RICE CRC

FINAL RESEARCH REPORT

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Title of Project:	Minerals for sustainable grain yield and grain quality.
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PROJECT SUMMARY

Rice cropping is an intensive enterprise. To be sustainable and to use water efficiently, rice requires adequate plant-essential nutrients. Nutrient supply has an impact on both grain yield and grain quality.

In this project we have developed a nutrient balance model which summarises the impact of rice cropping on soil nutrients. The main concerns highlighted from this model are that, on average, all soil nutrients, except sulphur and calcium are being depleted. This work should alert rice growers to the potential for yield losses due to nutrient depletion. A plant nutrient diagnostic protocol is still required for Australian rice varieties.

A protocol has been developed to induce the yield-reducing disorder known as straighthead. This will facilitate the design of studies aimed at understanding the cause of this problem. The current theory being tested is that micronutrient deficiencies, e.g., copper or zinc, cause the problem. Further testing is required to confirm the findings made up to now.

This project has also demonstrated for the first time, that grain Fe and Zn can be increased in rice grains by as much as 44 and 26% respectively following applications of these elements in foliar fertilizers. During this study we also demonstrated the value of non-contaminating grain processing equipment for use in the study of micro-nutrients in rice.

Variation in germplasm is seen as an asset to the breeding program. A literature review of world data from non-cultivated species of the genus *Oryza* has been assembled and will be a valuable source of information for plant breeders and other scientists seeking specific traits. During this study we also developed a new taxonomic key to aid the correct identification of the 4 Oryza species which are found in Australia.

Rice accumulates phosphorus (P) to about 0.35% by weight in brown grains. As 85% of Australia's rice is exported we sought germplasm to reduce this loss. Samples we obtained from a long-term study in Japan clearly demonstrated the impact of P-deficiency on grain yield and grain quality (low P, K and Mg concentrations). Preliminary studies were made at Yanco of the mutant rice known as lpa-1. The key feature of lpa-1 is that it deposits more phosphorus into inorganic P but less into organic or phytate P in the grain. We suggest that the line lpa-1 should be incorporated into high yielding Australian rices to produce a rice which could provide a better nutrient intake for humans and monogastric animals.

Linkages have been established with the Yezin Agricultural University in Myanmar and the rice program of the Central Agricultural Research Institute. These linkages have the potential to boost our understanding of the nutrient requirements of rice under long-term cultivation and also provide access to cold-tolerant germplasm from regions with higher altitudes.

This report represents the end of research supported by the Rice CRC . Project 2302 has enabled us to better understand the importance of nutrients to sustainable rice production but, at the same time, has left many promising lines of research worth further study.

1. Background to the Project

Project Synopsis

The sustainability of rice production is threatened by the net mining of soil organic matter, nitrogen, P, K and micronutrients, declining soil pH values, and increasing sodium levels. Except for nitrogen, which has been widely researched over many years, the impact of changes in soil chemical properties is only partially understood and the consequences for grain quality, including its value for human consumption, are scarcely known.

This project set out to provide data which could be included in a model for a sustainable rice industry (Strategic Plan Objective 2.3.1.1) and review the role and importance of micro and macro-elements Strategic Plan Objective 2.3.3.1). This study also sought to address issues raised by Prof Ross Welch in his review of this program in 2001. The strategies adopted during this study included fertilizer inputs, management options, new genotypes, and linkages with foreign scientists.

2. Objectives

2.1 Develop a plant nutrient symptoms diagnosis protocol.
2.2 Develop a nutrient-based model of sustainable rice production.

3. Introductory technical information concerning the problem or research need.

This project provided the CRC with the opportunity to understand the significance of changes in soil fertility, especially the mineral nutrient content, on the yield and quality of the grain produced. Unless the impacts of changing mineral supplies on yield and quality are understood it is not possible to predict the sustainability of the current rice-based farming management.

The information generated in this project will be fed directly into models which assess the long term mineral requirements of rice, and ultimately the sustainability of rice-based farming systems.

