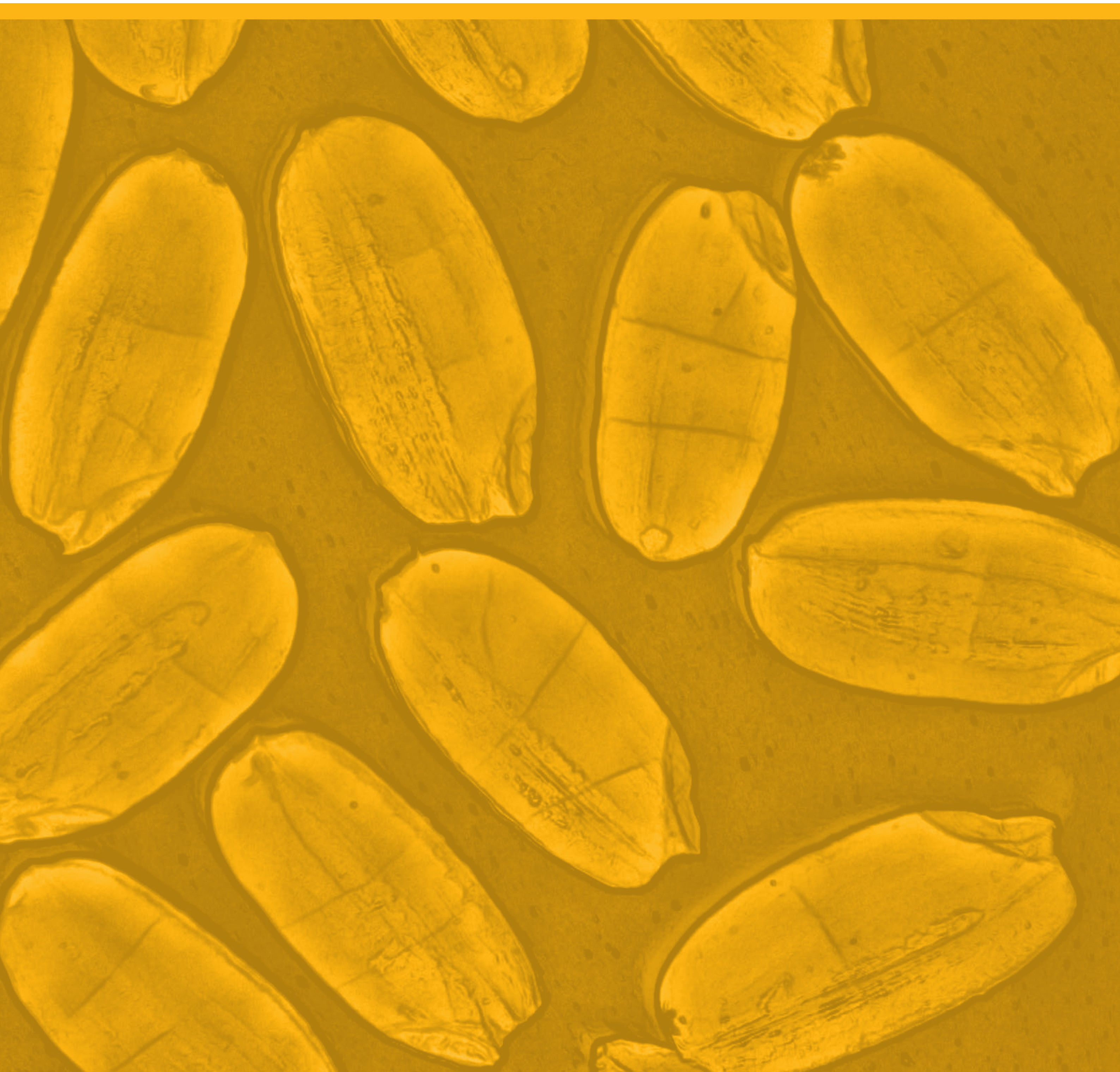
Rice Extension
funded by AgriFutures™

Improving the productivity, profitability and sustainability of the Australian rice industry

2018 Rice R&D Update



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In submitting this report, the researcher has agreed to AgriFutures Australia publishing this material in its edited form.

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AgriFutures Australia is the trading name for Rural Industries Research & Development Corporation (RIRDC), a statutory authority of the Federal Government established by the Primary Industries Research and Development Act 1989.

Front cover: Composite image of brown medium grain rice. IMAGE: Mark Talbot
Back cover: Microscope image of rice pollen germination. IMAGE: Aleesha Turner

Foreword

AgriFutures Australia currently invests in over 20 rice research, development and extension projects across New South Wales and Queensland, covering the priority investment areas of plant breeding, farm productivity, development of an aerobic production system, and extension, communication and partnership development. The AgriFutures™ Rice Program aims to help growers and industry increase average rice yields and improve water use productivity.

The release of the new short-season variety Viand, in March 2018, was a significant outcome for the Rice Breeding Partnership between AgriFutures Australia, NSW Department of Primary Industries (DPI) and SunRice. Viand combines water-saving attributes and offers flexibility to the farming system giving growers options to manage risk and extend the rice sowing window. Grain characteristics of the variety also mean it has the ability to meet high-value markets demands.

A number of recently completed projects are also set to provide important outcomes for the industry. These include:

- development of a screening methodology to enable identification of varieties with suitable cold tolerance characteristics
- understanding the application of remote sensing for in-crop nitrogen prediction and management decisions
- evaluation of new herbicides and refinement of the application strategies.

The Northern Australian Rice Project is focused on variety development, identifying and understanding the impact of pests and disease, and understanding agronomic requirements. The project is a collaboration between AgriFutures Australia, Rice Research Australia Pty Ltd, SunRice, NSW DPI, the University of Southern Queensland and the University of Queensland.

AgriFutures Australia established a new AgriFutures™ Rice Advisory Panel panel in late 2017, made up of growers, industry and researchers. The panel looks for and works toward opportunities to make major and immediate inroads into further improving water use efficiency of rice production systems.

This publication highlights the significant and broad investment in R&D across the rice industry by AgriFutures. The efforts of Rice Extension in bringing together this publication are gratefully acknowledged. This publication is an addition to AgriFutures Australia's diverse range of over 2000 research publications and forms an important output of the AgriFutures™ Rice Program.

John Harvey
Managing Director
AgriFutures Australia

Notes for readers

Abbreviations, acronyms and symbols

Every industry has its own language, and increasingly its own set of abbreviations and acronyms. As much as possible we have tried to minimise the use of shortened forms of words, however, there are a few we expect most readers will be comfortable with, or some that aid the reading of articles.

CIA	Coleambally Irrigation Area
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNA	Deoxyribonucleic acid
ha	hectares
kg	kilogram
MIA	Murrumbidgee Irrigation Area
MCP	multi-level capacitance probes
N	nitrogen
NSW DPI	New South Wales Department of Primary Industries
PI	panicle initiation
QTL	Quantitative trait loci (sections of DNA that correlate with cold tolerance and underlying physiological mechanisms in the plant)
t	tonne (metric)
WGY	whole grain yield

Plant Breeders Rights

Several Australian rice varieties are granted Plant Breeders Rights by IP Australia. This publication acknowledges PBR for Opus, Reiziq, Sherpa, Topaz and Viand. The symbol indicating PBR is not used each time the variety is named throughout this publication.

Registered trademark

Product names for herbicides are used for easy communication, rather than using complex names of the active ingredients. Reference to these products is not an endorsement of the product over others using the same active ingredient under a different name.

Symbols indicating registered brands or trademarks are not used each time the product is named throughout this publication. This publication acknowledges the registered trademark of the following products: Agixa, Aura, Barnstorm, Gramoxone, Londax, Magister, MCPA, Ordram, Saturn, Stomp, Stam and Taipan.

Contents

Determining best practice for current and new rice varieties

Brian Dunn, Tina Dunn, Craig Hodges and Chris Dawe
NSW Department of Primary Industries, Yanco Agricultural Institute

AgriFutures Australia Project PRJ-009790

Rice variety, nitrogen and agronomic management

Project timeframe
July 2015 to June 2020

Photograph
Hand sowing an aerial sown variety by nitrogen experiment

THE SHORT STORY

This project was developed to provide growers with agronomic information on how best to manage current and new rice varieties.

Improved management maximises grain yield and water productivity and improves the consistency of achieving both.

The project identifies how rice varieties respond across seasons and regions to different sowing methods, water management practices, nitrogen rates and application timings.

The impact of all these factors on crop growth and development, grain yield and grain quality is measured to determine best management practice.

Each season rice experiments are established across the growing regions of southern New South Wales using current and near-to-release rice varieties to determine the effects of agronomic management on crop growth, production and quality.

These experiments for the *Rice variety nitrogen and agronomic management* project are often located in growers' commercial fields and include aerial, dry broadcast, conventional drill and drill with delayed permanent water (DPW) growing methods. The experiments conducted in the 2017–18 season and their treatments are listed in Table 1. The Jerilderie drill, Yanco DPW and the Leeton water management experiments all had split sowing dates so the reproductive periods of different varieties and treatments aligned, so that true comparisons could be achieved.

The experiments are continually monitored and sampled throughout the season to determine key growth stages with panicle initiation (PI), microspore, flowering and maturity (22% grain moisture) determined for each variety. Plant establishment is counted and physical plant samples are collected at PI and maturity so crop growth and all components that contribute to yield can be determined. Water depth and water and air temperature are also recorded at each site so their impact can be accounted for.

Grain quality samples are collected from many of the experiments as each variety reaches maturity. This allows the evaluation of sowing, water management and nitrogen treatments for their impact on grain quality. Three short grain experiments were conducted in the 2017–18 season that investigated the impact of three plant densities and ten nitrogen rate by timing treatments on grain quality of the sushi varieties (Opus, Koshihikari and YRK5).

Table 1. Details of rice variety by nitrogen experiments conducted in the 2017–18 season

Location	Sowing method	Varieties	Nitrogen rates (kg N/ha)
Mayrung	Aerial	Reiziq, Sherpa, Doongara, Opus, Koshihikari, Illabong	0, 90, 150, 90-60
Coleambally	Dry broadcast	Reiziq, Sherpa, Doongara, Viand, Langi, Topaz	0, 120, 180, 120-60
Wakool	Drill	Reiziq, Sherpa, Opus, Koshihikari, Illabong, YDP	0, 60, 120, 60-60
Jerilderie	Drill	Reiziq, Opus, Koshihikari, Viand, YRK5, YDP	0, 90, 150, 90-60
Jerilderie	Drill density	Koshihikari, Opus, YRK5, Viand – 3 densities	10 treatments
Yanco	DPW	Reiziq, Opus, Doongara, Koshihikari, Viand, YRK5, YDP	0, 60, 120
Yanco	Fully aerobic	Reiziq, Sherpa, Opus, Doongara, Langi, Topaz, Koshihikari, Viand, YRK5 & YDP	60 mid till + 60 PI
Leeton WM	Aerial, drill, DPW	Reiziq & Sherpa	0, 120, 180, 240

Aerial photo of Leeton Field Station water management experiment, evaluating a range of sowing and water management methods.

Table 2. Rice variety yield, maturity, seedling vigour, height and lodging score characteristics

Variety	Yield potential % of Reiziq	Maturity days different to flower than Reiziq	Seedling vigour 1 = weak 5 = strong	Height (cm)	Lodging score (the higher number, the more prone to lodging)
Reiziq	100	Standard	4	80	1
Sherpa	105	-3	3	83	1
Opus	100	+2	3	81	2
Langi	95	-2	3	86	2
Topaz	85	+1	1	81	1
Illlabong	105	+4	2	86	2
Doongara	95	+1	3	75	1
Koshihakari	80	+4	3	91	6
Viand	95	-10	4	85	3
YRK5	85	-10	4	93	6

Implication of results

The results obtained from each season's experiments are combined with results from previous seasons to update and improve variety recommendations. Seedling vigour, plant number, PI date, PI nitrogen uptake, flowering and maturity dates, grain yield, floret sterility, plant height, lodging scores (Table 2) and other measurements are used to update the *Rice Variety Guide* each season and develop individual growing guides for current and new varieties. Information is also presented to growers and agronomists at field days and pre-season meetings.

The data collected on plant growth stage is also being combined with temperature data to develop more accurate models for predicting PI date for aerial, dry broadcast, drill and DPW sowing methods. The development of models to predict flowering and maturity (22% grain moisture) dates is also planned and will use this data. This data is also the basis for sowing date recommendations which have been modified considerably over the last three seasons.

The nitrogen rate and split timing treatments and their impact of grain yield and lodging for each variety under different water management practices is important for determining nitrogen requirements, including total nitrogen (N) and split timings, for optimal growth and grain yield of current and new varieties when released. The PI nitrogen topdressing recommendations used in the NIR Tissue Test program are updated using this information.

Growing rice with less water

As competition for water becomes an ever increasing issue much of our research involves understanding how current and new varieties respond to a reduced period of ponding. Many experiments are conducted on drill and DPW water management each season and in 2017–18 we gave our varieties a preliminary test at being grown fully aerobically (no ponding). The severe heat and cold that can occur in our environment during the reproductive period make this practice unviable using current varieties in southern NSW but it is useful to determine which varieties are most durable in this situation.

In 2017–18 an experiment was conducted at Leeton Field Station where Reiziq and Sherpa varieties were grown with replicated water management treatments. Aerial, drill, drill with DPW and post flower flushing (PFF) methods were sown at different times in order to align their reproductive periods and allow a valid comparison. Grain yield results highlighted how rice grown using DPW has the same yield potential as aerial and drill sown rice (Figure 1) and also its increased nitrogen use efficiency. When permanent water was removed from the crop after flowering and it was regularly flushed (PPF), grain yield was reduced, even though it was never water stressed.

Going forward

Research will continue to be conducted in southern NSW rice growing areas testing varieties across water management practices. It is important that water productivity of rice is increased without risking the reliability of achieving high yields and grain quality. In some experiments water use will be measured to quantify water savings and the water productivity (t/ML) that can be achieved. Agronomic management information on current and new varieties will continue to be passed onto growers and agronomists.

Acknowledgements

This research was co-funded by the NSW Department of Primary Industries and AgriFutures Australia. We wish to thank the growers who support this research by allowing us to conduct experiments on their properties.

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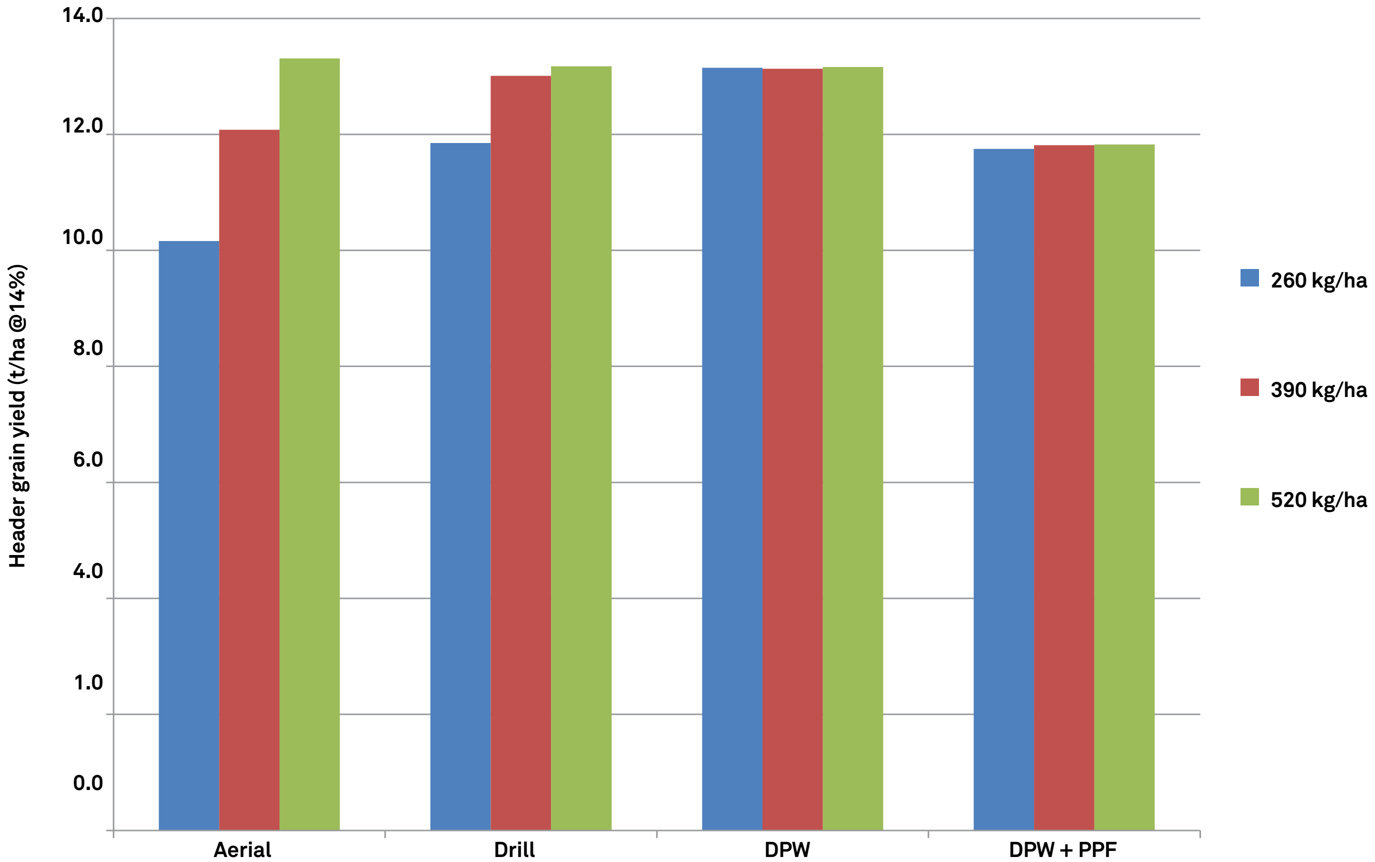

Figure 1. Header grain yield of water management treatments from Leeton experiment, at 260, 390 and 520 kg/ha urea, average of Reiziq and Sherpa varieties (l.s.d. (P<0.05) = 0.95)

Collecting tiller samples for yield component analysis, to understand effect of management on grain yield and water productivity.

Impact of farm practices on rice grain quality

PhD study

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John Mawson, Dan Waters & Chris Blanchard
Functional Grains Centre, Charles Sturt University

AgriFutures Australia Project PRJ-009805
Next generation healthy rice

Project timeframe
August 2016 to August 2019

Photograph
The author hand collecting quality samples to ensure all plots are harvested between 18-22% grain moisture for true comparisons between management practices.

Rice grain quality is an important aspect of rice production and has the potential to significantly influence growers' profit margins.

The primary method to assess grain quality is *whole grain yield*, which is the percentage of grain that remains whole in a sample after the hull and bran layers are removed, as occurs during milling. Much remains unknown in regards to grain quality and how growers can improve whole grain yield.

Charles Sturt University's Functional Grains Centre and the NSW Department of Primary Industries are collaborating to learn more about the impact of crop management practices on grain quality of rice grown in south-eastern Australia. As part of a PhD project, two seasons of field results from the NSW DPI *Rice variety, nitrogen and agronomic management* project (PRJ-009790) were used to investigate how irrigation management, plant densities, and nitrogen rate and timing of application affect grain quality.

Irrigation management

Analysis from milling data in 2016–17 showed that delaying permanent water with post-flower flushing (DPW+PFF) did not reduce whole grain yield percentage (WGY%). Further, under high nitrogen application (120, 180 & 240 kg N/ha), WGY% was greater in the DPW+PFF treatment compared with conventional drill irrigation (Drill). However, both bays were sown on the same date resulting in a difference in the timing and duration of the reproductive period between treatments. This may have influenced quality due to temperature changes at critical times during the reproductive stage. Water treatments in the 2017–18 field season were sown on different dates to remove this issue and align the reproductive periods. Milling results showed DPW and DPW+PFF produced higher WGY% compared with Drill and aerial sown (Aerial) treatments (Figure 1).

Plant densities

In 2016–17 the short season varieties (YRK5 and Viand) were grown under different nitrogen treatments and sowing rates. Milling data demonstrated that the lower sowing rate (50 kg/ha) produced a greater whole grain yield percentage compared with the higher sowing rate (150 kg/ha) for both varieties.

Our results also revealed differences between varieties in response to nitrogen treatments. Under high nitrogen (150 kg N/ha) there was no difference in WGY% between the sowing rates. However, the high nitrogen rate split into two applications (90-60 kg N/ha) resulted in a greater WGY% in the lower sowing rate (50 kg/ha) for Viand, while YRK5 showed no difference in WGY% between sowing rates.

The lowest nitrogen rate (90-0 kg N/ha) and the lowest sowing rate (50 kg/ha) produced the highest WGY% for both varieties. The same result occurred when analysing the number of whole grains produced per hectare (Figure 2).

Nitrogen rate and application timing

The application of nitrogen after PI to combat sterility from high nitrogen uptake and cold temperatures during the reproductive phase, is a valuable management tool. It is also useful for varieties that are prone to lodging. However, research regarding how grain quality is affected using this split nitrogen method is limited.

Using quality data from drill sown experiments in 2016–17, we compared milling results of different varieties grown using different nitrogen application methods (Figure 3). For all varieties analysed the single nitrogen application (total rate in one application pre-permanent water) produced a higher WGY% than the split nitrogen application (one pre-permanent water and one at PI).

Milling data in 2016–17 also demonstrated that increasing the total nitrogen rate increases whole grain yield due to an increase in grain protein content. However, our results revealed grain protein and WGY% did not further increase after a particular nitrogen rate, which was specific to each variety. Before reporting on results, analysis over multiple years and locations is needed.

Implication of results

Results from this project will give better understanding of how crop management practices can influence grain quality parameters. These results can be used to update the *Rice Variety Guide* and help develop individual growing guides for current and new varieties.

Acknowledgements

This research was co-funded by the NSW Department of Primary Industries, ARC ITTC for Functional Grains and AgriFutures Australia.

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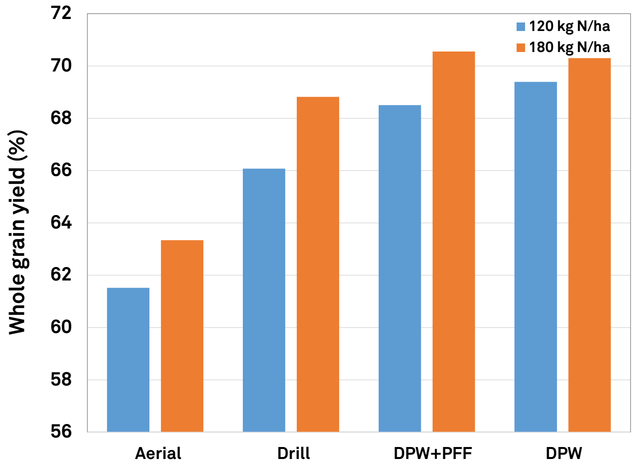

Figure 1. Impact of water management on whole grain yield from Leeton experiment (2017–18), at 120 and 180 kg N/ha nitrogen rates, an average of Reiziq and Sherpa varieties.

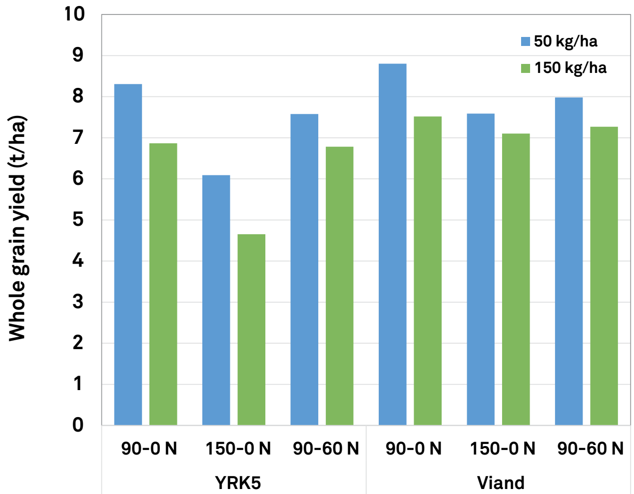

Figure 2. Whole grain yield per hectare of short season varieties YRK5 and Viand from Finley experiment (2016–17), at 90-0, 150-0 and 90-60 kg N/ha nitrogen rates and 50 and 150 kg/ha sowing rates.

