pollen grains, and elongation of pollen tubes (Yoshida 1981). More than 10 germinated pollen grains on a stigma is needed for normal fertilisation (Togari and Kashiwakura 1958; cited in Yoshida 1981). Yoshida (1981) suggested that spikelet sterility was caused by high temperature on the day of flowering only. Anthesis usually occurs between 1000 hours and 1200 hours, with temperature rising in the morning and exceeding the critical temperature (35°C) by 1000 hours in high temperature areas. Therefore, early morning anthesis is highly desirable because high temperature is avoided and sterility is reduced (Yoshida 1981). The flowers of *Oryza glaberrima*, an African cultivated rice species, open early in the morning (IRRI, 1979) has been a source of earliness for *Oryza sativa* species of rice. The one-hour advance in the flower opening time may have a significant effect in decreasing sterility, since air temperature rises at a rate of 3-4°C/hr in many areas in the tropics. In screening tolerant materials, eight-hour treatments of 35°C and 38°C were effective in selecting heat susceptible and tolerant lines respectively (Yoshida 1981). Two methods are therefore possible to improve the heat tolerance cultivars in Laos. Increasing the true tolerance is possible through the use of cultivars that have improved pollen shedding and pollen germination, and avoidance of high temperatures is possible through flowering earlier in the day.

Conclusion

Although Australia and Laos have very different environments, the problems relating to the effect of extreme temperatures on rice production are shared. Altitude accounts for a large proportion of the temperature variability in Laos. In the northern and central regions, low temperature causes problems during establishment and the reproductive period, whereas high temperatures during flowering causes damage in the lowlands to the south. Identifying and screening genotypes to minimise the impact of extreme temperatures at the establishment, reproductive and flowering stage must remain a major target of research efforts. Collaboration between international scientists on the common problem of temperature constraints to rice production can contribute to increased productivity and worldwide food security.

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Table 3

Estimates of rice production in Australia and Laos in 1998.

	Australia	Laos
Planting Method	Aerial sowing (90%)	Transplanting (100%)
Rice area (ha)	139, 902	650, 000
Total annual rice production (tons)	1.32 million	1.67 million
Average yield (t/ha)	9.42	2.7
Export (%)	85	10
Percentage of cropped land (%)	0.76 ^A	80
Irrigated land (%)	100	8.3

^A Calculated from ABARE's (2000) commodity report**Table 4**

Comparison of average minimum and maximum temperatures during 1 month of establishment at Yanco Agricultural Institute, Australia, and 6 provinces in Laos.

Month	Location	Country	Min °C	Across ^A cv%	Within ^B cv%	Max °C
Nov	Yanco	Australia	12.3	10.0	32.4	26.6
Dec	Luang Namtha	Laos	15.0	8.2	16.9	24.6
Dec	Oudomxay	Laos	11.5	16.0	26.3	24.5
Dec	Houaphanh	Laos	11.1	11.9	28.4	20.8
Dec	Xieng Khouang	Laos	8.3	22.1	38.6	21.6
Dec	Vientiane	Laos	17.2	7.4	13.9	28.3
Dec	Champassak	Laos	18.5	-	-	31.2

^A Coefficient of variation across years relative to the mean^B Coefficient of variation within years relative to the mean