About one third of the world's population suffers from health problems due to mineral deficiencies in their diet, in particular iron. Rice CRC Sub-Program 2.3, has been investigating the possibility of manipulating the iron and zinc concentration in rice grain through fertilizer inputs. Masters student, Mr Rob Duncan, reported that iron and zinc applied to rice plants in the early grain filling stage increased iron and zinc in the grain. To confirm these findings Dr Lindsay Campbell, with Prof Batten and Mrs Tina Dunn, set up a series of experiments at Yanco Agricultural Institute. Three different iron solutions and two different zinc solutions were applied to trial plots just after anthesis. At maturity total dry matter, yield and percent grain sterility were all measured and samples taken to determine iron and zinc concentrations in the grain.

Micronutrients have also been suggested as a cause of the disorder known as straighthead which costs the rice industry over a million dollars per year. This project sought to clarify the importance of nutrients to the sustainability of rice cropping.

Sustainable cropping must involve the breeding for or inclusion of exotic germplasm. Several options were investigated during this project.

4. The Methodology

This project continued the work commenced in the previous phase of P2.3.02. The specific steps were

4.1 A nutrient balance model for rice production.

Grain and straw samples from commercial crops grown across the rice growing region of southern NSW were analysed using ICP spectroscopy for plant-essential nutrients. With industry average fertilizer input data, inputs from irrigation water, and average grain and straw yield data the elemental compositions were used to calculate the amounts of each nutrient in the plant at harvest and the balance between inputs and losses in grain, due to burning and when stubble was removed..

4.2 Grain mineral density and rice quality.

Studies were conducted in the field at Yanco NSW (lat -34 36º S, long 146 25º E) over three seasons to test the effect of iron and zinc solutions sprayed onto the leaves of the medium grain rice variety Namaga and the long grain rice variety Langi (Figure 1). The experiment had three replicates and six treatments including three iron sprays, two zinc sprays and a control. The iron sprays were in the form of freshly prepared iron (II) sulphate, iron (II) ammonium EDTA and Ferriplex 40™ (iron EDDHA chelate). Zinc was applied as zinc sulphate and Supa zinc™ (zinc EDETATE chelate). The iron and zinc concentrations were equivalent to1370 and 8100 g/ha. All treatments were applied 8 days after anthesis. At maturity, shoots were cut by hand to determine total dry matter, grain yield and percent grain sterility. A separate sample of 30 heads was removed for the determination of grain iron and zinc concentrations. A hand dehuller (made of a very low Fe PVC compound to minimize contamination) was used to remove the hull from the grain. Brown grain was milled using a brush mill to obtain white grain. Iron and zinc concentrations of the brown and white grain were determined by inductively coupled plasma (ICP) analysis. The results presented are from the 2002-3 season.

Figure 1. Applying foliar spray to field plots using hand boom spray.

4.3 Establish a protocol to test the hypothesis that micronutrient deficiencies contribute to the disorder known as straighthead.

Throughout the world mid season draining has been found to reduce the problem of straighthead. The availability of Cu decreases at flooding because of the insoluble Cu sulphides and Cu ferrite. When the soil is dried after draining it reverts to an oxidised state which increases the availability of copper to the plant. If copper deficiency is playing a role in straighthead the increased copper availability after mid season draining may be helping to alleviate the straighthead disorder. The plant availability of Cu also decreases with increasing pH and organic matter content. Surveys carried out as part of this CRC Program (P2.3.03) confirmed that straighthead is more severe on soils with a high organic matter content.

In experimental plots at Yanco, in 2003 / 2004 and in 2004 / 2005 we grew rice with nil and low nitrogen inputs in combination with the input of nil or 20 t straw /ha.

Figure 2. Incorporating 20 t straw per ha to induce straighthead.

4.4 Review literature to gauge the potential of wild relatives of rice and techniques which could aid the plant breeding program.

Mrs Carole Campbell, University of Sydney, led the search for published information on the wild relatives of *Oryza sativa.* A CD containing the current data base has been lodged with the CRC office.

4.5 Evaluate the mineral balance and grain quality of rice

<u>Grain from a long-term study in Japan</u>

Thanks to Dr Yukihiro Hamada, who worked at Yanco institute under this CRC, we were aware of and given grain samples from plots in Aichi Prefecture Japan which had grown 75 and 76 successive rice crops. The grain was dehulled and analysed for plant-essential elements.

Germplasm with the lpa-1 mutant gene.