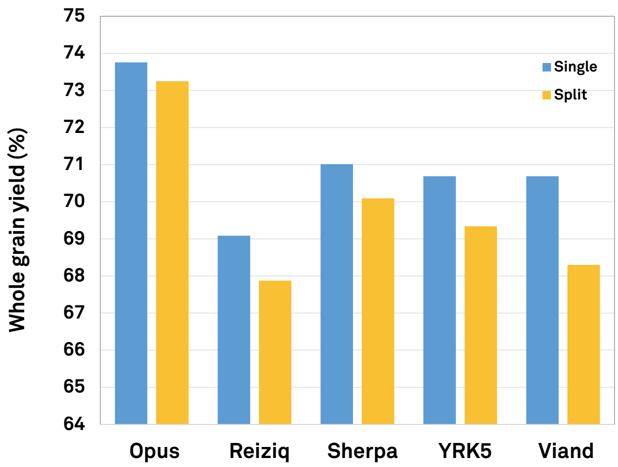

Figure 3. Whole grain yield with single application of nitrogen (total rate pre-permanent water) and split application of nitrogen (total rate split into two: one pre-permanent water and one at PI). Data averaged across multiple locations (2016–17) using the same total nitrogen rate.

Where are we at with remote sensing in rice?

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Remy Dehaan
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Andrew Robson
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AgriFutures Australia Project PRJ-009772
Moving forward with NIR and remote sensing

Project timeframe
July 2015 to June 2018

Photograph
Aerial view of plots at Leeton Field Station, January 2018, where different remote sensing technologies were assessed for accuracy of predicting nitrogen uptake at PI.

THE SHORT STORY

This project was developed to investigate options that allow growers to move away from physical sampling of their rice crops at panicle initiation (PI) to determine crop nitrogen requirements.

An industry-based, remotely-sensed option would enable the generation of nitrogen topdressing recommendation maps for rice fields, which would be available to growers and agronomists.

Field experiments with plots of varying nitrogen levels across different varieties were established to develop relationships between remotely-sensed imagery and plant samples from the field. This enabled the accuracy of several sensors for predicting crop nitrogen uptake at PI to be determined.

Remote sensing of rice for nitrogen requirements was tested on large plots over three seasons. At the outset of the project a range of sensors was tested but this reduced as the project continued to the sensors best suited to rice crops and the rice growing environment.

Experiments were established at Leeton Field Station and Yanco Agricultural Institute where rice was topdressed with varying rates of nitrogen just before the application of pre-permanent water. This provided a range of nitrogen uptakes at panicle initiation (PI).

In the 2017–18 season, six rice varieties were grown: Reiziq, Langi, Topaz, Viand, YRK5 and YDP44 (an experimental variety). Table 1 lists the treatments, of which the combinations and replications resulted in 144 plots. The plots were large (11.4 m x 10.5 m) to cater for the varying spatial resolutions of the sensors evaluated.

Sensors used in 2017–18 season

Previous research showed that sensors for rice at PI must include the red edge waveband due to its sensitivity to foliar nitrogen concentrations at high biomass levels. Normalized difference vegetation index (NDVI), which is a commonly-used remote sensing index for vegetation, proved to be of little value in rice at PI. NDVI saturates at nitrogen uptake levels above 75–80 kg N/ha, therefore no difference can be seen at higher PI nitrogen uptake levels, which are common in rice at PI and still often require topdressing.

At first, all available sensors including those mounted on satellite, aerial and drone platforms were used. In the 2017–18 season, only sensors measuring the red edge waveband and have potential for industry-wide application were assessed (Table 2).

Platforms used for capture of red edge imagery

Results from this project demonstrated that red edge sensors and drones have a role for rice growers looking at spatial variability of nitrogen in individual fields. However, as an industry-wide option drones are limited by short flying time (battery life), line of site sight regulations, wind and cloud conditions, often 75% image overlap requirements, the influence of sun angle (only three hours either side of solar noon), questionable accuracy of data pre-processing, and ability to store and process large volumes of data produced.

It is important when comparing imagery over time or developing algorithms for direct prediction of physical measurements such as crop nitrogen uptake that the image collection procedure is standard across all captures. Even the time of day within the three-hour period either side of solar noon can have a significant impact on reflectance due to changes in crop shadowing.

Imagery collected from satellite or manned aircraft are the only practical options for covering all of the rice crops in the southern NSW industry in the short PI timing window.

Worldview-3

The Worldview-3 satellite based sensor showed considerable potential with good correlations with PI nitrogen uptake (r^2 = 0.87), daily revisit time and 1.2 m resolution, which can be pan sharpened to 30 cm. However images are very expensive, i.e. approximately \$55 per km^2 with a minimum capture of 100 km^2. The relatively small pixel resolution of the Worldview 3 satellite sensor provides a very detailed map of nitrogen variability across a rice crop (Figure 1). Although variable rate topdressing cannot be used at a resolution this low, the image is valuable for showing poor practice in applying pre-permanent water nitrogen.

RapidEye

Another option, which was investigated for the first time in the 2017–18 season, is the RapidEye satellite based sensor which has a red edge waveband at 690 to 730 nm, daily revisit time and 5 m pixel resolution. Data from the RapidEye sensor is considerably more cost effective than Worldview and the 5 m pixel resolution is potentially suitable for variable rate nitrogen topdressing of rice fields (Figure 2). The preliminary algorithm created from one season of RapidEye data, correlating NDRE with the physical measurements of nitrogen uptake collected in the nitrogen by variety experiments, was encouraging producing an r^2 = 0.71.

Sentinel-2

Sentinel-2 is a satellite based sensor and is popular in dryland agriculture because images are freely available. The spatial resolution of Sentinel-2 bands for calculating NDVI is 10 m while the red edge waveband (705 nm) has 20 m spatial resolution. Although the red edge waveband is 20 m resolution, when used to derive the NDRE index it is often resampled to 10 m, which makes it inaccurate for deriving algorithms.The larger pixel size of the red edge waveband makes it difficult to provide accurate results in rice fields with contour banks. Any pixel containing a bank is compromised, taking out a large area of a field, therefore the Sentinel data was not used to develop algorithms for predicting

Table 1. Variety by nitrogen experiments used to obtain physical data to correlate against remotely sensed imagery in the 2017–18 season

Site	Varieties	Nitrogen rates (kg N/ha)	No. plots	First flush date
LFS 1	Reiziq, Langi & Topaz	0, 60, 120, 180, 240, 300	54	30-Oct-17
LFS 2	Viand YRK5 & YDP	0, 60, 120, 180, 240, 300	54	15-Nov-17
YAI	Reiziq, Langi & Topaz	0, 60, 120, 180	36	27-Oct-17

Table 2. Sensors used to collect imagery from field experiments and commercial fields in the 2017–18 season

Sensor	Acquisition	Resolution	Wavebands
WorldView-3	Satellite	1.2 m	8 bands (400–1040 nm)
RapidEye	Satellite	5 m	5 bands (440–850 nm)
Ceres Imagery	Aerial	50 cm	5 bands (480–800 nm)
MicaSense RedEdge	Drone	8 cm	5 bands (450–850 nm)

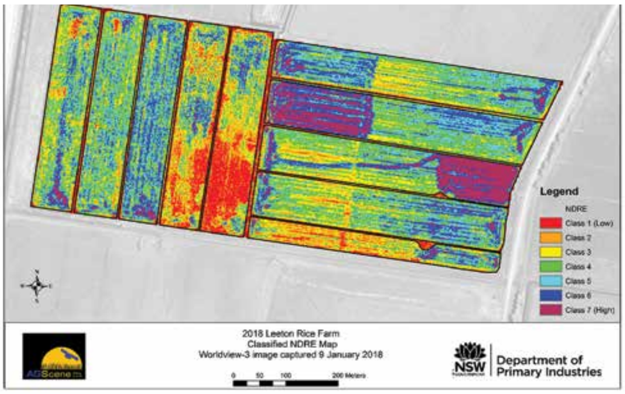

Figure 1. NDRE Image of a commercial rice field collected using Worldview-3 satellite sensor.

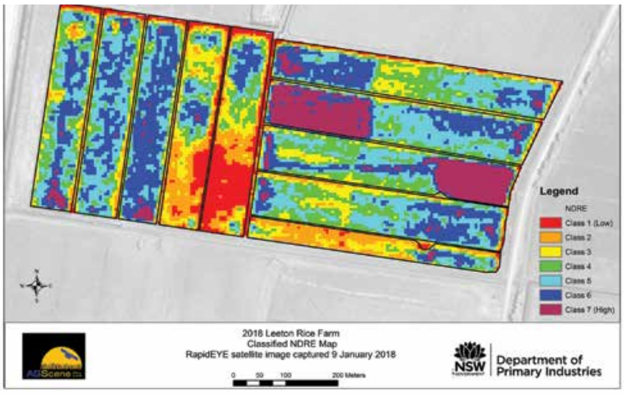

Figure 2. NDRE Image of a commercial rice field collected using RapidEye satellite sensor.

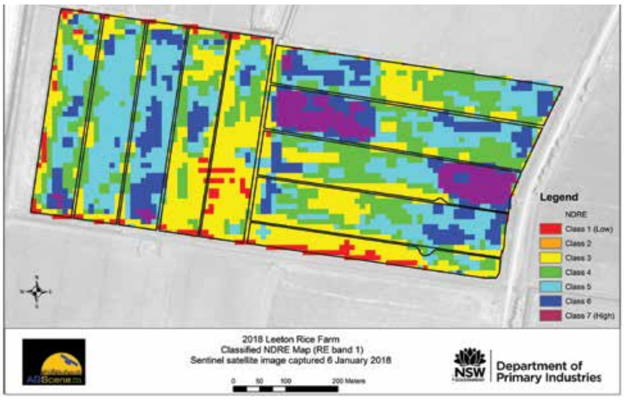

Figure 3. NDRE Image of a commercial rice field collected using Sentinel-2 satellite based sensor pan sharpened to 10 m resolution.

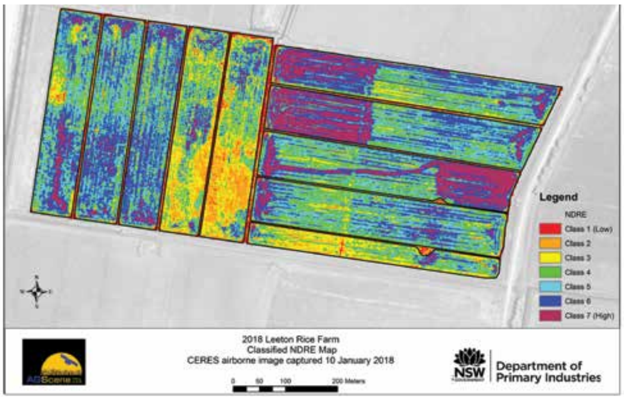

Figure 4. NDRE Image of a commercial rice field collected using Ceres Imagery aircraft based sensor at 0.5 m resolution.

nitrogen uptake but imagery of commercial fields has been compared to imagery from other sources. In the Sentinel NDRE image of the commercial rice field (Figure 3) the 20 m red edge pixel size has been sharpened to the 10 m NIR band which has produced a classified NDRE map that looks somewhat comparable to the higher resolution sensors.

Ceres Imagery

In the 2017–18 season Ceres Imagery collected images of our variety by nitrogen experiments and also several commercial rice fields (Figure 4). Ceres Imagery provide a crop imaging service using cameras mounted in a manned aircraft where they capture, process, and deliver high resolution spectral imagery to growers of various crops. The aerial imagery is collected at wavebands at 480, 550, 670, 700, 800 nm with the pixel resolution typically around 0.55 m. The red edge imagery provided by Ceres Imagery was of high quality and easy for researchers to utilise when creating algorithms. The preliminary algorithm created from one seasons of Ceres data, correlating NDRE with the physical measurements of nitrogen uptake collected in the nitrogen by variety experiments, was very encouraging producing an $r^2 = 0.92$.

Potential for remotely-sensed nitrogen

Several remote sensors containing the red edge waveband were tested with all showing considerable potential for predicting rice nitrogen uptake at panicle initiation. Preliminary algorithms predicting PI nitrogen uptake for red edge imagery were developed for the Worldview-3, RapidEye and Ceres Imaging sensors, however due to the cost of imagery the latter two options are more suitable for industry-wide application. The possibility of generating nitrogen topdressing recommendations directly from remotely-sensed data with reduced or no physical sampling is very exciting.

This project is planned to roll into a follow-on project that will see remotely-sensed red edge imagery integrated into the SunRice GIS as it is upgraded. The SunRice GIS has grower field boundaries and crop data information already available, which will allow the incorporation of the PI date prediction model that is also currently being developed. Combining the grower data, PI date model and remotely sensed imagery will provide multiple benefits to growers, agronomists and the industry going forward.

Further development of algorithms that predict PI nitrogen uptake in rice directly from red edge imagery will support growers and agronomists in determining the PI nitrogen requirements with limited or no physical sampling required. Once this technology is further developed and rolled out to farmers over the next couple of seasons, significant improvement in nitrogen management will increase grain yields, profitability and water productivity.

Acknowledgements

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In-field sensing systems for maximising rice farm productivity

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AgriFutures Australia Project PRJ-0092710
Developing and testing tools for measuring and managing variability in rice

Project timeframe
June 2014 to July 2018

Photograph
A WiField logger in a rice field near Whitton, April 2018. The logger measures water depth using an ultrasonic sensor and an Enviropro multi-level capacitance probe, as well as measuring the temperature profile and soil moisture. PHOTO: J Brinkhoff

THE SHORT STORY

The use of in-field sensing tools for rice production has lagged behind other industries.

A WiFi-enabled sensing system developed specifically for rice production systems, by Deakin University, simultaneously monitors soil moisture, temperature and water level with one probe, enabling growers to save water and maximise yield.

The system can be used for optimising irrigation timing when using delayed permanent water, precisely managing water depth to protect the crop during cold periods and monitoring dry down after lock up.

Data is available online in real time and can be linked to automation.

— Continued

Increasing costs of irrigation water are continuously driving rice growers to maximise returns on water and reduce water use as much as practically possible.

Moving to management approaches such as delayed permanent water and precision ponding to optimise water use requires good knowledge of the soil and water environment in order to maintain productivity and profitability.

The demands of growing rice in temperate regions are quite different from those of growing other crops.

Low temperatures at the microspore stage cause spikelet sterility, particularly for low temperatures around the rice plant panicle and to a lesser extent around the root zone. Deep ponded water has been used in temperate rice-growing regions to insulate against cold-temperature events. However, water availability is decreasing, and ponded water leads to an increase in rice crop water use.

Careful management of water depth in rice fields is critical to achieve environmental and productivity goals. This necessitates monitoring and management of water level, as well as monitoring of temperatures at the root zone, in the water, at panicle height and the ambient environment.

Recently, rice-growing techniques to minimise water use have been investigated, such as alternate wetting and drying and delayed permanent water. Also, growing rice aerobically (i.e. without ponded water) in temperate regions is gathering interest. These developments require the monitoring of soil moisture to ensure sufficient water is available for rice plant growth during periods when the water is drained.

Water scarcity and resulting competition to secure water is seeing many farmers looking to dynamically manage water height for controlling the temperature the rice crop is exposed to during critical growth periods. This will aid in maximising yield and improving water use efficiency by maintaining high water levels only when required.

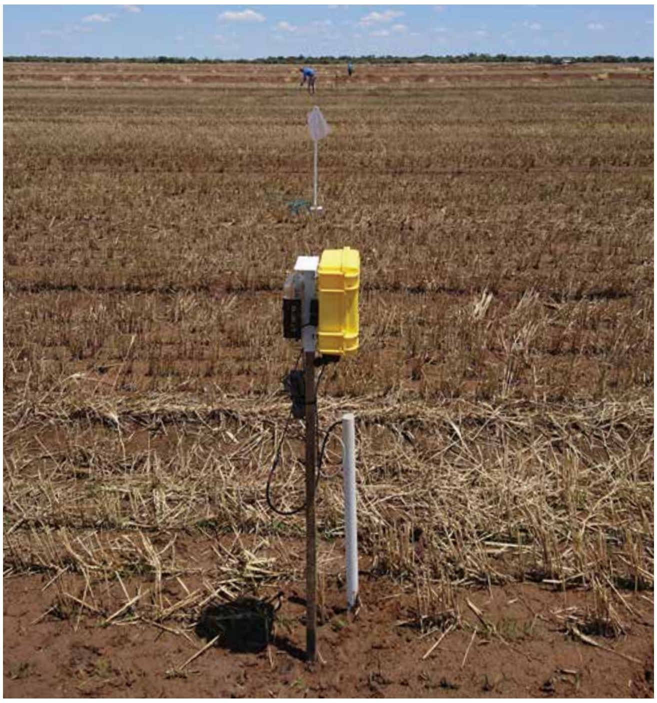
Various sensors can be used to automatically monitor these parameters (water depth, temperatures, soil moisture status) in research settings, however simple, compact and robust options for commercial production environments have not been available. In order to overcome this limitation, the application of commercially available multi-level capacitance probes (MCPs) commonly used in cotton and horticultural industries (e.g. Enviropro probes) was investigated.

Determining water levels from MCPs

Water level is a critical measurement for rice crop management. MCPs have not previously been used for water level measurement. Commonly available MCPs have capacitance sensors spaced at 10 cm increments along the probe, allowing them to sense moisture throughout the soil profile. This project set about developing new relationships between these capacitance measurements and water levels. Laboratory and field-based tests undertaken during the project showed a strong agreement between MCP-based determinations of water levels and those directly measured using ultrasonic sensors and manually. This provides advantages over the traditional method of using multiple sets of discrete sensors. A single MCP can measure temperatures at multiple heights and soil volumetric water content data, along with water depth.

Simple sensor installation

The installation of MCPs in rice fields is similar to that used in non-ponded crops. However, rather than install the probe to full depth, half of the probe is installed in the soil and the other half of the



A multi-level capacitance probe sensor installed at rice sowing time. The installation of the sensor with half above and half below the ground allows a full characterisation of the rice growing environment (soil-water-ambient) from a single robust probe.

The same multi-level capacitance probe sensor as pictured above, just prior to rice harvest.

probe above soil level. This allows a single probe to measure both the soil moisture and root zone temperatures as well as measure ponded water depth and crop temperatures, all at 10 cm intervals.

Common probe lengths are 80 cm, 100 cm, 120 cm, so that at least 40 cm is available for soil measurement and 40 cm for water and ambient measurement.

Data at your finger tips

The MCP sensors can be linked to WiFi data loggers developed by Deakin University and sold through Goanna Telemetry, called WiFields. This approach provides up-to-the-hour data on websites that can be viewed from computers or mobile phones. One advantage of using MCPs in this application is the range of useful data available. As well as water depth, soil moisture and temperature readings at fine intervals (10 cm) can be obtained.

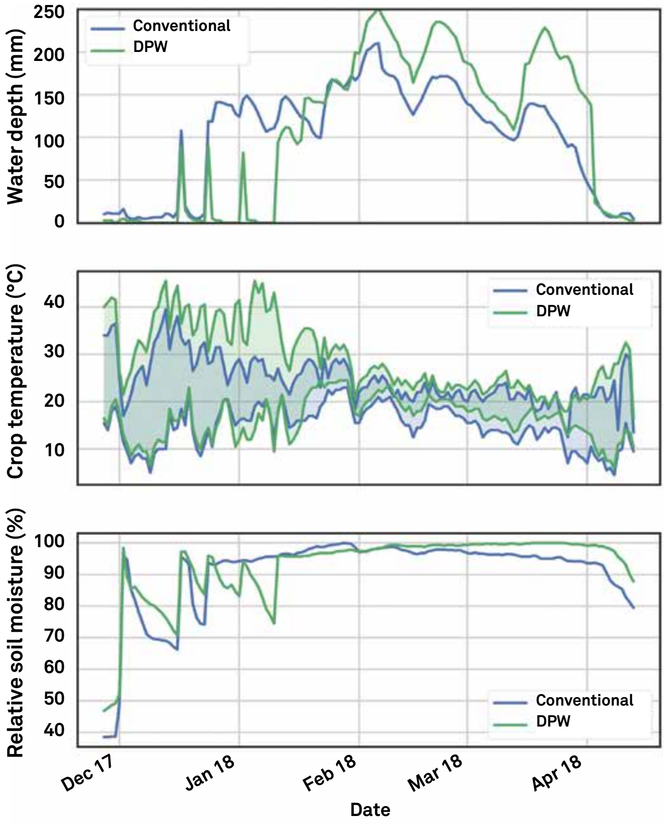


Figure 1. MCP sensor data for a comparison of DPW and conventional rice growing systems. Water depth, minimum and maximum daily temperatures at 15cm above the soil and total relative soil moisture are shown.

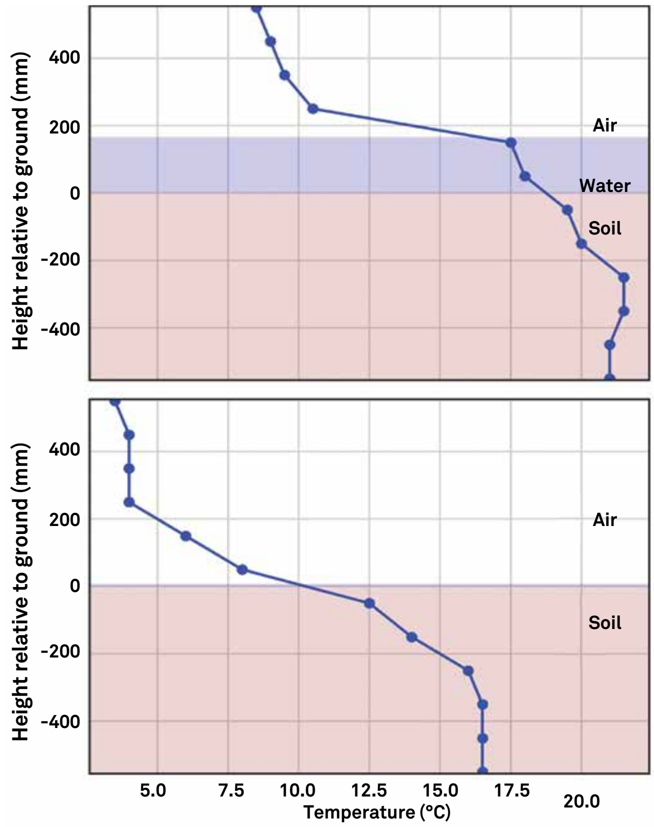


Figure 2. Temperature profiles measured by the multi-level capacitance probe during cold temperature events, at 6 am on 15 February 2018 (top) and 8 April 2018 (bottom). The measured water depth is indicated with blue shading.

The soil moisture data is shown in the lower graph of Figure 1. Early in the season before permanent ponded water is applied, the soil at 50 mm and 150 mm starts to dry out considerably during the delayed permanent water phase and the sensors can be used to trigger irrigation events to ensure the rice root system is not stressed. Figure 1 shows that the soil starts to dry again after the ponded water is drained in early April. Using the soil moisture information is particularly important in these early and late parts of the rice growing season to ensure the soil does not reach moisture stress levels, which would be detrimental to yield.

Figure 1 also shows associated crop temperature data over the growing season. It can be seen that there are periods when the crop temperature is falling below the critical 15 °C level, which is likely to have impacts on crop yield. The MCPs can be used to see the impact of ponded water depth and its effect on temperature buffering the crop from cold weather events, which in turn can be used as a basis to modify water depth.

Temperature data from the rice field at two dates is shown in Figure 2. On both of these dates, there were significant cold events. The first date is 15 February 2018, which for a late-sown crop in southern NSW would fall close to the critical microspore phase. If the rice panicle was subject to the cold ambient temperature of 6 °C, there would likely be a significant negative impact on yield. The second date is 8 April 2018, when there would not be such sensitivity to cold because the rice has passed the microspore phase. On the first date, the water was around 200 mm. It can be seen that this provided effective insulation against the cold temperatures at panicle height (around 200 mm), keeping the temperature there above 12 °C. The water effectively maintains warmer temperatures above the surface of the water through its stored energy. In contrast, at the second date, no such insulation was provided as the water had been nearly drained. This provides a useful illustration of how temperature at multiple heights can be used to manage rice paddy water depth to effectively insulate the crop from cold temperatures.