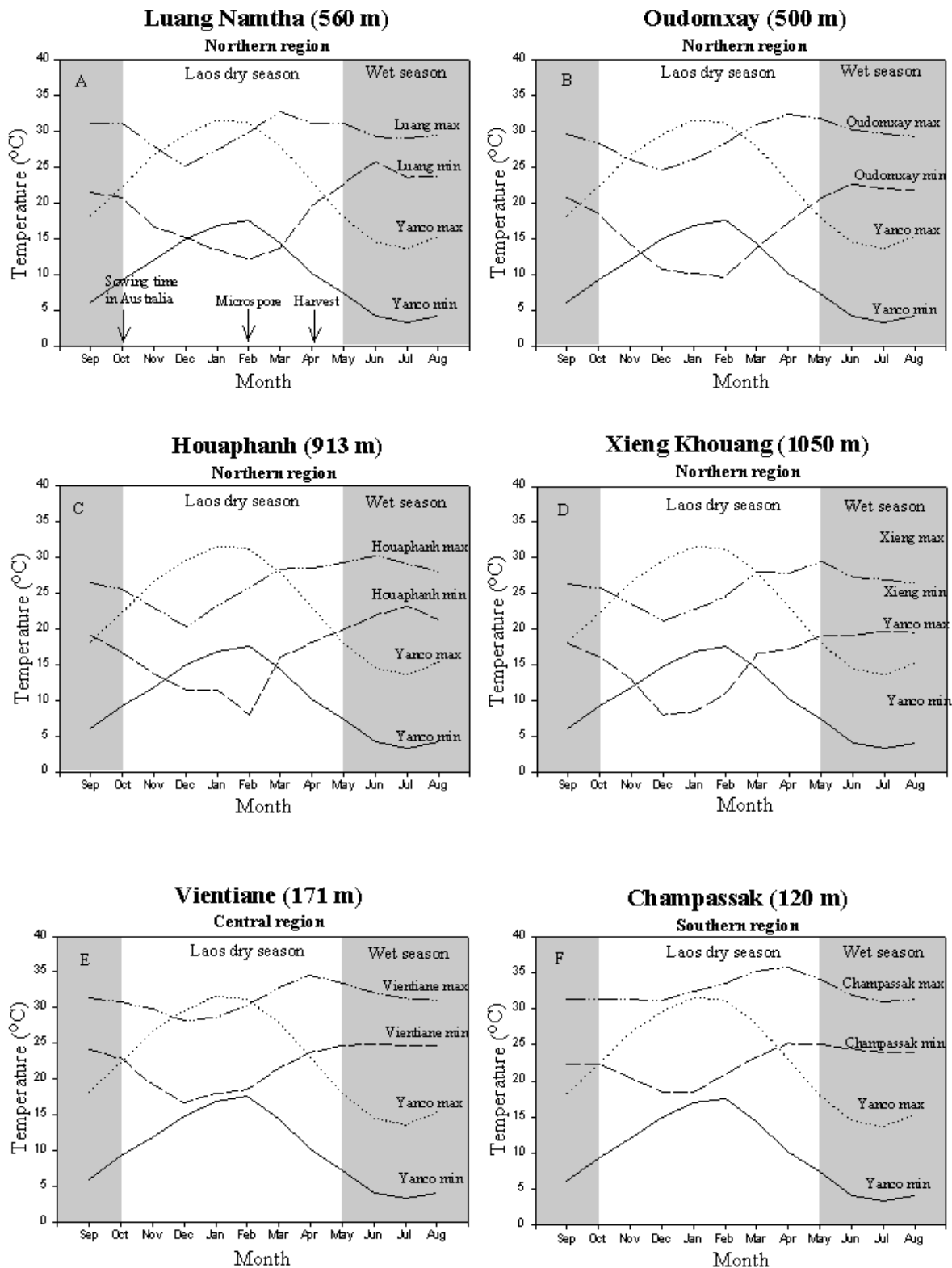


Figure 1 The long-term maximum and minimum temperatures of Yanco, Australia compared to six provinces in Laos. (A) Luang Namtha, (B) Oudomxay, (C) Houaphanh, (D) Xieng Khouang (E) Vientiane, and (F) Champassak.

