The Future of Australian Rice Production

A Focus on Water Use Efficiency in the Australian Temperate Rice System

A report for

By Mark Groat

2017 Nuffield Scholar

May 2020

Nuffield Australia Project No 1704

Supported by:

Scholar Contact Details

Mark Groat

Farm 1641, PO Box 31

BEELBANGERA, NSW 2680

Phone: 0427 686 966

Email: westraymt@gmail.com

NUFFIELD AUSTRALIA Contact Details

Nuffield Australia

Telephone: 0402 453 299

Email: enquiries@nuffield.com.au

Address: PO Box 1021, NORTH SYDNEY NSW 2059

Executive Summary

Australian rice growers can justifiably call themselves some of the world's most efficient producers. As an industry, it grows more top quality rice with less water than anywhere else in the world.

Australia's southern irrigation areas of the Murrumbidgee and Murray Valleys (where over 99% of Australia's rice is grown) is a system where water supply is sourced from reservoirs that rely on annual runoff. Supply is variable and there is now less water available for agricultural use since the implementation of the 2012 Murray Darling Basin Plan (see footnote).

Water is also an annually tradable commodity. Huge variability of rice production exists each year, not only due to variations in water availability but commodity prices of a whole range of crops competing for the same water. This has become more acute in recent years with the increase in cotton plantings in the Murrumbidgee Valley, and rapid expansion of nut plantations. This production variability poses major challenges, not only to the farmer but also industry as a whole.

The future survival and growth of the Australian rice industry depends on making the most of every drop of water. An urgent step-change is required for rice to remain competitive and continue to thrive as an industry.

This report compares Australia's rice industry to those in other temperate regions of the world, mostly in terms of production but also where water lies in social consciousness and government policy. This gives a frame of reference to focus on and identifies opportunities for Australia.

It explores the role of genetics and industry's reliance on genetic improvement to provide the 'silver bullet' for water use efficiency (WUE).

It also identifies the role that industry must play to enhance farm systems; what it can learn from not only looking elsewhere but the opportunities that exist from looking within.

It analyses current rice production practices and explores potential step changes for the 'rice system' to increase WUE and profitability, as well as enhance industry's reputation and international marketability.

This is an extremely challenging time for the Australian rice industry but also a time of immense opportunity. Decisions made today will decide if the industry over the next decade is surviving from one year to the next, or is an example and inspiration of what Australian producers, and an Australian commodity industry, can achieve.

Footnote: The Murray Darling Basin Plan was conceived in 2007 (Commonwealth Water Act 2007) and implementation scheduled from 2012 to 2019. Approximately one third (3200GL) of currently available water is to be diverted from agricultural use. Further explanation is in the Introduction section following. For more information see https://www.mdba.gov.au/basin-plan

Table of Contents

List of Tables

List of Figures

Foreword

Having experienced the so called ‘millennium drought’ at a critical time in our (rice based) farming business of asset expansion and business vulnerability, I saw firsthand how exposed and unprepared the irrigation industry, and particularly the rice industry, was to such devastating circumstances.

As with most irrigation systems, cashflow is based on intensive, high-turnover production. Production is based on water, and when water became scarce for an extended period of time the industry was in a lot of pain.

Drought, the separation of land and water titles (since 2008 water is a commodity in a free market system going to the highest bidder), and the implementation of the Murray Darling Basin Plan have changed the goalposts of water availability permanently.

Rice has an undeserved reputation of high water use and comparatively low WUE, or the amount of product produced per unit of water. Regardless, rice is just another crop competing within a common water market. Therefore, profitability per megalitre is paramount and increasing WUE is the key driver to sustained production of Australian rice.

Over 98% of Australia’s rice is marketed through Ricegrowers Cooperative Limited (trading as SunRice), which dries, stores, processes and markets both core rice and value-added products. Farm gate price to the grower is a function of cost of processing and marketing. The continuity of supply therefore enables the industry to minimise cost of processing and maintain high value markets for rice, which in turn increases the farm gate price to the grower.

Supply, high value marketing, and grower returns are all intrinsically linked with WUE.

Arguably, the combination of technology, irrigation design, crop protection products and rice genetics have opened the door to maximise WUE in rice like never before. As a rice grower with an agronomic / extension background and experience in irrigation layout and design, I wanted to explore how we compare to other rice growing areas of the world. In particular:

- What is their attitude to water and what can we learn from each other?
- What opportunities exist not only at the farm level but also at industry level?
- How does an emphasis on WUE give the industry a marketing edge and enhance the reputation of the Australian rice industry on a world stage?

I studied the rice industries in the USA, Brazil, Uruguay, China, India, and, through the International Rice Research Institute (IRRI) in the Philippines, a brief insight into much of the world’s equatorial rice systems in south-east Asia, South Asia and Sub Saharan Africa. All areas visited had unique issues and particularly political and social attitudes to water and food production. Some of these are summarised as case studies in this report.

Acknowledgments

Without the support of Nuffield, and particularly a few 'Nuffielders' that first encouraged me to apply, I never would have experienced the past two years. Nuffield is an incredible organisation that sits very strongly with my values of respect and integrity. It's a privilege to be a part of it.

Nuffield cannot do this alone and without AgriFutures Australia (Rice R & D) this project would never have come to fruition. Although Australia is a small market at the 'bottom of the world', its world reputation is much bigger than its market size. This opportunity provided by AgriFutures to meet some of the industry leaders in the world of rice research hopefully enhances that reputation.

I acknowledge many individuals that I have had the pleasure to be inspired by and become friends with. The 2017 international scholars, the 'Africa' Global Focus Program group and the many hosts along the way. The individuals and teams of researchers, agronomists, extension officers and farmers that were exceptionally generous with their time and knowledge. I hope that one day I can repay the debt to you. In particular a few individuals who gave me a disproportionate amount of their time and opened their lives and families to me including: Joao Antonio Martins (Brazil), Gonzalo Carracelas (Uruguay), Cleber, Eduardo and Lorenzo and the 'SimulArroz Team' (Brazil), Merle Anders (Arkansas, US), James Quilty (IRRI).

Sunrice has been very generous with knowledge, time and resources. Sunrice, Rice Research Australia, Rice Extension and the NSW DPI have a fantastic team of researchers, agronomists and extension staff that are a pleasure to work with, and an example of collaborative research and extension that punch way above their weight. It is a company that others can use as inspiration in what an Australian commodity industry can achieve.

And of course my family. As incredible an experience Nuffield is for me, it leaves a whirlwind of a void at home. Michele, you are a champion. Thanks for your patience and support. My girls Emma, Molly, Sally and Rebecca for your unwavering belief. My wider family for always just being there when needed. I'm a lucky man.

Figure 1: Mark Groat, 2017 Scholar

Abbreviations

AWD Alternate Wet / Dry, an irrigation technique where the rice field is allowed to dry out before water is reapplied. This method being promoted world-wide to alleviate methane emissions and increase water efficiencies

BISA Borlaug Institute for South Asia

DPW Delayed Permanent Water, an irrigation technique used in Australia where permanent water is not applied on the crop until prior to the reproductive phase of the rice crop

DSR Direct Seeded Rice. Planting dry rice seed directly into dry/moist ground rather than transplanting or broadcasting into flooded fields

FAO Food and Agriculture Organisation of the United Nations

IRRI International Rice Research Institute, The Philippines

INIA Instito Nacional de Investigacion Agropecuaria (Department of Agriculture, Uruguay)

MIRI Multiple Inlet Rice Irrigation

ML Megalitre, volumetric measure of water equivalent to 100mm of water over 1 hectare

RCL Ricegrowers Cooperative Limited, a vertically integrated, grower owned cooperative (trading as Sunrice) that is responsible for seed, delivery, storage, drying, processing, packaging and marketing of rice and rice products

RTWG 37th Rice Technical Working Group Conference, Feb 19-22, Long Beach, California

SAARC South Asian Association of Regional Cooperation

SRP Sustainable Rice Platform, a United Nations standard for sustainable worldwide rice production. Partnership between the United Nations Environmental Programme and IRRI.

WUE Water Use Efficiency, or the amount of product or dollars produced per unit of water (expressed in T/ML or $/ML)

Objectives

This project was initially looking at maximising water use efficiency (WUE) with the specific focus on 'aerobic' rice production – that is without ponding water at any stage of the crop lifecycle. 'Aerobic' production however is only part of the story, and possibly not necessarily the whole answer to a better or more efficient rice system.

Therefore the objective of this report evolved from initially looking for a recipe for 'aerobic' rice production, to one of maximising water use efficiency that includes all components of the 'system'. In analysing WUE, the following key areas were focussed on:

1. The role of genetics - is it realistic to assume that dramatic changes in WUE, particularly in the short term, will come from genetic gains?
2. Provide a frame of reference for the Australian industry by comparing production and where water lies in social consciousness and government policy in other temperate areas of the world. This helps to identify areas of improvement and what opportunities exist for the grower and the industry. Areas of comparison to the Australian crop include the USA, Uruguay, India and China.
3. Identify the role that industry must play to enhance farm systems, what it can learn from looking elsewhere and the opportunities that exist from looking within.
4. Analyse current rice production practices and explore not only where improvements could be made, but potentially identify a whole paradigm shift within the 'rice system', particularly in terms of stubble management.

Introduction

While this report focuses on the Australian rice production, it is important to put it into context the demands from an increasing human population and what this means over the next generation.

The big picture - feeding the world

According to the Food and Agriculture Organisation (FAO) of the United Nations, global population is estimated to increase by 32% to 9.7 billion people within the next 30 years. To meet the needs of this expanding population it is estimated that food production will need to increase by 50%.

Currently, irrigation represents 20% of cultivated landmass worldwide but contributes 40% of total food production (FAO). With yields of rainfed crops stagnating over the past two decades (Cassman 2018), much of the increase will need to come from intensification and development of irrigation resources. However, many global water aquifers and regulated river systems are already under stress, and water demand to cities of increasing size directly affects irrigation. A changing global climate, with greater variability of rainfall, adds to these challenges.

In addition, the need to preserve the biodiversity of remaining natural ecosystems is becoming a more urgent priority (FAO Symposium, 2018). Therefore, the need for agricultural production to utilise its existing footprint in a much more productive and efficient manner is paramount.

Arguably there has never been a more critical time for the need for effective government policy and industry collaboration in areas of water regulation, agricultural research, development and extension. This, however, is too big a topic for this report.

However, the focus on rice production is not lost in this context.

Rice is the third largest crop in the world and the one most consumed by humans (IRRI). Over half the world's population rely on rice as their main staple. Globally, there is approximately 158 million hectares producing 700 million tonne of paddy rice, averaging approximately 4.4T/ha. 80% of this is under irrigated systems, producing over 96% of total production.

Rice uses 40% of the world's irrigation water and around 30% of the world's developed freshwater resources (IRRI).