Where to from here

The in-field sensing systems developed using MCPs have proven to be robust and well suited to the rice-growing environment. Parameters measured by the sensing system are suitable for automation, and this would provide maximum benefit for rice growers. A smart automated rice irrigation system that linked this sensing data with weather forecasts and automated water control has the potential to deliver significant water saving and productivity gains.

Acknowledgments

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For more information on the method, see the full paper: http://www.mdpi.com/1424-8220/18/1/53

The developed in-field sensing systems using MCPs and WiField loggers are available from Goanna Telemetry: info@goannatelemetry.com.au

Reliable weed control in drill sown rice

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AgriFutures Australia Project PRJ-009923
Weed control in Australian rice

Project timeframe
May 2015 to July 2018

Photograph
Six demonstration trials were conducted in commercial fields and research blocks throughout the Riverina during the 2017–18 rice-growing season. PHOTO: Malcolm Taylor

THE SHORT STORY

Drill seeding rice inevitably encourages the establishment and strongly competitive growth of barnyard grass.

Sequential herbicide programs of Gramoxone plus Stomp plus Magister applied post-flush, pre-emergence followed by Barnstorm or Agixa post-emergence consistently produced weed-free rice stands with maximum rice yield potential in six field trials last season.

Such programs deliver reliable results for excellent economic returns and multiple modes of action to defer herbicide resistance in barnyard grass populations.

Drill seeding rice with associated sequential flush irrigations will often induce major challenges of barnyard grass that can render a crop unprofitable or even a total failure if left unchecked.

Establishment of barnyard grass (*Echinochloa crus galli*) is favoured by moist aerobic soils. A most competitive weed, barnyard grass mimics the growth of rice. Options for herbicide control in rice crops have been limited, and particularly so with the development of herbicide resistance.

Residual selective herbicides to prevent grass weed competition in rice have been sought in Australia for over 40 years. In the past 20 seasons both pendimethalin (Stomp) and clomazone (Magister) were registered for this purpose. Group A post-emergence selective herbicides (Aura and Barnstorm) can be used to remove grass weeds prior to permanent water, however they present a high risk of resistance development and do not prevent early season weed competition with the crop.

Sequences of pre and post-emergence herbicides are sought for drill sown rice to overlay multiple modes of herbicide action for resistance management whilst ensuring season long freedom from weed competition. Agixa is a new post-emergence rice herbicide under development by Dow AgroSciences Australia Ltd that contains both Group I and A herbicide components. Rice Extension, Dow AgroSciences Australia Ltd and Agropraisals Pty Ltd co-operated during the 2017–18 season to demonstrate the ability of sequential herbicide programs to control weeds in drill sown rice.

Testing herbicide strategies

Six replicated field trials were conducted in the Riverina near Widgelli, Coleambally, Niemer, Logie Brae and Cobram during the 2017–18 season. Trial designs were randomised complete blocks using four replications of six or seven treatments at recommended rates.

All spray treatments were applied using a hand held boom sprayer delivering approximately 100 L/ha. The timings of treatments were *post-flush, pre-emergence* or *post-emergence* prior to permanent water.

Aerial view of the Widgelli trial site. Greener areas are weeds in untreated plots. Other plots have been treated with 'Gramoxone plus Magister plus Stomp'. PHOTO: Leah Garnett

Visual ratings of percentage weed control were conducted and grain yields harvested and recorded.

Field days were conducted at most of the sites to enable growers and agronomists the opportunity to inspect and interpret the results first hand.

Heavy barnyard grass populations at the Coleambally trial site. Left is an untreated plot compared with a plot controlled with 'Gramoxone plus Magister plus Stomp' on the right. PHOTO: Leah Garnett

Table 1. Average barnyard grass percentage control ratings from five field trials in drill sown rice, Riverina, 2017–18 (100% = no weeds)

	Treatment	Timing	RRAPL	Cobram	Logie Brae	Coleambally	Widgelli	Average %
1	Untreated		0	0	0	0	0	0
2	0.8 L/ha Gramoxone plus 3.4 L/ha Stomp plus 0.6 L/ha Magister	PFPE	55	90	99	85	91	84
3	0.8 L/ha Gramoxone plus 3.4 L/ha Stomp plus 0.6 L/ha Magister followed by 1.0 L/ha Barnstorm	PFPE POST	99	97	100	99	100	99
4	1.0 L/ha Barnstorm	POST	74	82	71	78	89	79
5	2 L/ha Agixa	POST	92	90	100	93	95	94
6	0.8 L/ha Gramoxone plus 3.4 L/ha Stomp plus 0.6 L/ha Magister followed by 2 L/ha Agixa	PFPE POST	100	100	100	100	100	100

Timing: PFPE Applied post-flush, pre-emergence, POST Applied post -emergence prior to permanent water

Higher costs = higher yield

The post-flush, pre-emergence treatments of Gramoxone plus Stomp plus Magister were all timed immediately prior to crop emergence, in accordance with recommendations in the *Rice Crop Protection Guide*. These treatments consistently controlled any emergent or emerging grass weeds for in excess of 20 days after application, enabling freedom from early competition (Table 1). Minor and transient bleaching was common in addition to some minor loss of rice plant stand.

Post-emergence treatments of Barnstorm or Agixa alone were often applied to dense barnyard grass populations that were clearly impacting upon the vigour of the remaining rice. Agixa demonstrated a more rapid and ultimately more effective kill of barnyard grass than Barnstorm (Table 1).

Where Agixa or Barnstorm followed the Gramoxone plus Stomp plus Magister, barnyard grass control was highly effective throughout the crop establishment phase, resulting in the most vigorous rice stands and ultimately the highest grain yields (Figure 1).

Despite higher herbicide costs, the higher yields received where Barnstorm followed Gramoxone plus Stomp plus Magister resulted in the highest gross margin compared to other treatments with commercially available herbicides (Table 2). Treatments containing Agixa could not be included in gross margin analysis, as it is not commercially available and the cost is yet to be determined at the time of writing.

Multiple modes essential

Herbicide failures can radically drop water use productivity and profitability as the costs of purchasing and applying herbicides are incurred, yet the crop yield potential is reduced. We must achieve near 100% control of weeds for the first two months of rice crop life to maximise yield and profitability.

The sequential herbicide applications tested in these field trials consistently achieved freedom from weed competition and produced maximum rice yield potential.

Sustainability of rice growing can be compromised by resistance development to the herbicides that we rely upon. Seasoned ricegrowers will recall the spectacular success of Londax from 1987 onwards to eliminate early weed competition in water seeded rice. Over 95% of the crop was treated in successive seasons with the product, yet within four years the product was failing due to widespread resistant weed escapes. Londax is no longer reliable for the purpose it was developed.

In rice growing regions throughout the world herbicide resistance is impacting in a substantive way on how farmers manage their

Table 2. Gross margins for herbicide treatments (with known costs) using average yields from Coleambally and Widgelli herbicide trial sites (2018)

Gross margin	1. Untreated	2. Gramoxone plus Magister plus Stomp	3. Gramoxone plus Magister plus Stomp followed by Barnstorm	4. Barnstorm only
Yield (t/ha)	7.19	10.3	14.2	8.8
Price ($/t)*	$400	$400	$400	$400
Return ($/ha)	$2876	$4124	$5660	$3532
Herbicide program costs ($/ha)	$0	$83	$184	$102
Other rice costs**	$1,246	$1,246	$1,246	$1,246
Gross margin/ha	**$1,630**	**$2,795**	**$4,229**	**$2,184**

Note, costs for the new experimental chemical (Treatment 5) are not included due to it not yet being available for commercial sale.
*based on Reiziq contract price at time of writing
**sourced from 2016–17 NSW DPI Rice Growing Guide and doesn't include water purchases

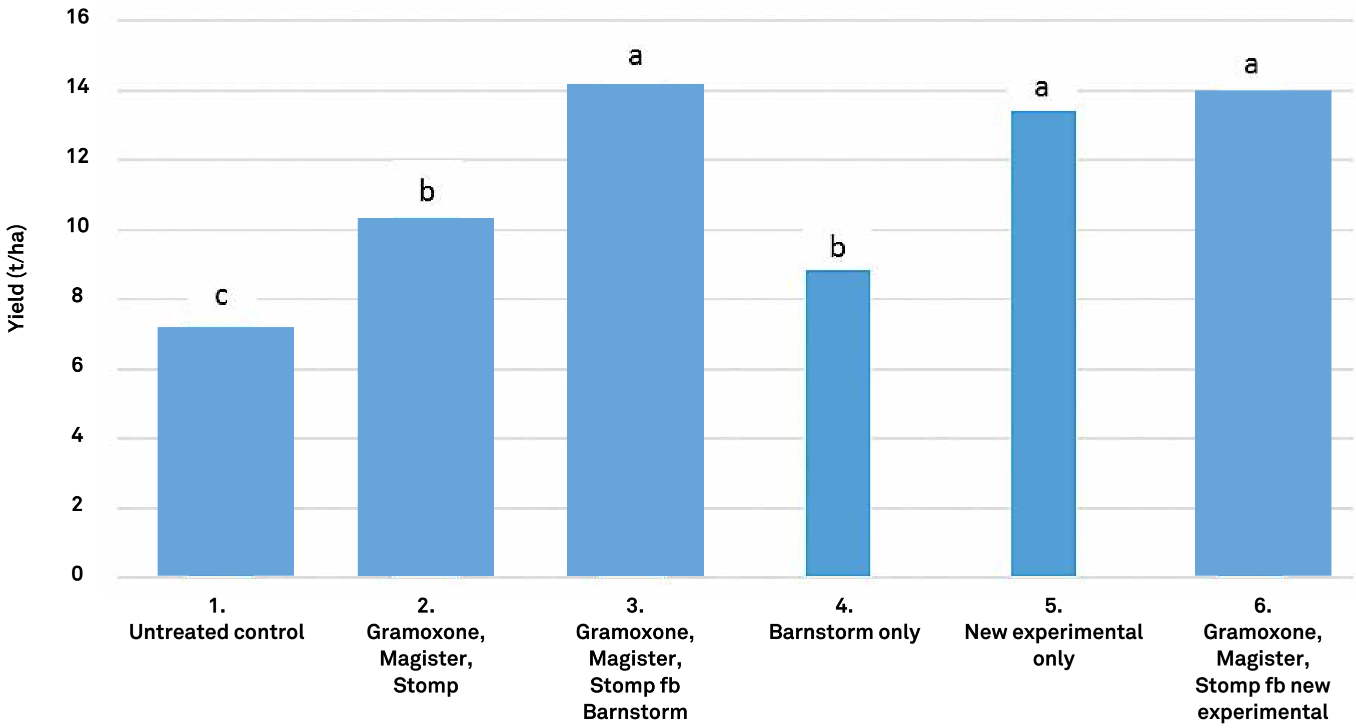

Figure 1. Average rice yield from each different herbicide treatment at the Widgelli and Coleambally trial sites (located in commercial crops). Note the herbicide treatments labeled with the same letter are not statistically different.

crops. Group A, B and C resistance is now common in barnyard grass populations growing in overseas rice fields. In each instance, resistance management principles were ignored and practices have failed.

Australian rice weed management guidelines have been drafted to attempt to deliver multiple modes of herbicide action to the same cohort of weeds in the same season. For example, Gramoxone (Group L) eliminates early emerging weeds, then Stomp (Group D) and Magister (Group Q) act simultaneously on barnyard grass during germination. If then sequenced with Barnstorm (Group A) or Agixa (Group A and I) we see that up to five alternate modes of action can be delivered to the same cohort of weeds in any one season. Importantly, the post-flush, pre-emergence mixture reduces the numbers of weeds that the post-emergence treatment will be challenged by, thus reducing selection intensity for resistance.

Sequential application successful

Overall these experiments demonstrated that sequential application of Gramoxone plus Stomp plus Magister followed by Agixa produced consistently weed free rice whilst delivering five alternate modes of action herbicides to the same cohort of weeds in a single season. This herbicide program can therefore be expected to suit delayed permanent water rice production systems.

Acknowledgements

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Tracking herbicide resistance in weeds of rice crops

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AgriFutures Australia Project PRJ-010136
Herbicide resistance in rice

Project timeframe
July 2015 to May 2018

Photograph
A rice crop with arrowhead and barnyard grass, one of 122 paddocks surveyed. Overall, barnyard grass was the most common weed and herbicide resistance in dirty Dora and arrowhead populations had increased since the last survey.

THE SHORT STORY

This project is determining the extent of resistance in populations of weeds of rice crops so that more strategic weed management recommendations can be developed for farmers and advisors.

Since the last major resistance survey conducted in 1999, the rate of herbicide resistance to Londax increased in two of the major aquatic weed species: dirty Dora and arrowhead.

Presently, herbicide resistance is limited to one herbicide but there is selection pressue on alternative herbicides. To maintain the long-term effectiveness of current herbicides, non-herbicidal weed control options, such as harvest weed seed control, are required.

Herbicide resistance is a major problem for cropping industries throughout Australia and the rice industry is no different in this regard. The industry has depended on a few herbicides only for weed control in rice.

Significant levels of resistance have been reported to Londax, one of the major herbicides used by rice growers. In 1999 a survey of random rice paddocks found that approximately 50% of dirty Dora, 40% of starfruit and 35% of arrowhead populations were resistant to this herbicide.

Barnyard grass is also a problem weed of rice crops and traditionally has been associated with combine sown rice. In 1999, Charles Sturt University found barnyard grass in over 86% of rice screenings samples from the Rice Growers Mill Laboratories; and occasionally, barnyard grass seeds accounted for most of the weight of the 30–60 gram sample.

While resistant populations of barnyard grass are yet to be reported in Australian rice fields, populations of awnless barnyard grass resistant to atrazine or glyphosate have been reported in other Australian cropping regions. Two of the herbicides used for the control of barnyard grass in rice, Barnstorm and Aura, are Group A herbicides, which are considered to be high risk with regards to the development of herbicide resistance.

By determining the extent of resistance in sample weed populations, this project will provide a basis for the development of more strategic recommendations for rice farmers and advisors. This will enhance the life of current herbicides through better chemical rotations; minimise additional herbicide use; and reduce the incidence of weed control failure, due to resistance.

This project involved a paddock survey of rice crops, herbicide resistance screening of seed collected during the survey, and analysis for barnyard grass seed in screening samples from delivered rice grain.

Field survey

Two surveys of random fields were conducted just before rice harvest, one in 2016 and the second in 2017. A total of 122 paddocks was visited — 59 in the Murrumbidgee Irrigation Area, 18 in the Coleambally Irrigation Area and 45 in the Murray Valley Irrigation Districts (Figure 1). The surveys involved collecting rice weeds and classing the density of the collected weeds using the categories of:

- very low (occasional plant)
- low (<1 per m^2)
- medium (approx. 1 per m^2)
- high (>1 per m^2)
- very high (>>1 per m^2, dominating crop).

Barnyard grass was the most commonly collected species. It was found in 116 paddocks, followed by dirty Dora in 66 paddocks, starfruit in 35 and arrowhead in 27. Less commonly found were awnless barnyard grass in 12 paddocks, silver top in nine, jerry jerry in seven, umbrella sedge in six and water plantain in two.

Four paddocks in the survey contained none of the range of weed species collected, 35 paddocks contained only one species, 36 paddocks contained two, 23 paddocks contained three, 19 paddocks contained four, two paddocks contained five and three paddocks contained six of the collected species.

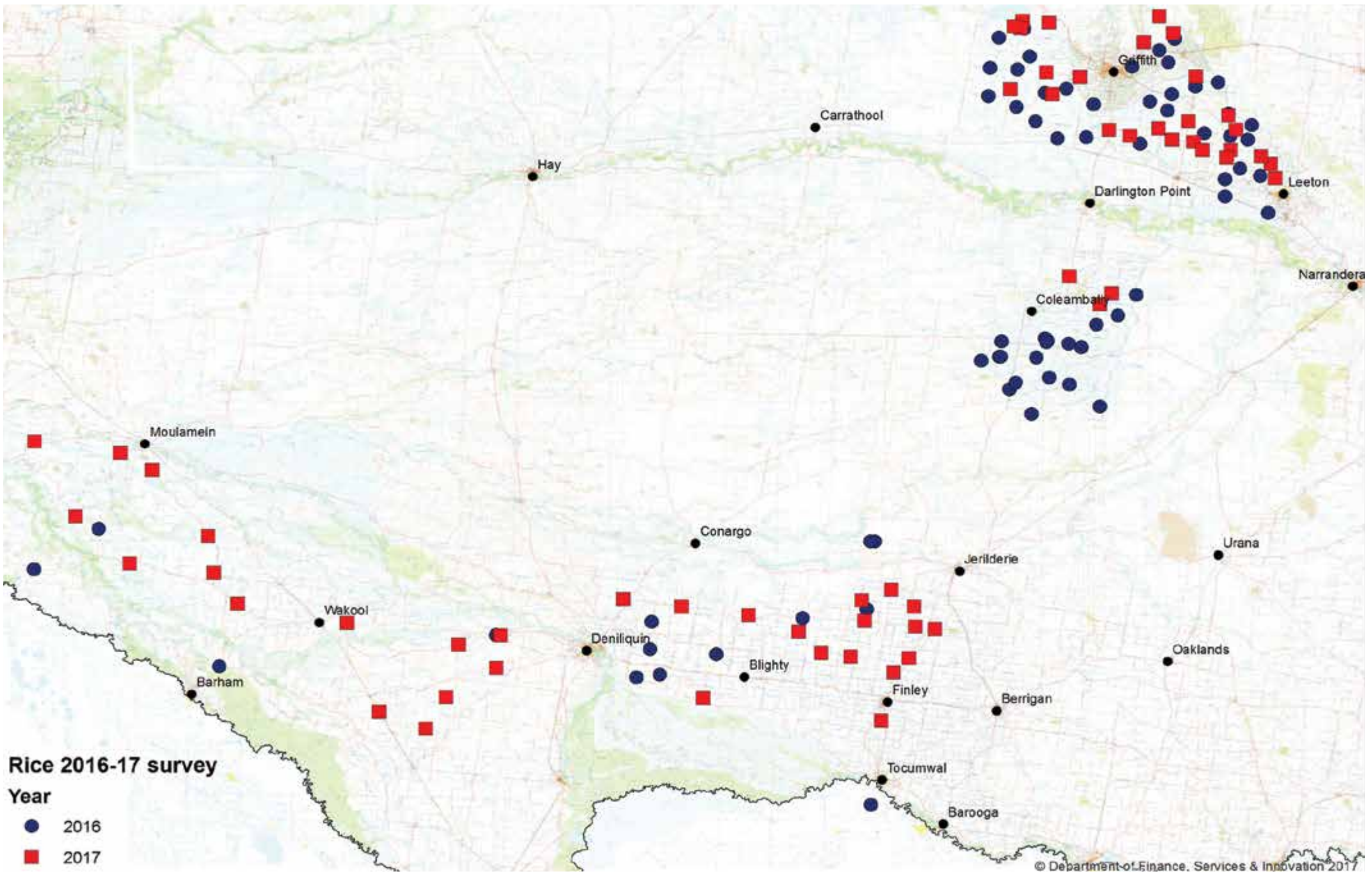

Figure 1. Locations of randomly selected sample sites in 2016 and 2017 field surveys of weeds of rice crops

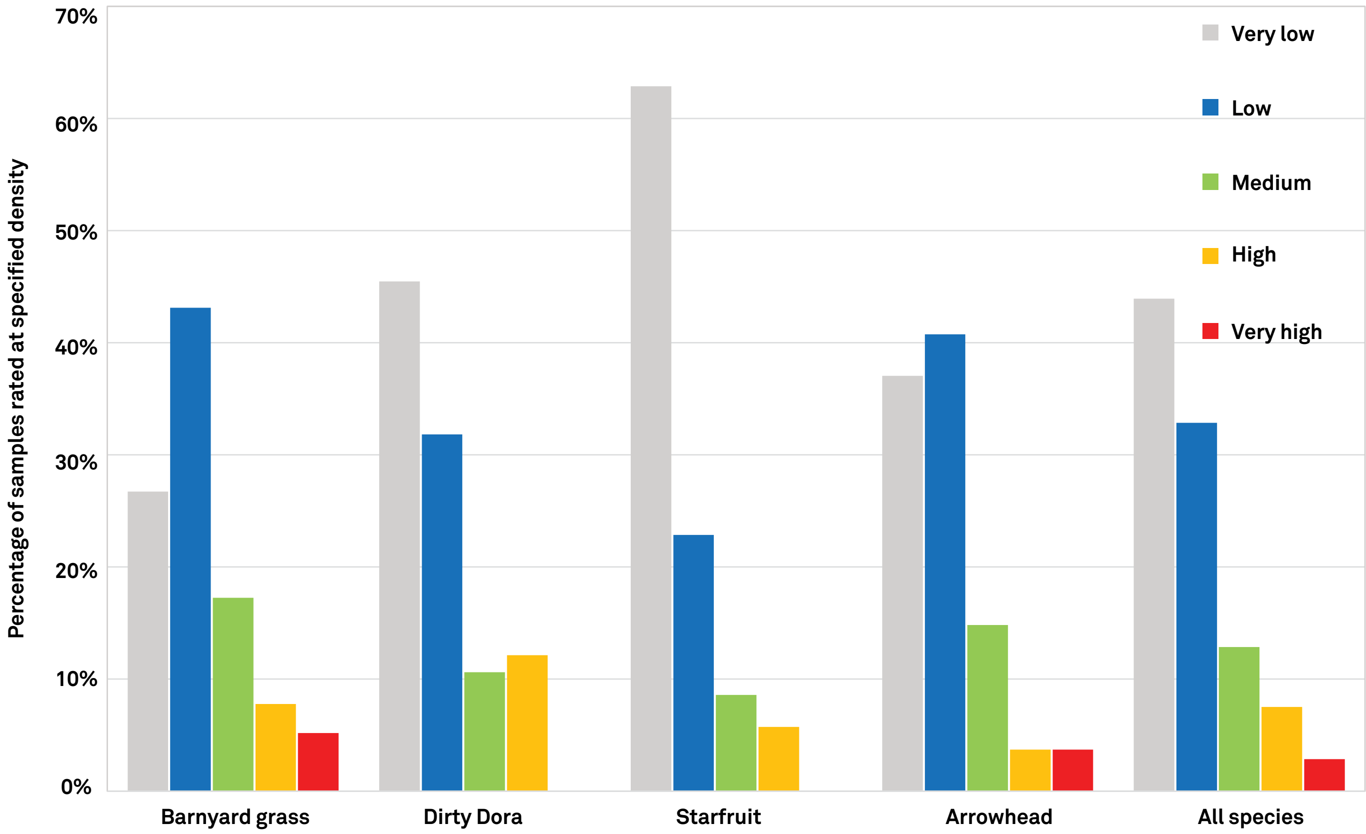

Figure 2. Density ratings for weeds collected from 122 paddocks

A total of 280 weed samples was collected from 122 paddocks. Four paddocks contained no weed species and 35 paddocks contained only one weed species, with the reminder containing between two (36 paddocks) and six species (three paddocks).

Seventy seven per cent of samples were rated at either a very low or low density, and only 3% were rated at a very high density and out-competing the crop (Figure 2).

Of the four most commonly collected species, dirty Dora and starfruit were most commonly rated at very low density, while the most commonly collected species, barnyard grass, was recorded at a low density in nearly 50% of samples. Of the eight weed populations rated at very high density, six were barnyard grass, one was arrowhead and one was awnless barnyard grass.

Herbicide resistance screening

Londax (bensulfuron) resistance levels

The level of resistance to Londax increased, with 70% of the dirty Dora populations resistant in the 2016 and 2017 survey compared with 46% reported in 1999. Resistance in arrowhead populations was 61% in this survey compared with 38% in 1999. Fifty percent of starfruit were resistant in both surveys (Table 1).

The rate of increase in resistance is much lower than that experienced by other sulfonylurea herbicides in dryland crops over a similar time period.

Other herbicides

Aside from Londax, there was also minimal or no resistance to other herbicides tested.

Two dirty Dora populations from the 2016 and 2017 surveys were classed as resistant to Taipan (benzofenap), which has not been reported previously in Australian rice fields. These populations will be retested at several rates to confirm the result. While the previous resistance survey in 1999 classed all populations as susceptible to Taipan, it is apparent that some populations had surviving plants.

