TRAVEL REPORT

Presented to the Rice CRC and NSW Agriculture

Study tour of rice production in South Korea and China

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OBJECTIVES OF THE VISIT

- Evaluate the rice cold tolerance screening system operating in South Korea;
- Discuss rice research areas common to Australia and China, and research unique at the Provincial and National Rice Research Institute in Hangzhou;
- Meet with breeders and physiologists at the Yunnan Agricultural University to compare data on the level of cold tolerance captured in cultivars originating in the high altitude areas;
- Participate in the International Rice Research Conference in Beijing, China;
- Develop links with international rice physiologists and rice breeders in South Korea, China and those attending the Rice Conference in Beijing.

EXECUTIVE SUMMARY

Rice production has a long history in Korea and China and has substantially increased in recent times. These rises in yield reflect advances in hybrid rice technology, an improved plant type, better nutrient and farm management. During my visit many rice related issues of interest to Australia's rice industry. In this report I have focused on reporting four key areas (climate change, cold tolerance, hybrid rice technology and aerobic rice) which I believe will have a major impact on rice production in Australia. It is vital that scientists around the world continue to collaborate on such areas to ensure global food security. Following my visit I am excited and looking forward to collaborating with scientists from Korea, China and others international organisations.

1 RICE IN SOUTH KOREA

1.1 Introduction

The Korean Peninsula is situated in far East Asia (33-43°N, 124-132°E). As a result of the extent of mountainous topography, the arable land in South Korea is approximately 1.9 million hectares (19% of total area), of which about 60% are paddy fields. The climate is very seasonal with generally warm humid summers and snowy winters. As a result of temperature conditions, rice cropping occurs once each year from April to late September or early October. The south and the coastal areas have generally higher temperatures than the north and inland, respectively. Lower temperatures in the mountainous area result in low temperature damage to rice crops.

About one million hectares are sown to rice each year producing over 5 million tonnes of rice. There has been a gradual increase in the national average rice yield, from 2.5t ha^{-1} in 1950 to 5.18t ha^{-1} in 1997. The improved yield is largely due to developments in breeding varieties and improved cultural practices. The average rainfall in South Korea is 1300mm, with 70% of rainfall occurring from July to September. Most rice is transplanted, largely by machine, and 8% is direct seeded. The majority (95%) of South Korea's rice area is irrigated and the remainder is rainfed. The average size of a South Korean rice farm is 1.3 hectares. The Rice Processing Complex (RPC) organises the drying, milling and storage of 40% of rice produced in South Korea. The remaining 60% of rice is milled, stored and consumed by farmers.

Unlike Australia where rice crops are continuously ponded from sowing to harvest, most South Korean farmers drain water twice. Firstly, water is drained at maximum tillering to temporarily change the root zone into an oxidised state. Its major benefits include increased stem strength and reduction in unproductive tillers. Breeders are reducing plant height of cultivars to reduce lodging. Some growers are applying silicon every 4 years to increase stem strength. Re-shooting is a major problem for lodged crops in South Korea. The crop is drained again 2 weeks prior to harvest.

1.2 Pests and disease

Major biological constraints to rice production in South Korea are disease and insect pests. The distribution and extent of disease each year in South Korea is related to weather conditions. The annual yield losses of rice due to rice diseases have been estimated at around 4% of the total production during the last three decades. Fungi cause the majority of rice diseases, particularly sheath blight (*Thanatephorus cucumeris*) and rice blast (*Pyricularia grisea*), affecting the seedling, leaf and panicle. Bacterial and viral diseases also occur in South Korea. Minor diseases have increased since the 1970's, including stripe virus, bacterial blight and dwarf virus. Rice breeders have developed some new varieties to resist disease. For example, HG101 is an introgression line that has delayed heading and resistance to bacterial blight. Disease occurrence has been reduced by changes in cultural practices, such as high nitrogen application and early transplanting. About half of South Korea's cultivars are blast tolerant. Sachuchungyeo is considered a multi-resistant cultivar.

Major rice insects are brown planthopper, white backed planthopper, rice leaf folder, rice stem maggots, rice water weevil and rice leaf beetle. Brown planthopper is the most significant rice pest, carried by the summer wind and typhoons during the rice season. Herbicides and insecticides are applied throughout the season as necessary.

1.3 Climate change

At the National Crop Experiment Station, Dr Choi (plant physiologist) has recently begun to investigate the effect of elevated CO_2 and temperature on rice growth. The phytotron (established in 1970) consists of 6 glasshouses where temperature (10-35°C range), humidity (60-85% range) and CO_2 (500-1000 ppm) can be accurately controlled. Artificial lighting chambers enables treatments of temperature (5-40°C range), humidity (50-90%) and daylength (0-24 hours).

Dr Choi has only recently begun experiments with elevated CO_2. He believes that emissions from factories, cars and the like will double CO_2 levels in 50 years. In 2000, the growth of *japonica*-type and *tongil*-type rice cultivars was investigated in the phytotron under high concentrations of atmospheric CO_2 (500ppm and 700ppm). As the CO_2 concentration increased, rice plants became shorter and produced more tillers per hill with darker leaves. The photosynthetic activity of rice plant decreased at 500ppm of CO_2 and low temperature of 24°C in both *japonica*-type and *tongil*-type rice varieties (Table 1). Higher photosynthesis was observed with the increase in temperature up to 26°C. Dr Choi intends to do more detailed experiments to clarify the effect of CO_2 and temperature on the rice plant.