The Australian rice industry

Background

The Australian rice crop is a fully irrigated crop, over 99% of which is grown in the southern region of New South Wales between the Murray and Murrumbidgee River systems known as the Riverina (Figure 2). This area is in the southern reaches of the Murray Darling Basin and is collectively known as the Southern Connected Basin. Note that there is also a small amount of rice (less than 10,000T total, some of which is totally rainfed) grown in the Northern Rivers area of northern NSW and in North Queensland. Although potential for extensive development exists in these areas, particularly North Queensland, the focus of this report is on the temperate Riverina Crop.

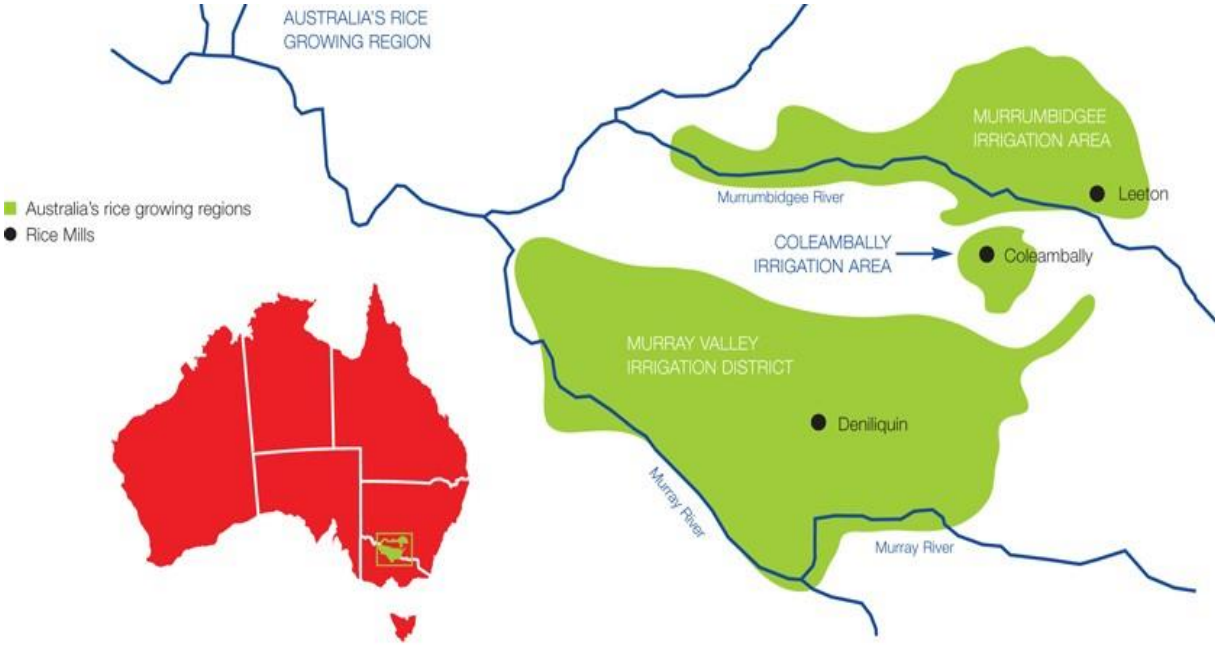

Figure 2: Location of Australia's Temperate Rice Growing Area (Source: Ricegrowers Association of Australia)

One crop per year is grown between the months of October/November to March/April, with minimal effective in crop rainfall. Yields average 10.4T/ha, with the main variety (medium grain Reiziq) averaging 11.0T/ha. There is approximately 77,000 hectares grown annually producing 800,000t of paddy, however this varies dramatically with seasonal water availability.

Ricegrowers Ltd (trading as Sunrice) is a fully vertically integrated company involved in all aspects of the crop from research and development, rice breeding, seed development and production, through to drying, storage, milling, packaging and marketing. All of the crop is sold as packaged finished product (either as household size packets of core rice, or value-added snack food product), or food ingredients, of which 80% is exported. Being a grower-based company, it is an assumption that the higher the price that can be achieved from the finished product, the higher the farm gate price for the paddy.

Water availability and competition for water

Within the southern connected basin, rice is grown using surface water runoff that is stored in the major dam systems in the headwaters of these rivers. Water is delivered via channels and is volumetrically measured on farm. Although growers own a water entitlement, the actual water allocated (percentage of the entitlement) varies annually and depends on rainfall runoff and water stored in dams. Water can be traded both annually and permanently as a commodity both within and between the Murray and Murrumbidgee Valleys. As seen in Figure 3, the price of the annual transfer varies dramatically with water availability.

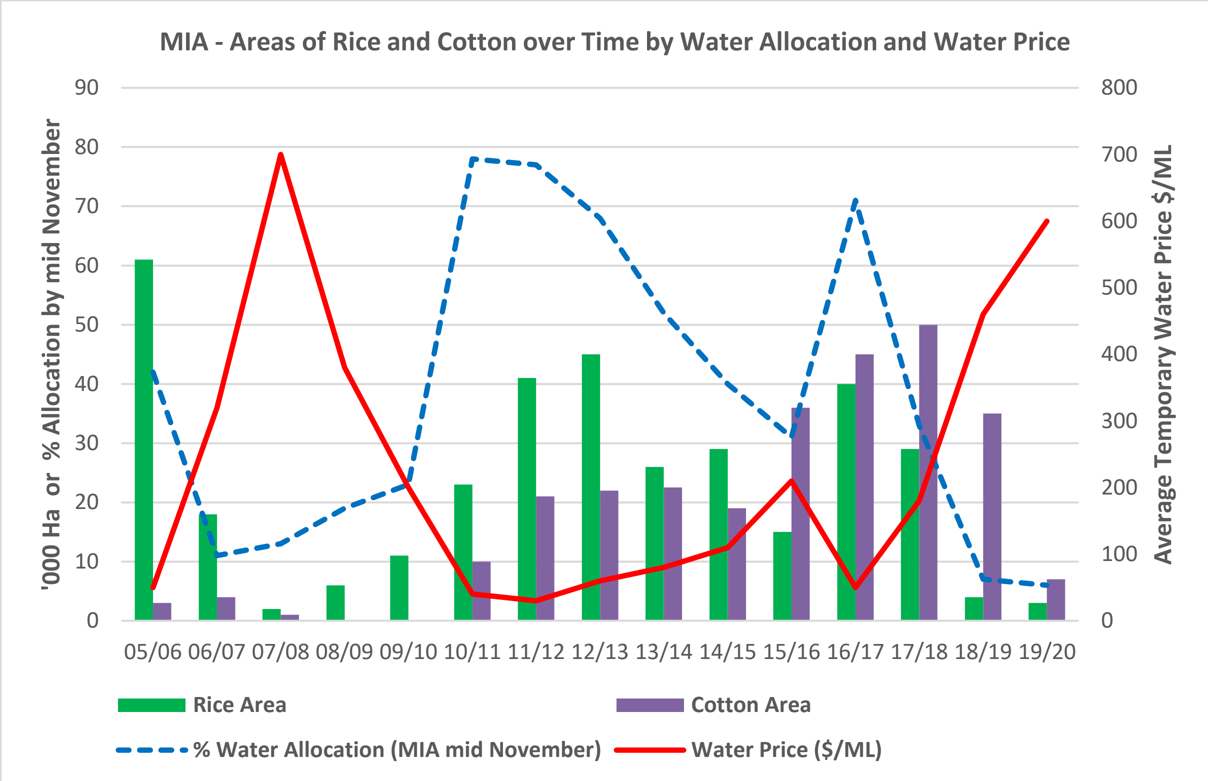

Figure 3: Area of Rice and Cotton in the Murrumbidgee Valley since 2005 by Water Allocation and Water Price (Source: Murrumbidgee Irrigation Ltd, SunRice, Cotton Australia, ABARES)

Since the millennium drought, where Australian rice production hit a record high of 1.7 million tonne in 2001 to a record low of 19,000T in 2007, factors have come into play (RMCG, 2016) including:

1. Decreased water availability to agricultural use due to changing water policy and recovery for environmental water use. This accounts for 14% less water in the Murrumbidgee and 21% in the Murray.
2. Increased competition for water from other annual summer crops, particularly cotton (Figure 3). As an industry average cotton uses around 9ML/ha of water compared to rice of 12ML/ha. This and historically high cotton prices over the last five years has seen a dramatic increase in cotton plantings, particularly in the Murrumbidgee Valley (which produces approximately half of Australia's rice).
3. Increased competition and change in water demand for water from increased permanent horticultural plantings, particularly almonds. In 2001 there were 5200ha of almonds in Australia. In 2015 31,115 ha and in 2018 45,000 ha. Almost all of this expansion is in the Southern Connected Basin (ANIC, 2016) and much of this based on the temporary water market.
4. Lower allocations more often due to carry over rules, less run off into storages and allocation policy.
5. Increased market price for temporary water due to the above factors.

6. Higher water charges inside irrigation corporations due to lower water volumes of throughput which increases annual water delivery costs.

The variability and the expense of water supply is the most limiting factor to rice production (and irrigated crops generally) in the Murray Darling Basin area. Water is a tradable commodity as opposed to a resource, as in other parts of the world. It therefore goes to the highest bidder, or the one that makes the most per megalitre. Competition for water exists for a range of summer, winter, annual and perennial crops. Huge variability of rice production can exist annually due to water availability and alternate crop commodity prices.

Variation in water allocations, and particularly longer periods of low water availability, poses major challenges to not only farm profitability but the whole industry. Continuity of supply means continued injection of over $500M and the stability of over 850 jobs in regional Australia (Sunrice, 2017), utilising drying, storage and milling facilities worth hundreds of millions of dollars; and maintenance and growth high value markets.

Water use efficiency

WUE is the key to sustained rice production in the Riverina. Besides intensive breeding programs looking at specific water use traits, on a world scale, WUE is focussed on areas of irrigation management and planting techniques. Practices such as Alternate Wetting and Drying (AWD), Direct Seeded Rice (DSR), and various water management techniques are all focussed on increasing WUE.

Australia’s highly mechanised system on laser levelled bays means Australia’s WUE for rice is already the world’s best. Although figures are difficult to obtain (as the majority of the world does not volumetrically measure water onto farms), water use (including rainfall) averages 3,000 L/kg (Bouman 2009), or 0.3T/ML. Australia averages 0.85T/ML with individual growers achieving 1.3T/ML (Sunrice). In Australia, the difference between the average and the best (top 20%) is a 35% increase in WUE. At a farm level this is the difference between producing 850T or 1,300T with the same water, land and labour. At an industry level this is the difference between a year producing 500,000T or 760,000T with the same water. Achieving these efficiencies is imperative to Riverina rice production.

The concept of WUE is more than just using less water for production but gaining a greater return for that water. WUE needs to be measured in $/ML. Increasing the value of a tonne of rice is as important as increasing production. This puts a focus on quality, consumer demand (traceability and provenance) and company reputation (integrity, clean and green, sustainability) in the marketplace.

With the efficiencies that Australian producers already achieve and new research priorities already in place, what can be learnt from both overseas and local experiences? Are genetic improvements the key to further increased water use efficiencies, or can more immediate gains be obtained in other areas? Given the efficiencies already being achieved in Australia, where can further gains be made?