Dirty Dora populations were also screened for resistance to MCPA and Saturn; and starfruit and arrowhead populations were screened for resistance to Taipan. Barnyard grass and awnless

Table 1. Londax resistance levels in 2016 and 2017

Herbicide	No. of populations tested	No. of populations resistant	% resistant	% resistant in 1999 survey
Dirty Dora	70	49	70	46
Starfruit	26	13	50	50
Arrowhead	23	14	61	38

barnyard grass were screened for resistance to Barnstorm, Aura, Gramoxone, Ordram, Stam, Saturn and Magister while silvertop was screened to Barnstorm, Ordram and Magister.

None of the screened populations were classified as resistant to any of the herbicides named. While some populations did have plants that survived the herbicide application, the level of survival was below the threshold for resistance. These populations are being further tested to confirm that they are in fact susceptible.

Weed seeds in delivered grain

In 2017, the screenings of 10% of samples processed by the AGS Quality Appraisals Centre at Leeton were collected by the project. These samples were further processed at Charles Sturt University to collect and quantify all weed seeds present and to determine relationships between crop variety and weed infestation.

Of the 153 screenings samples obtained, 144 contained barnyard grass seeds (94%), 13 contained starfruit, eight contained arrowhead, five contained silvertop and three contained dirty Dora. Only two samples contained no weed seeds.

A rice crop in the survey that was classified as having a high density of starfruit.

Prevalence of barnyard grass

The screening samples (1.2 kg grain samples) contained an average of 0.743 grams of barnyard grass seed and up to a maximum of 18.06 grams per sample.

Grain samples from Koshihikari crops contained more barnyard grass seed than all other varieties, except Illabong. However screenings samples were obtained only from one Illabong crop. Even though screening samples were obtained from only five Koshihikari crops, all the samples were all in the top 12% for barnyard grass seed weight.

There was no difference in the amount of barnyard grass seed present in the samples obtained from Doongara, Topaz, Langi, Opus, Reziq, Sherpa or YRM70 rice crops. Screenings from YRK5 crops contained more barnyard grass than all of these varieties except YRM70, however this result may have been influenced by specific aspects of the YRM70 samples.

The total rice area grown for the 2016–17 season was 80,100 hectares and the yield and percentage of total rice area sown is known for each variety (Table 2). From the data collected it was estimated that over 150 billion barnyard grass seeds (or 331 tonnes) were delivered with the rice grain for the 2016–17 harvest (Table 2). This equates to more than 260,000 seeds per tonne of rice or nearly 1.9 million seeds per hectare.

This number is an estimate for several reasons. It assumes all samples represent an equal area of rice crop, that each sample attains the overall average yield for that variety regardless of barnyard grass seed numbers and the number of samples for each variety is proportional to the percentage of that variety grown.

Implications for resistance management

The findings of the 1999 survey provided an awareness of the extent of herbicide resistance in weeds of rice crops. Due to its smaller size relative to dryland cropping, the rice industry has been able to better address the issue than other industries, and this is evident in the results of the 2016 and 2017 field surveys.

The delivery of hundreds of tonnes of barnyard grass seed is a cost to rice growers in several ways. Barnyard grass in the crop can

Table 2. Estimation of barnyard grass seed delivered to silos for the 2016–17 season, based on AGS Quality Appraisals Centre samples

Variety	Samples	Area sown		Rice yield		Barnyard grass seed				
	no.	%	hectares	t/ha	total tonnes	grams per sample	seeds per sample	seeds per tonne rice	seeds per hectare	Seeds delivered (million)
Doongara	6	1.6	1282	9.8	12,560	0.061	28	23,239	227,741	292
Topaz	9	5.3	4245	8.8	37,359	0.101	41	34,082	299,925	1,273
Langi	11	5.5	4406	8.6	37,887	0.297	123	102,321	879,959	3,877
Reiziq	53	38.1	30,518	10.6	323,492	0.340	140	116,735	1,237,386	37,763
Opus	10	7.0	5607	9.9	55,509	0.333	151	126,144	1,248,826	7,002
YRM70	13	5.1	4085	9.7	39,625	0.772	351	292,494	2,837,194	11,590
Sherpa	38	33.0	26,433	10.0	264,330	0.492	212	176,408	1,764,076	46,630
YRK5	7	2.3	1842	7.1	13,080	2.474	1125	937,262	6,654,559	12,260
Koshihikari	5	1.9	1522	7.2	10,958	5.596	2544	2,119 849	15,262,910	23,229
Illabong	1	0.2	160	10.5	1682	10.106	4594	3,828,106	40,195,113	6,439
Mean						0.743	583	264,978	1,877,082	
Total	**153**		**80100**		**796,482**					**150,354**

A rice crop sampled in the field survey with a barnyard grass population rated as very high density.

decrease rice growth and production resulting in yield losses and decreased income to the farmer. Additionally, the cost of removing the barnyard grass seed from the rice during processing may reduce the price per tonne paid to all growers.

Further, it can be assumed that not all barnyard grass seed is harvested and delivered with the rice grain. A certain portion of seed will shed in the field as the barnyard grass matures and another portion will exit the harvester in either the chaff or straw, both replenishing the existing seed bank.

The percentage of barnyard grass seed in the three portions identified is unknown. Even if 50% of the barnyard grass seed ends up in delivered grain then approximately 190 seeds/m^2 are added to the seed bank. If only 10% are found in the grain fraction, then nearly 1700 seeds/m^2 will be added to the seed bank.

This high number of seed being added to the seed bank with each rice crop results in increased selection pressure for herbicide resistance, especially for the higher risk herbicides, cyhalofop and profoxydim. That no populations surveyed were found to be resistant to these herbicides is most likely a combination of awareness of herbicide resistance, low rice crop area in recent years and the ability for many farmers to grow alternative summer crops that use different herbicides for barnyard grass control.

The findings from this research show that while herbicide resistance is present in weeds of rice crops, it is limited to a single herbicide. However, the ineffectiveness of that herbicide has already resulted in management changes to rice production and associated increased selection pressure on alternative herbicides. To maintain the long-term effectiveness of the current herbicides there needs to be an increase in alternative, non-herbicidal control options, such as harvest weed seed control, for weed control.

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- Casual staff and students at Charles Sturt University who assisted in the survey collection, resistance screening and sorting of the AGS Quality Appraisals Centre samples

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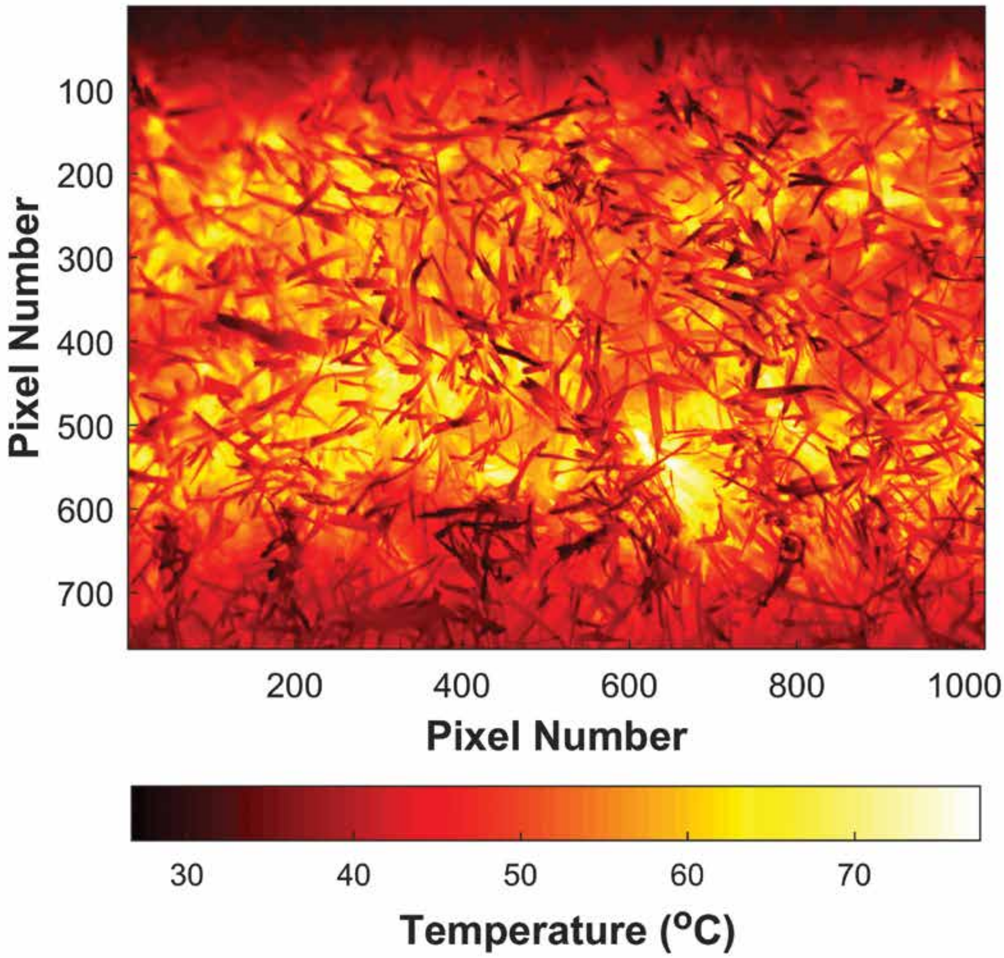
An opportunity for microwave weed and soil treatment in the rice industry



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AgriFutures Australia Project PRJ-008765
A study of microwave-based weed management in the rice industry

Project timeframe
July 2013 to June 2017

Photograph
A thermal image of kikuyu grass treated with a 2 kW microwave system travelling at approximately 1 km/h. Microwave treatment of weeds provides an opportunity for chemical-free weed management in rice cropping systems.

THE SHORT STORY

With increasing demand for more efficient and sustainable crop production, microwave treatment of soil has the potential to be a chemical-free weed management strategy.

Research has shown that microwave energy can kill weed seeds in the soil when the soil temperature is raised above 80 °C.

This project has shown that microwave weed plant treatment is an effective 'knock-down' technique.

Based on preliminary work with a trailer-based prototype with four 2 kW microwave generators, the estimated cost of this form of weed control may be similar to that of conventional weed management techniques.

— Continued

In order to reduce herbicide dependence of cropping systems and extend the life of effective herbicide chemistry, an opportunity exists for a novel weed management technology, which is also compatible with no-till agricultural practices.

Herbicide resistance is a serious constraint of modern agricultural practices, which reduces the range of available herbicide options. Many resistant weed biotypes (specific populations of a species rather than species wide) withstand exposure to herbicides from different herbicide families that target the same site of action, a phenomenon known as cross resistance. An alarming increase in weed biotypes resistant to herbicides targeting different sites of action, referred to as multiple resistance, has also been reported.

The declining availability of herbicide chemistries over the last 25 years due to environmental and human health concerns, lack of market, perceived lack of profitability and the absence of discovery of novel herbicide chemicals in recent decades has further compounded the availability of suitable herbicide options.

Consequently, the opportunity exists for novel weed management technology, which is also compatible with no-till agricultural practices. Various alternative weed management technologies are being considered. These include tillage, flaming, steam treatment, electrocution, electrostatic fields, microwave, infrared, ultraviolet, lasers and robotics. Many of these show promise; however, microwave treatment of weed plants and soil seems most compatible with no-till agriculture. It can substitute as a knock-down weed plant killer or be applied to the soil as a pre-sowing soil fumigation treatment.

Background on microwaves

Microwaves are a form of invisible light. Microwave frequencies occupy the portion of the electromagnetic spectrum (300 MHz to 300 GHz) that lies between VHF radio-waves and thermal infrared. Their application falls into two categories, depending on whether the wave is used to transmit information or energy.

Applications in information transmission include terrestrial and satellite communication links, radar, radio-astronomy, microwave thermography (used among other things to measure soil moisture levels from space), material permittivity measurements and so on.

Energy transfer applications are associated with microwave heating and wireless power transmission. In the case of microwave heating, there is usually no signal modulation and the electromagnetic wave interacts directly with solid or liquid materials. Microwave weed management and soil treatment fits into the second category of applications.

Microwave as weed treatment

Intense microwave fields rapidly boil water in living cells, resulting in micro-steam explosions inside the cells. This may be heard as a series of crackling, popping and hissing sounds. The effect of these steam explosions in plant cells is shown in Figure 1.

Generally, broadleaf weeds are more susceptible to microwave treatment than grasses. This is probably due to the location of the growing point of each type of weed, which is at the base of the plant in the case of grasses and at the stem tips in broadleaf weeds. The picture on page 25 of this report shows a thermal image of microwave treatment of kikuyu grass, while Figure 2 shows the effect on the grass patch, one day after treatment.

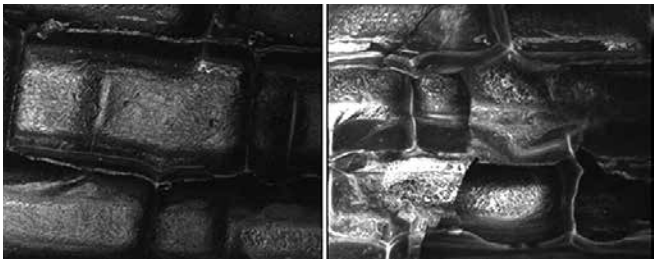

Figure 1. A magnified view of plant cells showing the difference between normal untreated cells on the left and microwave treated cells on the right.

Figure 2. Patches of grass treated with microwave energy using a 2 kW, 2.45 GHz source. Image captured approximately 20 hours after treatment.

Figure 3. Comparison of three randomly selected plants from microwave treated plots and control plots

Microwave soil treatment

Soil treatment, to kill weed seeds, requires significantly more energy than is needed to kill weeds. However, there are secondary benefits for crops that are planted into microwave treated soil. These include a significant reduction of the dormant weed seed bank (fewer weeds emerge during the cropping phase), significant reductions of nematode populations, significant reductions of fungal populations, better availability of indigenous soil nitrogen for the plants, more rapid humification and significant increases in crop growth and yield.

Table 1: Summary of yield data from pot and field trials

Treatment	Control	Hand weeded	Microwave treatment (J cm^{-2})			LSD (P = 0.05)	Change from hand weeded/ control
			80	160	320		
Pot trials							
Rice grain yield (g/pot)	40.0[a]	41.3[a]	43.3[a]	59.0[ab]	64.0[b]	18.9	**55%**
Field trials							
Dookie Yr1 (2015–16) (t/ha)	7.5[a]	––	––	––	10.1[b]	2	**35%**
Dookie Yr2(2016–17) (t/ha – cold affected)	2.1[a]	––	––	––	3.9[b]	1.3	**84%**
Old Coree (2016–17) (t/ha)	7.7[a]	––	––	––	9.1[b]	1.2	**19%**

Table 2. Summary of key measurements from initial field trial at Dookie (2015–16)

Measured parameter	Treatments		LSD	% Change from control
	Microwave treated	Control	(p = 0.05)	
Grain yield at harvest (oven dry) (g/quadrate)	225.1	168.1	44.2	34%
Tiller numbers at harvest (number/quadrate)	419	292	113.9	43%
Weed density (number/plot)	17.6	94.8	37.7	-81%
Weed biomass dry matter (g/plot)	21.6	122.6	69.6	-82%

In pot experiments, crop yields from microwave treated soils were 55% higher than in the hand-weeded untreated controls. Under field conditions, the increase in yield was generally between 19% and 84% higher than the untreated controls (Table 1). These responses are linked to reduced competition from weeds (Table 2), increased tillering (Table 2 and Figure 3), changes in the soil biota brought about by the thermal death of some species (Figure 4), and the resilience of nitrifying bacteria.

Potential new method for weed management

Microwave weed plant treatment can be regarded as a 'knock-down' technique. Based on preliminary work with a trailer-based prototype with four 2 kW microwave generators, the estimated cost of this form of weed control may be like that of conventional weed management techniques.

Microwave soil treatment is far more expensive and should be considered as equivalent to soil fumigation. Both microwave soil treatment and soil fumigation provide equivalent crop growth and yield benefits, and preliminary estimates suggest that microwave soil treatment is cheaper than chemical soil fumigation.

Microwave weed management and soil treatment is not restricted by weather conditions and has no withholding period before other agricultural activities can start; therefore, the technology may offer some timeliness and environmental benefits, which are yet to be quantified in a cropping system.

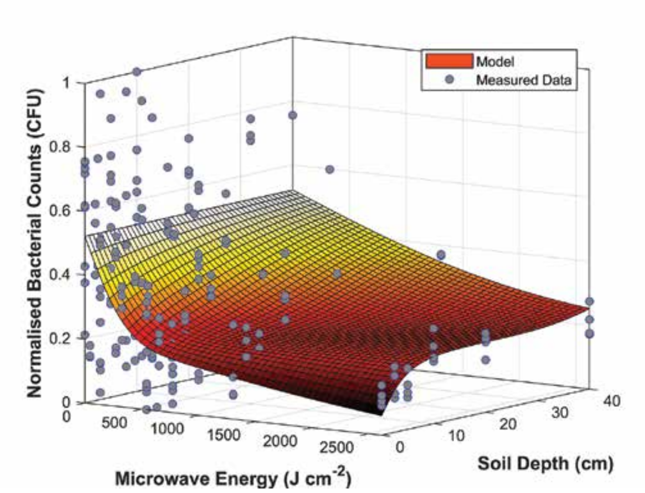

Figure 4. Response of soil bacteria to microwave treatment as a function of soil depth

Acknowledgements

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Driving the barnyard grass seed bank towards bankruptcy

PhD study

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Charles Sturt University, Wagga Wagga

AgriFutures Australia Project PRJ-010758
Impacts of pasture legume phase on the seed bank dynamics of barnyard grass in drill-sown rice

Photograph
Winter pasture legume paddock in Moulamein, October 2017. Legume pastures provide an opportunity to break the weed cycle and reduce the build-up of the weed seed bank in the rice rotations.

Reduced water availability is a major driver of increased adoption of drill-sown rice and other water-saving rice growing practices. However, grass weeds can be a major constraint on production in these systems.

Direct drilling rice into dry soil reduces total water use for the crop, thus increasing water productivity. Further water savings can be achieved in drill-sown rice by delaying the application of permanent water until late tillering. However, delayed application of permanent water during the early stages of a drill-sown rice crop, provides an attractive environment for the proliferation of terrestrial summer weeds such as barnyard grass (*Echinochloa crus-galli*).

Barnyard grass is reported as a problem weed in 61 countries and in 36 crop species and can cause reductions in rice yield of 30–100%. It also contaminates rice seed at harvest and is considered the most problematic weed species in Australian rice growing systems.

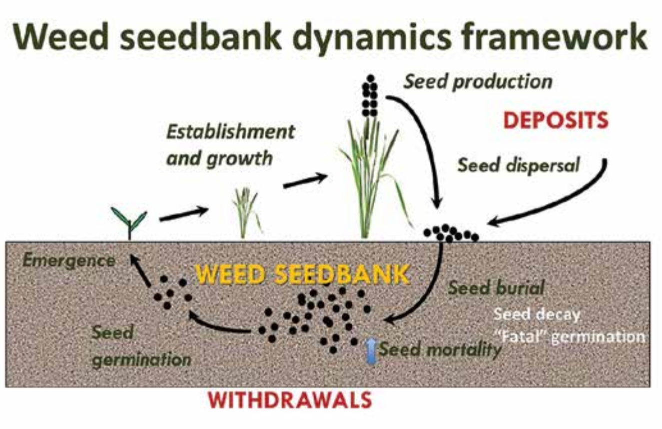

Figure 1. Deposits and withdrawals from the weed seed bank

Barnyard grass is considered the most problematic weed species in Australian rice production systems.

In addition, barnyard grass has been reported to have developed herbicide resistance to nine herbicide modes of action in 20 countries. Depending on the herbicide program they opt to choose, growers can spend in the range of $255–665/ha for weed control. A major risk with delayed permanent water is maintaining effective residual herbicide control for barnyard grass.

Rice growers face a considerable challenge to effectively manage barnyard grass in order to reduce its impact on the productivity of drill-sown rice.

The inclusion of crops and pastures in the rice rotation provides an opportunity to break the weed cycle through preventing and/or reducing the build-up of the weed seed bank. The value of pasture legumes in crop rotation to reduce high reliance on pesticides and inorganic nitrogen fertilisers, and reduce weed pressure, thereby reducing input costs has been demonstrated for many decades. Moreover, early studies have observed residues from pasture legume reducing the growth of barnyard grass.

Can pasture legumes bankrupt the barnyard grass seed bank?

The weed seed bank is what remains in the soil from deposits and withdrawals of seed throughout a weed's life cycle, as shown in Figure 1. To drive the seed bank towards bankruptcy, there is a need to reduce the seed deposits and at the same time increase the seed withdrawals. One way to increase the withdrawals is to enhance seed mortality, which can be done by promoting weed seed decay and fatal germination.

Therefore the question in respect of the barnyard grass seed bank is whether depletion can occur during the winter/pasture legume phase?

My research project was designed to determine the different ways that pasture legumes might prevent or suppress germination from the seed bank, as well as prevent or suppress establishment and early growth of barnyard grass seedlings. These are called suppressive mechanisms.

Suppressive mechanisms such as inhibition/delay of establishment, restriction of growth, and reduction of seed longevity will be determined through glasshouse pot trials, field experiments, and laboratory assays. Furthermore, the effects of ecological factors such as temperature, light, burial depth, and flooding on the germination/emergence and early growth of barnyard grass will be investigated in order to have a better understanding of the seed bank dynamics of barnyard grass.

My work aims to provide an understanding of how pasture legumes in the rice rotation can prevent or suppress the proliferation of barnyard grass in drill-sown rice.

Ground-truthing the benefits of pasture legumes

To better understand the pasture legume-rice rotation system we conducted a scoping study. The information gathered from farm visits and meeting with rice growers influenced the design of my studies.

Some of the key things I picked up from rice growers were:

- "There is a need to manage the weed seed bank."
- "We know legumes will clean up barnyard grass."
- "Pasture legumes in the rotation are increasing due to increasing price of lambs; there needs to be a 10–15 year program to rehabilitate pastures."

In the future, as water for irrigation may be more limited and with increased adoption of water-saving strategies, there is a need to develop new tools and practices to reduce risk to the productivity of the rice system. My work will provide an understanding of how the pasture legumes in the rice rotation can suppress the proliferation of the seed bank of barnyard grass in drill-sown rice.

Acknowledgements

Charles Sturt University and AgriFutures Australia for the scholarship and operating funds.

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Changing priorities for rice pest and disease management

Mark Stevens and Andrew Watson
NSW Department of Primary Industries, Yanco Agricultural Institute

AgriFutures Australia Project PRJ-010188
Rice pest and disease biosecurity II

Project timeframe
July 2016 to May 2019

Photograph
A niclosamide snail trial north of Finley in November 2017. Trials with stainless steel rings allow different chemical rates and formulations to be tested. Snails are added to the rings before individual chemical applications.
PHOTO: Mark Stevens

THE SHORT STORY

Drill-sown crops are less vulnerable to bloodworms than aerial sown crops, and effective chemicals are available.

Snails remain a major issue in aerial sown repeat crops, with drill-sown repeat crops often (but not always) less severely affected.

Armyworms are becoming a more widespread problem. Delayed permanent water and mid-season drying are believed to increase the likelihood of serious armyworm infestations.

Good progress is being made towards developing new chemicals for both snails and armyworms.

Stem rot issues are increasing, exacerbated by repeat cropping and poor stubble management.

Changes in rice production practices have altered the status of many of the pests affecting the industry, and increased the importance of stem rot, the only established disease that poses a significant threat to production.

In recent years, rice growing practices have focused on increasing water use efficiency and reducing water usage, with many growers now repeat cropping on a regular basis. There has also been a swing back to drill sowing, and agronomic practices such as delayed permanent water and mid-season drying have seen strong adoption across the industry.

Changing practices are changing the priorities for rice pest and disease management, both for growers and researchers.