Kaybonnet and a low-phytate mutant (lpa-1) were sown in the field at Yanco in 2001-2002 and 2002-2003. In the first season the 2 lines were grown with either 60 or 120 kg N / ha while in the second season they were grown with nil or 100 kg P / ha applied at sowing. At maturity yields were assessed by cutting quadrats and brown rice grains then analysed for plant-essential nutrients.

4.6 Enhance linkages and exchange material and information with plant scientists in USA and Myanmar.

A Memorandum of Understanding between Charles Sturt University and Yezin Agricultural University in Myanmar has been signed and several CRC staff have visited Myanmar in the last 2 years. Contacts have been established with both YAU and the Central Agricultural Research Institute at Yezin.

5. Detailed results - including the statistical analysis of results.

5.1 A nutrient balance model for rice production

The inputs and exports of nutrients have been modelled to summarise the impact of rice cropping on the soil (Table 1 - Page 17). All nutrients except sulphur and calcium are, on average, being mined from the soil. This has led to extension and research staff being more alert to P , K and other element deficiencies. The model also reveals the negative impact of stubble burning, and even more so threat of stubble removal on the soil nutrient reserves.

5.2 Grain mineral density and rice quality

Field experiments at Yanco confirmed the finding by Mr Duncan (Thesis not yet submitted) that foliar applications of Fe and Zn can increase the amount and concentration of these micro nutrients in rice grains.

Studies conducted in the 2001-2002 season tested spraying solutions of Fe and Zn onto the leaves of the two rice cultivars (Namaga and Langi) during the grain filling period. Application of Fe (Ferriplex 40^{TM}) solution led to brown colouring of the leaves whereas other forms ($FeSO_4$ and $FeNH_4EDTA$) did not affect the leaves. Application of Zn as either the sulphate or as a chelate resulted in no colour differences of the leaves.

The yields of the treated crops were reduced by up to 38% when Fe was applied depending on the form of Fe and the cultivar. When Zn was sprayed onto the rice leaves one cultivar had a reduction in yield of 13% while the other cultivar increased yield by 14 to 23%.

Grain was carefully dehulled to avoid contamination and analysed for trace elements. The concentration of Fe in the grain increased by between 0.5 and 44% while the Zn application increased the Zn concentration in the grain by between 4 and 26%.

It was found however, that if the grain was milled to produce white rice, the foliar applications made no difference to the resulting mineral concentration in the grain.

This work fits with important studies generated from the International Rice Research Institute, Philippines and the USDA-ARS at Cornell University. They are attempting to improve human nutrition by producing cultivars with the ability to accumulate high iron content.

Non-contaminating milling equipment

Plant trace element research demands a high degree of attention to avoiding contamination and for this study we developed sample processing techniques which do not contaminate the samples with trace elements. For rice the paddy sample is usually dehulled and the brown grain and hulls are analysed separately. Dehulling grains by hand using teflon-coated tweezers is slow and difficult. Working with Dr Stangulis from The University of Adelaide and Dr Sisons from the International Rice Research Institute we found that the small hand held dehulling units and large mechanical dehullers were the source of considerable contamination of Fe and Zn as there is contact with metal parts in the apparatus.

In a paper presented at the 2003 ASPAC (Australian Soil and Plant Analysis Council (ASPAC) conference (see Dunn et al.) we reported the development of a hand dehulling unit for small samples and modifications to a Satake laboratory dehuller which significantly reduced Fe and Zn contamination of brown rice during the dehulling process.

Study 1

Compared to the grains dehulled by hand, the grains which passed through the mechanical dehuller had higher concentrations of Zn and Fe (Table 1).

*Table 1***.** Mean Zn and Fe concentrations (mg/kg) in brown rice dehulled by hand and a mechanical method.

	Zn		**Fe**	
Dehulling method **Rice sample**	**Hand**	**Satake**	**Hand**	**Satake**
Langi + foliar Fe	**21.2**	**28.5**	**13.5**	**16.3**
Langi + foliar Zn	**27.8**	**34.2**	**9.6**	**10.8**
Amaroo	**15.9**	**17.9**	**9.7**	**10.3**
Lsd P=0.05	**1.1**		**1.3**	

Study 2

Compared to the grains dehulled by hand, the brown rice prepared by the Satake dehuller with the standard rubber-coated rollers had higher concentrations of Zn and Fe (Table 2). Grains dehulled by the Satake dehuller fitted with polyurethane-coated rollers had Zn and Fe concentrations which were comparable with the hand dehulled samples (Table 2).