Is this the beginning of the end for the Australian rice industry, or does it create exciting opportunities for an enhanced beginning? This is a focus of the report.

Figure 4: Agronomic and breeding trials at Yanco Research Farm, NSW. (Source: Brian Dunn, NSW DPI)

In summary, lower water allocations and higher water prices pose major challenges to the viability of rice enterprises. Competition for water from other crops, particularly cotton and more dramatically almonds are a continued and immediate threat. Increasing water use efficiency in terms of both production per ML and returns per ML is the key driver, and therefore must be a focus for the industry.

Chapter 1: Genetics

A silver bullet?

Within all agricultural industries, production and quality gains from genetic improvement is rightfully considered the cornerstone for long-term growth of the relevant industry.

Global rice yields have increased at a compound rate of around 1% per year since 1961 (Ray et al, 2013). In Australia, this figure is around 1.2% since 1992 (Figure 5). Whilst very difficult to assess how much is due to genetic gain verses agronomic advances, it is generally accepted that around half of this is due to genetic gain. Ray also states to keep pace with expected demand from a growing population, this rate needs to increase to 1.4% or a 42% trend increase. Is this a realistic projection?

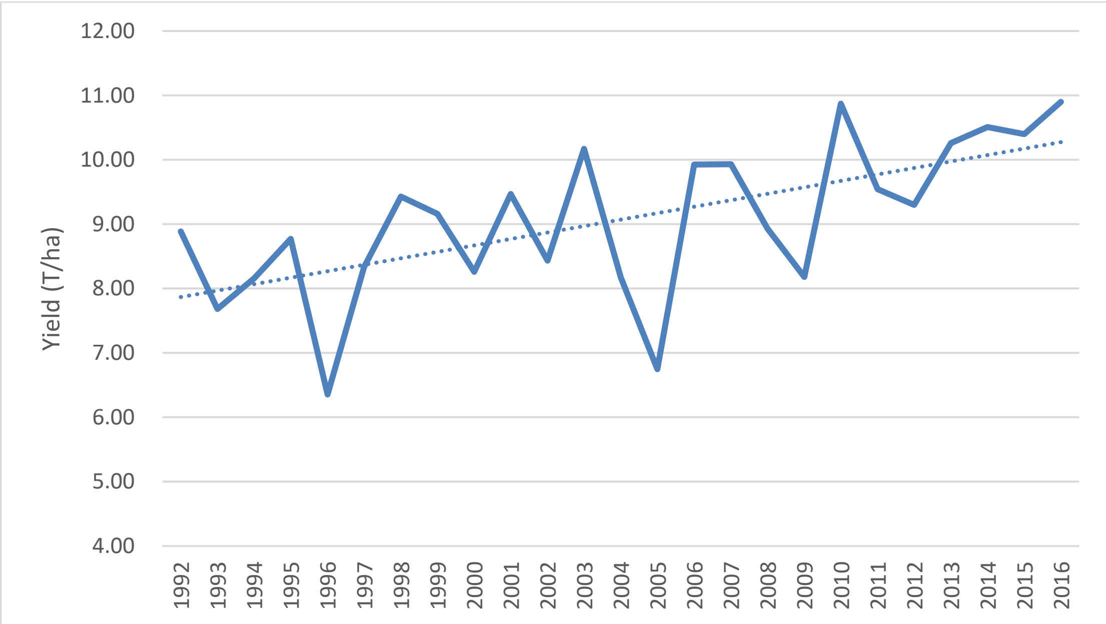

Figure 5: Australian rice yields since 1992 (Source: Dr Peter Snell, NSW DPI 2017)

To put this in perspective, Grassini et al (2013) states that many projections of global future food production assume compound rates of yield gain that are not consistent with historical yield trends. Furthermore, there is evidence of yield plateaus, or abrupt decreases in rate of yield gain in many staple food crops, including rice, wheat and maize.

Some estimate that the Australian crop on average needs to improve WUE by 30% to remain 'competitive' as a viable crop in the Southern Connected Basin. Breeding provides steady, incremental yield increases, however technological advancements are rapidly increasing. How much gain can therefore be expected from genetics?

According to Dr Ye Changrong, geneticists at Yunnan Academy of Agricultural Sciences, technological development has been exponential over the past decade, particularly in gene sequencing. This enables traits to be selected for prior to planting a seed and whole populations can be selected based on their genetic makeup, vastly accelerating the selection ability of the breeder. As an example, IRRI is home to the largest rice gene bank in the world that holds over 127,000 different accessions of rice. The first was sequenced in 2010. Since then around 3000 have been sequenced and it is estimated that all 127,000 will be sequenced within the next decade (James Quilty, 2018).

Rice is seen as the ‘pin up’ grain when it comes to breeding criteria. As a staple foodstuff for many of the world’s poorest nations, a level of cooperation that transcends political boundaries exists as with no other grain. One example, the South Asian Association of Regional Cooperation (SAARC) facilitates seed transfer between eight member nations in South Asia. Due to this collaboration and that rice is still in ‘public’ hands rather than private (such as maize) information can be transferred to all. This means that technological progressions are worked on by a greater number of essentially collaborative researchers, potentially increasing the benefits or speed of advancement (Changrong, pers. com. 2018).

One success attributed solely to genetic gain is the development of short season varieties. 110-day rice varieties (compared to conventional 140-day) developed in north-west India, enabled planting to be delayed one month, thus missing extreme heat mid-May to mid-June. This also meant planting occurred closer to monsoon rains expected at the end of June. It is estimated this measure alone decreased water use by 35% with no decrease in yield (Sidhu, 2018). Similarly, short season varieties have been released in Australia. Although these provide flexibility in the rice system by extending the sowing window by around 20 days, some argue that WUE has declined as the commercial yields obtained from these varieties are not as high as longer season varieties. (Improvements and management of these varieties is ongoing with trial yields being 95% of longer season varieties).

Australia uniquely practices an ‘advanced’ form of AWD called Delayed Permanent Water (DPW). Whilst successful in increasing WUE, this would be made more robust with wider adaptive characteristics of varieties that could ultimately lead to growing rice under non-flooded conditions. Breeding for abiotic stress tolerance, where plants can recover from moisture stress, heat and cold extremes and so on, is a requirement for this. Jacqui Mitchell, a rice geneticist at Queensland University, says breeding lines that can tolerate cold stresses at pollen formation of seven degrees Celsius less than current lines is a prerequisite for non-flooded rice production.

Some of these abiotic characteristics fall under the term ‘drought tolerance’, a term relevant to non-flooded production and rice WUE. It makes sense for a plant to have deeper roots, better transpiration efficiency, heat and cold tolerance and so on. However, in the opinion of Dr Tao (pers. com., June 2018) the term ‘drought tolerance’ is somewhat of an enigma. There is not one single trait that determines drought tolerance, but more a complex interaction of many different traits, and ‘pulling one lever sets a whole range of cogs turning’. Drought tolerance is more the ability of plants to recover from stress, perform when conditions are right and still yield some (if diminished) quality grain in adverse conditions. Under fully irrigated Australian conditions is this more water management than breeding criteria? There is a Nuffield report by Dr Leigh Vial, 2006 Scholar, that documented drought tolerance in breeding programs in IRRI, China and the USA. Much of what is mentioned is still the focus of breeding research today with seemingly little progression.

Even though technological advances have been rapid, and the promise of these projects are drawing nearer, genetic gains are fundamentally long-term and incremental in nature. So whilst the importance of maintaining a strategic breeding program cannot be overstated (in Australia, dollar return on investment from the rice breeding program is estimated at 8:1, Snell, 2017), it is unlikely that dramatic changes in short-term WUE, such as the 30% mentioned previously, will come from genetic gain.

In summary, continued genetic improvement in yield, quality and short season varieties should remain the cornerstone of rice research in Australia. Increasing technological advances in genetic screening have the potential to increase the success and speed of breeding programs, with reference to enhanced 'aerobic' traits. Whilst significant and needs to continue as the cornerstone of rice research, genetic improvement is incremental over time. Whilst technological advancements are rapid and increasing, this alone will not provide the dramatic short-term increase in water use efficiency that is paramount to continued viable rice production in Australia.

Developments in hybrid technology

This chapter has concentrated on conventional (inbred) rice breeding and does not account for developments in hybrid technology and particularly transgenics. Whilst these methods are not a focus of this report, they are worth a mention. In 2005, 50% of rice grown in southern China was hybrid and between 10-20% in mid-south of the USA and Brazil. Today around 60% of China's rice is hybrid and 60% of rice in the USA mid-south and Brazil (Ottis, 2018). Opinions and emotions vary wildly with the mention of transgenic technology, and although it remains unacceptable in the marketplace (particularly to the Australian markets) it is still a focus of much research worldwide.

Hybrid seed

Whether or not to introduce hybrid seed production into the Australian seed program is an ongoing discussion within the industry (hybrid seed production is much more expensive than conventional in-breeding techniques). Although commonly agreed that there is increased early vigour, is there value in hybrid seed production for Australia?

Brian Ottis, from the hybrid seed company RiceTec in Texas, has an opinion on this. Virtually all global hybrid seed is from Indica-type rice. It has a huge genetic diversity thus increasing the advantages of heterosis. In Australia, the crop is all Japonica. The genetic diversity of Japonica is much more closely defined and the advantages of heterosis is therefore less.

Transgenic technology

Current transgenic technology exists that fortifies rice grains with iron and zinc, two of the most limiting minerals in human nutrition (Wessels and Brown, 2012). Another exists for Vitamin A in the grain (Golden Rice). Another has the Bt gene, or resistance to insect attack. From a developing countries perspective, this technology helps to improve nutrition, yield, personal and environmental health. Many researchers with a focus on feeding the world question 'where is the downside?' Whilst there is currently no market for transgenic rice, research particularly in the area of abiotic stress tolerance (such as heat, cold, salinity, and drought), mineral fortification, and disease and insect resistance continues to be developed around the world (IRRI).

Whilst Australia needs to keep abreast of this it is important to consider our position in the marketplace. Australia's crop aims at the higher priced markets, thus requiring the very best quality and Brand reputation. If the Australian breeding program looks at including genetically modified organisms within the breeding program does it enhance either of these?

The following chapter looks at other areas in the world for comparison to bring the Australian industry into focus.

Chapter 2: Australia's Place in the World of Rice

How does Australia's water footprint compare?

Australia is ranked number one in rice yield per hectare in the world (Figure 6). At 10.4T/ha it is 1.0T/ha above second ranked Egypt, 1.8T/ha above third ranked Uruguay and 2.3T/ha above forth ranked USA.