Bloodworm management

Bloodworms, like snails, require an aquatic environment in which to feed and develop. Unlike snails, bloodworms cannot enter dormancy in the soil — the adult insects are midges that superficially resemble mosquitoes, and lay their eggs into the water opportunistically. The incidence and severity of bloodworm infestations is largely unaffected by cropping history, and repeat cropping is not a factor. Aerial sown crops provide the constant aquatic environment that allows bloodworms to thrive, and these crops need to be treated by air on a precautionary basis each season. Effective chemicals are available and are listed in the *Rice Crop Protection Guide*, which is updated prior to the start of each season.

The situation in regard to bloodworms in drill sown crops is more complex. Drill sown crops do not provide bloodworms with a stable aquatic environment until after permanent water is applied, and although eggs will be laid into any standing water during flushes, the young larvae will die when the paddock dries out before they can reach a size where they are capable of damaging the plants. Whilst big populations of larger bloodworms may develop after permanent water, they seldom cause significant damage because the plants have developed much tougher secondary roots. Drill-sown crops should only be treated for bloodworms after permanent water if plant damage is observed. None of the bloodworm species found in NSW rice fields are obligate rice feeders — they can all feed and develop on algae, decaying plant materials and similar food sources.

The bloodworm trial program at Yanco is set to resume in the 2018–19 season, where we will be focusing on developing fipronil as a direct spray treatment. Because a highly effective fipronil seed treatment (Cosmos®) is already registered for bloodworm control, development of an alternative formulation for aerial application is unlikely to involve major regulatory issues.

Snails

Rice snails continue to be a major issue for growers because of the strong move towards repeat cropping. A proportion of snails enter dormancy in the soil when crops are drained or dried down, and around 50% of these dormant snails will survive over winter and become active again as soon as the ground is flooded. Reproduction rates are high, and during the establishment period there is often very little available to the snails as a food source, other than the crop itself.

Snail control with copper sulphate is problematic, as snail eggs are rarely affected and overall efficacy is affected by aspects of water and soil chemistry. Because snails are molluscs rather than insects, they do not respond to conventional insecticides and there is only one chemical, niclosamide, that has the potential to replace copper. Commercialisation of this compound has been a long process — initially no commercial registrant could be found, however in 2012 Conquest Chemicals agreed to work with us on its development. After extensive work on-site at Yanco, trials in commercial crops were conducted under permit in the 2016–17 and 2017–18 seasons (main picture), and we anticipate Conquest will apply for product registration later this year. Large amounts of residue work were needed to meet regulatory requirements, as niclosamide has no other registered crop uses in Australia.

Figure 1. A manually defoliated Reiziq trial plot. 50% of each leaf (by length) has been removed across the 1 m^2 plot at panicle initiation. Only the central area of each plot was assessed at harvest to avoid edge effects.

Armyworms

For many years armyworms were a minor and sporadic problem for the rice industry, and were not the subject of detailed research. The situation started to change around five years ago, when agronomists noted that delayed permanent water crops, and particularly aerially sown crops subjected to mid-season drying, were experiencing high levels of armyworm damage. This hasn't yet been investigated in great detail, but there are good biological reasons why it may be happening — stressed plants emit a different blend of compounds to unstressed plants, and these could preferentially attract female armyworm moths. Of greater concern however, is that over about the last three years the armyworm problem has expanded to the point where all rice crops, regardless of water management practices, run a high risk of becoming infested. An increasing number of reports have also been received of crops being attacked by armyworm much earlier in the growing season, often well before panicle initiation.

Armyworm damage occurs during two phases: vegetative growth and grain development. The worst damage occurs when panicles are exposed and grain is approaching maturity, and armyworm caterpillars chew through the spikelets, allowing grain to drop from the plant. To understand how earlier vegetative damage affects yield, we manually removed either 25% or 50% of each leaf (by length) from Reiziq plots at panicle initiation, then assessed yield at harvest from the central section of each plot (Figure 1). Results for the first trial, conducted in 2016–17, are shown in Figure 2. A significant decrease in total grain yield (around 14%) occurred in response to 50% defoliation, but the plants compensated effectively in response to the 25% defoliation treatment. Both defoliation treatments led to declines in grain weight per panicle, but in the 25% defoliation treatment only, this was compensated for by an increase in the total number of panicles produced.

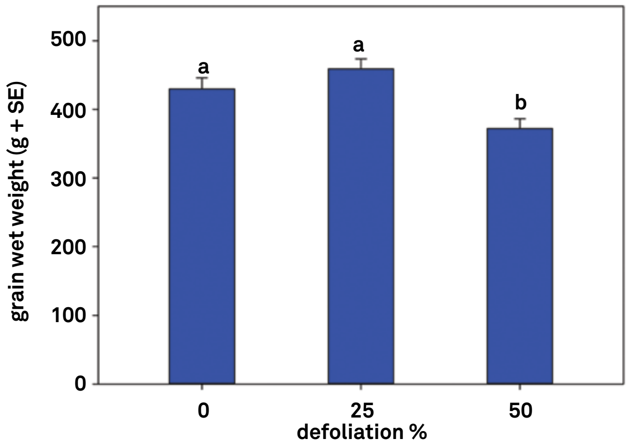

Figure 2. Wet grain weights from Reiziq plots manually defoliated at panicle initiation. Bars with different letters are statistically different (P < 0.05).

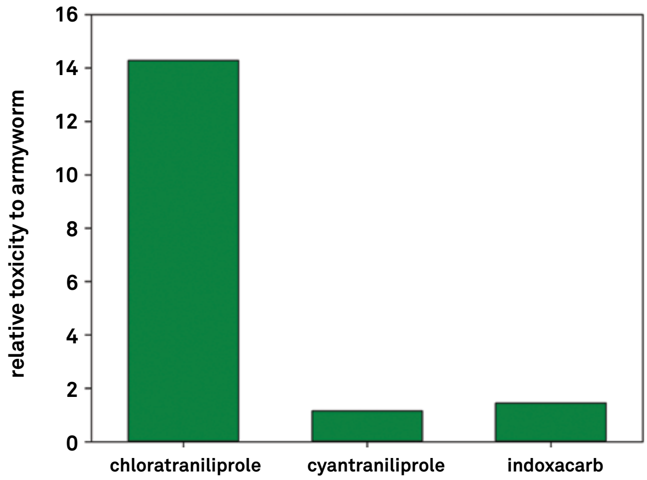

Figure 3. Relative toxicity of three candidate armyworm control chemicals in dietary bioassays. Provisional data. Units are 1/LC_{50} value (µg/g of food).

Results for the 2017–18 season are still being analysed, and whilst 'simulated' and 'genuine' armyworm defoliation are not the same thing, it is still clear that rice can experience quite severe foliage loss during vegetative growth before a yield penalty occurs. This contrasts with late-season armyworm infestations, where spikelet loss caused by relatively low armyworm populations can cause direct and significant yield loss at a time when there is no opportunity for further compensatory growth by the plants.

Better armyworm control

Armyworms in rice are very heavily parasitised by various wasps and flies. The practical significance of this in the rice system is still being evaluated, however chemical sprays that control armyworms but have little or no impact on their parasitoids have the potential to lessen the likelihood of serious reinfestations occurring. Currently registered chemicals do not have this selectivity, so we have been using dietary bioassays in the laboratory to assess the toxicity of four insecticides from newer chemical groups to armyworms. Results to date are summarised in Figure 3. In dietary bioassays chlorantraniliprole is the standout performer in terms of activity against armyworm. One additional chemical, emamectin, is currently being screened, and topical bioassays will follow. These tests will determine which materials we evaluate under field conditions in coming seasons.

Stem rot

A large number of farms had stem rot in the Finley area prior to the 2017 harvest. The outbreak was due to a combination of disease build-up caused by increased repeat cropping in the area and difficult conditions for effective stubble burning after harvest of the previous crop. Yield loss was only minimal, but an indication that management practices need to be put in place for the reduction of disease incidence in the future. Slashing crops that have had sclerotia within the stubble also potentially favours the disease, as it allows sclerotia released from the plant stems to fall on the ground and into cracks in the soil, avoiding the temperatures needed to destroy them during burning.

A greenhouse trial was undertaken to assess whether different cultivars have different levels of susceptibility to stem rot. Sclerotia were extracted from rice stubble collected in Finley and used in the trial. An example of early stem rot symptoms in test plants is shown in Figure 4. All current commercial cultivars were susceptible to stem rot, however there was some variability. Sherpa was the most susceptible cultivar to stem rot, whilst Reiziq showed the highest level of tolerance.

Figure 4. Stem rot symptoms in deliberately-infected rice during a cultivar susceptibility trial. Sherpa was the most susceptible cultivar, whilst Reiziq was the most tolerant. No cultivars showed high levels of resistance to the disease. PHOTO: Andrew Watson

Acknowledgements

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Delivering research findings, advice and information to rice growers

Gae Plunkett, Troy Mauger and Leah Garnett
Rice Extension

AgriFutures Australia Project PRJ-009296
Rice extension coordination

Project timeframe
July 2014 to June 2020

Photograph
Leah Garnett of Rice Extension discusses the rice harvest with Clint Badoco at Widgelli. Clint was very happy with the yield of his crops in 2018, which was the first time he has used the drill sowing method.

THE SHORT STORY

Rice Extension shares research findings, agronomic advice, and information about best management practices through print, email, social media and grower meetings.

The ultimate aim of Rice Extension is to improve grower profitability, productivity and sustainability. We do this through collaboration, networking and sharing of ideas to support the adoption of best management practices and new technology in rice farming systems.

Rice Extension is funded directly by rice R&D levies and the Australian Government through AgriFutures Australia. We have formal linkages with our Grower Steering Group, SunRice, RGA and AgriFutures Australia to identify emerging issues.

— Continued

Rice Extension was established in June 2014 to ensure rice growers have access to information about new technologies and practices, and have opportunities to participate in group and industry events to develop the skills required for a successful rice growing business.

The Rice Extension team has three staff:

- Troy Mauger – Murray Valley Extension Officer
- Leah Garnett – Murrumbidgee Valley Extension Officer
- Gae Plunkett – Coordinator.

The Rice Extension team has held over 125 events that:

- 4893 people attended
- 1504 people attended 17 whole of industry events
- 1607 attended 43 local events across the Murray Valley region
- 655 attended 24 local events held in Coleambally.
- 1127 attended 41 local events in the MIA.

Rice Extension field walks were hosted by 73 growers on their farms showcasing their growing practices and sharing their tips on rice growing. Over 25 grower case studies are available on our website, and past event resources contain information about the field walks.

The Rice Extension website has had over 7500 page views since its launch in December 2017. It contains a broad range of practical and grower-focused articles, and research and best practice information on rice growing. It is available here: riceextension.org.au. A link to the website is also available directly to growers in the SunRice Grower Services website.

The PI Predictor, supported and promoted by Rice Extension, was used to assess the PI date of over 1000 crops last season. This tool, developed with NSW DPI researchers and using live BoM data, has ensured growers can correctly time NIR sampling and topdressing for maximum nitrogen effectiveness.

Rice$cenario, developed by Rice Extension and a team of experts, has been used by 30% of rice growers. It is an online planning tool for growers and their advisors for water budgeting, gross margin analysis and cash flow budgeting. Users can plan enterprise scenarios to gain an understanding of how much water they need and what price can they afford to purchase water.

The @RiceExtension Twitter account has over 1000 followers. The Rice Extension Facebook page has almost 600 'likes' and there are 118 members in the Women in Rice Facebook group. Social media is an effective way to get important messages out to rice growers, researchers and advisors and to hear back from them. Monthly newsletters, fact sheets and grower publications aim to be easy to read, targeted, topical and timely.

Rice Extension will be calling for applications for the next Rice Industry Graduate program in August–September 2018 and we will be advertising extensively. If you are interested, let us know. The program has been successful in attracting new expertise to the rice industry. Leah Garnett completed the first 12-month Rice Industry Graduate program and stepped into the role of Rice Industry Extension Officer in July 2015. The 2015–16 Rice Industry Graduate, Erika McAllister, now works with Murray Landcare and RGA, Deniliquin. The 2016–17 Rice Industry Graduate, Courtney Dillon, is currently a Policy and Communications Officer at RGA, Leeton.

Troy Mauger (right) of Rice Extension with Peter and Renee Burke at Mayrung who will drill sow rice crops again because yields were great and weeds, wind, and ducks were not a problem.

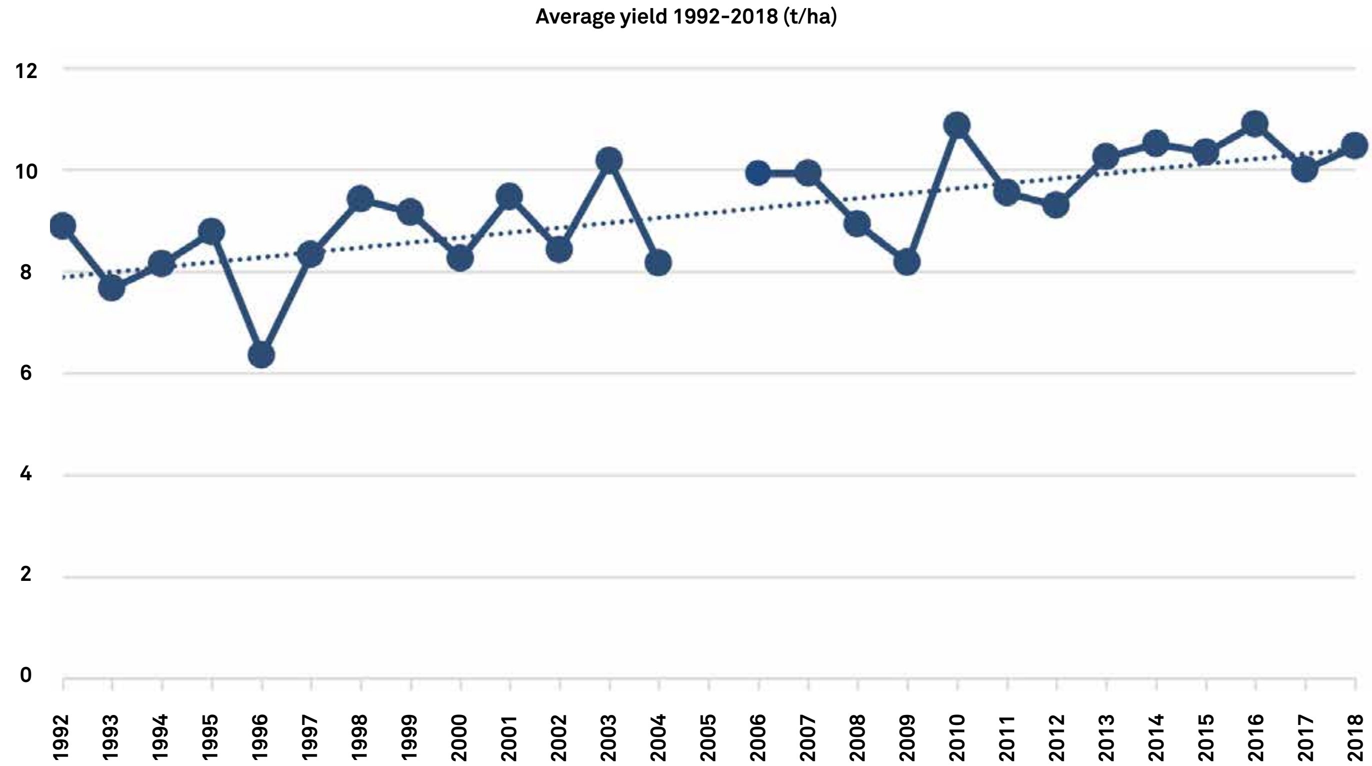

Figure 1. Average yield of rice in dry tonnes per hectare, 1992–2018 (Source: SunRice)

Table 1. Percentage of paddocks in each region using each sowing method for the 2015–16, 2016–17 and 2017–18 seasons

Sowing method	2015–16	2016–17					2017–18				
	Total	MIA	CIA	WMV	EMV	Total	MIA	CIA	WMV	EMV	Total
Aerial	25.2	8.7	33.7	80.8	47.6	41.5	5.9	12.8	60.9	36.8	24.9
Drill	41.3	29.8	46.0	14.7	30.4	30.4	42.8	58.6	30.4	45.1	45.1
Dry broadcast	33.5	61.5	20.4	4.5	22.0	34.2	51.0	25.3	8.2	13.3	30.0

(Source: SunRice Grower Services GIS RiceMap)

Continuous improvement in rice yields and grower productivity is an objective of the Rice Extension team. The adoption of R&D outcomes and new technology on farm will improve farm business profitability and sustainability. Figure 1 shows an overall steady increase in the average yield across the industry over 26 years.

Rice Extension promotes the water saving opportunity of drill sowing and delayed permanent water to maximise productivity. Growers are adopting drill sowing as a water-saving technique and for reduced wind, duck and snail damage, which are all costly to control in aerial sown crops. The rice industry has had a traditionally high percentage of aerial sown crops, but in 2017–18 the percentage of drill sown crops increased to almost 60% in Coleambally Irrigation Area (CIA), 43% in the Murrumbidgee Irrigation Area (MIA), 45% in the Eastern Murray Valley (EMV) and 30% in the Western Murray Valley (WMV) (Table 1).

Lower total water allocation has resulted in increased drill sowing. Water availability in 2016–17 was high with 100–110% allocation, however allocations were much lower in the 2015–16 and 2017–18 seasons, and growers were looking for water-saving techniques.

For the coming season, the Rice Extension team is going to be out in the field talking to growers and planning farm field walks, workshops and training to share information. These events along with our newsletters and email alerts will keep you up to date with on-farm innovations and new research outcomes. We will continue to work closely with researchers and others in the rice industry to identify emerging issues and help target research investment to industry needs.

Acknowledgement

This is an AgriFutures Australia funded project.

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Investing in the future leaders of the rice industry

Ainsley Massina
Ricegrowers' Association of Australia

AgriFutures Australia Project PRJ-11075
Leadership in the Rice Industry

Project timeframe
April 2018 to August 2020

Photograph
The first *Foundation of Leadership* program commenced in May of 2018. Pictured are some of the rice industry's future leaders at the first week of the program in Deniliquin.

THE SHORT STORY

The Ricegrowers Association of Australia Inc. believes that developing leaders is an investment in the future of our industry. The 2018–2020 Rice Industry Leadership Program has been established to provide that opportunity to potential leaders of our industry.

The development of strong and effective industry leaders assists the rice industry to not only structurally adjust to the many drivers of change influencing the industry, but to allow the industry to continue it's economic, environmental and innovation success.

Through strong leadership development, the industry is better positioned to embrace both the opportunities and challenges facing our industry.

For the past decade, the rice industry has evolved and grown to understand the importance of strong leadership, and working towards an industry that truly believes in its people and its people's ability to move the industry forward.

Leaders are not only leaders within the rice industry, they are also seen as leaders within their communities. This is something that the rice industry is very proud of and hopes these leaders continue to influence not only industry but also regional communities.

The Ricegrowers Association of Australia Inc (RGA) saw the opportunity to continue great work in this leadership space, and was successful in receiving $367,960 of funding from the Australian Government's $5 million Leadership in Agricultural Industries Fund. In addition to federal funding, the RGA also is supported by the key organisations within the rice industry, these being AgriFutures Australia, SunRice, The Rice Marketing Board of the State of NSW and Rice Extension. This funding amounts to $662,760 and has enabled the 2018–20 Rice Industry Leadership Program to be born.

Establishing leaders

The vision for this leadership project was, 'To establish a self-replenishing cohort of rice industry leaders who are diverse in knowledge and experience and who are skilled, confident and self-aware to take on the leadership roles presented to them via the organisation within and directly and indirectly associated with the industry'.

To achieve this vision, RGA developed a three-tier approach. The first tier is a program entitled *Introduction to the Rice Industry*, which has been designed for new and/or inexperienced people with a passion and interest in the rice industry. The focus of this program will be to engage the next generation of leaders with the challenges and opportunities facing agriculture and to gain exposure to the industry and associated organisations. The program will run over two sessions, with one session taking the participants to Canberra to gain invaluable experience and networking opportunities.

The second tier program, *Foundation of Leadership*, has been developed in conjunction with the Australian Rural Leadership Foundation. This program is for rice growers and industry representatives who have already demonstrated an interest in pursuing leadership opportunities within the sector/region. This program gives participants an opportunity to develop self-leadership skills alongside increasing their knowledge base on corporate governance and critical thinking. The RGA sees this program as a great opportunity for individuals to make a decision about what their leadership pathway may be.

The third tier program, *Established Leaders*, targets rice growers and industry representatives who have experience and ambitions to take on a directorship position in the future. Understanding the importance of succession planning, this program is being developed to ensure future directors have the skills, knowledge and experience to effectively steer organisations in the rice industry into the future. To develop this program, the RGA will work with the Australian Institute of Company Directors to bring their program *Foundations of Directorship* to the region. The RGA believes this program is a very exciting opportunity for five successful candidates.

Not only are these programs an opportunity to strengthen the leaders within the industry but also provide an opportunity for growers to take the skills and knowledge they have learnt to strengthen their own businesses and our rural communities.

The rice industry believes that great leadership in the past has brought the industry to where it is today, and through this funding and these programs we can ensure our leaders will continue to adapt and grow our industry.

More information

For more information or to be part of any of these programs, please visit our website or contact the Leadership Coordinator.

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***Foundation of Leadship* participants develop leadership skills and knowledge on corporate governance and critical thinking.**

Participants at their graduation dinner in Leeton. Leadership programs ensure the rice industry continues to adapt and grow.

Finding a rice variety for the hot tropics of northern Queensland

PhD study

Charissa Rixon
PhD Student
Central Queensland University, Rockhampton

AgriFutures Australia Project PRJ-010705
Characterisation of morphological, physiological and biochemical traits for heat tolerance in aerobic rice

Photograph
Experiment 1 in the Glasshouse at CQUniversity Rockhampton, 2017, showed a large genetic variation for heat tolerance at flowering within the genotypes.

For the rice industry in north Queensland to continue to develop into a commercially-viable industry with long-term viability, all new rice varieties need to be adapted to a tropical environment.

Rice in north Queensland predominantly is being integrated into an established cane cropping system, as an alternative fallow crop, along with traditional legume fallow crops. As the temperatures in north Queensland can exceed the optimal temperature for rice growing, which is 22–28 °C (night–day), summer rice crops can experience heat stress, particularly at flowering, which in turn causes spikelet sterility.

In Tully, the variety Topaz was observed to have up to 34% spikelet sterility. With commercial crops averaging 4.0 t/ha, this level of spikelet sterility equates to a yield loss of 2.0 t/ha, which makes rice production commercially unviable. Varieties such as Topaz and Doongara were bred for the southern rice industry, which is a traditional paddy system in a temperate climate.

Charissa Rixon, in Experiment 4, a field experiment evaluating genotypes and traits at different heat stress regimes, at Tully.

Southern varieties are now being grown in an aerobic system in a tropical environment, which regularly experiences high temperatures in conjunction with high humidity during the wet season. Soil, canopy and panicle temperatures can be higher in aerobic production systems than in a flooded system.

This study aims to improve yields by selecting varieties with appropriate physiological, morphological and biochemical traits for heat tolerance in a tropical aerobic system.

Research objectives

Previous heat tolerance research has predominantly focused on flooded rice systems. This research aims to identify the morphological, physiological and biochemical traits associated with heat tolerance for an aerobic farming system in a tropical environment. Identification and better understanding of appropriate morphological, physiological and biochemical traits and associated quantitative trait loci (QTLs) will provide the robust tools for effective selection of tolerant genotypes from a large population of segregating lines for future rice variety development.

There are two key research objectives:

- Investigate the correlation of yield in a tropical aerobic environment with a range of morphological, physiological and biochemical traits for heat tolerance at the reproductive stage on a diverse set of genotypes (30 genotypes sourced from NSW DPI).
- Phenotype a large japonica 'genome wide association' population (305 genotypes from NSW DPI) for key traits that confer heat tolerance in a tropical aerobic environment and conduct genotype-phenotype associations to investigate genetic control of these traits.

Research to date

A series of five experiments is planned for the period of this research project.