*Table 2***.** Mean Zn and Fe concentrations (mg/kg) in brown rice after hand and mechanical dehulling with standard and modified rollers.

Dehulling method	Zn	Fe
Hand	**20.9± 0.4**	**11.0± 0.3**
Satake – rubber-coated rollers	**27.5 ± 0.6**	**11.5 ± 0.1**
Satake – polyurethane-coated rollers	**19.8 ± 0.2**	**10.9 ± 0.1**

This study confirmed earlier observations that dehulling can lead to contamination of brown rice with micro-nutrients and assessment of these grains for micronutrients would give unreliable data. By simply changing to polyurethane-coated rollers the Satake dehuller is non-contaminating. The dehuller can now be used to process samples prior to both quality and mineral analysis.

The modified Satake dehuller has now been used to prepare batches of brown rice in adequate quantities for animal feeding studies. In routine use, the rollers warm up with constant use and the polyurethane compound tends to become softer. This limits the throughput per hour.

5.3 A protocol to test the hypothesis that micronutrient deficiencies contribute to the disorder known as straighthead

In this project we showed –

i) The Cu concentration of the whole plant at PI was 4.15, 4.62 and 6.42 mg/kg respectively for the zero, 75 and 250 kg N/ha PF applied rates (Table 2, figure 2). The zero and 75 kg N/ha treatments have lower concentrations of Cu in the plant than classified as critical and these treatments were where straighthead was observed at harvest. See paper by Dunn et al . (submitted).

ii) In experimental plots at Yanco, we demonstrated in 2003 / 2004 and in 2004 / 2005 that the disorder can be induced using a low nitrogen status in combination with the input of 20 t straw /ha.

This is important new knowledge which will facilitate the study of the problem and screening of genotypes in the mainstream breeding program. Whole shoot tissues collected at the panicle initiation stage indicated that the 20 T / ha straw treatments were associated with reduced dry matter / ha and reduced concentrations of Ca, Cu, Zn, (Mn not sig.) and N/ha but increased concentrations of Fe,K, N, S, Na.

Further data are required to determine the actual cause of the problem.

5.4. Review literature to gauge the potential of wild relatives of rice and techniques which could aid the plant breeding program.

During this year we concentrated on the *Oryza* species which are known to occur in Australia. Specimens of several species were examined in herbaria in NSW, Queensland and the Northern Territory. Following email discussions with Dr Vaughan in Japan (formerly based at the International Rice Research Institute in the Philippines) we determined that there is confusion in the identification of some specimens. We are preparing a key to aid the identification of the *Oryza* species which occur in Australia (Figure 2). An outcome of this study has been the renaming of some rice plant specimens in Australian Herbaria.

On the continent of Australia there are four wild relatives in the cultivated rice, Oryza sativa, L in the genus *Oryza*, namely *O. australiensis, O. meridionalis, O. rufipogan and O. officinalis* (previously known as *O. minuta*). Whilst it is possible to differentiate these at the species level using RAPD and RFLP techniques field identification is difficult as there are few type specimens and few botanists with experience in their taxonomy. Consequently, many *Oryza spp*. specimens in Australian collections have been reclassified and some remain misclassified. A paper has been prepared which describes the species found in Australia, their occurrence, and their identification using a key based on visible features using only a hand lens. The field guide will aid those interested in the identification and preservation of *Oryza* gemplasm, especially at sites which are under threat of extinction.

Figure 3. **A Field Guide Key to distinguish 4 species of Oryza**

1. Callus or bump at the base of awn. Spikelets inserted at angle to the pedicel. Ligule membraneous, split with two peaks.
Go to 2.

1*. Callus or bump absent from base of awn. Spikelets inserted more or less horizontally on their pedicels. Ligule membraneous, not split, truncated.
Go to 3

2. Panicle compact, tightly adpressed to main axis. Awn often a goldy coloured with glassy hairs pointing towards the tip. Anthers 1.5-2.0mm. Plant erect (generally 1-2m).
O. meridionalis

2*. Panicle exerted and spreading. Awn with a reddish tinge. Spikelets may turn black when mature. Anthers >3mm. Plant decumbent or floating, rooting at the nodes; tillering at nodes. O. rufipogon.