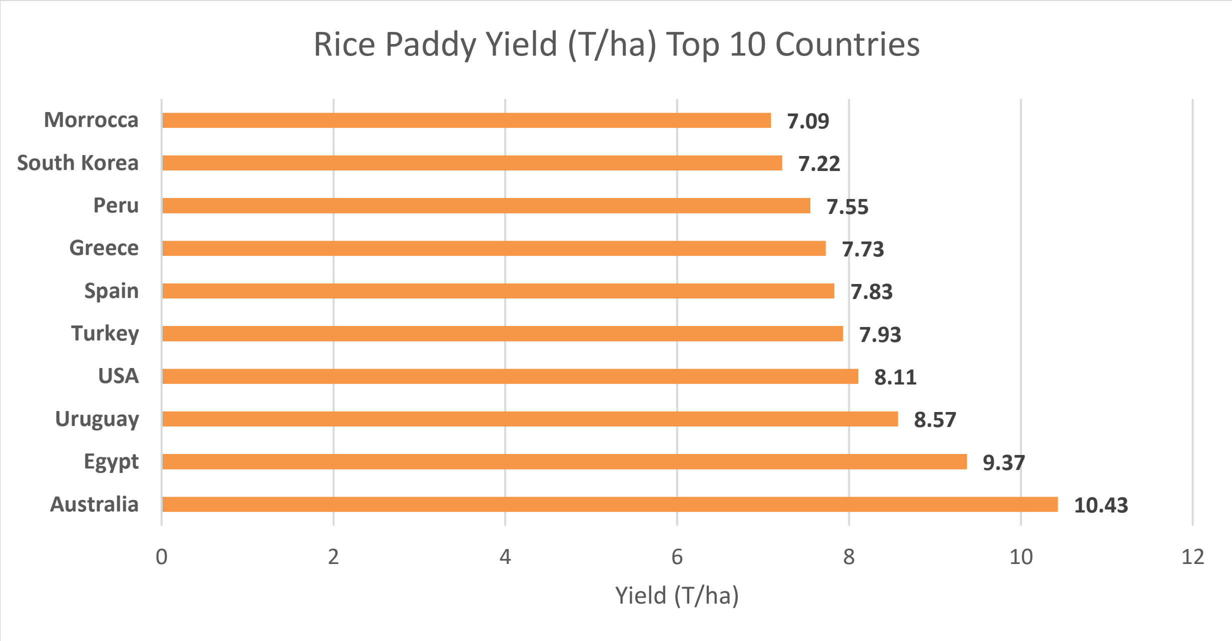

Figure 6: Top 10 World Rice Yield by Country (2016 data). Source FAOStat

Whilst claims of yield and quality are relatively easy to substantiate the more difficult data to find is on WUE. Where is Australia's place on WUE compared to the rest of the world? Where is research focussed not just at the producer level but also the wider community and political level? Only by having more of a grasp on this data can Australia then focus on what it can learn from the rest of the world. Five case studies are highlighted, looking at key aspects of rice production and the rice system, with a focus on the water footprint. They are mostly focused on areas of similar latitude and comparative temperate climate to the Riverina rice crop.

Case Study 1: Mississippi Delta, USA

The Mississippi Delta, including the States of Mississippi, Louisiana and Arkansas, produce approximately 75% of the 9.1 million tonne US rice crop. Arkansas alone produces 50% of US rice - almost 575,000 ha – with an average yield of 7.5T/ha. Most rice research is in this region, with the Dale Bumpers National Rice Research Centre located in Stuttgart the largest rice research centre in the USA. The focus of this case study will be on Arkansas.

The main rice growing area lies between the latitudes of 34 to 36 degrees N. Soils are mostly heavy clay, the native landscape in these areas being swampland. Most of the fields have been laser levelled (approximately 10% zero grade within bays and 90% with a 0.1% constant slope).

Rainfall is approximately 1,250mm with around 500mm falling in the rice season. It is classed as a temperate climate, with summer temperatures averaging over 30 degrees Celsius.

Most water is pumped from the Mississippi River Valley Alluvial Aquifer with no regulation on extraction and no charge for water. In Arkansas, land title has riparian rights, meaning the landowner has rights over everything under the ground, including minerals and water. Portions of this aquifer are depleting at a rate of between 0.15 and 0.45m per year (Arkansas Natural Resource Commission). In some areas (known as 'black zones') extraction will need to decrease by 75% to reach sustainable levels (Runkle, 2018).

Figure 7: Multiple Inlet Rice Irrigation practices in the Mississippi Delta (Source J Massey USDA)

Initial efforts to address aquifer overdraft are focussed on irrigation efficiency, particularly in rice. Most rice is direct seeded with a delayed flood, applied at the five-leaf stage of the crop.

Water is not volumetrically measured on farm, however research by Massey (2017) showed depending on layout, water application varied from 12ML/ha for contour layouts down to 6ML/ha for zero grade bays (an increased efficiency of 55% in applied water). With the addition of 5ML/ha in season rainfall, the range of the two figures equates to a WUE between 0.44 and 0.63 T/ML. With the introduction of Multiple Inlet Rice Irrigation (MIRI) (Figure 7) decreased water us to 5.2ML of applied water, with a WUE of 0.8T/ha.

This figure does not include the practice of 'winter flooding' of rice stubbles (Figure 8). This is a relatively common practice where rice fields are locked up and flooded with a combination of rainfall and applied water. This is a valuable tool to not only decompose rice stubble but also to provide temporary wetlands for water fowl migration. This practice is seen as an ecological benefit funded by government (Natural Resource Commission) and private organisations such as 'Ducks Unlimited' (Anders, 2018).

Figure 8: Winter Flooding of Rice Fields for Stubble Breakdown and waterfowl migration. The practice of winter flooding is not included in WUE figures (author)

Despite excellent research in water savings and government subsidies for infrastructure works and water measuring technology, grower uptake of new technologies has been poor (Anders 2018). There are however a number of exceptional farmers that are achieving significant water savings. Jim Whittaker for example, grows 3000ha of rice 20 km west of the Mississippi River. He has decreased aquifer extraction by 60% in the last 10 years through innovative irrigation, rainfall capture and storage. Jim is also one of three Mississippi Delta farmers (the others Carter Murrell and Chris Isbell) that have sold carbon credits to Microsoft due to methane savings from practicing efficient and effective AWD irrigation. Chris believes that "*water will be the single biggest issue facing the next generation of farmers*", however as Carter says "*It's not about creating sustainable rice, it's about creating a sustainable system*".

Highly mechanised and large-scale industry, majority of fields laser leveled and mostly drill sown.

In summary:

- Average Yield 7.5T/ha with WUE between 0.5 to 0.8T/ML.
- Crop rotations are mostly rice on rice.
- Majority of water is aquifer extracted, not measured or charged for, with aquifer depletion between 0.15 to 0.35m/year, in some areas extremely severe.
- Some excellent research and infrastructure subsidies for increased WUE in rice but uptake has been very poor.
- WUE research focus on irrigation methods and infrastructure.

Case Study 2: Uruguay

Uruguay's rice growing areas are located in the west, centre and the eastern areas in the northern half of the country near the Brazilian border. Water resources are immense, to the west is the Uruguay River on the border of Argentina flowing south at over 4,000ML/second past the border of Brazil/Uruguay. In the Eastern region sits one of the world's largest freshwater bodies, Lagoon Mirim. In addition, the area of northern Uruguay and southern Brazil sits on the largest (and untapped) aquifer in the world.

Approximately 150,000 ha of rice is planted with yields averaging 8.6T/ha producing 1.3 million tonnes of mostly Indica paddy rice, of which 95% is exported. 20% is grown in the west, 10% centre and 70% in the east. The average rice area is 300ha per grower.

The west and centre consists of undulating topography and are irrigated from rainfed, on-farm storage dams that are filled annually. The east has abundant water pumped from freshwater lagoons, rice areas are smaller and rotations are tighter. Generally, yields in the west and centre are higher than the east, 10T/ha not uncommon. Soils are mostly loamy to heavy clay with an organic carbon content of around 3%.

From 2001 to 2010, Uruguay had a dramatic increase in yield (Carracelas, 2018) from 6 to 8.5T/ha. During this time they were the fastest growing rice yields in the world. This has since plateaued and one of the challenges of their peak agricultural research bodies (INIA) is to address the exploitable and identified yield gap of 2.4T/ha.

Figure 9: Rice layout, central Uruguay. Note unlasered bays and drive over banks within the field (author)

The areas are situated between the latitudes of 30 to 33 degrees S. Climate is high rainfall temperate, the area receiving 1,200mm rain annually with approximately 600mm falling in the one crop per year rice season. There are two distinct growing seasons. In the west and centre often a pasture is grown in the winter months to be grazed by cattle and aide stubble breakdown. In the east where rotations are tighter, ground preparation occurs in the winter months. Stubble burning has been banned for 15 years.

It is a highly mechanised industry, with the main planting method being direct seeded into a dry seedbed. Irrigation is the most labour intensive operation, particularly in the undulating areas (approximately 1% slope) of the north and centre. One full time labour unit is required per 80ha for irrigation management. Water use per crop varies from 12 to 14ML/ha with another 5ML in crop rainfall, equating to a WUE of 0.48T/ML. However due to the nature of the irrigation layout (Figure 9), where water fills one bay and cascades to the next, means rainfall capture is inefficient (Santiago Ferres, pers com).

There is no charge for water, and if land and water is rented (as is over 60% of the rice area) water is charged for on an area rather than volumetric basis. Despite this, and particularly in the west and centre where water is an annually finite resource, there is incentive for water efficiency gains. In the east water is mostly pumped, and as energy costs are comparatively high in Uruguay (approximately 40% higher than Australia) any savings in pumping costs (thus decreased water use) significantly add to the bottom line.

Water efficiency research is focussed on two main areas. Firstly, on the system as a whole. Rotation is very important, and farmers will not compromise on this as they believe that yield, quality, weed control and fertiliser rates are maintained due to their rotation (Rafael Bottaro, pers. com). In the east where rotations are tighter, red rice is an issue with reliance on Clearfield rice varieties, nitrogen rates are around 30% higher and yields are on average 15 to 20% lower, this has a lot of merit (INIA Field Day, Treinta y Tres - Eastern region).

Practiced crop rotations include two years of rice followed by four years of pasture, or two rice and two soybeans. Some innovative areas (farm 'Tres figueiras' owned by the Dickinson Family in the western region) have a summer / winter rotation of rice / pasture / soybeans / pasture / rice. Although water use is not measured, having a green crop in the ground at all times means very efficient rainfall harvest as well as utilising any soil moisture from irrigation. Also practised is full stubble retention and zero till. This system has been in place for six years and according to farm manager Ramiro Toledo is getting 'better and better'.

Figure 10: Grower field day, Western Uruguay (author)

The second area of research is water application. According to Bernado Bocking, an agronomist and farm manager in the western region, water cascading from one bay to the next is an inefficient practice with poor rainfall capture ability. Piped systems where bays are filled independently save up to 40% in water use with no yield reduction. This also allows efficient rainfall capture as bays are not continually full. Multiple Inlet Rice Irrigation (in Case Study 1) is implemented on this property with 30% measured water savings and up to 80% better labour efficiency.