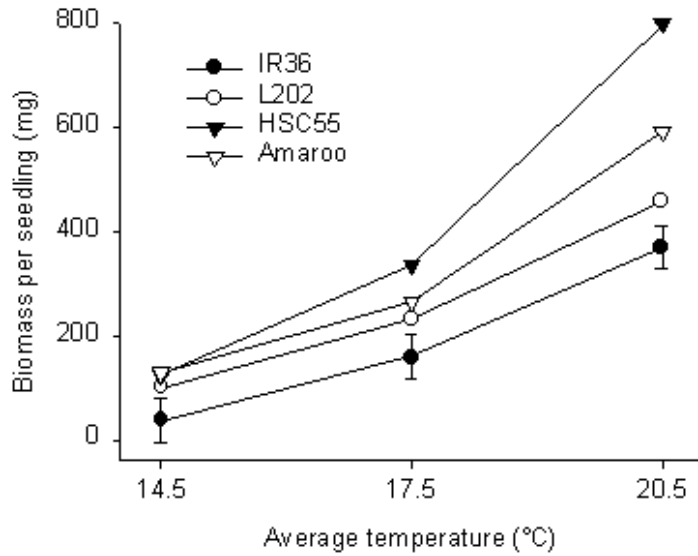
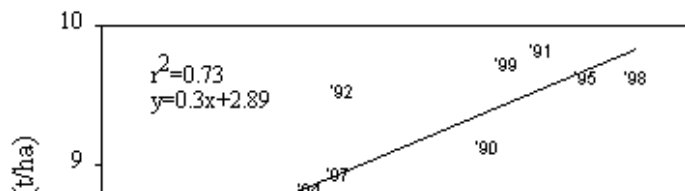
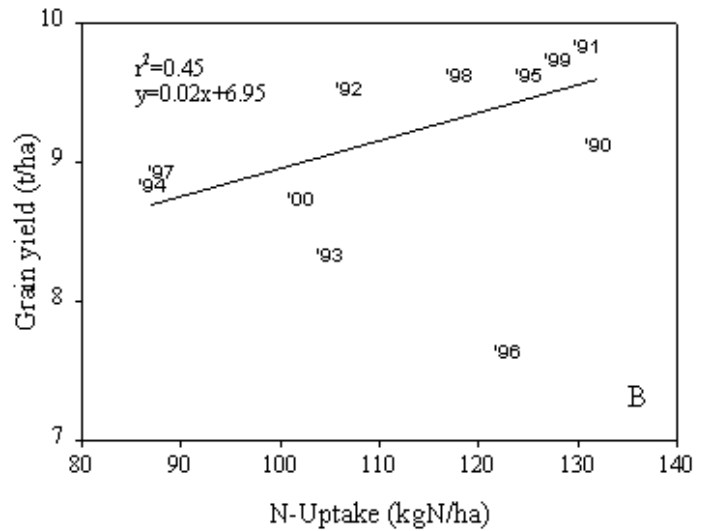
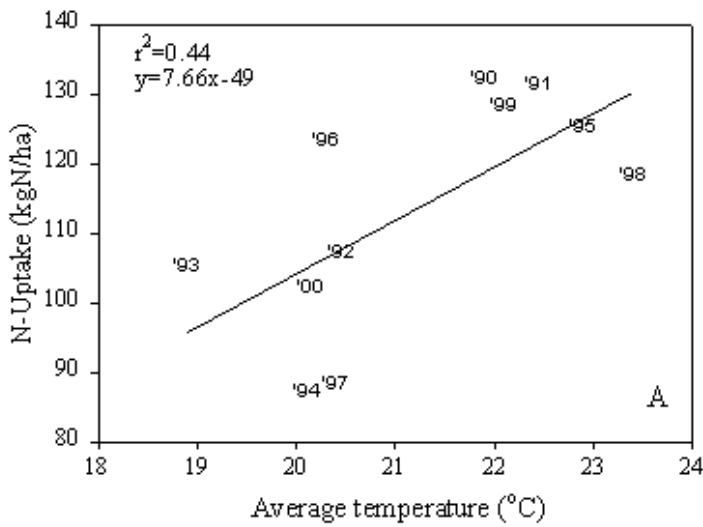


Figure 2 Effect of temperature on biomass per seedling, 41 days after sowing from a sub-set of cultivars displaying variation in temperature response. Vertical bars indicate standard error.



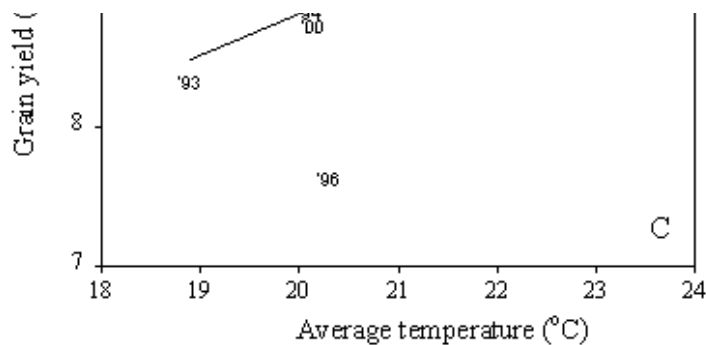


Figure 1 (A) Average temperature from November 1 to December 31 and PI Nitrogen uptake for Amaroo crops sown early October 1-7 from 1990-2000, **(B)** nitrogen uptake plotted against grain yield for Amaroo crops from 1989-2000, and **(C)** average temperature plotted against grain yield. The correlation of **(B)** and **(C)** does not include 1996, which experienced yield reduction due to low temperature during the reproductive phase (late January –early February).