3. Spikelet slender with wispy hair-like awn up to 50 mm. Pointed tip (apiculus) of palea up to 3 mm long. Pedicels with glassy hairs [important]. Two veins prominent on each side of fertile lemma. O. australiensis

3*. Spikelet 4-4.6 mm long with awn up to 20 mm in length. First node of inflorescence with whorl of panicle branches, mostly four. Base of sterile lemmas often pigmented. Clumped, rather erect perennial. O. officinalis.


Figure 4. **Specimen of the wild rive O. officinalis**

5.5 Evaluate the mineral balance and grain quality of rice

Grain from a long-term study in Japan

From the plots which have been managed with and without the input of N, P, K and compost since 1926, i.e., for 74 and 75 years when this study was undertaken, revealed that yields ranged from 18 to 116 % of the Prefecture average for the cv Nipponbare. Protein (N*5.95) ranged from 6.3 % to 11.0% on a 14% dry matter basis, being highest on the Nil-P and compost treatments.. The Nil-P treatment provided grain with the lowest P, K and Mg concentrations at 51, 63 and 64% of the concentrations in grain from the control plots. The phytate-P : Total-P ratio are now being assessed. The conclusion from this study is that P deficiency depresses grain K and Mg as well as P and this may have implications for human (or animal) nutrition..

Evaluation of rice germplasm with the lpa-1 mutant gene.
The 2 lines, Kaybonnet and the lpa-1 mutant, when sown on 28th September 2001 and reached panicle initiation on 23rd January. This PI date compared to Amaroo on 21st January and YRM63 on 14th January.

Yields of Kaybonnet and the lpa-1 mutant were 7.6 to 8.4 t / ha compared to 10.4 t / ha for Amaroo grown in a nearby plot but sown the same day.

The lpa-1 mutant generally had slightly higher concentrations of most minerals compared to Kaybonnet and both these had higher concentration than found in the grain from adjoining plots of Amaroo.
The inorganic: phytate ratios have not been determined todate.

5.6 Enhance linkages and exchange material and information with plant scientists in USA and Myanmar.

The studies reported in 4 and 5 were aided by linkages with Professor Ross Welch, a plant-human nutrition expert from the USDA –ARS / Cornell University, Ithaca New York and Professor John Lott a grain mineral and phytate expert from McMaster University, Hamilton Ontario Canada.

Interactions with scientists in Myanmar are detailed in ***APPENDIX A***

6. Discussion of results including an analysis of research outcomes compared with the objectives.

6.1 **Develop a plant nutrient symptoms diagnosis protocol**

There are few reliable deficiency symptoms available for rice crops and even less for Australian rice varieties. This is now seen by us as an aspect of rice research which requires a separate project. In addition to the mineral nutrient deficiency symptoms it will be necessary to record the visual symptoms which rice displays when subjected to low soil pH and high salinity.

6.2 **Develop a nutrient-based model of sustainable rice production.**

The nutrient model Table 1 summarises the average impact of rice cropping under southern Australian conditions. The nutrients of major concern are P, because it is not widely applied to rice soils and as shown above in Section 5 , P-deficiency has an impact on other elements in the grain; a cause for concern re the nutritional value of rice.

The other aspect of the model which is of concern is that of stubble retention. While it is important that stubbles be retained to conserve nutrients we appreciate that stubble retention is linked to the disorder “Straighthead”. We suggest that the ideal long-term strategy will be to retain stubbles. This will necessitate either (i) the breeding of rice varieties which are tolerant of straighthead , and / or (ii) an understanding of the cause of straighthead.

7. Implications and recommendations

The studies reported here represent applied basic research. There are no obvious short term benefits of this work but in the immediate term the nutrient model will aid the identification of threat to sustainable yields.

There nutrient budget has already heightened concerns about the sustainability of rice farming and prompted agronomist to look for sub-optimal yields due to nutrient deficiencies; prompted pathologists to look for links between low K and disease incidence; and raised the awareness of many producers to the impact of rice production on the soil resource.

This project confirms the need for a reliable key to the possible nutrient deficiency symptoms which may occur in Australian rice varieties.

8. A description of the Project Intellectual Property and of any commercially significant developments arising from the Project.

No IP issues arise from these studies?