In summary:

- Highly mechanised and large-scale industry but little laser land-formed areas with labour intensive irrigation.
- Mostly drill sown with average yield 8.6T/ha with estimated WUE 0.5T/ML.
- Intensive rice on rice rotation in the east, more emphasis on longer and more diverse rotations further west.
- Mostly surface water with abundant water resources, particularly in the east. Water licenses regulated but not volumetrically measured. Costs are on an area basis.
- Excellent research and extension from both industry and government on WUE and focused on irrigation application and rotations within a rice 'system'.

Case Study 3: Liaoning Province, China

China is the most populous nation on earth with 1.42 billion people and is both the largest producer and consumer of rice in the world. It produces around 200 million tonnes and imports another nine million tonnes. China's average yield is approximately 6.5T/ha, with 99% of China's rice irrigated. Approximately 80% is Indica (mostly in the south) and 20% Japonica (north and high altitude above 1500m in the south). Generally, the south and central is not water limited and uses mostly abundant surface water, and the north is and uses mainly aquifer water. Although water is not limited in the south, an estimated 17% of soils are contaminated with heavy metals, particularly Cadmium (Balcerak, 2018).

Urban sprawl is covering traditional farmland. Areas close to cities now grow intensive vegetable production under greenhouse rather than lower value crops such as rice. Rice imports are becoming more common place and are expected to grow.

It is difficult to get an accurate measure of the state of water resources in China (Zhang 2018, Pay 2018). There is however major infrastructure works diverting water over 1,000km from south to north. Major cities in the north traditionally relying on aquifer water are now reliant on this diversion. At a national level there is major water infrastructure development (including the south to north water diversion). China has four out of the top ten largest dams in the world, with the Three Gorges Dam (completed 2008) on the Yangtze River the largest. There were all built in the last decade.

Rice growing areas of the Liaoning Province lie between the latitudes of 40 to 42 degrees N. Approximately 600,000 ha of Japonica rice is grown, both short and medium grain varieties, with yields averaging approximately 7.5T/ha for short grain and 9T/ha for medium grain. Average farm size is less than one hectare, with farms of 0.3 ha common. Scale is being achieved by the adoption of a 'company' structure where landholders are shareholders within the company, and usually work off farm.

Figure 11: Aquifer pumping for Rice Production, Liaoning Province, China (author)

The climate is temperate with a defined warm summer (daytime average 30 degrees) and very cold winter (minus 20 degrees minimums). There is one growing season with the seedling stage requiring six weeks in a greenhouse to be ready for transplanting. Rainfall averages 650mm per year, with 500mm falling in the rice season. Depending on where in Liaoning Province, water is surface sourced, aquifer sourced, or both (Figure 11). There is no charge for water, and electricity for pumping is subsidised by 50%. Water use is estimated at 10ML/ha and another 5ML from rainfall. This equates to a WUE of between 0.5 - 0.6T/ML.

Even though stubble burning has been banned since 2013, much is still burnt as there is limited use off field and only about 20% of it breaks down between rice seasons due to the cold winter (Yuedong, 2018). Fields are usually rice on rice with operations semi mechanised. Cultivation, transplanting and harvest is mostly done by machine, spraying and fertilising by hand.

Figure 12: Breeding Trials, Liaoning Academy of Agriculture (author)

Compared to water infrastructure at a macro level, it appears little work is focussed on water efficiency at field level. Much emphasis is placed on breeding traits, and some work on DSR. However due to water losses via percolation this was shown to be less WUE (Zhiqiang, 2018) and puddling is still required for rice production. Short season varieties (ten days less) play a role. However, compared to the temperature extremes of north-west India, the relatively mild conditions of north east China mean ten days later sowing has a minor effect on WUE. Concentration on yield and efficiencies of scale at the grower level appear to have a greater impact on WUE than irrigation management or cultural practices.

In summary:

- Small landholdings are common with farm areas between 0.3 and 1 hectare. Larger amalgamations put together as company structure increase efficiencies.
- All mechanised transplanted rice. Labour intensive operations with intensive rice on rice systems.
- Yield (medium grain equivalent) is 9T/ha with WUE around 0.6T/ML.
- In the north water is mostly aquifer extraction. Reported aquifer depletion extreme in some areas (difficult to quantify).
- Water not volumetrically measured or charged for with a 50% subsidy on electricity for pumping.
- Emphasis on macro projects to increase water resources (dam / pipeline building).

Case Study 4: Punjab Area, Indo-Gangelic Plains, India

India is one of the world's leading exporters of rice. It is also the second most populous nation on earth with 1.35 billion people. India produces approximately 157 million tonnes of rice with an average yield of 3.5T/ha.

The Punjab area of north west India is located between the latitudes of 29 to 31 degrees N. This area produces approximately 12% of India's rice on 1.5% of the land mass. The majority of the area is irrigated Indica varieties, with 4 million tonnes of basmati rice also grown. The average farm size is less than two hectares.

The climate is sub-tropical monsoon, with a rainfall of 700mm, 500mm of which falls during the rice season. There are two distinct growing seasons, summer and winter. Rice is usually grown in rotation with wheat.

Figure 13: Transplanting Rice, NW India (author)

Other than planting, where rice is transplanted into flooded fields mostly by hand, the industry in the Punjab is highly mechanised. All fields have been laser levelled within the last decade. Machinery is used for cultivation and harvest. Average yields are 6.5T/ha, well above the countries average of 3.5T/ha. Average water use is around 18 - 20ML of applied water and another 5ML as rainfall per hectare (Sidhu 2018). This equates to a WUE of 0.27T/ML of water.

The Punjab area is traditionally a wheat area and did not start growing rice until the 1960's in accordance with government policy to be self-sufficient in grain production. Extensive irrigation development was carried out utilising the Indus River Aquifer (Humphries et al, 2010). Soil is generally porous with less than 35% classed as 'heavy'. Organic carbon content of the soils is typically around 0.5%.

Over the past 50 years, and particularly in the last decade, there has been an alarming rate of decline of the aquifer, in some areas more than a metre per year. Government policy of free water and free electricity for pumping, and a guaranteed minimum floor price for rice above other crops exacerbate the groundwater issues (Singh, 2018). Dr Sidhu, director of Borlaug Institute for South Asia, believes that the next decade is critical to address aquifer decline. The last ten years has seen research focussed on a number of directions to address water issues.

These include

- **Short Season Varieties** – varieties that have a growing season 30 days less than conventional allows planting to occur 30 days later with no yield penalty. This avoids extreme heat (thus high evaporation) early in the season and allows establishment of rice just before the monsoon arrives, usually at the end of June. Over 80% of the area is now planted to these varieties with an estimated water saving of 35%.
- **DSR** - direct seeding into a dry seedbed and flushing alleviates evaporation and percolation losses early in the season and establishes the crop prior to the monsoon rains. Weed control however is an issue compared to transplanted rice. Also, in the more porous soils (65% of the area) deep percolation losses decrease WUE. Puddling of these soils (cultivating with water ponded on the field to create a semi-impervious hardpan) is a requirement of flooded rice production.
- **Crop Intensification Trials** (Choudhary et al, 2018) – long term trials over the past ten years that are looking to improve water efficiency, profitability and soil characteristics have been carried out in NW India. These focus on full stubble retention, growing maize rather than rice on lighter soils, sub surface drip irrigation, and a third (short season) crop such as mung beans between wheat harvest and rice planting. Some of these are showing excellent results, with water savings of between 25 and 75%. The standout however is full stubble retention (See Chapter 3) under various planting regimes and crop rotations.

Dr Yadvinder Singh, a soil scientist with 55 years' experience in the Punjab area, was asked what the Punjab will potentially look like in the future. He answered "*When I was a boy, I could reach into the well to get a bucket of water. That well would now be over 40 metres deep and* *getting deeper by around a metre per year. Maybe civilisation will not be in this area in 100 or 200 years from now. Maybe this area will be desert and all people will have moved elsewhere*."

Fortunately, Research Agronomist with CSSIR, Dr Hanuman Jat and local farmer Manoj Earaori have a more positive outlook. "*We have the technology but not the adoption. We need good, strong government policy such as machinery subsidies and a guaranteed minimum price for maize, with well-resourced extension services. Change then will be very rapid with immediate positive results*".

Figure 14: Direct drill new crop into stubble, NW India (author)

In summary:

- Landholdings typically two hectares or less, highly mechanised (except manual transplanting) with all lasered field areas.
- Punjab yields 6.5T/ha, well above country average of 3.5T/ha. WUE 0.3T/ML.
- Rotations typically with wheat, continually double cropped.
- All water aquifer extraction. The Indo-Gangelic Plain aquifer is depleting at one meter a year with little policy to alleviate this issue. Both water and electricity to pump water is historically free and government struggling to unwind this and still remain self-sufficient in grain.
- Excellent research and results in short season varieties, planting and irrigation methods, rotations and stubble retention. Uptake requires policy to implement.

Case Study 5: Riverina, Australia

The rice growing areas of the Riverina lie between the latitudes of 34-35 degrees S, between the Murray and Murrumbidgee Rivers. Approximately 70,000 – 80,000 hectares of irrigated Japonica type rice is grown, however this varies dramatically (from less than 2,000ha to 160,000) depending on available water resources. The average farm size is around 500ha, with average rice area per grower 100ha, however ranges from 50 to 1000ha. Soils are mostly heavy clay, some sodic areas where soil slaking is an issue. Organic carbon content of the soils is less than 1%. Total rice production is less than 0.15% of total world production, however as 85% is exported this accounts for approximately 20% of world Japonica medium grain trade.

The climate is temperate, averaging 400mm of rainfall. On average, less than 150mm falls within the rice season, often as storms. Summers are hot with average temperatures above 33 degrees Celsius (40 degrees plus is common). Solar radiation is high. There are two distinct growing seasons, summer and winter. One rice crop a year is grown in the summer often in rotation with wheat or pastures in the winter.

This is a highly mechanised industry with a high level of technology utilised. Most fields are laser levelled (Figure 15) with accurate and high flow water command. The majority of farms also have water reuse systems (Figure 16). Yields are classed as the best in the world, averaging 10.4 tonne for all varieties. The main variety Reiziq averages 11.0T/ha with more than 10% of growers achieving over 13T/ha (Sunrice Grower Services).

Figure 15: Efficient irrigation layout and mechanised rice industry of the Riverina (Source: Rice Extension)

Most water used is surface water from reservoirs in the headwaters of the Murrumbidgee and Murray River systems. Water is volumetrically measured and charged for on a farm basis. Australia is in the unique position around the world where water is a tradable commodity between the two river systems, and can be traded both on an annual and a permanent basis. Rice therefore is just another crop that is in competition for limited water resources.

In the majority of seasons, water is the most limiting and one of the most expensive inputs of the rice crop. Water efficiency is therefore a priority. Ten years ago, the majority of rice was aerial sown, with fields flooded from planting onwards. In the 2017 season 60% of the crop was direct seeded into a dry seedbed with a focus to decrease water use. The direct seeding system has evolved to a uniquely Australian system of DPW where the crop is flush irrigated right up to the reproductive phase of the crop, when ‘flood’ water is then applied. Accurate industry data is not available for overall water use, however it is estimated from data obtained from growers, irrigation companies and Sunrice that on average WUE is approximately 0.9T/ML. Some growers are achieving up to 1.3T/ML, with 1.1T/ML not uncommon.