Table 1 Photosynthetic activity of rice plants at 35 days after transplanting in different CO_2 levels and temperature (Annual Report, 2000).

Cultivar	*Treatment* (CO_2*ppm - °C)*	Transpiration *(mmol/m²/s)*	*Stomatal conductivity (mmol/m²/s)*	*Photosynthetic activity (μmol/m²/s)*
Hwaseongbyeo	500 – 26	3.17	714	9.2
	500 – 24	2.96	411	14.5
	Control – 24	3.13	540	15.8
Andabyeo	500 – 26	3.49	766	10.9
	500 – 24	3.44	854	12.9
	Control – 24	4.59	1103	18.5

A major difference in the rice-growing environment between South Korea and Australia is the different amounts of solar radiation. South Korea receives about 2/3 the radiation of Australia and they have more cloudy days. My visit to South Korea was during early September, which coincided with grain filling. The days were either cloudy or misty which was suggested to be associated with typhoon activity. As a result of low radiation levels during the September 2002 season, researchers believed that the grain filling period was being extended and that grain quality will be poor.

Dr Choi was also investigating the effect of different daylengths in the artificial lighting chambers. The experiment was investigating genotypic variation to 6 experiments of different daylength including:

1. 14 hour light
2. 1 day full light, next day 4 hours full light (cloudy)
3. 2 hours light
4. 4 hours light
5. 7 hours light
6. 9 hours light

The trial results are not yet known. It is important to understand how cultivars respond to such variable patterns of solar radiation in South Korea.

1.4 Rice breeding program

Dr Hwang is the Director of the rice-breeding program at the National Crop Experiment Station. About seven rice breeders work under Dr Hwang. They focus mainly on producing high-quality and high-yielding rice varieties tolerant to a wide range of biotic and abiotic stresses. About 120 different cultivars are grown throughout South Korea (approximately 30 are early maturing). The cultivars are selected based on characters ranging from plant height, phenology, leaf colour, culm length, spikelet sterility and grain quality. Parts of the program are focused on anther culture, transformations and investigating useful characters of the wild species.

Dr Kang is a breeder who has had very good success with anther culture. He has developed a very simple but effective tool to sample anthers from spikelets and capture them on a callose media. A small pump is connected to one end of a cylinder, with callose media located half way to capture the anthers. The anthers are excised from the spikelets near the open end of the cylinder and the draft draws the anthers onto the callose media. Dr Kang believes this system is successful and has less contamination. On each callose media he has between 150-200 anthers.

In another laboratory there was a wide range of equipment to measure different aspects of grain quality including grain colour, fragrance, amylose content, peptides, amino acid analyser (Hitachi can measure 40 kinds of amino acids), HPLC, GC system (fatty acids) and organic acid. They are dedicated to increasing whole grain mill out to over 60%, which will require optimum N, water and post harvest management.

As well as conventional rice breeding, research on molecular biology and genetics is conducted. Genetic specificity of 165 native South Korean varieties has been fingerprinted using 19 microsatellite or simple sequence repeats (SSRs) and randomly amplified polymorphic DNA (RAPDs) markers, Quantitative trait loci (QTLs) for rice grain quality and blast resistance were mapped to the chromosome level.

The establishment of embryo rescue technique was used to obtain an interspecific hybrid between different genomic wild species and cultivars and to introduce resistant genes for diseases and insect pests from wild species to cultivars via recurrent backcrossing during the 1990's (Choi, 2001).

1.5 Nutrition

Generally the soils are a clay-sandy soil that have poor nutrient levels following many years of consecutive rice crops. Rice soils are mostly deficient in nitrogen, phosphorous and potassium. The average N application may be 110kg ha^{-1}, however some growers apply 200kgN ha^{-1} to increase yield. Nitrogen is usually applied three times: prior to cultivation (50% of total), 2 weeks after transplanting (20% of total) and at PI (30% of total). Occasionally, nitrogen may also be applied during grain filling, but this is said to reduce grain quality. More recently, growers have been encouraged to reduce N application to improve grain quality. Reducing the amount of N application also decreases the risk of lodging, a major threat in South Korea because of typhoon activity. Unlike Australia's PI N test, a similar test is not available to assist South Korean rice growers with N recommendations. Mg is sometimes applied to increase grain quality. Often it is mixed with NPK. It is believed that Mg:K ratio affects quality and taste.

1.6 Rice physiology and cultivation

Dr Kim is the Director of the Rice physiology and cultivation division. He said that the highest yield of milled rice was 8t ha^{-1}, and their target is 10t ha^{-1}. He intends to achieve this with his team of 7 scientists aiming to increase yield potential and stability by:

- improved cold tolerance
- using genes from wild species
- improve plant type (reduced panicle length)
- increased photosynthesis
- higher RUE
- better understanding of root morphology
- improved post harvest management

1.7 Cold screening

In 1980 and 1993, low temperature seriously damaged the South Korean rice crop. Grain yield was decreased by 26% and 9% respectively, compared with the national average of other years. Today, 57% of varieties released in South Korea are highly tolerant to low temperatures. (Lee, 2001). Low temperature damage is more common in high altitude areas. There are many different types of cold damage experienced in South Korea (Table 2). Since the 1970's, South Korea has dedicated many resources into reducing the level of low temperature damage. They have developed an effective system to screen for cold tolerance in South Korea (Table 3).