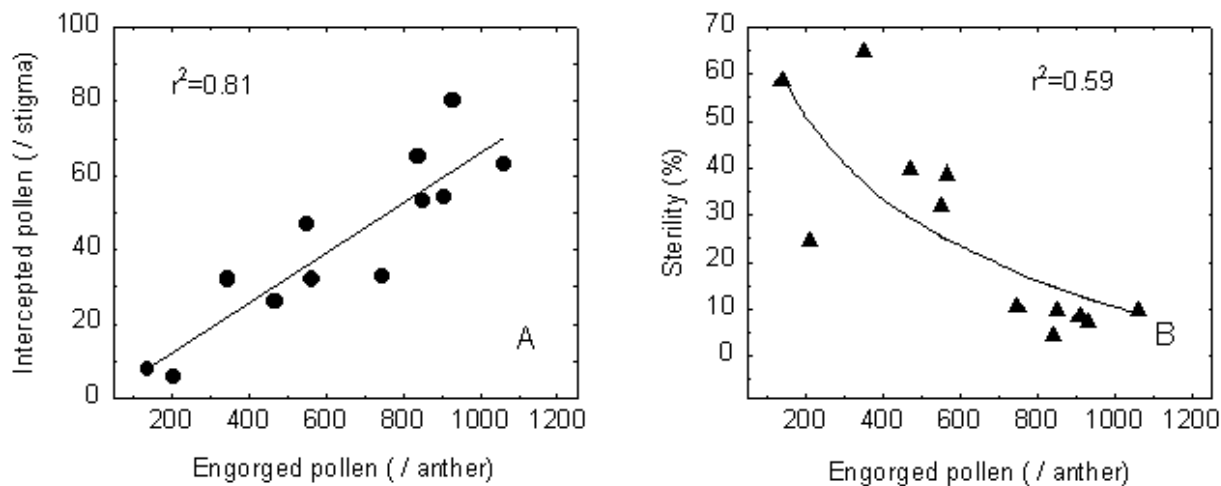


Figure 4 (A)

Number of engorged pollen grains per anther regressed against intercepted pollen per stigma for Amaroo. **(B)** Number of engorged pollen grains per anther plotted against spikelet sterility (Gunawardena, unpublished).

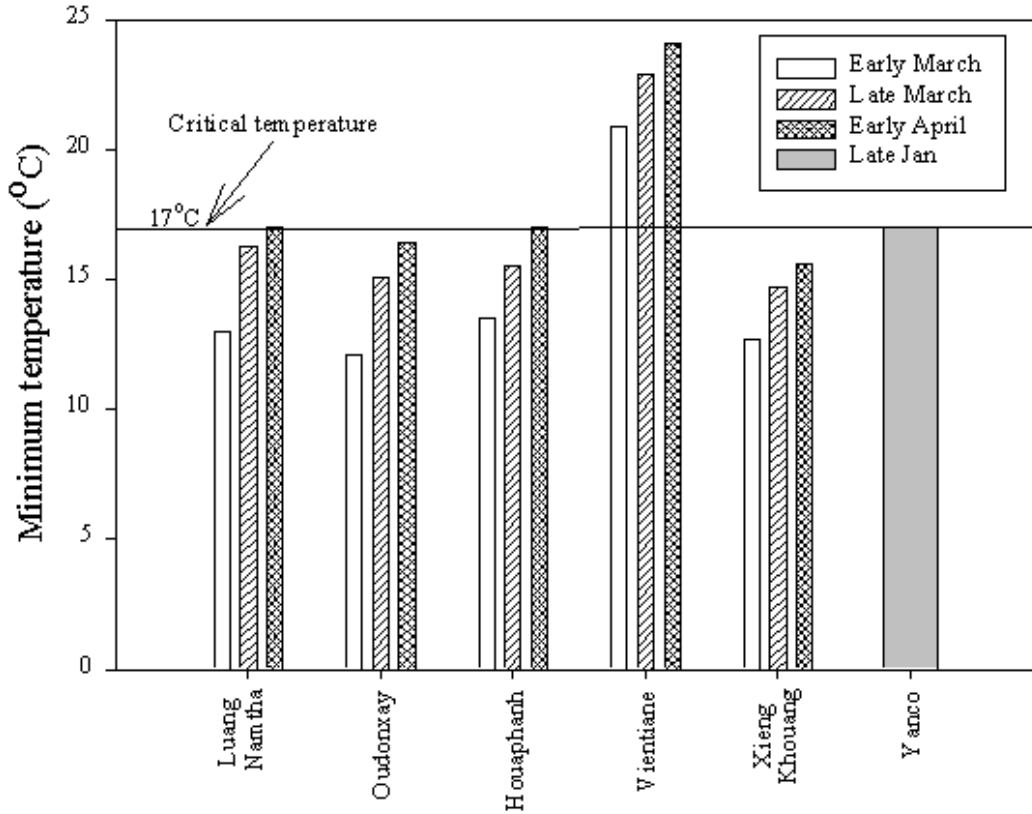


Figure 5 Temperature variability between the microspore period in Yanco and alternative periods in five Laos provinces. Champassak data was not available.