To facilitate winter crop planting immediately after rice harvest, the majority of stubble is burned and the winter crop is direct drilled into the field. This is a cheap and very effective way to establish the winter crop and utilise the 150 to 200mm of profile moisture that exists after the rice crop.

Figure 16: Recycle System for water re-use within farm, Riverina (author)

Australia's rice crop is stored, dried, processed and marketed by a grower directed company Ricegrowers Ltd (trading as Sunrice). Sunrice provide new generation, pure to type seed to growers every year, thus have data of each variety, each year for each farm. All crop data is inputted into a central GIS system. Sunrice therefore has accurate data of the crop area, tonnes delivered by farm by variety, planting date and planting method.

In summary:

- Highly mechanised with high degree of technology in terms of laser landforming, irrigation and nutrient management.
- Average industry yield 10.4T/ha (11T/ha medium grain equivalent). WUE averages 0.85T/ML.
- Extensive rotations with usually no more than two years of rice, followed by winter cereals or pastures.
- Water mostly surface water from upriver storages, water availability and price vary dramatically. Water can be traded and transferred between enterprises and valleys.
- Research focus on short season varieties, planting methods, irrigation techniques, automation technology, grain quality and nutrient management.

Chapter 3: Factors Contributing to Increasing WUE

Key learnings from case studies

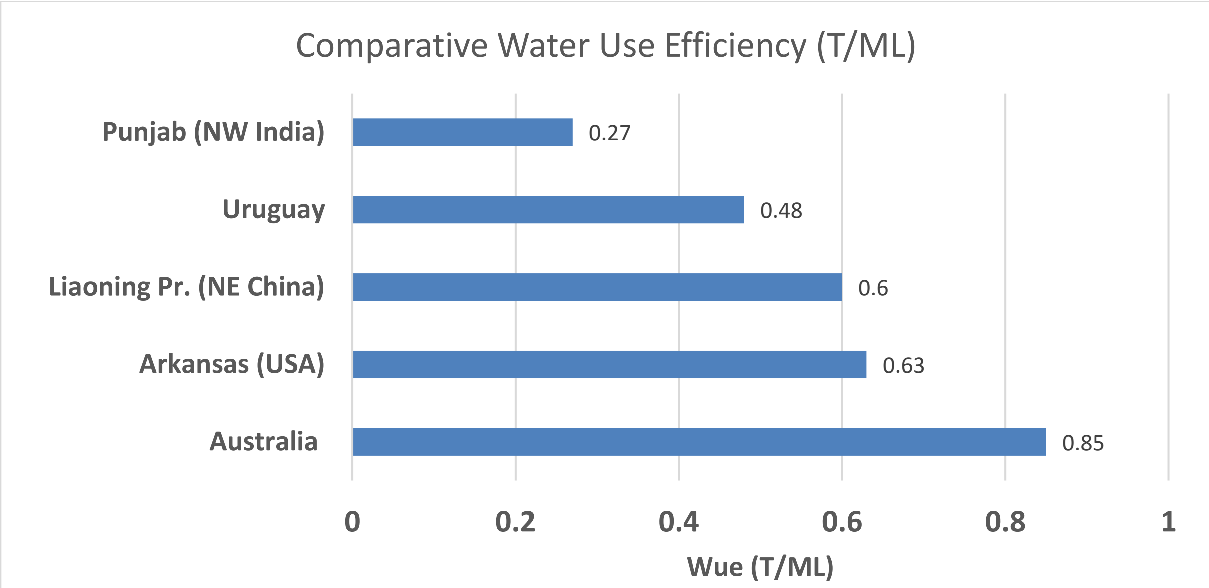

Figure 17: Comparative WUE (T/ML) (Source: Author - using numerous sources from combined case studies)

Australia is the most water efficient rice producer in the world. It is also one of the only countries that measures and pays for water volumetrically on farm. Whilst there are other areas where rice is just another crop in competition with available water resources, nowhere is this more pronounced in the 'free water market' in Australia. Water is a commodity that goes to the highest bidder, and rice is a crop that must position itself to remain competitive.

So, what can Australia learn from overseas? When looking at WUE in dollars per megalitre, the three key drivers are increase yield, decrease water use and increase dollars per tonne. Genetics aside, this report will look at these individually from overseas observations.

Key Driver 1: Increase yield

Data published from Sunrice shows Australia's average rice yield for all varieties is 10.4 T/ha. The main variety, Reiziq has a five year average yield of 11T/ha. Whilst there are individual areas and crops averaging this elsewhere in the world, Australia's combination of scale, mechanisation and technology use in crop management and irrigation methods make it the best yielding rice industry in the world.

Australia has the unique and enviable advantage of having over 99% of the industry data all on one database (within Sunrice). Yield (and grain quality) can be ordered and divided to an individual farm level by region, sowing date, sowing method, and so on. Data supplied by Sunrice Grower Services is illustrated in Table 1.

Variety	Average Yield (T/ha)	Top 20% Yield (T/ha)	Difference (T/ha)
Sherpa	10.63	12.60	**1.97**
Reiziq	10.98	13.49	**2.51**
Viand	9.48	11.89	**2.41**
Opus	9.92	11.73	**1.81**
Koshihikari	7.49	9.08	**1.59**
YRK5	7.26	9.71	**2.45**
Langi	9.44	11.47	**2.03**
Doongara	10.74	13.30	**2.56**
Topaz	8.88	11.04	**2.16**

Table 1: Riverina five year rolling average and Top 20% yields 2014 -2018 Source: Sunrice

The average annual yield of all varieties compared to the Top 20% differ by around 2T/ha. This trend holds true for every variety and for every geographical region. This is neighbour to neighbour comparisons under similar soil types and climatic conditions. If the top 20% of yields could be achieved across the industry, not only would it dramatically increase the profitability to the grower, in the 2018 season (producing just over 600,000T) it would have added 115,000T of extra paddy rice to the harvest for no extra land, labour and, most notably, water (estimated economic increase after variable costs of 35% in WUE).

In Uruguay, INIA has identified a similar yield gap of 2.4T/ha from its current average yield of 8.5T/ha. Closing this gap is a major focus of much of the rice research work performed by INIA.

The importance of maintaining a strategic breeding and associated agronomic programmes cannot be overstated. However an intensive benchmarking and extension program will potentially reap immediate benefits to the grower and to the industry. The yields of the top 20% are systems that are working now within every region, using current varieties, current irrigation layouts and current technologies. The industry therefore needs to benchmark production across growers and identifying best practice to realise this achievable yield gap.

Key Driver 2: Decrease water use

As illustrated in Figure 18, water use within a crop is a combination of transpiration, evaporation, percolation and runoff.

Transpiration

Transpiration is ‘productive’ utilisation of water by the crop required for growth. Much work is being done worldwide to breed for increased transpiration efficiency of the plant. These include the C4 rice project (IRRI), crossing upland and lowland varieties (Tao, 2018) and waxy leaf gene technology (Luxiaochum 2018) to name a few. With current information there is little a producer can do to increase transpirational efficiency. The focus therefore needs to be on losses from the system that is in terms of evaporation, percolation and runoff.

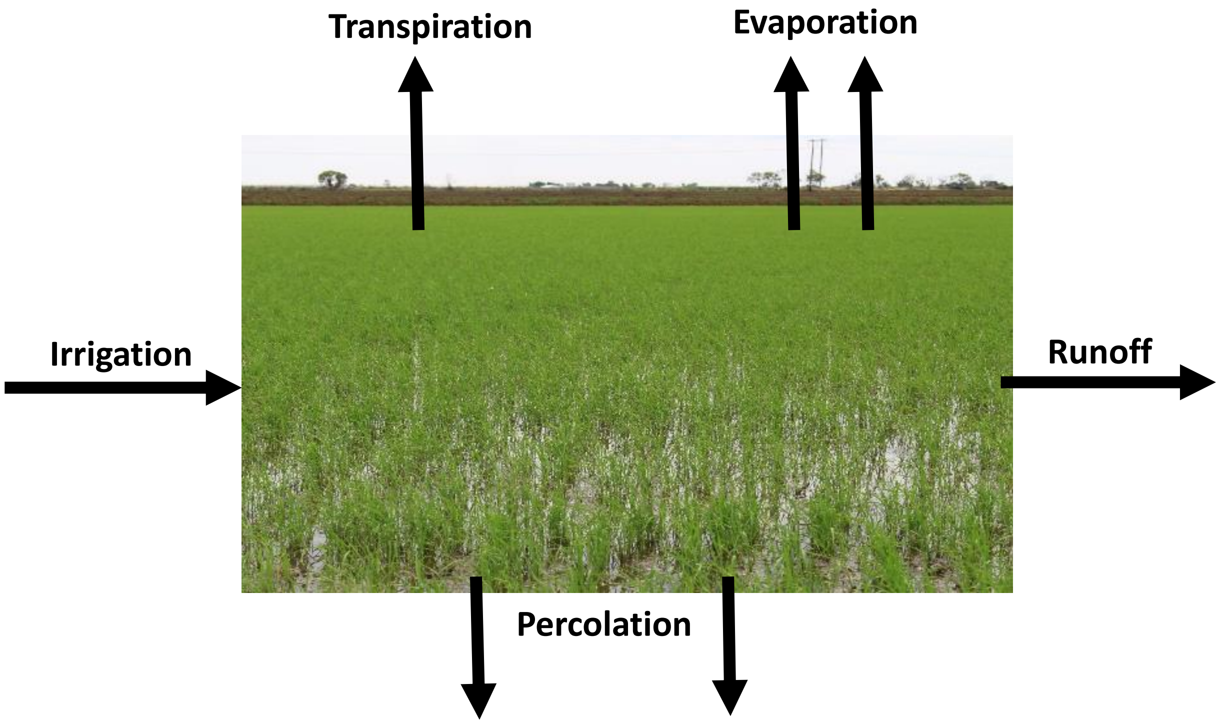

Figure 18: Water inputs and losses within an irrigated rice system (NSW DPI)

Percolation – growing crops that suit the soil

In the Punjab area of India, government incentives over the past few decades (water and electricity subsidies particularly) means rice is grown in unsuitable soil types. It is widely expected that within both India and Pakistan (Kumar, 2018), and areas of China (Wu, 2018) policy will soon dictate where certain crops can be grown.

In Australia, water market forces are already dictating this. In rice production, the highest yields and quality (and thus water efficiencies) occur when water is ponded for at least the reproductive period of the crop (Dunn, 2018). Although the Riverina Plain is a geological floodplain with much of the heavy clay soils suited to periods of inundation with minimal percolation losses, some soils are not.