Table 2 Type and symptoms of cold damage in rice, South Korea (NCES, 1985)

Growth stage	*Critical temp (°C)*	*Type and/or symptoms of cold injury*
Germination	10	Poor, delayed
Seeding	13	Retarded seedling growth Leaf discolouration Seedling rot
Vegetative	15	Inhibition rooting, growth and tillering Delayed panicle initiation
Reproductive	17	Inhibition of panicle development Degenerated spikelets Disturbed meiosis and pollen formation Delayed heading
Heading	17	Poor panicle exsertion Inhibition anther dehiscence and pollination
Maturity	14	Poor grain filling and quality Early leaf senescence

Table 3 Methods and facilities for screening cold tolerance in rice, South Korea (NCES 1990).

Types of damage	*Screening procedure[a]*	*Facilities*
Germinability Seedling	Water and air at 13-15°C for 7 days	Germinator
Chilling injury	Water and air at 5°C for 2-3 days at 2-leaf stage	Growth chamber
Growth and	Cool air treatment 12°/10°C (D/N) for 10 days at 3-leaf stage	Phytotron
Discolouration	Cold-water treatment at 13°C for 10 days at 3-leaf stage	Cold-water flowing test at Chuncheon
Delayed heading	18/10°C (D/N air) for 10 days at 10-20 days after transplanting	Phytotron
Sterility	18/18°C (air/water) for 10 days at meiosis 10/23°C (air/water) for 10 days at heading	Phytotron and greenhouse Phytotron and greenhouse
Combined type	Cold water at 17°C and flowing for the whole growing period from 20 days after transplanting	Cold-water irrigation screening nursery at Chuncheon
Grain filling	20/15°C (D/N air) for 20-30 days	Phytotron

[a]D/N =day/night

1.8 Chuncheon Substation

Chuncheon substation was established in the late 1970's. The substation is dedicated to cold tolerance screening of rice lines and cultivars at the seedling and reproductive stage. The site sources cool water (6°C) from 120m below the surface of Soyang Dam. The dam is used for irrigation and electricity. It is approximately 10°C by the time it is piped to Chuncheon substation (20km) where it is mixed in three tanks to maintain water temperatures of 13°, 17° and 20°C. Cold tolerance tests undertaken at Chuncheon can be summarised into 7 key areas:

1. Rice cold tolerance screening nursery
   - Treatment: 17°C water temperature from tillering to maturity
   - Material: Breeding lines (>1000 lines) from 3 national crop experimentation stations
2. Rice germplasm cold tolerance screening nursery
   - Treatment: 17°C water temperature from tillering to maturity
   - Material: Entries of rice germplasm
3. International rice cold tolerance screening nursery (IRCTN)
   - Treatment: 17°C water temperature from tillering to maturity
   - Material: Entries from IRRI and other countries
4. Cold tolerance screening at the seedling stage
   - Treatment: 13°C water temperature for 10 days at the 3rd leaf stage
   - Material: Breeding lines (F_3 and subsequent)
5. Pedigree nursery for cold tolerance
   - Treatment: 20°C water temperature from tillering to maturity
   - Material: F_2 crosses
F_3 and subsequent lines
6. Screening for tolerance of low air and water temperature at meiotic and heading stage
   - Treatment: Air/water temperature: 17/17°C for 10 days
   - Material: Breeding lines/varieties
7. Screening for germinability of rice varieties under low temperature
   - Treatment: 13°C for 25 days
   - Material: Breeding lines/varieties

The first three areas are similar to the type of screening that has been done on a smaller scale by the Rice CRC in Australia. However there are three key differences. Firstly the treatment with cold water is imposed earlier in South Korea (maximum tillering) than Australia (following PI). This reflects the added problem in South Korea of a reduced tillering during cool weather. The second difference is that the facility at Chuncheon had a temperature gradient from 17° to 25°C across each bay. Therefore each line and cultivar was exposed to a wide range of temperature treatments. This gradient assists in identifying the threshold temperature for different cultivars. The trend of sterility to fertility across the 17° to 25°C was visible between susceptible and cold tolerant cultivars. Screening for cold tolerance using cold water in Australia has so far been effective with a constant 19°C. The third (and most fascinating) was the level of damage imposed with shallow (5cm) cool water ensuring that the reproductive structures are not exposed to cold. This confirms the findings of Gunawardena (2001) who found that low root temperature contributes to sterility through a reduced engorgement efficiency of pollen grains.

The lines and cultivars were separated in the field screens based on maturity groups (early, medium and late) to ensure that the low temperature treatment was similar. Each line and cultivar was transplanted in one 5m row and treated to cool water. A small 1m row was transplanted in a line and irrigated with warm water as a control. At harvest, three panicles from 5 hills at set distances across the row are sampled and spikelet sterility calculated.

Despite the grouping based on duration, I suggested that it might be useful to use the flowering date of the control as a covariate in the analysis of low temperature damage to account for the variation in duration of low temperature treatment.

Some major agronomic factors that are important for cold tolerance and are measured at Chuncheon include: germination ability, seedling growth rate, leaf discolouration, heading delay, culm length shortening, spikelet number reduction, degenerated spikelets, poor panicle exsertion, spikelet sterility, and phenotypic acceptability (PA) at tillering and at maturity.

