

LITERATURE REVIEW – Production impacts

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1.1. Climate Change Impacts

Irrigation Water Supply

Practically all of Australia's rice is grown in conditions of shallow (10cm) ponded water. Consequently, total rice production in Australia has a strong linear relationship with total irrigation water allocations in the rice-growing districts (Figure 6.1). Deviations around this linear relationship are likely due to a range of other less influential factors affecting rice production such as temperatures, disease, and market dynamics.

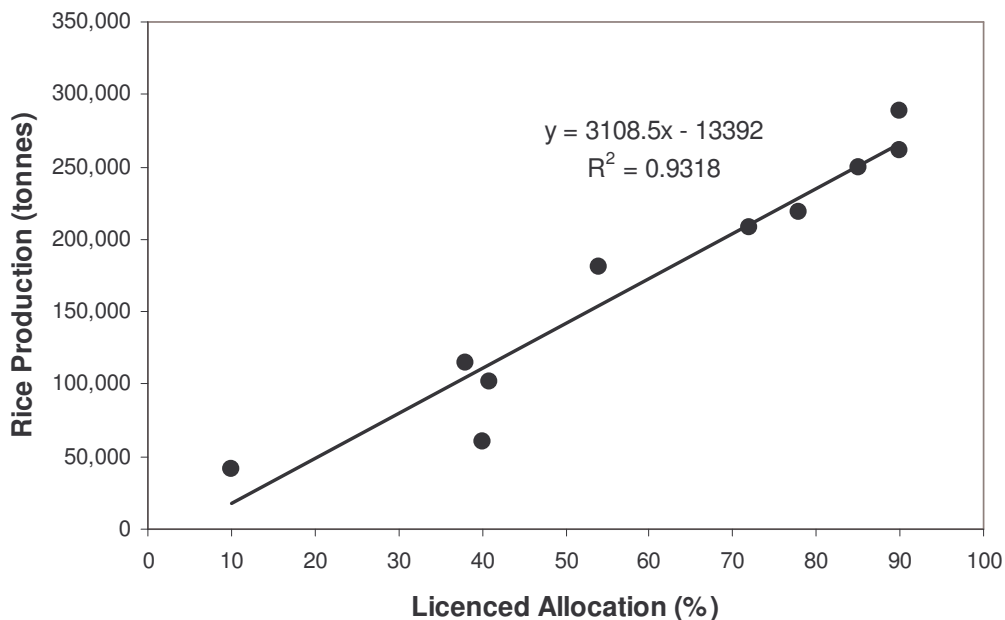


Figure 6.1: *The relationship between annual irrigation water allocation and annual rice production for the Coleambally Irrigation Area, NSW, (1998-2007) (statistical data provided courtesy Roger Clough, Grower Services, SunRice, Leeton).*

The effect of projected climate change on irrigation water supply to the Riverina rice growing areas is therefore a dominating factor in assessing climate change impacts on rice production. Recent climate change projections suggest 16-25% reduction in average Murray-Darling stream-flows by 2050 and 16-48% reduction by 2100 (Pittock 2003; Christensen *et al* 2007). This is likely to have dramatic implications for irrigation water allocations in the Riverina (Jones and Pittock 2003). The strong relationship between available irrigation water and production (Figure 6.1) would suggest significant impacts in future production in response to likely declines in average stream-flow, however there are a number of other confounding factors

relating to extent of changes in competing water sectors (i.e. domestic, environmental allocations, industrial etc) (Adamson *et al.* 2007; Humphreys and Robinson 2003).

What will be the impact of climate change on allocations in the Riverina?

Estimation of future water allocations under climate change was provided from the CSIRO Land & Water “Murray Darling Basin Sustainable Yields Project” for all catchments in the Murray Darling Basin (MDB), including the Murray and Murrumbidgee. This project has assessed a range of projected future climate scenarios (using the 4th IPCC archived modelling results for 15 GCMs) and potential future development scenarios (farm dams, surface and groundwater extractions, commercial plantations, domestic requirements etc), and reported on availability impacts.