1. Early booting and flowering stage heat stress screening (completed)
2. Field evaluation of physiological traits of rice varieties for heat tolerance in north Queensland (completed and to be repeated)
3. Effect of heat stress at flowering on lipid composition influencing reproductive traits (in progress)
4. Evaluation of genotypes and traits at different heat stress regimes in field conditions using multiple planting dates (in progress)
5. Genotyping of japonica population using a genome wide association study to map the quantitative trait loci (QTLs) for heat tolerance in rice (to be done this coming season)

Experiment 1 was conducted at CQUniversity Rockhampton in the glass house and growth chamber. Results showed a large genetic variation for heat tolerance at flowering within the genotypes, and the tolerance of some genotypes contradicted results previously reported for heat tolerance under flooded conditions.

Flowering dates across the genotypes ranged from end of March to mid-June. This led to the selection of six diverse genotypes for further studies in the growth chamber where all genotypes experienced the same temperature regimes, irrespective of time of flowering.

Experiment 2 was a field trial in Tully, which showed a wide diversity for spikelet sterility. Eight genotypes (Bala, Sherpa, WAB 450-I-B-P38-HB, CG14, Hayayuki, Lemont, Sasanishiki and N22) recorded significantly lower spikelet sterility compared with the 19 other genotypes in the study. However in Experiment 1, Hayayuki, Sasanishiki, Doongara, Tequin, Langi, Swarna and CG14 showed significantly lower spikelet sterility compared to other genotypes. The sterility differences in experiments 1 and 2 are due to the combined effect of temperature and flowering date.

Doongara (the variety in current commercial use in north Queensland) recorded substantial spikelet sterility in the field trial. This susceptibility weakens the commercial viability of the crop, and impedes industry growth.

Experiments 3 and 4 are currently in progress, and planning is underway for Experiment 5.

Acknowledgement

Central Queensland University and AgriFutures Australia

More information

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Understanding the mechanisms of cold tolerance for future rice varieties

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AgriFutures Australia Project PRJ-007580
Cold tolerant traits and QTL for improved efficiency of rice breeding program

Project timeframe
September 2012 to June 2018

Photograph
Jaquie Mitchell (left) with PhD student Chris Proud (far right) and Honours students, Siti Zulkafli and Hafiz Burkhan, at glasshouse facilities at University of Queensland.

THE SHORT STORY

This project identified cold tolerant genotypes of rice and improved the understanding of what functional, physical and genetic factors of the rice plant contribute to cold tolerance in current and new Australian rice varieties.

The results of this work will directly benefit the rice breeding program of the NSW Department of Primary Industries. Rice breeders will be able to incorporate genotypes identified by this project into the breeding program to potentially develop varieties with enhanced cold tolerance.

Better cold tolerance offers growers lower production risk and increased water use efficiency, for the benefit of the rice farmer and the industry as a whole.

Rice production in southern Australia can suffer from severe yield reductions due to cold damage at any time during the growing season but particularly at the reproductive stages of crop development.

With increasing irrigation costs and reduced availability of irrigation water, farmers are looking to practices of delayed and reduced permanent water on the rice crop. However, this can put the crop at greater risk of cold damage.

Rice varieties adapted to low temperatures would reduce year to year variability in production resulting from cold temperature events. Cold tolerant varieties would stabilise yield and economic returns for the farmer, which is why AgriFutures Australia invested in this project to identify cold tolerant traits (mechanisms) and quantitative trait loci (QTL) for improved efficiency of the rice breeding program. This project was looking for QTL, which are sections of DNA that correlate with cold tolerance and underlying physiological mechanisms in the plant.

This project was a 'pre-breeding' research project aimed at the identification of cold tolerant genotypes and improving the understanding of what physiological (plant function), morphological (physical characteristics) and genetic factors contributed to cold tolerance in existing and prospective Australian rice varieties.

Identifying cold tolerance

The identification of cold tolerant plant populations (genotypes) involved a series of trials, conducted in glasshouses at the University of Queensland and in rice fields in southern New South Wales.

- Populations of genotypes were screened for cold tolerance at young microspore under controlled temperature glasshouse conditions.
- Cold tolerant genotypes identified in glasshouse screening were evaluated for cold tolerance and general agronomic adaptation in the field in southern NSW.
- The performance of genotypes under cold conditions in aerobic systems was examined in the glasshouse and field.

Significant variation for spikelet fertility under cold air temperature conditions was observed. There were genotypes identified within all populations tested that had greater tolerance than currently available commercial varieties, as shown by results in Figure 1.

Specifically, more than 70 genotypes were identified that had greater cold tolerance than the commercially-available cold tolerant variety Sherpa. Most of these cold tolerant genotypes are not agronomically acceptable and need further introgression (i.e. transfer of genes) with elite Australian material to ensure production and quality. The best of these cold tolerant donor genotypes have been incorporated into the rice breeding program over the course of the project. New crosses were made and genetic material advanced through the breeding program and are now ready for screening through the University of Queensland cold tolerance phenotyping system.

A number of genotypes emanating from the M205ML population were identified as cold tolerant and appeared to be agronomically acceptable but these need to be evaluated further in the Riverina production environment. Furthermore, one M205ML line was identified that may be of use in a delayed permanent water system, again this needs evaluation in the Riverina production environment.

A subset of the Yanco core diversity set (117-135 genotypes) was phenotyped and consequently the commercial varieties have been benchmarked against potential donor genotypes from within this

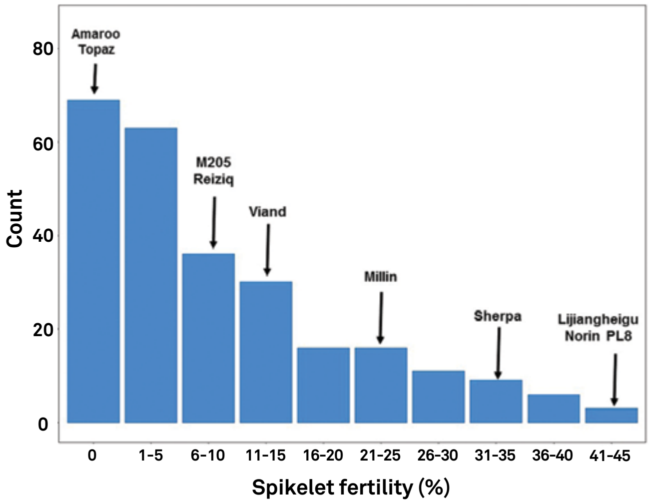

Figure 1. Benchmarking for spikelet fertility of Australian varieties and known cold tolerant genotypes (potential donors) alongside a mapping population (M205ML), when exposed to 14.5–18.8 °C night–day temperatures for 14 days at young microspore stage. (PhD work conducted by Chris Proud, University of Queensland)

Chris Proud, University of Queensland PhD student, planting a cold screening experiment in May in Mackay.

Venuste Nyandwi, University of Queensland Masters research student (course work) conducting a controlled-temperature glasshouse cold screening experiment.

and against the most cold tolerant genotypes emanating from the various populations screened.

Floral traits contributing to cold tolerance

Based on measurements of spikelet fertility, detailed studies were conducted under controlled temperature glasshouse facilities to determine the important floral characteristics of the rice plant in terms of cold tolerance (figures 2 and 3).

The project identified the key floral traits and their associations with spikelet fertility under cold conditions within a population. These traits are:

- number of dehisced (ruptured) anthers and dehiscence length (Figure 3)
- pollen number in anther
- pollen number on stigma.

Pollen number in anther, when exposed to cold at young microspore in a population (120 genotypes), accounted for 53% of variation in spikelet fertility. The number of ruptured anthers accounted for 58–69% of the variation in spikelet fertility at young microspore stage cold under permanent water conditions (5 cm depth) and 42% under aerobic conditions. While at flowering stage cold, the number of ruptured anthers accounted for 29–44% of the variation in spikelet fertility. The dehiscence at young microspore stage cold exposure was at least partly related to the number of pollen in anther, indicating the larger number of pollen swelling, inducing the rupture of the anther.

The pollen germination study revealed the large negative effect of cold on pollen viability when plants were exposed to cold temperature at young microspore (Figure 4). Poor pollen viability as a result of poorly developed or immature pollen caused by cold at young microspore is also likely to result in anthers not rupturing.

The number of ruptured anthers can be determined much more easily than the total dehiscence length or total number of pollen in anther. It is a floral trait upon which phenotyping can be conducted that is strongly associated with cold tolerance at young microspore stage. Thus, anther dehiscence is critical at both reproductive stages but it explained more variation in spikelet fertility at young microspore than at flowering stage under permanent water conditions.

Floral traits of importance to cold tolerance appear to differ between aerobic conditions and permanent water at young microspore. Thus, there is a need for research under aerobic conditions especially in relation to pollen viability and pollen tube growth. At the flowering stage under cold conditions, pollen viability was reduced but not to the extent as at the young microspore stage. It is likely that anther indehiscence at flowering was a major factor but also it is now hypothesised that the cessation of pollen tube growth under cold would likely account for the low spikelet fertility at flowering stage. While anther indehiscence played a significant role in flowering stage cold, more research is required on pollen tube growth under cold temperatures. Tolerant genotypes tended to have greater numbers of pollen on stigma.

There was strong correlation between spikelet fertility under cold temperature in aerobic and permanent water conditions. This indicates that current screening methods for cold tolerance under permanent water also is suitable for selection for cold tolerance under aerobic conditions.

However, there was some interaction between genotype and water availability (aerobic and permanent water) in a number of experiments. For example, in two experiments Sherpa demonstrated a decrease in spikelet fertility under aerobic

Figure 2. Stages of the process of collecting spikelets stored under air dry conditions to count pollen grains on stigma and anther dehiscence. Left – spikelets were collected only at a certain position of the main stem panicle; top right – spikelet ready to be sampled; bottom right – sampled spikelets. (PhD work conducted by Zuziana Susanti, University of Queensland)

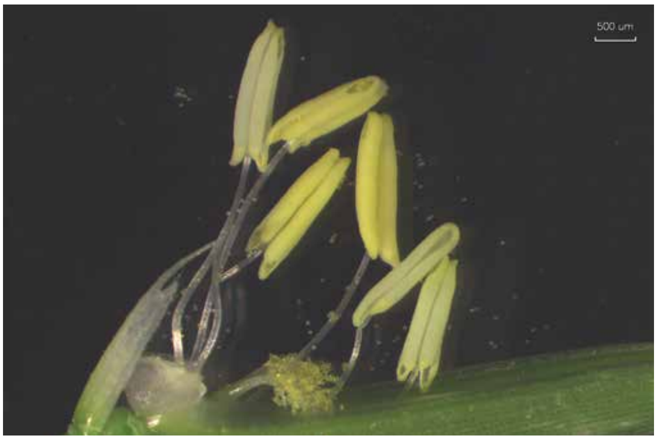

Figure 3. Image of dissected spikelet of Reiziq showing variable dehiscence (rupturing) of anthers and pollen grain number on the stigma.

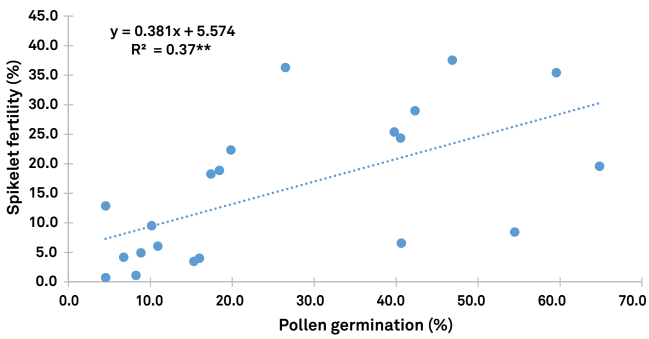

Figure 4. Relationship between spikelet fertility and pollen germination when exposed to 14 days cold at young microspore stage.

University of Queensland PhD student, Zuziana Susanti, explaining her floral trait dissection experiment to NSW DPI technical officer Kim Philpot and science student Ella Wherritt.

conditions compared with permanent water when exposed to cold temperatures at young microspore, which could have industry implications. In contrast, under warm temperature aerobic conditions Sherpa performed consistently well, achieving relatively high grain yield and maintaining high head rice yield (ACIAR project results). Thus, performance under aerobic conditions subjected to cold temperatures needs further investigation.

Enhancing the screening system

The two-stage screening system developed at the University of Queensland has enabled accurate identification of cold tolerant germplasm and floral traits (and associated QTL) contributing to cold tolerance at specific developmental stages. However, as with any system identifying physical plant traits (phenotyping) related to a particular environmental stress, the system is limited in the number of genotypes that can be evaluated each year. To this end, we were aiming to identify more QTL that could be used across thousands of genotypes through genotyping. DNA was extracted and analysed in the laboratory to identify likely QTL associated with floral traits and cold tolerance.

The phenotyping system enabled the best opportunity to identify genomic regions/QTL of importance for cold tolerance, and provided appropriate genetic material that was used. While significant progress was made with identification of genetic regions in industry-relevant varieties and genotypes (germplasm), limitations in the development of the germplasm prevented validation of the QTL identified in the project. However, progress has been made in the understanding of genomic regions of importance to cold tolerance in industry-relevant germplasm and this can provide valuable basis for future analysis on new germplasm. The improved understanding of underlying floral traits, and the co-location of the genomic regions identified for spikelet fertility and floral traits provides confidence in those identified regions.

Since 2016 the NSW DPI molecular rice breeding program has implemented a system to incorporate genetic markers (QTL) for marker assisted selection. It is understood that recently (March 2018) that the first cold tolerant markers identified have now been included in the system. Thus, there is now the opportunity for new cold tolerant markers to be added to the system used for rapid

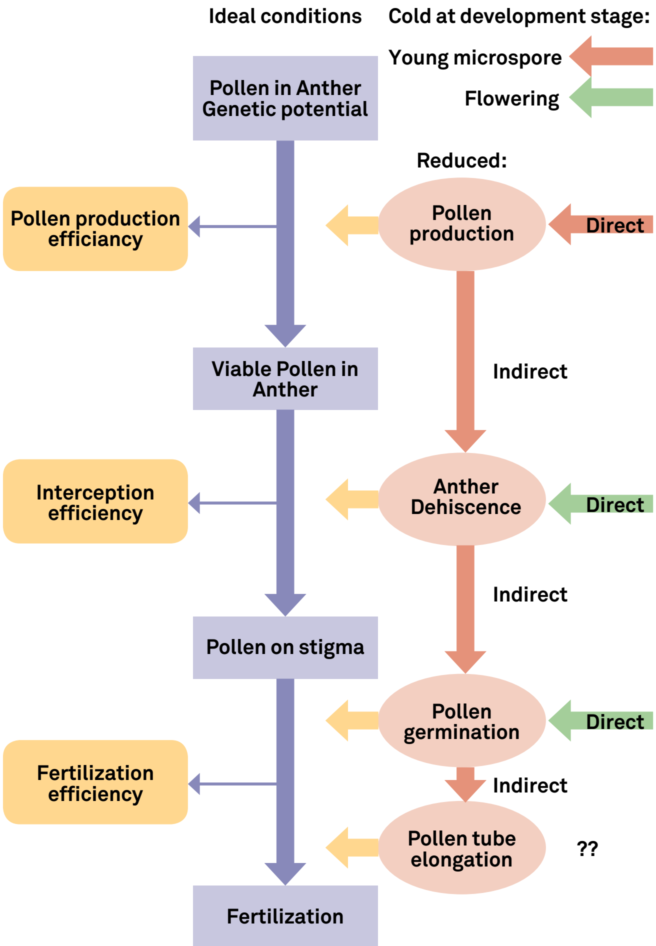

Figure 5. Schematic diagram of various floral traits as a result of 14 days cold temperature (21–15 °C) exposure at young microspore (booting) stage and flowering stage of development.

turnaround genotyping of specific loci for marker assisted selection and backcrossing. Once fully implemented, marker assisted selection would provide significant savings in both time and cost of developing new rice varieties.

Better understanding of cold tolerance mechanisms

Our understanding of the physiological mechanisms involved in cold tolerance has improved (e.g. Figure 5) and through the phenotyping system developed, our ability to identify putative QTL associated with cold tolerance has resulted. With the incorporation of identified donor material into the breeding program the base level cold tolerance across quality types within the NSW DPI rice breeding germplasm has improved. Combined, these will contribute and lead to an improved efficiency in the breeding program aimed at enhancing the cold tolerance of Australian germplasm.

New germplasm and potential varieties originating from the project are likely to offer additional cold tolerance, lower production risk and increased water use efficiency across a range of quality types. Combined, these results have led to gains in efficiency for cold tolerance in the Australian rice breeding program. This will have direct impact on growers and industry with the release of new varieties in the future that offer greater water productivity across a range of niche varieties suited to a wider range of rice growing environments across the southern region. Of note is the improvement of cold tolerance in fragrant long grain rice, which

Two Masters course work students showing NSW DPI molecular rice breeder Dr Ben Ovenden their rice experiments.

Professor Shu Fukai and a student inspecting aerobic rice experiments.

should support the growth of this commodity in the more southern irrigation valleys, i.e. Coleambally Irrigation Area and Murray Valley.

There has been good interaction and engagement with the rice breeders from NSW DPI over the duration of the project and this has ensured that as donor genotypes for cold tolerance have been identified they have been immediately incorporated into the crossing program of the rice breeding program at Yanco. As a result, NSW DPI now has populations developed between cold tolerant donor genotypes and elite germplasm that are already at an advanced generation some of which show promise with some preliminary evaluation conducted in the 2017–18 NSW DPI field experiments. Thus, it is recommended that these cold tolerant advanced genotypes, and others of known cold tolerance (not necessarily containing all the suite of agronomic and quality requirements of a variety) should be evaluated under both conventional permanent water conditions but also under delayed permanent water systems or other aerobic (dry rice) production systems in the Riverina. This field evaluation under various conditions in the Riverina would provide the breeders and industry a gauge as to whether the degree of cold tolerance that has been achieved to date is approaching that of the requirement for an aerobic production environment.

Outputs

There were seven expected outputs of this project all of which were met. We have:

1. identified key floral traits associated with cold tolerance
2. identified QTL (genetic markers) associated with cold tolerance
3. enhanced germplasm stocks with cold tolerance base level better than Sherpa
4. developed an accurate cold screening system using controlled temperature glasshouse facilities, with validation in the field
5. trained 21 students in total, including 2 PhD students (ongoing), 1 Masters by research, 9 Masters coursework research projects, 2 honours research projects and 7 undergraduate level short duration research projects
6. advanced generations of existing crosses for population work
7. benchmarked different cold tolerant varieties.

Next generation plant scientists

Through the course of this project, 21 students were trained in various aspects of plant and crop science research focused on rice. This training ranged from PhD study to undergraduate short duration research projects, as described in the previous section.

In addition to the students directly involved in research pertaining to cold tolerance, we also had three PhD students supported by the Australian Centre for International Agricultural Research working on various aspects including irrigation water requirement, quality in relation to water deficit post flowering, and effect of harvest time and germination on palatability of brown rice. While these studies were outside the scope of the project reported here, the information is pertinent in relation to the effect of aerobic production on grain quality of varieties of interest to the Australian industry. Furthermore, we have woven our research topics into the delivery of undergraduate courses thus exposing greater numbers of undergraduate students to rice as a crop and the environmental issues and challenges that the rice grower and industry faces.

Conclusion

The Australian rice production system in southern NSW has been reliant on the application of permanent water, often at depth, to protect the crop against low overnight minimum temperatures. With increasing irrigation costs and limited availability of irrigation water, adaptation to growing conditions using less water is sought.

As a consequence, there has been a research emphasis on aerobic (dry rice) production in the AgriFutures™ Rice Program R&D Plan 2016/17-2021/22. For a paradigm shift to a much lower water use rice production system for the Riverina, it is essential that donor varieties adapted to aerobic and cold conditions are identified. For an aerobic rice production system to be feasible in the Riverina production environment, only genotypes with a very high level of cold tolerance can be used.

Acknowledgement

This is an AgriFutures Australia funded project.

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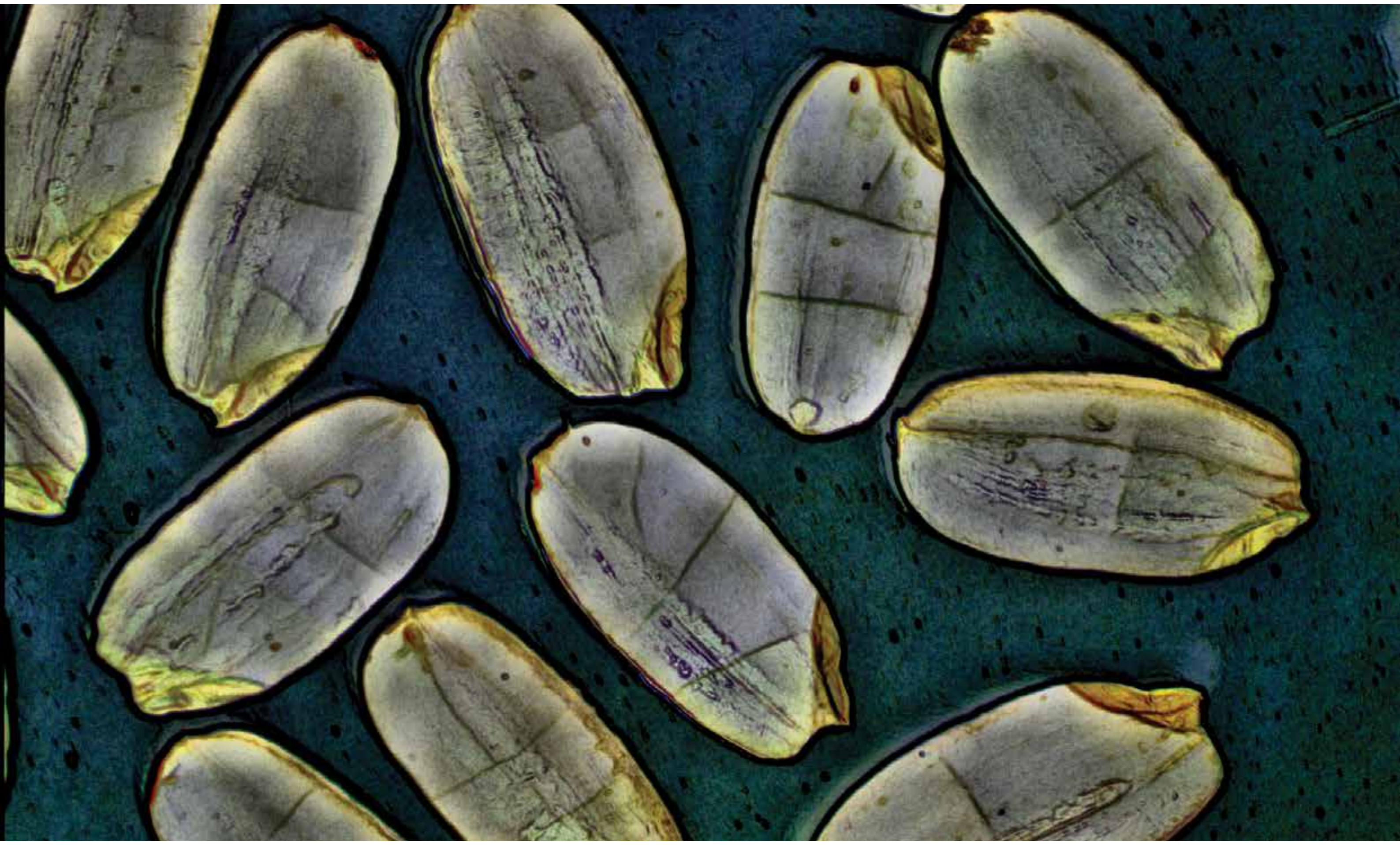
Research into grain cracking and breakage of rice



Mark Talbot[1], Prakash Oli[2] and Peter Snell[2]
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AgriFutures Australia Project PRJ-009950
Australian Rice Partnership II

Project timeframe
June 2015 to May 2020

Photograph
A composite image of brown medium grain rice. Several lighting angles and image analysis were used to compose the final image that accentuates the cracks in the grain, which are seen as the dark lines across the grain.
IMAGE: Mark Talbot

THE SHORT STORY

Cracked rice grain poses potential economic risks to the rice industry as it leads to broken rice during milling, reducing the quality and value of the rice.

Grains can also crack after milling, potentially leading to further breakage and reduction in quality and value. Rice cracking is especially sensitive to changes in relative humidity.

A collaboration between NSW Department of Primary Industries and SunRice is aimed at researching grain cracking and breakage before and after milling to reduce risk to the rice industry and ensure maximum whole grain yield and returns to growers and processors.