1.9 Sangju SUbstation

Dr Kim is the director of Sangju substation. Sangju is at higher altitude than Chuncheon. There is a wide range of activities undertaken at Sangju including:

- Developing early maturity cultivars (eg Jinbuolbyeo) for Southern Korea..
- Nursery testing for cold tolerance (eg Undubyeo) at seedling stage, using a two week treatment of 13°C cool water at 5cm depth. Measurements include seedling growth and leaf discolouration. 13°C water is drawn from an underground bore.
- Tolerance to rice leaf blast. Over 30, 000 lines tested. Measure shape and length of symptom and score it 1-9 (tolerant-susceptible).
- Tolerance to rice neck blast, a major disease throughout South Korea. Spreading infected leaves induces the disease.
- Lodging resistance. Research primarily focuses on measures of plant height and stem thickness.

2 NANTIONAL AND PROVINCIAL INSTITUTE IN HANGZHOU, CHINA

China National Rice Research Institute (CNRRI) is located in Hangzhou, Zhejiang province. Research involves using rice genetic studies and genome research for improving rice yield, grain quality, pest resistance and stress tolerance. The mean rice yields in the Zhejiang province is 6.5t ha^{-1} (paddy) which is equivalent to the national average. Approximately 80% of rice is transplanted with the remaining 20% direct seeded. The transplanted crops are higher yielding because there is more active rooting and better control of diseases. Most rice is grown on level ground, although some is established on small beds. The two major diseases are rice blast and bacterial blight and the major pests are brown planthopper and stem borer.

2.1 Hybrid Breeding at the Provincial Institute

There is a major focus on hybrid breeding of both *japonica* (Dr Zhang) and Indica (Dr Yu). They suggest that the rice yields of conventional cultivars is 8t ha^{-1}, compared to 10t ha^{-1} for hybrids. The yield advantage is over 10%, although grain quality is poor and amylose high. Rice varieties are selected for large panicles, appropriate plant type (eg height), deep roots (less susceptible to lodging) and efficient tillers (at least 5 grains per panicle). A strong correlation (R=0.8) was found between efficient tillering and yield.

2.2 Hybrid rice at CNRRI

Hybrid rice accounts for 50% of rice grown in China, of which *Japonica* hybrids account for less than 10%. *Japonica* hybrids appear to have less heterosis (or hybrid vigour), less resistance to blast and lower seed purity than *indica* CMS lines. It has been difficult to develop a restorer for *japonica* CMS lines. The thermo-sensitive CMS lines ensure the fatality of pollen production during the reproductive stage at temperatures over 23°C. A so-called "super rice" has been developed that is approximately 1.2m tall and has a tall flag leaf, strong roots, large panicle and large seed. The highest yield measured in trials of "super rice" is 13t ha^{-1}.

3 YUNNAN AGRICULTURAL UNIVERSITY

Research at Yunnan Agricultural University is primarily focused on improving:

- ♦ blast (neck and leaf) resistance(more susceptible at high N);
- ♦ screening for reproductive cold tolerance at high altitude (2200-2500m);
- ♦ grain quality;
- ♦ grain yield;
- ♦ drought tolerance;

3.1 Hybrid Rice

A rice line that cannot produce viable pollen due to the interaction between cytoplasmic and nuclear genes is described as being cytoplasmic male sterile (CMS). The maintainer line (or B line) is used as a pollinator for maintaining a CMS line (A line). The Restorer line (R line) is used as the pollinator for the CMS parent for hybrid seed production. There are over 700 CMS lines in Yunnan. They have 15 good R lines in Yunnan. However, because these lines are a cross between *indica* (more sensitive) and *japonica* (more tolerant) the cold tolerance is not as strong as possible.

The production of hybrid seed comprises of 2 rows of an interspecific (*indica* x *japonica*) restorer line and 8-10 rows of CMS line. Supplementary, manual pollination occurs 3-4 times in a 10-day period around flowering. Heterosis is high in F_2 seed but is quickly lost in following generations. High rain at flowering led to poor hybrid seed production this year (15-20% fertility). Fertility is usually around 30-60%.

At Yunnan Agricultural University, a molecular marker has been found for the restorer gene but is too expensive to use. A simpler system is being developed. Many seed companies run field trials, which show the yield benefits of hybrid rice over conventional rice. However, at one (unreplicated) trial site, the conventional variety out-yielded the hybrid rice. The reason for this was unclear. One hybrid line that I saw in the field yielded 9-10t ha^{-1}, but it was not to be continued because it was susceptible to blast, had poor grain quality and an extended duration. This hybrid line will be trialed in a new location next season.

Despite many useful markers being discovered at Yunnan Agricultural University markers are presently not being used for screening cultivars. It is not yet clear how to test a range of markers simultaneously (multi-plexing). A current project is to evaluate the cost of marker assisted selection. Presently, the researchers in Yunnan do not have a marker for amylose content and are enthusiastic to collaborate with the Rice CRC to implement the marker.

4 INTERNATIONAL RICE RESEARCH CONFERENCE

4.1 Introduction

The Chinese President Jiang Zemin joined 1,200 Chinese and foreign agricultural scientists and officials at the opening of the International Rice Conference in Beijing on September 16, 2002. The theme of the conference was to consider how to feed the growing global population when current predictions of production increases fall short.
There were many themes presented at the IRRC. I will briefly describe some of the issues involved in hybrid rice, aerobic rice and climate change.