9. A dissemination strategy and communications or extension plan for the Project Intellectual Property.

Information on straighthead and grain nutrient density have been reported to growers and the industry in general at rice field days.

Linkages with scientists within the CRC, within Australia and at centres in several countries (The Philippines, USA, Canada) have led to valuable discussions and improvements in the outcomes achieved.

See list of publications ***APPENDIX B***

10. A technical summary of all information developed as a part of the Project, including discoveries in methodology and equipment design.

See Summary on Page 1

APPENDIX A

A visit to Myanmar focusing on Agricultural and Irrigation Projects, Education and Research, January – February 2004

***Professor Graeme Batten** & **Mr Myo Win**, Charles Sturt University, Wagga Wagga, NSW*

***Dr Evan Christen**, CSIRO Land & Water, Griffith, NSW*
Ms Tamara Jackson and Ms Jennifer Hardwick, Final Year Students in the Bachelor of Science (Irrigation) course at Charles Sturt University, Wagga Wagga, NSW

Building on the visit in Dec 2002 when a Memorandum of Understanding was signed between Yeazin Agricultural University and CSU, the team established additional in-person contact with lecturers, researchers, extensions staff, and community groups in Ayeyarwadda Division, at Yezin Agricultural University, in Mandalay Division and in the Northern Shan State.

The team also inspected a wide range of agricultural and horticultural and irrigation systems and assessed some of the limitations to production.

The visit was highly successful and facilitated the following achievements:

1. A follow up to the agreement to facilitate the transferability of qualifications and registration of students with advanced standing;
2. the initiation of a joint research program to study irrigated agriculture, especially rice and legumes by CSU, YAU, CARD and ACIAR;
3. the delivery and donation of scientific and economic text books to YAU;
4. the initiation of training programs between CSU, ID and CSIRO in irrigation water management and pathology; and
5. initiation of actions which will enable the development of a staff and student exchange program

Identifying the issues and focus areas of Ministry of Agriculture and Irrigation:

Myanmar's main **objectives** for the agriculture sector in 2003 are:
1. surplus in paddy;
2. sufficiency in edible oils; and
3. increased production and export of pulses and industrial crops

To achieve those objectives the Department of Agricultural Planning (DAP) of the Ministry of Agriculture and Irrigation (MOAI) has adopted five improved strategies.

S1. Exploitation and expansion of agricultural land use
S2. Sufficient provision of irrigation water
S3. Increased used of agricultural machinery
S4. Improved technology
S5. Production and use of improved crop varieties and quality seeds

Official figures state that rice occupies 41% of the total cultivated area. Although 21.9 million tonnes of rice is produced from 6.4 million ha (2001/02 data), the average yield of only 3.4 tonnes / ha is insufficient to meet national demand; the Mandalay Division produced only 60% of its own rice needs in 2003. Consumption of rice per person is the highest in the world. The IRRI Rice Almanac state that the per capita consumption is 191 kg/head in Myanmar but figures in the Myanmar Times 2003 suggest that consumption is 129 kg/head in the city and 152 kg/head in rural areas, with the highest consumption being 211 kg/head in Rakhine State.

Ministry of Agriculture and Irrigation (MOAI) official figures in a booklet "Myanmar Agriculture 2003 in brief" suggest that the area of paddy has increased by 20% and the production by 30% in the last 5 years. Production is predominantly long grain with some medium and short grain, including sticky rice.

In Northern Shan State the Government has initiated a program to grow Chinese hybrid rice under irrigation in the summer season. Rice was mainly at the 3 – 5 leaf stage in nurseries when we visited in late January. At the sites we visited the morning air temperatures were below 10^{o}C but we were told that the water was 14^{o}C in the morning and >20^{o}C during the day under the plastic covers. Visibly better growth was observed in plants which were warmed under plastic mini shelters. The operation appeared labour intensive. The covers are left on for the first 20 days, removed during the day from day 20 to day 50, then left off until transplanting at day 60.

Rice yields in Myanmar are measured in baskets per acre. One basket holds 20kg of paddy. While yields vary widely, as in most countries, the following yields were cited in Northern Shan State: Highland rice 25 – 30 baskets/ac (1.2–1.5. t/ha) with one crop in 2003 apparently yielding 100 baskets (5 t / ha). This crop was possibly on new ground with adequate fertilizer input. Standard cultivars in the monsoon season yielded as follows over 2 years – IRRT 57 baskets (2.8 t / ha) FMR9 68 baskets (3.4 t / ha), CNER 52 baskets (2.6t/ha). The yield of hybrid in the same area but not in the same season was given as 60 baskets over 4 years (3.0 t / ha).