On these soils, practices and irrigation layouts that minimise crop flooding times can be practiced (such as DPW on beds in bays). However it is still likely that other crops may be more suitable and more water efficient. Breeding programs exist that focus on a hopeful 'silver bullet' that will enable producers to grow rice efficiently on any irrigation suitable soil type.

Whilst it is an important focus for research to strive towards this goal, the fact remains that there is not an aerobic system worldwide that can compete with Australia's current level of water efficiency, yields and grain quality. Sometimes the focus needs to be on matching the crop to the soil type.

Runoff

Lasered irrigation layouts, precision water control, and an emphasis on drainage and water re-use systems within farms, combined with relatively low rainfall throughout the rice growing season, enables Australian rice growers to capture any rainfall or excess water applied. Australia is exemplary in its irrigation management and whilst improvements in irrigation design is ongoing, runoff is not classed as a major loss from the Australian rice system.

Evaporation – taking the 'evapo' out of 'evapotranspiration'

As stated in Leigh Vial's Nuffield Report, 'evaporation occurs from any crop whenever there is less than full leaf canopy cover of the soil/water. Free surface water evaporates the most in any weather condition, followed by bare soil, and then mulched soil'.

20 years ago, 95% of Australia's rice grown area was aerial sown. In 2017, over 60% of the area was planted with the more water efficient drill sowing technique (see Figure 19), commonly known internationally as Direct Seeded Rice (DSR).

This trend is increasing, in some areas drill sowing accounts for 80% of rice area (Sunrice GIS data). With aerial sowing, bare water is exposed to evaporation from planting onwards. With drill sowing, dry seed is planted into a dry seed bed and water is 'flushed' across the bay. Permanent flood water is not applied until five-leaf to early tillering, or around 40 days after planting.

Figure 19: Aerial sown (L) compared to drill sown (R) techniques. Water is exposed to high evaporative demand for a greater period of time with aerial sown technique (author)

Delayed Permanent Water

Some Australian farmers and researchers have developed this concept even further with a practice known as DPW. This is where permanent water is not applied until just before the reproductive phase of the crop, about 70 days after planting.

Australian research agronomist Brian Dunn (2018) recorded increases in water savings per hectare compared to aerial sown and conventional drill sown crops of 4.5ML and 2.5ML respectively, and an increase in water productivity from 0.8T/ML to 1.1T/ML. This system is being improved and has the potential to be applied to layouts such as beds and practices such as stubble retention to further improve water efficiencies. Although only an estimated 10% of Riverina growers practice DPW, to the author's knowledge this method of irrigation is not practiced anywhere else in the world for irrigated rice production.

There can only be incremental improvements in water use while the practice of 'permanent' flood water is applied at planting. The paradigm shift required in the rice industry is to manage water as per any other crop (such as corn or cotton) up to the reproductive phase of the plant.

The biggest evaporation savings are possible on better water holding soils, because soil surface can be kept dry whilst supplying adequate water to the crop at depth. Whilst many of the heavy clay soils of the (particularly western) Riverine Plain have a high water holding capacity, they are also inherently sodic. This makes them hard to manage as they are 'wet one day, crusted the next and hard as a brick the next' so the majority of this area is still aerial sown. In addition, most of the soils of the Riverina have an organic carbon content of less than 1%. So, what is the relevance and how can Australia's system be enhanced from overseas experiences?

Increasing soil organic carbon to enhance soil moisture holding capacity and providing a cover mulch to prevent surface evaporation has the potential to 'perfect' the delayed permanent water method used by growers. So can rice growers source materials to enhance their own soils and profitability, provide flexibility within their system due to better soil characteristics, and significantly increase their water use efficiency? The author believes yes – almost a million tonnes of this resource goes up in smoke every autumn!

In-situ stubble management

The practice of stubble burning is well justified as 10 to 15T/ha of high silica rice stubble is a difficult material to work with. Growers rely heavily on burning rice stubble to get the following winter crop planted in a timely manner. This not only increases the profitability but also the WUE of the rice system as the winter crop utilises the 150-200mm of residual soil moisture left after rice harvest.

While there is a strong case that burning is currently a necessity and an advantage, this has little credibility when a town is covered in smoke. In the USA, burning is severely restricted and needs to be justified to authorities on a regular basis. In Uruguay and Brazil, rice stubble burning has been banned since 2003, in China since 2013 and India and Pakistan in the last two years. In India, in the Punjab area alone it was estimated over 20 million tonne of rice straw was burnt in under three days, blacking out local townships, and (in the case of three years ago) also Delhi 300km away (Sidhu, 2018). A ban was introduced the following season.

Although the Australian industry working with information on the best weather to burn for minimal social impact, issues still arise every year (Bull, 2018). In all areas visited, rice stubble burning was banned due to social issues, not scientific ones. Other than fire regulations on timing of a burn, Australia remains one of the few countries that has no laws that restrict or ban stubble burning. If Australia can learn something from other areas is that one day stubble burning will be regulated, and it is up to the industry to be proactive about this.

The industry can look at this in two ways:

1. avoid the ‘regulatory big stick’; or
2. embrace the opportunity to utilise a wasted resource that enhances soil fertility and water use efficiency, and ultimately increases farm profitability.

A 12T/ha crop will produce about 13T/ha of rice stubble. Table 2 shows the amount of nutrients per hectare as well as the amount lost when burnt.

Nutrient	Amount in stubble (kg/ha)	% lost by burning	Amount lost by burning (kg/ha)
Carbon	5520	80	4416
Nitrogen	84	82	69
Phosphorus	7	44	3
Potassium	292	40	117
Sulphur	8	81	6

Table 2: The amount of nutrient in 13T/ha of rice stubble (12T/ha grain harvested) and the amount lost due to burning. Source NSW DPI

Sunrice is currently working with the UN / IRRI initiative Sustainable Rice Platform (SRP) which provides a world standard for the sustainable best management practices for rice production. This assures multinational food companies that the rice they are sourcing is produced in an environmental and socially responsible way. Although the overall score of the Australian system is good, the main negative score is against the practice of stubble burning.

There are a number of innovative research projects looking at uses for rice straw once it has been removed from the field, including compost, burning for energy (Vagg, 2015), even processing to paper or particle board for building material. Yet the fact remains that baling, removing from the field and transporting a million tonne of rice straw is costly and time consuming. Currently the market is not there. The compaction issues alone in trafficking over the field; cutting, baling and removing each bale (on damp soil), is enough to negate any gain from removing stubble.

Stubble must be handled in situ for effective and widespread adoption of stubble management. This will require a major paradigm shift within the industry.

Case Study – Long-term trial ‘Indian Centre for Agricultural Research - Central Soil Salinity Research Institute’, (ICAR – CSSIR)

Such a paradigm shift is occurring in north-west India. An innovative machine 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 research trial currently in its tenth year (Choudhary et al, 2018).

Figure 20: Soil physical characteristics with zero till, full stubble retention compared to conventional tillage and irrigation (Karnal, NW India). Note severe crusting and soil surface exposure (author)

Results not only show a 40% decrease in water use, but also decreases in global warming potential, energy requirements, and weed seed bank. It also shows increases of 80% in soil organic matter, 170% microbial biomass, 40% higher system yields as well as increases in nutrient availability and soil physical properties (Figure 20).

If these results could be applied to the Australian system it could well surpass the 'step-change' the industry requires not only in terms of water use efficiency, but also profitability, marketability and social and environmental license.

Key Driver 3: Increase dollars per tonne

As stated the industry, through Ricegrowers Ltd (trading as Sunrice), markets all products as either finished (ready for the supermarket shelf) or as food ingredients, such as bran, flour or rice products for further processing by other food companies such as Kellogg's. Being a grower directed company, the higher return that can be obtained for the finished product, the higher the farm gate price to the grower.

Australian rice is marketed as a premium product rather than a commodity (Sunrice Annual Report, 2017). To achieve this the industry needs to focus on how it can capitalise on practices of Australian growers to not only gain a better return for the Riverina crop, but also enhance its international reputation to better position itself globally.

Sustainable Rice Platform

Multinational food companies, such as Kellogg's, Nestlé and Mars, all have an increased focus on sourcing environmentally sustainable and socially acceptable products (Holdorf, 2017). Besides social responsibilities, they want to know that the product they are buying today is not in tomorrow's news depicting unsafe practices, chemical residue, environmental damage, child labour and so on. Consumers are demanding more than ever food products they can trust, and want the readily available information to prove it. The 'clean and green' reputation of Australia cannot be relied upon solely as there are plenty of competitors operating in that space (Wu, 2018).

Sunrice is working with the UN based SRP, one of the world's first food companies to do so. Amongst many other things, included in the criteria are stubble burning, GHG emissions, water use and management.

A 'perfected' DPW system, practicing stubble retention and planted on beds would tick every box, providing a world leading example of rice production for others to strive for. This would not only improve Australia's marketability, but would also enhance company and brand reputation.

Tell the story

This is best portrayed by Dr Wyn Ellis, coordinator of the SRP, while touring the Riverina rice industry in 2017. He stated that "*on a world scale it is incredible what you (the Australian Rice Industry) are 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*".

Telling the 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' (Figure 21). Environmentalist now fight for flooded rice culture.

Figure 21: Rice as a reconciled ecosystem. Slides from a presentation from California Rice (RTWG Feb 2018)

Californian Rice has swung 180 degrees from a water hungry crop to the environmental crop through promotion of agronomic principles and ecological benefits.

Australia has a great story to tell. Few could disagree that that Australian rice leads the world in terms of yield, water use efficiency, best management and sustainable practices. As Wyn says '*we need to start shouting this from the rooftops*'.

Conclusion

Few could dispute Australia's position as the world leader in productive and sustainable rice production. However regardless of where Australia is positioned, the free market system of water within the Southern Basin means rice is another crop competing for water resources.

To position itself as the 'crop of choice' (and for its very survival) the Australian rice industry must focus on increasing WUE, particularly in terms of dollar return per megalitre.

Research focus is currently on 'aerobic' production, particularly centred on genetic improvement. Immediate gains to the industry however will be in addressing three key drivers of WUE – decreasing water use and increasing both yield and farm gate price per tonne.

The Australian industry is in the enviable position that all area, yield and quality data is on one database within Sunrice. Benchmarking shows there is an average of 2T/ha difference in yield between industry average and the Top 20%. While momentum is gaining in analysis and extension of this data, the industry needs to focus on a more robust and coordinated program to analyse why this yield gap exists and extension of results.

The irrigation practice of delayed permanent water is unique to the Australian rice system and has benefits to WUE and profitability. These benefits are evolving and improving. If results of long-term trial data of stubble retention and zero tillage from the Punjab region in India could be replicated in Australia, and this system applied to a bed layout with high water flow for efficient irrigation management, this could provide the required 'paradigm' shift for water efficiency in rice. Not only would this dramatically increase WUE, it would develop a rice system that is not only the world leader in sustainability and productivity but is an integral cog in the regeneration of soils and the environment.

This system would enhance Australia's reputation in terms of 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.

This is a challenging time for the Australian rice industry with variable water supply and water market forces it will likely remain so. Is this a threat or an opportunity? The choice is there.