4.2 Hybrid rice

The area planted to hybrid rice in China is about 15.5 million hectares, which accounts for 50% of the total planting rice area. The production of hybrid rice occupies nearly 60% of the total rice production. Encouraged by the success of hybrid rice in China, many countries are developing their own hybrid rice and much progress has been achieved. The average yield was 9.2t ha^{-1} in large-scale commercial production in 2001 in China. The variety P645/E32 reached 17t ha^{-1} in 1999 in Yunnan. Dr L.P Yuan ('the father of hybrid rice') suggested the approach including:

- morphological improvement of IRRI's new plant type (NPT) in the super hybrid rice program including lower panicle position to reduce lodging, and leaves that are long (increased LAI), erect (intercept solar radiation from both sides, narrow (occupy less space with higher LAI), v-shaped (for a stiffer leaf blade), thick (slower leaf senescence);
- raising heterosis level (*Indica* x *Japonica* has the strongest heterosis);
- using favourable genes from wild rice;
- using genomic DNA from barnyard grass to create a new source of rice.

Dr L.P Yuan spoke about his cloning of C4 genes from maize and transferring them into super hybrid rice.

4.3 Aerobic rice: challenges and opportunities

In Asia, irrigated agriculture accounts for 90% of total developed fresh water resources. Fresh water, however, is becoming increasingly scarce an is expected to decline further because of population growth, increasing urban and industrial demand, decreasing availability because of pollution. In Asia over 50% of irrigation water is used for rice. Rice requires more water than most crops as it mostly grown under flooded conditions. Most water saving technologies for rice focus on decreasing the non-productive seepage and percolation losses. In aerobic rice systems, there is no continuous flooding, and losses are reduced. There are two main target environments for tropical aerobic rice:

- wet season cropping in free-draining aerobic soils in rotation with other aerobic crops, where intermittent water logging can occur;
- dry season cropping in heavy soils where paddy rice has been grown, but where increasing scarcity of irrigation water makes aerobic rice attractive.

Much of Australia is in drought and aerobic rice is being considered for the potential water savings. Significant gains have been made in the development of cultivars for aerobic systems. In the Brazilian Cerrado and the water-short plains of northeast China, cultivars with high yield potential (5-7t ha^{-1}) and adapted to aerobic conditions have already been developed. Most of the cultivars have been developed from crosses between irrigated high yielding varieties (HYV's) and improved upland cultivars. Aerobic rice cultivars differ from traditional upland varieties mainly in having higher harvest index and resistance to lodging. HYV's contribute high yield potential, input responsiveness, lodging resistance and harvest index.

In contrast to lowland rice, aerobic rice uses far less irrigation. It grows in non-puddled, non-flooded soil under moderate external inputs, with only limited supplementary irrigation when natural rainfall is insufficient. The aerobic system (upland) includes:

- no puddling, no standing water;
- highly productive cultivars (responsive to high inputs);
- rainfed to supplement irrigation;
- tolerates occasional flooding;
- bunded or non-bunded fields.

However, rice yields are generally lower in aerobic soil than in saturated soil and there is a trade-off between yield and water use. In order to minimise this trade-off between yield and water use, new varieties must be bred and new management technologies developed specifically for irrigated aerobic soil conditions. Recent results obtained in Northern China and the Philippines indicate that with current germplasm and management technologies, aerobic rice systems yield about 30% less and reduce water requirements by up to 60% compared with flooded lowland systems, thereby increasing the water productivity.

Dr Bas Bouman (IRRI) suggested that the problems of aerobic rice include weed management, rat damage, lodging (at high N) and other new problems that are to be expected from a new system. Driven by the pressure of water scarcity, new-generation elite aerobic rice varieties have been developed and disseminated successfully to farmers in northern China in the 1990's. This includes the varieties Han Dao 2, Han Dao 297, Han Dao 277, Han Dao 502 (up to 8t ha^{-1}), Han 58, Han 72 Danjing 5 and Danjing 8 (good quality), Currently aerobic rice is grown on 300 000 ha, accounting for 1% of rice area in China. Apo was a variety that yielded 5t ha^{-1} in flooded and 4.5t ha^{-1} in reduced water conditions. Some aerobic Chinese varieties are of good grain quality. The semi-dwarf hybrid Magat, developed for irrigated conditions, is the highest yielding cultivar under aerobic management at IRRI, producing yield of more than 6t ha^{-1} in aerobic conditions and 8.5t ha^{-1} in flooded conditions. Aerobic adaptation is associated with ability to root deeply, to maintain leaf area development under nonsaturated conditions, and to tolerate moderate water stress at flowering. Dr Atlin (IRRI) believes that these traits appear to be polygenic in nature, but believes that evidence suggests that QTLs of moderate effect may be involved. Further, aerobic adaptation does not appear to be associated with reduced ability to tolerate water logging. The most effective approach to developing high-yield aerobic rice varieties is to select directly for grain yield under aerobic conditions and high-input management, in screening environments that can provide water at depths below 30cm.

Advances in crop management technologies such as seed coating (to prevent insect, mouse and bird damage), mechanical direct seeding, and herbicide-based weed control have facilitated the adoption of aerobic rice, with the area increasing from about 33,000ha in 1998 to 133,000 ha in 2000 in this region (North China). The grain yield is as high as 4.5-6t ha^{-1} normally, and can reach 7.5t ha^{-1} in some cases. These yields are about double those of traditional upland varieties and 20-30% lower than that of lowland rice. Aerobic rice requires about 50% as much water for irrigation as does lowland rice, and its water productivity is one to two times higher. Moreover, aerobic rice is generally highly mechanised, so it requires less labour than lowland rice. Dr Bouman presented trial results from IRRI and Beijing Table 4.