— Continued

The breakage of rice during milling, which is mostly due to cracked grains, has economic consequences for the whole rice industry. Growers receive lower returns for a low whole grain yield, and broken grain is of lower value and quality for processors.

There are many factors contributing to grain cracking, including variety, farm management, harvest moisture, storage and drying conditions, and milling conditions.

In order to better understand the phenomena of rice cracking and breakage, a collaboration was formed between the NSW Department of Primary Industries at Yanco Agricultural Institute and SunRice. This partnership brings together rice breeding, agronomy, cereal chemistry and biological research skills and industry experience to investigate the wider aspects of cracking and breakage, from planting in the field to packing the milled rice.

Although much is known about how cracking leads to milling breakage, little is known about cracking and breakage after milling. Post-milling breakage can be a significant problem, leading to reduced quality and negative processor and consumer preference. This article outlines what we already know, and what we have learnt from a preliminary study of milling processes that lead to cracking and breakage.

How and why do grains crack?

The main culprit of cracking in milled rice is large changes in relative humidity (moisture) of the surrounding environment. Rice grains are hygroscopic and they exchange moisture readily with their environment. When relatively dry grains (low moisture content) absorb moisture, or relatively high moisture grains dry out, stress forms within the grain, potentially leading to the formation of cracks. This can occur at any stage, from grain maturation in the field, to packing milled rice. However, the likelihood of grains to crack increases as the grains are de-hulled to brown and polished to white, as the hull and bran layers provide protection against the migration of moisture. Cracks can either form internally from absorption of moisture, or on the surface, as a result of moisture loss (Figure 1).

Breakage during and after milling

While removing the hull can induce some breakage, most of the breakage occurs when brown grains are polished to white. Brown grains containing two or more internal transverse cracks

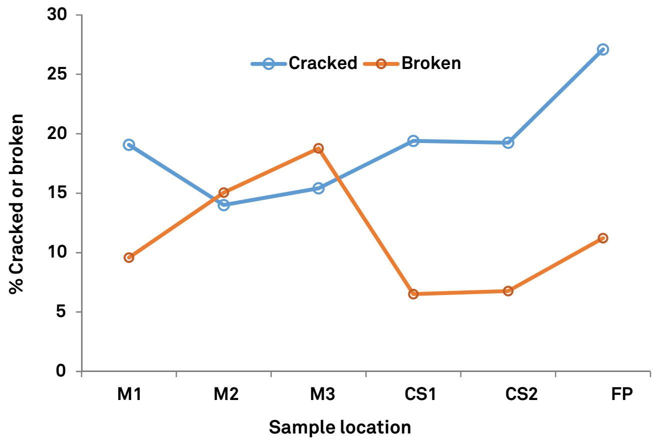


Figure 2. Percentage of whole grains that are cracked or broken during milling (M) and colour sorting (CS) and in final product (FP) processes at the mill. Averages of three sampling dates are shown for the period 6 December 2017 to 10 January 2018.

are weaker and are therefore more likely to break during milling than grains with single transverse cracks. Currently, cracks are measured in white (milled) grains. However, we are developing capacity to measure cracks in paddy and brown grains, as this will give an indication of whether the grains will break during milling.

Immediately after milling, broken grains are removed from the final product using an indenter machine before packing. However, as mentioned above, polished (white) grains are the most susceptible to changes in moisture and form cracks more readily than brown or paddy grains. Milled grains, whether they contain cracks or not, can potentially crack further and break if exposed to adverse conditions and rough processing or handling, leading to a lower quality rice post-milling.

It is known that exposure of milled rice to high (>75%) or low (<40%) relative humidity for just 20 minutes can increase breakage of rice when subjected to force. During summer, when maximum temperatures average 33 °C in the Riverina, relative humidity can be as low as 8% during the afternoon.

Samples taken at the mill during December 2017 and January 2018 show that on average the percentage of cracked grains increases during successive stages of milling, up to when the rice is ready to be packed (Figure 2). This can contribute to an increase in the

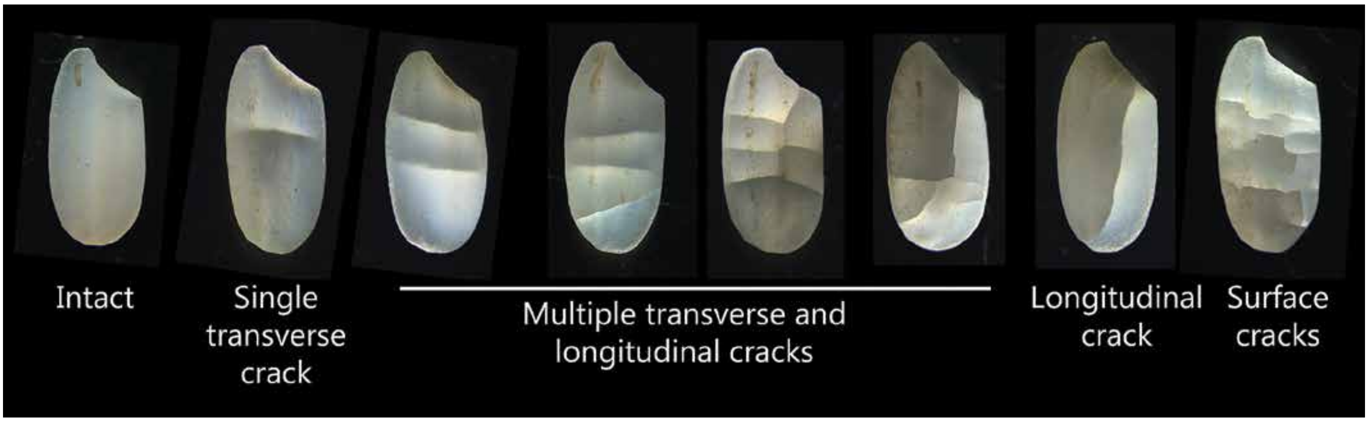
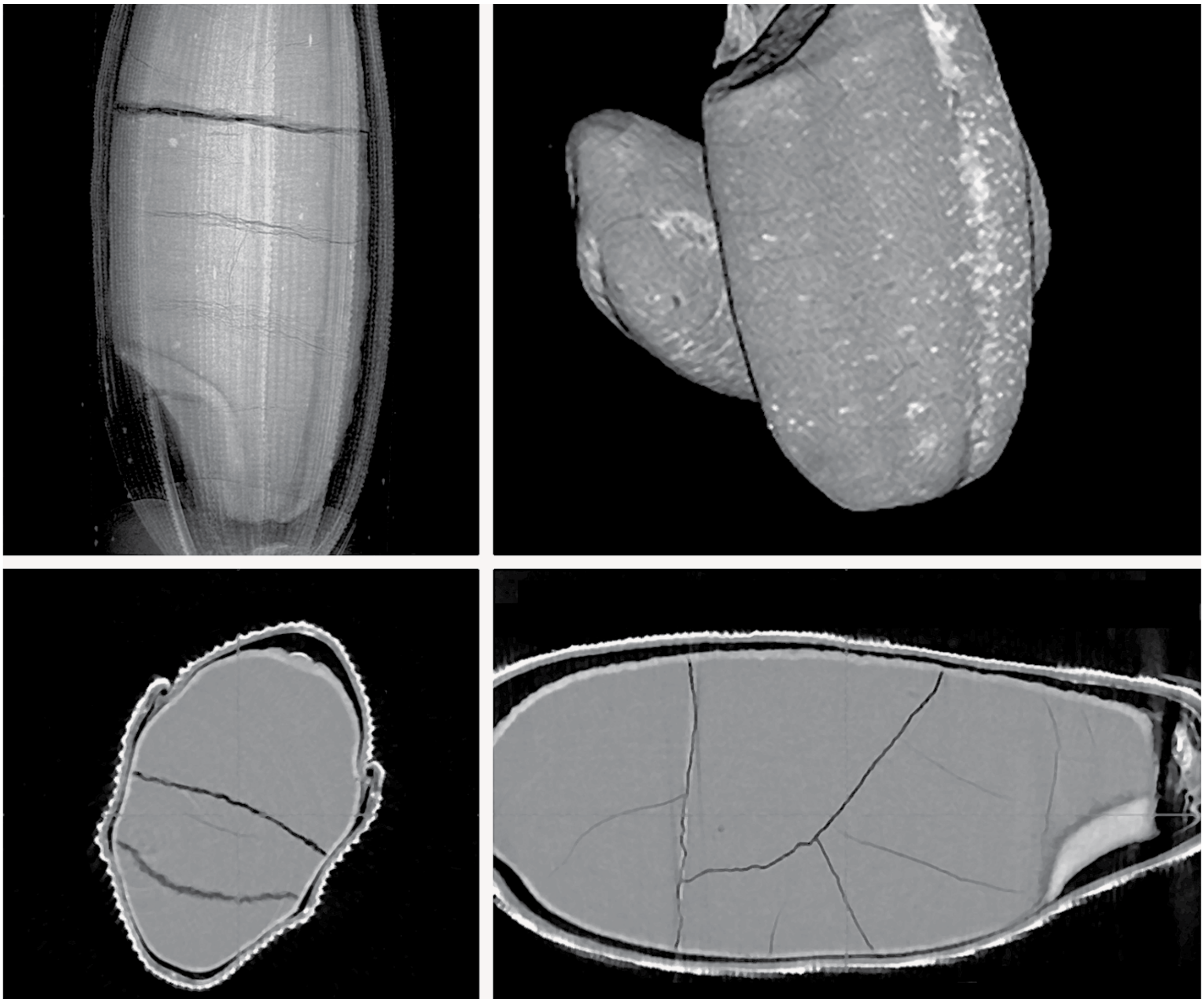


Figure 1. The extent of crack formation in polished white medium grains. The appearance of all types of cracks is similar in short, medium and long varieties, and in brown grains.



3-D imaging of cracked paddy rice with X-ray micro-CT scanning. X-rays can see through the hull (top left) and capture images of cracks right through the grain (dark lines in bottom left and right). A 3-D reconstruction of two grains is shown in the top right.

percentage of broken grain in the final packed product. Exposure of rice to dry, hot air is the most likely cause of such cracking and breakage.

Where to from here?

Our research is focused towards reducing post-milling cracking and breakage, through increasing knowledge of cracking, and the stages in milling processes that are most susceptible to changes in relative humidity. Study will be undertaken in the following areas:

1. Increased efforts to breed crack-resistant varieties. Further research into how farming practices can affect whole grain yield.
2. Investigating effects of relative humidity and temperature on cracking and breakage at different stages of milling and handling, throughout the different seasons.
3. Simulate relative humidity and temperature conditions experienced in the mill to establish safe environmental conditions for milling and handling of rice.

This research will ensure maximum whole grain yield and returns to growers and processors, and support the continued growth of the rice industry.

Acknowledgements

This research was co-funded by SunRice, NSW Department of Primary Industries and AgriFutures Australia.

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Dr Prakash Oli Pallas, Cereal Chemist, NSW DPI
Dr Peter Snell, Rice Breeder, NSW DPI

Coloured rice: a rich source of health promoting compounds

PhD study

Esther Callcott and Shiwangni Rao
PhD candidates, Charles Sturt University

AgriFutures Australia Project PRJ-009805
Next generation healthy rice

Photograph
Rice grain comes in many colours in addition to white. PhD students at Charles Sturt University are investigating the anti-obesity and anti-cancer potential of extracts from coloured rice. PHOTO: Shiwangni Rao

Coloured rice contains compounds that have a positive impact on cell growth and metabolism, and may assist with obesity and cancer prevention.

The wild ancestors of today's rice were the species *Orzya rufipogon*. The '*rufipogon*' part of the name reflects the red grain colour of wild rice. White rice grains would have been unusual among the many red grains grown and eaten over millennia. White grain must have been preferred and plants were selected, propagated and grown, so that white became the dominant grain colour of rice. Selection for white rice, however, is only part of the domestic rice story.

A diverse range of coloured rice varieties generated from *Orzya rufipogon* ancestors exists in Asia today, ranging from pale red through to deep purple-black. The coloured grain of these varieties is due to the presence of compounds called polyphenols; which are the very same compounds responsible for colours in fruits and berries, and their products such as fruit juice and red wine.

The link between 'red' colour and good health

During 1980s lower levels of circularity system disease were observed in French people, including heart disease. This 'French paradox' was attributed in part to moderate red wine consumption.

Anthocyanins, which give red wine its colour, are part of a group of related compounds called polyphenols. The French paradox inspired much research, which found polyphenols in grapes and many other fruits were responsible not only for fruit colour but they also were associated with positive effects on human health, most likely by virtue of their antioxidant and anti-inflammatory activity.

Given coloured rice contains polyphenols, it seemed likely coloured rice could also deliver similar outcomes. 'Likely', however, is not sufficient for a health claim and strong evidence is required. PhD students at the Functional Grains Centre, Esther Callcott and Shiwangni Rao, are looking at two different aspects of the health properties of coloured rice: the anti-obesity and anti-cancer potential of coloured rice. These aspects are linked to two important health issues, affecting many in our community.

Improved health-related markers for obesity

Rates of obesity are continuing to rise in Australia and many parts of the world. Obese individuals suffer from high levels of oxidative stress and inflammation, two important phenomena that can be measured in the laboratory. Oxidative stress leads to cellular damage by attacking the cells and initiating an inflammatory response. The intricate association between oxidative stress and inflammation contributes to a vicious cycle causing further destruction of cells, leading to tissue damage, which of itself can lead to negative outcomes such as heart disease or type 2 diabetes.

Cells under oxidative stress and or engaged in the inflammatory response express particular genetic and physiological markers, which are a signature of the oxidative stress and inflammation.

Human cells can be harvested and grown in a laboratory under simulated physiological conditions by a process known as tissue culture. Cells in tissue culture behave in a similar way to cells that are growing within the human body responding to stimuli.

Esther Callcott extracted and concentrated polyphenols from coloured rice varieties Yunlu29 and Purple, and non-coloured Reiziq and applied the extracts to stem cells at increasing concentrations in tissue culture. The stem cells were grown into fat cells in the presence of the rice extracts, and after seven days were harvested and fat accumulation and gene expression of the master regulatory gene responsible for fat cell development were measured.

Extracts of Yunlu29 and Purple applied to stem cells in tissue culture reduced expression of fat cell genes at low extract concentrations, while addition of Reiziq extracts only had an effect at high concentrations — five times that of the Purple and Yunlu29.

Perhaps the most compelling evidence of a response to the addition of extracts of coloured rice was the reduction in fat accumulation in the fat cells. Unfortunately, addition of Reiziq extracts had no effect on reducing fat accumulation (Figure 1).

The next step was to determine the anti-inflammatory and antioxidant effect of rice extracts on endothelial cells that are found in blood vessels. The cells were treated with extracts from Purple, Yunlu29 and Reiziq and placed in conditions that simulated oxidative stress. The polyphenol extracts from coloured and non-coloured rice extracts reduced proteins associated with inflammation. However, only coloured Yunlu29 had the most consistent and greatest impact on inflammatory protein reduction. Purple clearly had the greatest effect of increasing antioxidant levels in cells, while Yunlu 29 and Reiziq had a much lower effect.

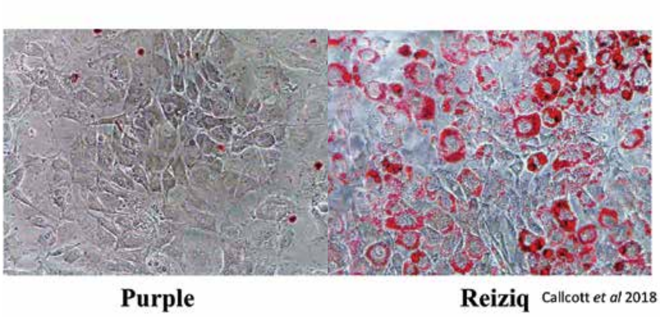

Figure 1. Laboratory studies showing extracts of coloured rice (Purple) added to fat cells in tissue culture reduced fat accumulation, as indicated by red dye, compared to white rice (Reiziq). IMAGE: Esther Callcott

Esther's work with endothelial and fat cells has clearly demonstrated coloured rice extracts reduce fat accumulation and oxidative and inflammatory responses. These results show that coloured rice could have a significant and positive impact on regulating cell growth and metabolism.

Coloured rice may be part of cancer prevention

Shiwangni Rao worked on cells to understand effects on cell growth. This work is part of a field where understanding the impact on cell growth is paramount — the prevention of cancer.

Shiwangni also worked with polyphenol extracts derived from coloured and non-coloured rice varieties. The coloured varieties were Yunlu 29, Purple, Black Gora and Lijiangheguie, while the non-coloured were Sherpa, Reiziq, Topaz and Langi. Shiwangni confirmed coloured varieties had higher concentrations of polyphenols with anti-oxidant activity than non-coloured varieties. In addition, the level of polyphenols in any one rice variety was influenced by environment, with total phenolic content and antioxidant activity higher in Yanco-grown rice compared with Mackay-grown rice, while the content of coloured compounds was higher in Mackay-grown than Yanco-grown rice. As significant as these results may be, the impact of addition of these extracts to cancer cells were the most compelling.

Cancerous cells do not follow the normal path of cell growth and division. Apoptosis is a term used to describe natural programmed cell death — a process by which the body disposes of dead, damaged or old cells. This process differs from cell death due to the toxic effects of an applied compound.

When Shiwangni added polyphenol extracts of rice to cancer cells growing in tissue culture, she found the extracts promoted cell death through apoptosis at a rate much higher than untreated cancer cells. Although coloured rice may not cure cancer, the results suggest coloured rice in combination with other factors may help in cancer prevention.

Acknowledgements

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Rice starch digestibility: glucose makes the world go round

PhD study

Wei Zou
Postdoctoral Fellow, Charles Sturt University

AgriFutures Australia Project PRJ-009805
Next generation healthy rice

The Functional Grains Centre has developed a rapid laboratory-based rice starch digestibility assay that will accelerate breeding new low GI rice varieties and the generation of new rice food products.

The human body and its organs are remarkably adaptable and can run on energy derived from fat, protein and carbohydrate — with one exception, the brain. The brain depends on one type of carbohydrate for energy — glucose. And it is needs a lot of glucose, using around 20% of the energy consumed by a human each day. Fortunately, high starch foods like rice are packed full of starch that is broken down into glucose during digestion, so we have many brain food options available.

This should be a good news story for rice, however, obesity rates are rising, both in Australia and around the world, and higher rates of obesity bring with it higher rates of adult-onset diabetes.

Adult-onset diabetics have difficulty keeping their blood sugar at levels compatible with good health. Excessively high blood sugar levels can damage small blood vessels (capillaries) in important organs such as the eyes and kidneys, potentially leading to blindness and kidney failure, respectively.

High starch digestibility is useful when you need a quick burst of energy, however the combination of adult onset diabetes and high starch digestibility is not a good match. Starch digestibly differs widely between rice varieties, which in turn mean some varieties are more suitable for adult-onset diabetics and people with a general concern in controlling their blood sugar levels than other varieties. Basmati rice is generally recognised as having rice starch of low digestibility while sushi-style rices are generally believed to have highly digestible starch.

The glycaemic index (GI) is one way of measuring the blood sugar response of particular foods, with consumption of low GI foods initiating a lower blood sugar response. The Australian rice variety Doongara is low GI, giving this variety a market place advantage and new improved low GI varieties are an important breeding target for the rice industry.

Breeding new low GI rice varieties

Low GI maybe a breeding target, however, hitting this target is easier said than done. Measuring GI is very slow and expensive. It involves feeding human subjects then taking blood samples over a period of two hours. There is wide variation in individual human starch digestion rates so we need to take the average GI of many individuals. A faster method is needed for a rice breeding program, which screens thousands of rice lines.

We know GI is associated with amylose content. The higher the amylose content, the lower the GI. But amylose content is only part of the picture since there is wide variation in GI between varieties that have the same amylose content. Since we don't know why this is the case, we need some ways of predicting GI without using laborious measurement of GI in human subjects.

New rapid laboratory analysis

The Functional Grains Centre has developed a rapid laboratory-based rice starch digestibility assay, which will accelerate breeding new low GI rice varieties. Several such assays have been developed, many of which attempt to mimic the complex process of human digestion. Research within the Functional Grains Centre, first by Dr Vito Burtado and more recently by Dr Wei Zou, has demonstrated complex assays are not necessary. A simple assay using only two enzymes, buffer and whole rice grains, allows accurate prediction of rice GI. This assay can process dozens of samples in one day and it is hoped it will assist the Australian rice industry to develop low GI rice varieties more quickly, while improving agronomic features.

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Exploring the health benefits of stabilised rice bran

PhD study

Nancy Saji
PhD candidate, Charles Sturt University

AgriFutures Australia Project PRJ-009805
Next generation healthy rice

The shelf life of rice is improved by milling because the outer layers of the grainremoved by milling, the bran, contain lipids that become rancid during storage. According to most rice consumers, milling also improves flavour and texture.

The risk of bran becoming rancid is reduced by a process of rice bran stabilisation. However, rice bran stabilisation may have other impacts on rice bran properties, including health benefits.

Rice bran is a rich source of nutrients that has a number of beneficial health properties. The lipids and phenolic compounds in rice bran in particular are known to modulate starch digestibility and have antioxidant, anti-inflammatory and cholesterol-lowering properties that can assist in the prevention of several diseases, including type 2 diabetes and cardiovascular disease.

PhD student at the Functional Grains Centre, Nancy Saji , is exploring the beneficial health properties of stabilised bran from the rice variety, Reiziq. Nancy is examining its impact on markers of type 2 diabetes and cardiovascular disease.

First, Nancy studied the chemical profile and antioxidant capacity of stabilised and non-stabilised rice bran and whether different stabilisation methods differ in their effect on the phenolic compounds of the bran.

Nancy analysed the fatty acid profile of Reiziq rice bran and found it to be abundant in palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid. All of these are fatty acids known to have a number of beneficial health properties including anti-carcinogenic, anti-blood clotting and cholesterol lowering properties, decreasing blood pressure and reducing the risk of stroke and heart disease. Importantly, Nancy found bran stabilisation did not affect the fatty acids and the fatty acid profiles did not differ between stabilisation processes.

Where the impact of bran stabilisation on fatty acid profiles was neutral, the impact on phenolic content was positive. The total phenolic content and hence antioxidant activity and free radical scavenging activity of stabilised rice bran was higher than non-stabilised rice bran. It seems the process of rice bran stabilisation releases compounds that will have health-promoting activity for people that eat stabilised rice bran.

These laboratory-based assays are just the start of Nancy's project. Nancy will undertake further research to look at the impact of rice bran stabilisation on starch digestibly and markers of blood clotting and blood vessel heath, culminating in human clinical trials that will assess the impact of stabilised rice bran on risk factors of associated with cardiovascular disease in type 2 diabetes patients.

Acknowledgements

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Rapid prediction of GI of rice through starch structure

PhD study

Matthew Van Leeuwen
PhD candidate, Western Sydney University

AgriFutures Australia Project PRJ-010712
Predicting the glycaemic index of rice

Photograph
Matthew Van Leeuwen is using nuclear magnetic resonance (NMR) spectroscopy to characterise starch to more expediently determine glycaemic index of breeding lines in the rice breeding program.

New opportunities arise frequently in the consumer market for rice, and currently we are experiencing a healthy food movement. Health-conscious consumers are seeking foods that are slower to digest and extend the feeling of satisfaction, i.e. low GI foods.

On the basis of costly laboratory testing, foods can be classified as being low, medium or high glycaemic index (GI). Foods with a GI below 55 are considered to be low GI.

The development of low (GI) rice varieties is a current focus of the rice industry to satisfy this health food consumer market. Currently, the only Australian long grain variety classified as low GI is Doongara, however there is interest in expanding consumer choice for low GI rices in different quality classes.