Recommendations

To remain a major summer crop in the Southern Connected Basin, the rice industry must have a step change increase in WUE, and it must have it soon, within five years. Recommendations include:

- **In-situ stubble management**
  - Effective stubble management has been shown to increase WUE by 40%, with associated increases in organic matter, nutrient use efficiency, microbial biomass and potentially rice value through its 'clean' image.
  - There are technologies available both in Australia and overseas that should be trialled and possibly adapted to Australian conditions. Australia should aim to position itself to be the world leader in rice stubble management.

- **Identify and prioritise extension services on yield gap**
  - For major varieties, between the Top 20% of yields and average, there is a yield gap of 2 - 2.5T/ha. If half this yield gap is met, this is a minimum of 10 – 15% increase in WUE using current varieties and current technologies.

- **Re-evaluate 'aerobic rice' research priorities**
  - Given climate extremities in southern NSW, assess whether a non-flooded system that is capable of high yield and high grain quality is possible and whether this be a research focus.
  - 'Aerobic rice' breeding is both incremental and long-term. The industry cannot rest its future on this concept.
  - For maximum short-term gain, 'aerobic rice' research needs a focus on irrigation systems and agronomic management. An example is perfecting the DPW system to minimise water use without penalty to yield or quality.

- **Tell the Story**
  - Australia is setting world benchmarks in yield and WUE. Enhance the story – particularly if stubble was managed in field – of a rice system that is not only a world leader in sustainability and productivity but is integral in the rejuvenation and enhancement of soils and environment.
  - This should be prioritised both in terms of an accredited and recognised sustainability program (e.g. SRP) and marketing a story at both grower and industry level.

References

Anders M. (Feb 2018). Personal Communication – retired Professor of Agronomy, University of Arkansas, Coordinator of Irrigation Efficiency Program for Natural Resource Commission, Mississippi Delta, Arkansas

Australian Nut Industry Council (2016) Australian Tree Nut Industry 2016 – Growing for Success https://nutindustry.org.au/wp-content/uploads/2019/01/Growing-for-Success-2016

Arkansas Natural Resources Commission (ANRC) (2016) Arkansas groundwater protection and management report for 2015. https://static.ark.org/eeuploads/anrc/FINAL_DRAFT_groundwater_rpt_2015-2016.pdf

Balcerak A (2018) Personal Communication. Agriculture Counsellor, Department of Agriculture, Australian Embassy. Beijing, China

Bocking B (2017) Improvements in Irrigation in Northern Uruguay - Rice Irrigation for Water Use in Other Crops, and General View of Uruguayan Condition. Presentation, May 2017

Bouman B (2009). How much water does rice use? Crop and Environmental Sciences, IRRI, Rice Today Jan-March 2009

Bull N (April 2018) Personal Communication. Environmental officer with Ricegrowers of Australia.

Carracelas G (March 2018) Personal Communication – Research Agronomist, Instituto Nacional de Investigacion Agropecuaria (INIA). Presentation at RTWG, Long Beach

Cassman K, (Feb 2018) Personal Communication From a presentation 37th Rice Technical Working Group Conference, Feb 19 – 22, 2018 Long Beach California, USA

Changrong Ye (June 2018) Personal Communication. Rice Genetics and Breeding, Yunnan Academy of Agricultural Sciences, Institute of Food Crops, China

Choudhary M. et. al. (2018) - Sustainable intensification influences soil quality, biota, and productivity in cereal-based agroecosystems. Applied Soil Ecology 126 (2018) pp189-198

Dunn B. (2018) Delayed Permanent water on Drill Sown Rice. Primefact 1238, 3rd Edition NSW Department of Primary Industries, Yanco

Ellis W, Sustainable Rice Platform Coordinator. Enabling Climate Smart Resource Efficient Sustainable Rice - Sustainable Rice Platform, UN Environment, www.sustainablerice.org

FAO. Second International Symposium on Agroecology, FAO 3-5 April 2018 Rome

FAOstat - http://www.factfish.com/statistic/rice%2C%20paddy%2C%20yield

Famoso A (Feb 2018) Personal Communication. Rice Breeder. Louisiana State University Ag Centre. Rayne, Louisiana, USA

GRiSP (Global Rice Science Partnership). 2013. Rice almanac, 4th edition. Los Baños (Philippines): International Rice Research Institute. 283 p.

Grissini P, Eskridge KM, Cassman KG (2013) Distinguishing between yield advances and yield plateaus in historical crop production trends. Nature Communications, 4:2918, DOI 10.1038, ncomms 3918

Holdorf D (November 2017) Personal Communication. Director of Sustainability, Kellogg's Presentation and discussion with Sunrice, Sydney

Humphries et al (2010) Halting the Groundwater Decline in NW India – which crop technologies will be the winners? Advances in Agronomy Vol 109 2010 pp155-217

Jat HS (June 2018) Personal Communication. Research Platform Coordinator, CIMMYT, Karnal

Kumar V. (June 2018) Personal Communication – Senior Weed Scientist IRRI, Philippines

Luxiaochun (June 2018) Personal Communication – National Molecular Breeding Industry System, Liaoning Academy of Agricultural Sciences. Shenyang, China

Massey et al. (2014) Farmer Adaptation to Intermittent Flooding using Multiple Inlet Rice Irrigation in Mississippi. Agricultural Water Management 146 (2014) 297-304

Massey, et al. (2017) Long-term measurements of agronomic crop irrigation made in the Mississippi Delta Portion of the Lower Mississippi River Valley. Irrigation Science DOI 10.1007/s00271-017-0543-y

Mitchell J (2018 Personal Communication) Research Officer School of Agriculture and Food Sciences | University of Queensland | St Lucia QLD 4072

Ottis B. (Feb 2108) Personal Communication – RiceTec research agronomist, Alvin, Texas, USA

Pay E. (June 2018) Personal Communication. Research Consultant, China Policy, Beijing, China

Quilty J., (June 2018) Personal Communication. Director of Experimental Research, IRRI

Ray DK, et al (2013) Yield Trends Are Insufficient to Double Global Crop Production by 2050. PLoS ONE 8(6): e66428. https://doi.org/10.1371/journal.pone.0066428

RMCG (2016) Presentation: Water Availability Impacts of NSW Riverina Rice Production by 2021

Runkle B. (Feb 2018) Personal Communication - Assistant Professor University of Arkansas, College of Engineering, Arkansas

Sidhu H (June 2018) Personal Communication. Director BISA, Ludhiana, Punjab India

Singh Y (June 2018) Personal Communication. Punjab Agricultural University and BISA, Ludhiana, Punjab, India

Snell P (2018) Personal Communication, Rice Breeder NSW Department of Primary Industries, Yanco Agricultural Research Centre (Rice Partnership), Yanco Australia

Sunrice (2017) (pers com) Presentation at RGA Annual Conference

Sunrice Grower Services, Benchmark Data presented grower meetings 2018

Tao D, (2018) Personal Communication. Director, International Cooperation Division & Deputy Director, Scientific Management Division, Yunnan Academy of Agricultural Sciences, China

Vagg A (2015) Rice straw Utilisation. Value Adding and Alternative Uses for the Australian Rice Industry. Nuffield Report #1450736731 http://nuffieldinternational.org/live/Reports

Vial L (2005) Aerobic and Alternate-Wet-and-Dry (AWD) Rice Systems. Nuffield Report #1221627835 http://nuffieldinternational.org/live/Reports

Wessells, K. R., and Brown, K. H. (2012). Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. PLoS ONE 7:e50568. doi: 10.1371/journal.pone.0050568

Wu S (June 2018) Personal Communication. Business Development Manager, Austrade Beijing China

Yuedong Li (June 2018) Personal Communication. Deputy Director, Liaoning Academy of Agriculture, Liaoning Province, NE China

Zhang S (June 2018) Personal Communication. Senior Business Development Manager, Austrade. Australian Embassy. Beijing, China

Zhiqiang T (June 2018) Personal Communication. Deputy Director of Liaoning Academy of Agriculture, Liaoning Province, NE China

The author would also like to acknowledge the groups of researchers, extension staff, consultants and students at the following institutions that held group discussions from which a lot of the background knowledge was gained:

- University of Santa Maria - The Simul Arroz team. Santa Maria, Brazil
- Pampa University, Itique, Brazil
- Mississippi Delta Water Management Team, Arkansas USA
- Punjab Agricultural University - Rice Team, Ludhiana, Punjab, India
- Liaoning Academy of Agricultural Sciences – Rice Team, Shenyang, Liaoning Province, China
- Australian Embassy – Department of Agriculture, and Austrade. Beijing, China

Plain English Compendium Summary

Project Title:	The Future of Australian Rice Production A Focus on Water Use Efficiency in the Australian Temperate Rice System
Nuffield Australia Project No.:	1704
Scholar:	Mark Groat
Organisation:	Westray Farm 1641 BEELBANGERA NSW 2680 Australia
Phone:	+61 427 686 966
Email:	westraymt@gmail.com
Objectives	1. Analyse the role genetic gain will have on water use efficiency of rice in the short and long term. 2. Provide a frame a reference for the Australian rice Industry by comparing production and water awareness in the US, Uruguay, China and India. 3. Identify the role the industry must play to enhance the Australian rice system, what can be learnt looking elsewhere and what opportunities exist from looking within. 4. Analyse current rice production practices and explore not only where improvements could be made in water use efficiency, but a paradigm shift within the production system, particularly in regards to stubble management. This could dramatically increase WUE and profitability, as well as the industry's reputation and marketability.
Background	Water in the Southern Connected Basin is seasonally variable and an annually tradeable commodity that goes to the highest bidder. Rice production therefore is not only linked to water availability but also to the price of a range of annual and perennial commodity crops that compete for the same water. Water Use Efficiency (WUE) is therefore the key to continued rice production and surety of supply
Research	Compare production techniques, water awareness and policy as a frame of reference to the Australian Industry. Analyse what can be learnt from this, and where are the opportunities at both the grower and industry level. Areas studied were Brazil, Uruguay, the USA, China, India and through the International Rice Research Institute in the Philippines an overview of the world's equatorial rice in SE Asia, South Asia and sub-Saharan Africa.
Outcomes	Australia is the most efficient rice industry in the world in terms of yield and WUE. However the Australian rice system needs to be competitive to other crops for the same water. Benchmarking shows an identifiable yield gap of 2T/ha between the average and the Top 20%. Increasing yield, decreasing evaporation and increasing marketability, and thus price per tonne, are key components to increasing WUE in terms of $/ML
Implications	This report recommends to the industry a future focus of benchmarking, extension and research into in-situ stubble management. In addition Australia is a world leader in production statistics and 'sustainable development goals' in rice production. That good news story needs to be told more effectively to enhance reputation and marketability.
Publications	• Sunrice AGRO annual conference, August 2018 • Rice R&D Workshop, August 2018. • Published extract in Rice R&D publication, September 2018 • 2018 Nuffield National Conference, Melbourne, September 2018