Table 4 Results from IRRI and Beijing trials comparing aerobic rice to lowland rice (Dr Bouman – IRRI)

	IRRI			Beijing		
	Aerobic rice		Lowland	Aerobic rice		Lowland
	Aerobic	Flooded		Aerobic	Flooded	
Yield	4.5-6.0	6.5-8.6	8-10	4.7-5.3	5.4-6.8	8.8
Water use (mm)	750-850	1300-1700		600-650	1300-1400	
Soil Type	clay 59%, silt 32%, sand 9%			Clay 7%, silt 38%, sand 35%		
Duration	110-125 days					

The water saving of aerobic rice presented by Wang Huaqi of China sounded attractive (Table 5)

Table 5 A comparison of number of irrigations, water use and yield of lowland and aerobic rice in Northern China (Wang Huaqi)

	Irrigations (no)	water (mm)	yield (t ha^{-1}
Lowland	12-15	1500	7.5
Aerobic	4-5	375	6

Dr Bouman summarised the state of aerobic rice as:

- aerobic rice cultivars exist;
- yields of 5.6 t ha^{-1} have used very little water (470-850mm vs 1300-1800mmin lowland);
- increases in water productivity
- can grow on light textured soils with deep groundwater (irrigated upland)
- dedicated breeding is required to make aerobic rice successful
- appropriate management strategies need to be developed
- screen for high HI, lodging resistance, reproductive stage drought tolerance and yield potential
- technology is deliverable now

Both opportunities and challenges remain to be addressed in the further development of this new cropping system in China.

4.4 Climate change

There has been a gradual increase in temperature throughout the world over the last 50 years. Temperature changes can effect photosynthesis, which can alter yield. It is expected that in some regions rice yields may be reduced as the growth duration is shortened because of a warming climate, and yields may increase in other high altitude areas. Many models suggest that yields will decrease without adaptation of rice cultivars to a changing climate. CERES Rice 3.5 model suggests that yields will decrease in most areas of China, if CO_2 was not accounted for. Therefore, the development of more CO_2 responsive cultivars is important. Nakagawa showed that season-long doubling of CO_2 increased rice biomass by about 25%, while extremely high temperatures may increase sterility.

A warmer climate suggests that the low temperature damage may be alleviated. However, the real threat that remains is the climatic variability. There are still many important issues to be addressed on the impact of climate change, including:

- acclimation of rice crop to elevated CO_2 levels;
- crop/weed interaction. The idea that crops will be favoured over weeds as CO_2 increases is an overgeneralisation. Spraying glyphosphate at 100% of recommended rate did not kill lambs-quarters (weed) grown at elevated (700ppm) CO_2. The effect of CO_2 on allelopathy is unknown;
- effect of changes in the water cycle on rice production;
- rainfall/irrigation supplies;
- sea level changes affecting the rice growing areas.

Professor Horie (Japan) suggested that doubling CO_2 increases photosynthesis and yield by 50% and 20% respectively. We need to consider how we can better harness the higher levels of CO_2. Higher temperatures during flowering cause pollen abortion. High temperature damage is also worse at higher humidity. However, high temperature damage is rare in Australia due to the high level of evaporative cooling in the rice bays. We need to better understand the microclimate effect and leaf temperature. During discussions, I suggested that warmer temperatures have given higher yields in Australia. However, if the level of cold tolerance increases by 7°C in Australia's cultivars then rice may not require ponding during the reproductive period. If this level of tolerance is achieved in Australia, high temperature tolerance may be required as evaporative cooling will be decreased. An improved understanding of panicle respiration during the reproductive stage required for an improved physiological understanding of plant response.

5 RECOMMENDATIONS

That collaboration be established between the Rice CRC and South Korea and China including links with all institutions visited:

South Korea RDA
It is important that the Rice CRC have close links and collaboration with the plant physiologists and breeders at South Korea RDA, in order to have free exchange of genetic material that is cold tolerant, blast resistant, good grain quality and high yield potential. Additionally the Rice CRC should access South Korean CMS lines to evaluate the potential of hybrid rice from South Korea. Scientists are enthusiastic about evaluating the yield potential of their cultivars in Australia's favourable rice growing environment. Screening for cold tolerance of Australia's material in Chuncheon and South Korea's material in Yanco is important to confirm the expression of tolerance in another environment. Dr Kwang (Director of Rice Breeding) was enthusiastic about collaborating with the Rice CRC and I have written a letter Dr Kwang to outline areas of mutual interest (Appendix 1). Many other areas of mutual interest (such as Australia's PI N test) will arise during this collaboration

Provincial Rice Institute, Hangzhou
The major strength of this institute is the dedicated research on hybrid rice. They have a *japonica* and an *indica* hybrid rice breeder. I have sent a letter to Professor Qingsheng (Director) outlining our interest in collaborating in hybrid rice research (Appendix 2). Professor Qingsheng kindly gave me eight F1 hybrid lines for evaluation. They will be sown in quarantine during October. Langi and Amaroo seed will be sown as well, for comparisons between plant types. I hope that Professor Qingsheng may be able to send some CMS lines for evaluation.