Selection for low GI in breeding lines is dependent on having the ability to directly or indirectly measure digestibility. It is also critical to understand the drivers of GI so that selection processes can

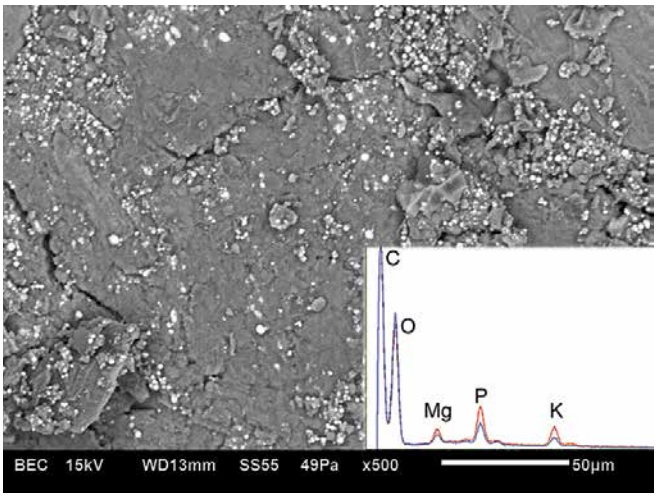

Figure 1. Electron microscope image of a raw Doongara grain and the elemental composition of the grain (inset)

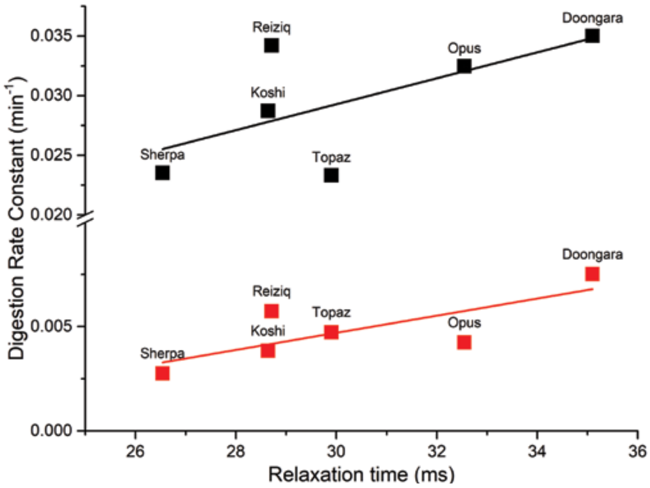

Figure 2. Relaxation time of cooked rice grains plotted against the initial rate (black) and secondary rate (red) of digestion

occur earlier in the breeding program. An added consideration is the need to screen a few samples from a large number of lines, with minimal cost and ideally before sowing decisions of the next crop in the breeding program.

Developing tests for the rice breeding program

This project aims to develop a suite of phenotypic screening techniques (i.e. identify physical characteristics or aspects of the rice grain associated with low GI) that can be implemented at the F5-6 stage of the rice breeding program to select breeding lines with low GI, by focusing on the characterisation of starch in rice.

Native rice starch is incredibly complex, with a hierarchical structure at six different levels of organisation ranging in scale from nano- to micrometres. Starch structure will be characterised at each level by advanced analytical techniques. Samples used in the project are directly relevant to the rice breeding and quality program (Australian Rice Partnership II PRJ-009950).

The different levels of starch organisation of milled samples will be analysed both raw and after cooking using the excess water method. Surface morphology and atomic composition of the raw milled rice grains will also be assessed by electron microscopy with the aim of discriminating breeding lines (Figure 1).

The link between starch structure and rice digestibility is a major focus of this work. Starch is composed of varying proportions of amylose and amylopectin. Apparent amylose content is a quality trait used extensively in the selection of new varieties, and has been shown to have a link with digestibility. However, the apparent amylose content is not the only driver of digestibility.

At the molecular level, capillary electrophoresis is used for decoding genomes, but was an underexplored technique for starch in rice. We can now use it to separate the amylose in rice from the more branched amylopectin molecules, allowing more accurate determination of amylose content and an ability to quantify starch structure. This structural information also offers further insight about other rice grain properties such as texture.

Also at the molecular level, we have probed the molecular dynamics of the starch structure through 1H solid-state nuclear magnetic resonance (NMR) spectroscopy. Using the same technology as an MRI in a hospital, this is a relatively new approach in the study of rice, and early results have been promising. Figure 2 shows the influence on digestibility of relaxation time, an intrinsic magnetic property affected by starch structure on the molecular scale.

At the nanometre level, X-rays will be used to assess the amount of ordered starch structure, focusing on semi crystalline and crystalline regions within the starch granule. A complementary analysis of the crystalline components is done by solid-state NMR spectroscopy; however, this time we are monitoring the ^{13}C atoms rather than the ^{1}H atoms within the sample. This more fundamental analysis aims to fill some gaps in the scientific literature about the structure of starch in rice and how it can be affected by factors from genetics to growing conditions.

Reliable, affordable GI prediction

The value of each of these sophisticated measurements of starch structure to predict the digestibility of rice is compounded by the ability for the research and development community to adopt the technology, techniques and analysis of results. Instrumentation is relatively affordable with minimal operating costs, requires minimal sample size, has high sample throughput and operators need minimal training.

Working on a diverse sample set relevant to the rice breeding and quality program, interpretation of results and their application to digestibility (and other eating qualities) is highly beneficial to the goal of more low GI rice choices for consumers.

Acknowledgements

Dr Marion Gaborieau, Dr Patrice Castignolles, Prof. Gerald Muench and Dr Rachelle Ward (NSW DPI), Prof. Elliot Gilbert (ANSTO) and Prof. Chris Blanchard and his team, for discussions and guidance.
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Managing greenhouse gas emissions in rice growing systems

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AgriFutures Australia Project No PRJ-008574
Rice stubble, fertiliser and water management options to reduce nitrous oxide emissions and build soil carbon

Project timeframe
June 2014 to April 2017

Photograph
Static chambers positioned in plots with external reflective foil to minimise heat build-up within the chamber during the 1.5 hour incubation period.

THE SHORT STORY

Emissions of methane from temperate rice crops under current farmer practices were within the range of similar productions systems across the globe.

Drill sowing and delayed permanent water in the temperate Australian rice industry reduced in-crop methane emissions by more than 50% without significantly increasing nitrous oxide emissions.

Pyrolysing stubble (creating biochar) and re-applying it to soils did not appear to increase methane emissions from rice crops. The addition of pyrolysed rice stubble also resulted in significant increases in soil carbon when applied over three consecutive seasons.

Autochambers used to quantify methane and nitrous oxide emissions in the 2015–16 season.

The potential to manage greenhouse gas emissions in rice production systems was investigated in the Murray Valley over three seasons.

This project established a hub site at Rice Research Australia, Jerilderie, to investigate the impact of water management on methane and nitrous oxide emissions from flooded rice crops. The project also investigated whether changes to stubble management could maintain or reduce methane emissions while increasing soil carbon over three seasons.

A satellite site was established to investigate stubble management options to build soil carbon without increasing methane emissions. Two sites were also established in the subtropics of northern New South Wales to investigate whether changes in nitrogen fertiliser management could reduce nitrous oxide emissions from aerobic rice systems. The outcomes and outputs of the project have established baseline methane and nitrous oxide emissions for temperate (flooded) and subtropical (aerobic) rice systems; and provided rice farmers with management options practices to minimise these emissions and build soil carbon.

Key findings and implications

Emissions of methane from temperate rice crops under current farmer practices, of around 30 g methane/m^2/season, were within the range reported for similar systems across the globe. Methane emissions were the dominant greenhouse gas contributor to global warming potential in these systems, with nitrous oxide emissions making a near negligible contribution.

Methane emissions could be reduced to less than 15 g methane/m^2/season without increasing nitrous oxide emissions by drill sowing crops and applying permanent water 4–5 weeks after sowing, instead of flooding soils prior to sowing followed by aerial seeding. Given the water savings associated with drill sowing systems, this appears to be a viable option for significantly reducing the temperate rice industry's methane emissions while maintaining grain yields.

While methane emissions increased when stubble was incorporated rather than being burnt or baled and removed, applying pryolysed (biochar) or composted stubble did not increases methane emissions, and applying pyrolysed stubble over three consecutive seasons resulted in increases in soil carbon.

One key question as a result of the trials in this project is whether pyrolysing stubble is economically viable, and a full life cycle analysis is required.

The trials in this project also focused on rice-on-rice rotations, but given the increase in rice following winter cereal or oilseed crops further studies are needed to resolve baseline emissions and potential mitigation options in these rotational systems.

Current commercially-available nitrogen fertilisers containing nitrification or urease inhibitors did not show any consistent abatement in cumulative seasonal nitrous oxide emissions in rice crops grown in the subtropics. These products have been shown to reduce nitrous oxide emissions by, on average, 40% elsewhere in the world. Therefore, steps need to be taken to resolve why they had minimal impact in the warm, humid wet subtropical region of northern NSW and efforts are needed to develop products that can lower nitrous oxide emissions in these environments.

Acknowledgements

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Advancing rice cropping systems with new rotations and layouts

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AgriFutures Australia Project PRJ-010083
Maximising on-farm irrigation profitability — rice farming systems

Project timeframe
July 2015 to May 2018

Photograph
A short season rice such as Viand, pictured sown into wheat stubble on 13 November, makes double cropping with wheat and rice possible.

THE SHORT STORY

Crop management and irrigation design were investigated to increase production and profitability of contour and bankless channel systems used by rice and cotton growers in southern NSW.

Double cropping with rice and wheat was viable when using a short season rice variety like Viand, sown in mid-November. A short season or earlier maturing winter crop was needed to ensure harvest in time for sowing of the next rice crop.

While the benefits of delayed permanent water are well proven, flush irrigating during grain filling is a risky practice. Further research is required to confirm potential water savings and impact on rice grain yield and quality.

Better understanding of irrigation layouts suited to all crops and soil behaviour after ponding for rice will help move farmers towards profitable double-cropping systems and the industry towards its longer-term aspiration of rice grown with reduced ponding.

NSW DPI and Deakin University recently completed a three-year project *Maximising on-farm irrigation profitability*, which was run in conjunction with three grower groups: Irrigation Research & Extension Committee (IREC), Irrigated Cropping Council (ICC) and Southern Grower Group (SGG).

The project aimed to increase production and profitability of rice and cotton growers in southern New South Wales. who irrigate with surface basin systems (i.e. contour and bankless channel systems). Two areas for improvement were identified: crop management and irrigation design.

Farmers from the SGG considered the greatest opportunity to improve productivity in rice farming systems lay with developing reliable and successful double-cropping practices and achieving higher yields from non-rice crops in the rotation. The key impediment to these opportunities was perceived to be the low yields of winter crops grown straight after rice, due to waterlogging.

Two possible ways of reducing waterlogging to lift winter crop yields were considered by SGG and the project team:

- the use of raised beds to improve winter drainage
- flush irrigation of rice to provide a more aerobic soil environment.

Ideally, irrigation layouts should allow crops to be watered and drained within 10 hours. This is considered necessary to avoid waterlogging losses and achieve high yields in non-rice crops. It is also essential for successful flush irrigation of rice during establishment. Slow drainage times are a major issue in rice layouts (basin layouts) with side-ditches but there are no current design criteria to inform the construction of faster draining basins.

The fact that water backs up in contour bays through the side-ditch can be clearly seen in Figure 1. Drainage times in excess of 40 hours were measured in this instance. Both irrigation measurements and the modelling show that drainage times can be markedly decreased and that irrigation opportunity times of 10 hours are achievable.

Rice–wheat double cropping trial

As part of the 'Max' project a field experiment/demonstration was established on a sodic transitional red brown earth soil at Rice Research Australia Pty Ltd (RRAPL), Jerilderie.

The three-year field trial was established in October 2015 in three 2.6 ha bays on a basin layout. In the first season each bay was divided in half into flat and bed layouts and sown to rice. There was no significant difference between the yield of rice grown on flat and bed layouts in the 2015–16 rice crop (Table 1).

A wheat crop was grown in 2016 directly after the rice crop on the flat and bed layouts but the crop failed due to waterlogging. Following the 2016 wheat crop, the site was redeveloped to provide bays with individual layouts and another wheat crop grown in the 2017 season. This crop was cut for hay so that rice could be sown on time, in 2017.

The short season rice variety, Viand, was sown after the wheat crop was cut and the crop area was split into conventional drill and delayed permanent water (DPW) treatments on both flat and bed layouts.

Grain yield from the conventional drill sown rice was significantly higher than delayed permanent water in 2017–18 (Table 1). This was primarily due to sterility caused by the delayed permanent water treatment developing later than the conventional drill treatment, with both treatments sown at the same time. There was no significant difference between the yields from the flat and the beds within each irrigation treatment (Table 1).

In the 2016–17 season, while the RRAPL site was being redeveloped, a demonstration between a conventional drill sown rice crop and delayed permanent water with flush finish crop was monitored at Yanco. There was a 2.0 t/ha difference between the water treatments (Table 1) but it was not possible to make any conclusions about this difference as there was no replication between the treatments.

Figure 1. A contour basin system irrigated using the side-ditch on the 21 March 2017. The right-most bay is the lowest bay in the block and is being irrigated. Water is shown backed up in the six bays upstream of the bay being irrigated. The slope on the block is 1:2000 and the supply through the farm inlet was 15 ML/day. Drainage times for individual bays were in excess of 40 hours.

Table 1. Yields (t/ha) from the crops grown at Jerilderie (2015–16, 2016, 2017 and 2017–18) and at Yanco (2016-17)

Season & crop	Conventional drill sown		Delayed permanent water		Significance	LSD
	Flats	Beds	Flats	Beds		
2015–16 rice	12.0	11.1			*ns*	
2016 wheat	Crop failed					
2016–17 rice [(a)]	13.6		11.4 +PFF[(b)]		Demo only	
2017 wheat	8.6 t/ha of hay					
2017–18 rice	10.8 ***a***	10.2 ***a***	8.8 ***b***	9.5 ***b***	***sig***	0.8

(a) This was the demonstration in the two bays at Yanco Agricultural Institute
(b) This treatment had both DPW and post flower flush irrigation during grain fill

Lessons learnt about double cropping with rice

A number of 'lessons' were learnt about the viability of double cropping in the rice rotation.

- Using a short season rice variety like Viand proved a successful strategy, with good yields obtained from a mid-November sowing.
- Draining and harvesting the rice as early as possible is critical to ensure the stubble can be mulched and burned and the winter crop sown while conditions are still warm.
- A short season or earlier maturing winter crop is needed if the goal is to harvest grain in time for rice to be sown.

Discussions with growers who regularly and successfully grow wheat straight after rice highlighted the importance of getting a good plant stand by sowing the wheat before the onset of cool and/or wet winter conditions. This was not achieved in the trial block in 2016. In these experiments short-season rice followed by short-season wheat did not allow a long enough duration to harvest grain from the wheat and still enable planting of another crop.

The low soil nitrogen status in autumn and winter 2016 confirmed the need for high up-front and topdressing nitrogen rates for wheat following rice. Because there is very little nitrogen left in the soil after rice it is important to apply a higher rate of starter fertiliser and to topdress early.

There was no yield advantage from growing either rice or wheat on beds in these trials. However, raised beds have been clearly shown to provide better surface drainage in other trials, with winter cereal yields around 1.0 t/ha higher on beds than on the flat in average and wet winters in the Riverina.

Moving towards reduced ponded rice system

Rice grain yields attained under the delayed permanent water and flush finish treatments indicated good yields are possible with these irrigation treatments. The combination of sowing a short season variety, drill sowing and flushing until panicle initiation (i.e. late delayed permanent water), and draining at early grain filling and flush finishing has the potential to reduce the time that the soil is ponded (anaerobic) to around 50 days.

However, while the benefits of delayed permanent water are well proven and considerable work has gone into producing short season varieties, **flush irrigating during grain filling is a very risky practice and is not recommended for growers**. Further research is required to confirm what water savings can be achieved and potential grain yield and quality losses that could potentially occur with this practice.

Grounds for further investigation

Due to number of aspects of the field experiment program and site, it is not possible to make definitive conclusions from this research about the feasibility of double cropping and the benefits of raised beds in rice farming systems in southern NSW.

However, the project provided an indication that growing a short season rice variety, drill sowing and delaying permanent water, and draining at early grain fill and flush finishing has the potential to reduce the duration of anaerobic soil conditions to around 50 days and still produce a satisfactory yield. Further research is required to better understand the agronomy of such a system and the requirements for improved layouts, as well as develop successful techniques and tools to allow this to happen with no penalty to rice grain yield or quality.

Acknowledgements

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A focus on water use efficiency in the Australian temperate rice system

Mark Groat
Nuffield Scholar 2018

AgriFutures Australia Project PRJ-007707
Nuffield Scholarships for a rice grower

Project timeframe
August 2014 to April 2018

Photograph
Recognising diminishing availability of water and increasing competing uses of water, maximising water use efficiency in temperate rice production was the focus of Mark Groat's Nuffield Scholarship.

THE SHORT STORY

For Australian rice to remain competitive with other crops in terms of dollar returns and tonnes produced per megalitre, a paradigm shift is required in the rice production system.

Adoption of practices and systems of the top growers in the southern rice growing regions has the potential to lift average yields by two tonnes per hectare, without increasing the average water use.

A system of no till and full stubble retention in trials in India, is leading to dramatic positive results in increasing productivity, reducing water use and improving soil quality.

— Continued

Australian rice growers of the Murrumbidgee and Murray valleys (where 99% of Australia's rice is grown) can justifiably call themselves the world's most efficient rice growers.

Australians grow more top quality rice with less water than growers anywhere else in the world, with production per ML approaching one tonne and individual growers achieving 1.2–1.3 t/ML regularly. In other comparable temperate rice-growing areas of the world, 0.3–0.5 t/ML is common.

Compared with many areas of the world, Australia's irrigation water supply is relatively unique.

- Water supply is highly variable and depends on rainfall within the catchment of storage dams many hundreds of kilometres from the irrigation area. Water allocations can vary widely from one year to the next.
- Water available for irrigation has been reduced over many years through community pressure and government programs and regulations. Most recently, water availability has reduced through return of water to the environment under the Murray–Darling Basin Plan.
- Water is not only measured and paid for volumetrically on farm, it is also an annually tradable commodity that potentially goes to the highest bidder within the whole connected basin.

Rice production is not only linked to water supply but also to the price cycles of a range of other crops, all vying for the same water in any one season. This has become more acute in recent years with increased cotton plantings in the Murrumbidgee Valley (traditionally a region considered too far south for cotton), and the rapid expansion of nut plantations.

Variability of water supply and competing demands for water use poses major challenges not only to the farmer but to the rice industry as a whole.

More grain with less water

Despite Australia's world-leading benchmark water use efficiency figures, the survival and growth of the Australian rice industry depends on making the most out of every drop of water — that is, maximising water use efficiency not just in terms of tonnes per megalitre but also, when considering competition with other crops, in terms of dollars per megalitre. Although there are many factors that can contribute to increased efficiency, a 'step-change' is required for rice to remain competitive with other crops for water, and this needs to occur soon. This may mean a paradigm shift in the whole rice production system.

With this in mind, as part of a Nuffield Scholarship sponsored by AgriFutures Australia, I studied rice industries in the USA, Brazil, Uruguay, China and India. Through a visit to the International Rice Research Institute (IRRI) in the Philippines, I gained a brief insight into equatorial rice production in South-East Asia, South Asia and Sub Saharan Africa. All areas visited had unique issues and unique political and social attitudes to water use. Comparison of these areas gave a frame of reference and focus on the Australian industry. It helped identify areas where Australia can improve and what opportunities exist at both the grower and the industry level.

At its most basic, increasing water use efficiency is a combination of three key drivers:

- increasing yield
- decreasing water use
- increasing the dollar return per tonne.

Increasing yield

It is well documented that as an industry, Australia leads the world in rice yields. Whilst there is always something to learn looking outwards, sometimes it is also applicable to look inwards. The Australian rice industry is in the enviable position that crop area, yield and quality data is collected annually and stored on the one database within SunRice.

A rice field layout in Uruguay. Bays fill by cascading water over the bank into the next bay. This irrigation system is labour intensive and storm water capture and runoff control are poor.

Transplanting rice in India. Ten men can plant one hectare per day. Throughout India, 41 million hectares are planted this way. The dust storm occuring while this photo was taken carries dust from the deserts of Iran 2500 km away.

Data from the SunRice database shows an average difference of 2.0 t/ha in yield between the average industry yield and the average of the top 20% yielding crops (Table 1). While momentum is gaining in analysis and extension of this data, the industry needs to focus on a more robust and coordinated program of analysis as to why this yield gap exists and the extension of these results.

Decreasing water use

Water use by a rice crop is a combination of:

- transpiration – productive use of water the crop requires for growth
- percolation – water lost beyond the root zone of the plant
- runoff – water drained off the field and not available for reuse
- evaporation – water evaporated from the field that is not part of transpirational use.

Decreasing water use requires crop production systems that can manage one or several of these factors. There is little a grower can do to decrease transpirational losses, and losses from percolation and runoff are a factor of soil type ,and irrigation layout and design. Evaporative losses however, are a different story.

Evaporation occurs from any crop whenever there is less than full leaf canopy covering the soil/water. Evaporation is greatest from surface water (ponded water), followed by bare soil, and comparatively least from mulched soil. Evaporation is least on soils with good water holding capacity, because the soil surface can be kept dry whilst supplying adequate water to the crop at depth. Water holding capacity is a function of soil texture, soil structure and organic carbon levels.

Table 1. Five-year rolling average yields (t/ha) of southern Australian rice crops, 2014–18

Variety	Average	Top 20%	Difference
Sherpa	10.6	12.6	2.0
Reiziq	11.0	13.5	2.5
Viand[a]	9.5	11.9	2.4
Opus	9.9	11.7	1.8
Koshihikari	7.5	9.1	1.6
YRK5	7.3	9.7	2.4
Langi	9.4	11.5	2.1
Doongara	10.7	13.3	2.6
Topaz[b]	8.9	11.0	2.1

a – two years of commercial data available
b – four years of commercial data available

While many of our rice growing soils are heavy clay, they often are sodic (with poor soil structure) and have organic carbon levels of less than 1%. Could these soils be enhanced to influence water use efficiency and farm profitability? The exciting results of a long-term trial in the Punjab area of north-west India on stubble retention and zero tillage show promise for our rice production systems as well.

Figure 2. Soil physical characteristics in a long-term trial with zero till and full stubble retention (left) compared to conventional tillage showing severe crusting and soil surface exposure (right), in a wheat–rice cropping system.

Long-term tillage trial

An innovative machine (conceived by engineers from the Griffith Laboratory of CSIRO back in the 1990s) that mulches heavy stubble loads directly in front of the planting tine enables wheat to be planted directly into heavy rice stubble loads. The associated effects of full stubble retention and zero tillage in rice–wheat rotation is the subject of a long-term research trial currently in its tenth year at the Indian Centre for Agricultural Research, Karnal, north-west India.

Results show a 40% decrease in water use within the cropping system, decreases in global warming potential, energy requirements, and weed seed bank. It also shows increases of 80% in organic carbon, 290% microbial biomass, 40% higher system yields as well as increases in nutrient availability and soil physical properties (Figure 2).

If the practices and results of this trial could be repeated in Australia, and then integrated with a delayed permanent water system for rice, on a bed layout with high water flow for efficient irrigation management, this could provide the 'paradigm shift' of water efficiency within Australia's rice system.

Not only would this dramatically increase water use efficiency, it would develop a rice production system that is the world leader in sustainability and productivity, as well as an integral cog in the rejuvenation and enhancement of physical, chemical and biological aspects of the soil.

Increasing dollars per tonne

A new rice production system would greatly enhance the (already excellent) international reputation of the Australian rice industry in terms production and sustainability. International food companies have a greater focus on sourcing environmentally sustainable and socially acceptable products. Individual consumers want to know more about their food and trust in its source. Australia has a great story to tell, and opportunities lie in getting this positive message to customers and consumers.

Telling the rice story in a coordinated and effective way turned community perception of the Californian rice industry from a 'water hungry environmental vandal' to one of 'an essential part of an ecological success story of water fowl migration across the Americas' (California Rice presentation Feb 2018). Environmentalists now fight for flooded rice culture.

A better production system that uses fewer resources and meets consumer expectation potentially increases the value of the product

In the words of Wyn Ellis, coordinator of the UN initiative Sustainable Rice Platform, "on a world scale it is incredible what you [the Australian rice industry] is achieving in sustainable rice production. It is also admirable that you are so humble in your achievements but at some stage you need to start shouting this from the rooftops".

Yes, this is a challenging time for the Australian rice industry, and variable water supply and water market forces means it will likely remain so. Is this a threat or an opportunity?

The choice is ours.

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