The problems for rice yields in Myanmar include limited water for summer dry season crops, blast, sheath rot, bacterial blight and stem borer. Straw is burnt to reduce these problems. The fertilizer inputs quoted to us were consistently 2 x 50 kg bags urea/acre, (~112 kg N /ha) applied in 3 splits, 1 x 50 kg bag of triple super/ac (20 kg P / ha) and 0.5 x bag of KCl / acre (30kg K/ha). But from talking to farmers and other sources it is clear that many farmers cannot afford adequate fertilizer.

Throughout the rice growing area there are large (about 2 x 10m) posters showing a Leaf Chlorophyll Chart. This has 6 shades of green. Rice farmers are advised to topdress standard varieties if they have greenness equal to 1 or 2 on the LCC, while hybrid rice is topdressed if showing greenness equal to 1, 2 or 3 on the LCC.

At the Naung Mon Agricultural Research Farm we were shown some climatic data which led us to suspect that the hybrid rice would be exposed to temperatures as low as 0 ^{0}C in January-February and possibly 10-15 ^{0} C in March-April when the early pollen microspore stage possibly occurs. These temperatures would be expected to cause serious reductions in crop establishment and grain fertility (and hence low final yields).

Two final year Irrigation students from CSU, Ms Jennifer Hardwicke and Ms Tamara Jackson, held discussions with the head staff of the MOAI in Yangon. Jennifer and Tamara then travelled to Yezin to interact with University staff and students. Their mission in Yezin was to study the aspirations and opportunities for young women in rural Myanmar. They attended lectures to assess undergraduate standards and also present a seminar titled *"The role of women in rural Australia"*. Jennifer and Tamara also visited the dry zone to gain impressions of the challenges for farmers in that region. A high proportion of the students studying agriculture, both past and present, came from an urban background with parents employed in very different "field."

Recommendations for future collaboration

1. Maintain face-to-face contact through annual visits.
2. Agree on the transferability of key subjects between CSU and YAU
3. Commence a joint research program
4. Deliver books and journals waiting transport to YAU
5. Maintain contact with key persons met in Jan-Feb 2004
6. Commence training/short course exchange program
7. Build on the staff and student exchange program
8. Seek funding to facilitate the above

Rice harvest in Myanmar: This sheaf of rice is tied with rice stems after being harvested by hand before the water drained from the paddy. It will be threshed with the aid of oxen power or a small motorised threshing unit owned by a contractor.

APPENDIX B

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TABLE 1.

Nutrient balance sheet for a rice crop grown with 13.3ML water to yield 12 t/ha (All values in kg/ha)

	N	S	P	K	Mg	Ca	Cu	Fe	Mn	Na	Zn
INPUTS											
SEED	1.50	0.12	0.37	0.47	0.16	0.04	0.001	0.004	0.014	0.011	0.003
FERTILISER	163	3.5	20 *	0	0	3.6	0	0	0	0	0.015
IRRIGATION WATER	4.6	18	0.67	3.86	15.3	24.5	*	*	*	42	*
RAINFALL*	1	1		1	0.4	2				5	
Total Inputs	170	23	21	5	16	30	0.001	0.004	0.014	47	0.018
EXPORTS											
Unexplained losses of N	57										
In 12 paddy grain	122	10	30	37	13	3	0.043	0.301	1.2	1	0.215
When 12 t stubble is burnt	63	8	5	86	8	17	0.014	4.552	4.7	12	0.119
When 12 t stubble removed	77	10	10	216	18	33	0.030	10.116	10.4	26	0.264
BALANCE											
STUBBLE INCORPORATED	-9	13	-9	-32	3	27	-0.042	-0.3	-1.1	47	-0.197
STUBBLE BURNT	-72	5	-13	-119	-5	10	-0.056	-4.8	-5.8	35	-0.316
STUBBLE REMOVED	-86	3	-19	-248	-14	-5	-0.072	-10.4	-11.5	21	-0.461
* assumed P input											