Yunnan Agricultural University

The Rice CRC is in the process of establishing formal collaboration with Yunnan Agricultural University. The agreement needs to be authorised quickly. Yunnan is ready to send their *japonica* CMS lines and would like Australia's molecular marker for amylose to evaluate this year's trials. I have written a letter to Dr Tan to help speed up the process (Appendix 3).

Hybrid rice

Most rice producing countries (excluding Australia) are enjoying the benefits of hybrid rice. Countries such as South Korea and China have had large increases in yield and continue to produce grain of high quality. Australia must now move fast and evaluate the benefits of *japonica* hybrid rice in our environment. It is hoped that *japonica* CMS lines will be brought into Australia in the near future through collaboration with groups in South Korea and China. In the past year *indica* CMS lines have been brought into Australia. Clearly, *japonica* hybrids will be most beneficial to Australia because of there higher level of cold tolerance. However, it is worthwhile for Australia's rice breeders to persevere with these lines to improve techniques of hybrid seed production. The Rice Knowledge Bank (has some useful information on hybrid seed production. Also there is an International Hybrid Rice Training Course held at IRRI each year. If hybrid rice breeding is initiated in Australia it may be beneficial for the breeder to attend this training course. Clearly the three crucial questions in relation to hybrid rice that need to be considered for Australia:

1. How much can hybrid rice increase yield?
2. Can we maintain good grain quality?
3. Is hybrid seed production economical (labour, helicopters etc)?

Aerobic Rice

Aerobic rice cultivars may be a crucial ingredient in the success of farming systems such as rice on beds. Countries such as Brazil and China have cultivars that have originated in upland conditions and are adapted to aerobic conditions. I will write a letter to Dr Pinheiro (Brazil) and Dr Huaqi (China) to access this genetic material.

Seminar

I will give a seminar to staff at Yanco Agricultural Institute on October 17, 2002. Additionally, Laurie Lewin has suggested that I present a seminar at the Rice Symposium in February 2003. This is an ideal opportunity to share what I have learnt and highlight the collaboration that has been developed.

6 ACKNOWLEDGEMENT

My thanks are due to the Rice CRC for funding this visit to South Korea and China. 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 gratefully acknowledged.

7 INTERESTING FACTS

- On August 31, 2000, 871mm of rain fell during a typhoon in South Korea, which is equivalent to two years rainfall at Yanco.
- South Korea is sending 40,000 tonnes of rice to North Korea as aid.
- During this trip to South Korea and China I consumed large quantities of food that were foreign to my palate, including bees, frog, coagulated blood, grasshoppers, silk worm, turtle, pigeon, raw fish, and stem borer. Needless to say, I ended up with an upset tummy.
- There are no work cars at the National Crop Experimentation Station RDA (South Korea) and the researchers use there own cars to get around.
- 60% of South Korea is mountainous and roads tunnel straight through mountains.
- Many trees in South Korea and China have support structures to protect them from typhoons.
- Very few people get social security in South Korea. It is expected that their family and savings support the aged.
- 2 ½ years of military service is compulsory for men in South Korea but not compulsory in China.
- In South Korea they get one week of vacation each year. Unemployment is 5%.
- South Koreans don't say goodbye at the end of phone calls.
- In South Korea, about 50% of the population is Buddhist, 30% Protestant and 8% Catholic.
- Many Mountain forests were cleared during the Korean War. Reforestation has occurred since then.
- Water is paid per land area in South Korea.
- Every 3.1 seconds someone in the world dies from starvation .
- 90% of fresh water resources in Asia are diverted for irrigated agriculture (of which 50% is for rice).
- A lady in Hangzhou was employed from 6am to 6pm to scare birds away with a stick, earning 40 yuan ($8/day).
- Less than 5% of world rice production is traded.
- At the IRRC it was suggested that education is lacking in adoption of biotechnology. To the statement: Ordinary tomatoes do not contain genes but genetically modified tomatoes do. 50% of people answered yes and 50% no.

8 APPENDIX

APPENDIX 1

October 9, 2002

Dear Dr Kwang,

Thankyou for welcoming me to your institute during September 2002. I appreciate your effort in organising my visit to learn about rice growing in South Korea. I enjoyed discussions with scientists from your rice breeding group and Dr Kim's plant physiology and cultivation group. I was impressed at the breadth and quality of research undertaken by both groups and I enjoyed visiting Dr Yea at the famous Chuncheon substation with Dr Jeong. I learnt much about all aspects of South Korea when visiting Dr Kim at Sangju substation with Mr Park.

I returned to Yanco with added enthusiasm following my visit to South Korea. Since then, I have discussed with Dr Laurie Lewin, our Director of the Cooperative Research Centre, about avenues of collaboration with both groups at the National Crop Experimentation Station, RDA, Korea. Dr Lewin was enthusiastic about collaboration on all the key areas that I discussed with Dr Kim and you and any others of mutual interest that may arise. He agrees that there are clear benefits to be achieved through collaboration in areas of plant breeding, plant physiology and grain quality. The exchange of a range of cultivars that are tolerant to low temperature, desirable grain quality attributes, tolerance to disease (such as blast) and high yield potential would be of benefit to both countries. Recently a CRC scientist has implemented a molecular marker for amylose content that may be beneficial to your breeding team. Dr Kim was excited by the opportunity to grow Korean cultivars in Australia to explore the yield potential of cultivars under ideal conditions of high solar radiation, warm temperatures, large diurnal range and no damage by pests or diseases. We have never evaluated the benefits of hybrid rice in Australia and I am keen to explore the yield advantage of hybrids over commercial cultivars in Australia using Korea's *japonica* 2- and 3-line hybrids. The sharing of knowledge arising from these areas of collaboration is exciting for South Korea and Australia.