Murray System : Key findings

- Average surface water availability for the MDB aggregated to Wentworth under the historical climate is 14,493 GL/year. For the Murray region, average surface water availability is 11,162 GL/year. Under current development, surface water use across the MDB aggregated to Wentworth (including downstream use) is extremely high with 56% of the average available water used. Average surface water use within the Murray region aggregated to Wentworth is 4045 GL/year or a high 36% of the average surface water available in the region. Current groundwater use within the region is about 233 GL/year or 5% of total water use in the region.
- If the recent (1997 to 2006) climate were to persist, average surface water availability for the Murray region would fall by 30%, average diversions in the Murray region would fall by 13% and end-of-system flows would fall by 50%. The relative level of surface water use across the MDB would be 66%.
- Given the uncertain nature of climate change projections, the extreme estimates (from the high global warming scenario) range from a 37% reduction to a 7% increase in average annual runoff.
- Under the wet extreme 2030 climate, average surface water availability for the MDB and Murray Region would increase by 7%. End-of-system flows would increase by 20%. Diversions in New South Wales would, on average, increase by 2%, while total Victorian and South Australian diversions would be essentially unaffected.
- The best estimate (median) of climate change by 2030 is less severe than the recent past. Under this climate, average surface water availability for the Murray region would fall by 14%, average diversions in the Murray region would fall by 4% and end-of-system flows would fall by 24%.
- Under the dry extreme 2030 climate, average surface water availability would fall by 37% for the MDB and by 41% for the Murray region. Total diversions in the region would fall by 23% and end-of-system flows would fall by 69%. New South Wales diversions in the region would fall by 32% on average and Victorian diversions in the region would fall by 18% on average. Diversions in South Australia would fall by 30%.

- Future development of farm dams by 2030 is expected to reduce total runoff across the region by less than 1%. Although likely commercial plantation forestry expansion by 2030 would have significant local effects on runoff, the impact on average annual runoff for the entire Murray region would be negligible. Groundwater use in the region is expected to treble by 2030 to be 701 GL/year or 15% of total average water use.

Murrumbidgee: Key findings

- Average surface water availability for the region under the historical climate is 4270 GL/year. The relative level of surface water use under current development is 53% (2257 GL/year). This is an extremely high level of development. Groundwater use within the region is about 407 GL/year or 17% of total water use.
- If the recent climate (1997 to 2006) were to persist, average surface water availability would reduce by 30%, diversions by 18% and end-of-system flow by 46%. The relative level of surface water use would be 62%.
- Given the uncertain nature of climate change projections, the extreme estimates (which come from the high global warming scenario) range from a 31% reduction to a 13% increase in average annual runoff.
- Under the wet extreme 2030 climate, average surface water availability would increase by 13%, diversions would increase by 5% and end-of-system flows would increase by 20%.
- The best estimate of climate change by 2030 is less severe than the recent past. Average surface water availability would reduce by 9%, diversions by 2% and end-of-system flow by 17%.
- Under the dry extreme 2030 climate average surface water availability would reduce by 28%, diversions would reduce by 16% and end-of-system flows would reduce by 44%.
- Likely future development of farm dams would reduce total runoff by 1%. Although likely commercial plantation forestry expansion would have significant local effects on runoff, the impact on average annual runoff for the entire region would be negligible. Groundwater extraction is expected to increase by around 22% to become 21% of total average annual water use by 2030.

These summary points above are for 'current level of development and future climate'. Projections are given in terms of 'wet', 'dry' and 'best' estimates for climate change. It is important to note that our current level of greenhouse gas emissions and global temperature estimates are aligned with the 'dry' estimate. That is, we are currently heading down the 'dry' path.

For further information: <http://www.csiro.au/partnerships/MDBSY.html>

Irrigation Water Demand

Seasonal irrigation water requirements in the Riverina have historically exhibited high levels of variability. Annual water requirement for rice crops to meet evapotranspiration can rise above the mean value by up to 30% (up to 16 MI/ha with a mean of 12 MI/ha, (Peter Sheppard rice farmer, pers com)). Modelled annual whole-of-farm water requirement for a sample farm at Kerang, Vic, growing perennial pasture was noted to vary between approximately 210 MI to 370 MI, around an average of approximately 290 MI over the period 1975-1996 (Jones 2000), a variation of roughly 30% either side of the mean. A global modelling study on the impacts of climate change on irrigation water requirements found that significant variation could be expected geographically (Döll 2002). For South-Eastern Australia, this study found that the projected impact of climate changes on irrigation demand is smaller than the existing interannual climate variability. Figure 6.2 shows the comparison between historical pan evaporation at Griffith (1900-2006), and projected pan evaporation at Griffith using the HadleyCM2 GCM for low and high forcing climate change scenarios (IPCC B1 and A1F1 respectively) for (a) 2030 and (b) 2070. (Gaydon & Crimp, in prep)

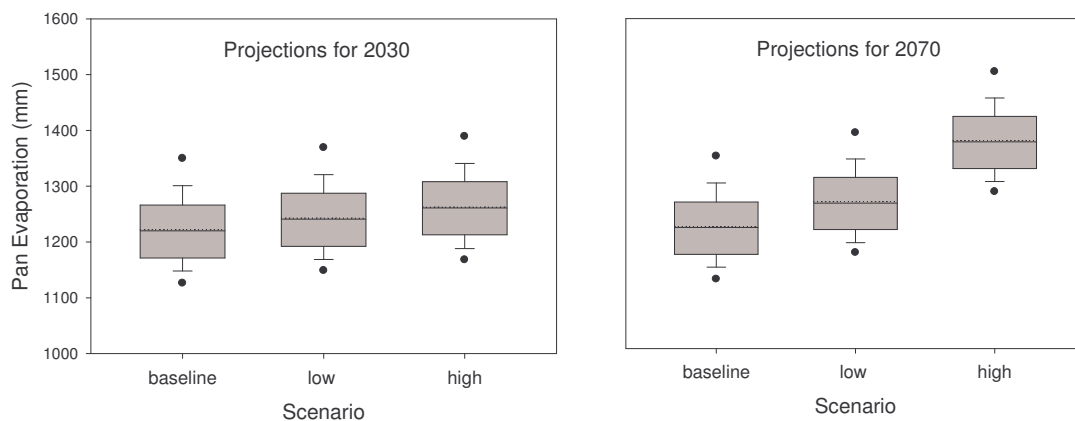


Figure 6.2: *Historical and projected cumulative seasonal pan evaporation over the rice growing season (15 October – 15 April) for Griffith. Projections developed using the HadleyCM2 GCM for low and high forcing scenarios (IPCC B1 and A1F1 respectively) for (a) 2030 and (b) 2070. ‘Baseline’ refers to historical records. Within the grey boxes, the dotted line is the mean, the solid line the median.*

We could find no published research on potential impacts of climate change scenarios on Australian water use in rice crops, however international research suggests that a combination of increased evaporative demand and decreased rainfall would result in average Sri Lankan paddy water requirement increasing by 13-23% depending on the GCM forcing scenario (De Silva et al. 2007). Given that Australia represents a markedly different rice-growing environment, and is less reliant on in-crop rainfall, further research into this issue is required.

In summary we can expect that climate change will increase the irrigation water demand of rice crops, however mean increases will most likely not exceed the range of historically-experienced variability although individual years may exceed the range. Extending the projection to 2070 could see some large increases in water

demand if a high forcing projection is considered. Also, projected decreases in regional rainfall (Christensen, 2007) could also see the contribution to total rice water requirement from irrigation water increase as the rainfall contribution decreases, thereby further adding to irrigation water demand.