I feel that the collaboration had already begun during my visit to South Korea as information was shared on many issues. On October 1, 2002 we hosted Dr Yang-Ho Park from the Plant Nutrition Division, National Institute of Agricultural Science and Technology, RDA, Korea. Again I would like to thank everyone at South Korea for making my visit fruitful and I look forward to developing our friendship further. I have enclosed two Annual Reports from the Rice CRC for Dr Kim and yourself. I have also included a maNage rice CD that Dr Kim requested. This is a widely adopted decision support system that is used by Australian rice growers to determine how much N is top-dressed at PI.

It was great to catch up with Drs Kim, Kang, Kim and yourself at the International Rice Research Conference in Beijing.

Yours sincerely

Tim Farrell
Plant Physiologist

Laurie Lewin
Director and Plant Breeder

APPENDIX 2

October 9, 2002

Dear Professor Qingsheng,

Thankyou for welcoming me at your institute during September 2002. I really enjoyed my visit to your the Provincial and National Institutes in Hangzhou. Your hospitality during my brief visit was greatly appreciated. The rice CRC and Australia's rice industry are very keen to collaborate with institute such as yours. I enjoyed the discussions with scientists from the National and Provincial Institutes.

I believe the areas of mutual interest are in the areas of plant breeding, plant physiology and grain quality. The exchange of a range of cultivars that have desired grain quality attributes, CMS lines and high yield potential. Scientists in the Rice CRC recently implemented a molecular marker for amylose content that may be beneficial to your breeding team. I was impressed with the dedicated *indica* and *japonica* hybrid breeding programs at your institute. As we discussed, I am keen to quantify the benefits of hybrid rice compared to conventional cultivars in our environment. It is vital to determine the impact on yield, grain quality and consider the viability of hybrid seed production. We presently do not have the genetic material but believe that Japonica 2 and 3 line hybrids may more useful in our environment. With the drought that is covering Australia we are also interested in aerobic rice to reduce water use.

I returned to Yanco with added enthusiasm following my visit to China. Since then, I have discussed with Dr Laurie Lewin, our Director of the Cooperative Research Centre, about avenues of collaboration with China. Dr Lewin was enthusiastic about collaboration on all the key areas that I have outlined that reflect our discussions in China and any others of mutual interest that may arise. He agrees that there are clear benefits for both countries. The sharing of knowledge arising from these areas of collaboration is exciting for China and Australia.

I feel that the collaboration had already began during my visit to China as information was shared on many issues. I enjoyed your visit to Yanco during your extended visit at Southern Cross University in Lismore. The Rice CRC and I look forward to returning the hospitality when you or your colleagues next visit Yanco. Again I would like to thank everyone at China for making my visit fruitful and I look forward to developing our friendship further. I have enclosed an Annual Report from the Rice CRC for your interest.

It was great to catch up with you in Hangzhou and again at the International Rice Research Conference in Beijing.

Yours sincerely

Tim Farrell
Plant Physiologist

Endorsed

Laurie Lewin
Director and Plant Breeder

APPENDIX 3

October 9, 2002

Dear Dr Tan,

Thankyou for welcoming me at Yunnan Agricultural University during September 2002. I really enjoyed my visit to your University and particularly the opportunity to visit your field trials. It was a perfect time to see hybrid rice production. I was most impressed with Yunnan Agricultural University's contribution to increased rice yields of good grain quality in Yunnan using hybrid rice. We are looking forward to close collaboration in areas such as these through close collaboration.

The Rice CRC Director and committee has fully endorsed our collaboration and we are now looking forward to working closely with your University. The sharing of knowledge arising from these areas of collaboration is exciting for China and Australia.

I returned to Yanco with added enthusiasm, which reflects your hospitality during my visit. Thankyou again. I have included the Annual Reports from the Rice CRC for your interest.

Yours sincerely

Tim Farrell Laurie Lewin
Plant Physiologist Rice CRC Director and Plant Breeder

APPENDIX 4

TRAVEL ITINERARY

DATE	ACTIVITY
Thursday August 29	Travel Yanco-Sydney
Friday August 30	Travel Sydney- Seoul
Saturday August 31	Travel Seoul-Suwon
Sunday September 1-3	National Crop Experimentation Station, Suwon
Wednesday September 4	Visit cold screening nursery at Chuncheon
Thursday September 5	Visit high altitude screening at Sangju
Friday September 6	Travel Suwon to Seoul
Saturday September 7	Travel Seoul, South Korea to Shanghai, China
Sunday September 8	Travel Shanghai to Hangzhou
Monday September 9	National Crop Research Institute
Tuesday September 10	Provincial Crop Research Institute
Wednesday September 11	Travel from Hangzhou to Kunming, Yunnan Province
Thursday September 12-13	Meet with breeders and physiologists at the Yunnan Agricultural University
Friday September 14	Visit and discuss cold tolerant rice grown at higher altitudes
Sunday September 15	Travel to Beijing Register for IRRC
Monday September 16-19	International Rice Research Conference
Friday September 20	Meet with cold tolerant scientists
Saturday September 21	Travel Beijing to Sydney
Sunday September 22	Travel Sydney to Yanco