Increased temperatures

There is little published work on impacts of increased maximum and minimum temperatures on Australian rice varieties, however there is substantial literature from international research. Flowering and booting (microsporogenesis) are the most susceptible stages of development to temperature in rice (Satake and Yoshida 1978; Farrell *et al.* 2006a). Studies detailed in Satake and Yoshida (1978) indicate that spikelets which are exposed to temperatures $>35^{\circ}\text{C}$ for about 5 days during the flowering period are sterilized and do not seed. Jagadish *et al.* (2007) in greenhouse experiments with both *indica* and *japonica* genotypes, found that less than one hour of exposure to temperatures above 33.7°C was sufficient to induce sterility. However it is important to note that the temperatures quoted in each of these studies refers to the actual temperatures experienced by the spikelets, not the ambient temperature. There is generally significant cooling at the spikelet due to transpiration within the canopy, particularly in the low humidity rice growing environments of Australia. This has been measured at $4 - 6.8^{\circ}\text{C}$ under conditions of 34.8°C ambient temperature and 20% relative humidity in Australian environments (Matsui *et al.* 2007). Australian rice crops regularly receive ambient temperatures in excess of 35°C during this period, hence if it were not for the low humidity and consequent evaporative canopy cooling, it appears that high temperature sterility issues could be a major limiting factor for rice production in Australia. There is the possibility that climatic change could produce even greater cooling differentials. However despite this, the potential for greater extremes in maximum temperatures under climate change (Christensen *et al.* 2007) still pose a risk to rice at flowering and booting stages in Australia. Each of these periods lasts for around 5 days in most rice genotypes, and in the Riverina occurs sometime between 5th Jan – 15th Feb (Farrell *et al.* 2006b). Figure 6.3 (from Gaydon & Crimp, in prep) shows the significantly increased likelihood of dangerously high canopy temperatures ($> 35^{\circ}\text{C}$) during this period, assuming a 6°C cooling within the canopy at time of maximum temperature. The risk of high temperature more than doubled for flowering rice crops at Griffith by 2070. There is also evidence that in addition to large negative yield impacts from short periods above very high temperatures, damage may be cumulative with duration of exposure above certain lower, threshold temperatures. These will vary between cultivar (Jagadish *et al.* 2007), however this has not been considered in this analysis.

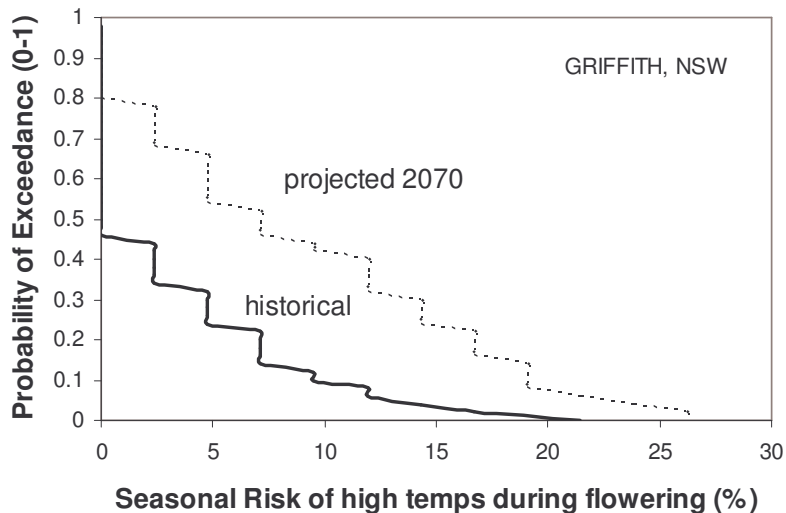


Figure 6.3: *Effect of climate change scenarios on risk of experiencing dangerous high temperatures at rice flowering/booting for Griffith. Warming projection developed using the HadleyCM2 GCM for a high forcing scenario (IPCC A1F1) (Gaydon & Crimp, in prep).*

It is suggested that increases in average minimum temperatures may be more significant in overall terms than increases in maximum temperatures (Peng et al. 2004). In trends at the International Rice Research Institute (IRRI) Farm, Los Baños, Philippines, between 1979 and 2003, rice grain yield declined by 10% for each 1°C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant. Decreases in rice yields are attributed to increasing night-time temperatures associated with global warming. IRRI annual mean maximum and minimum temperatures increased by 0.35°C and 1.13°C respectively, during the 25-year sampled period. This equates to 0.014 and 0.045 °C per year for average maximum and minimum temperatures respectively. The increase in minimum temperature was 3.2 times greater than the increase in maximum temperature, which is consistent with the observation that minimum temperature has increased approximately three times as much as the corresponding maximum temperature from 1951 to 1990 over much of the Earth's surface (Karl 1991). Figure 6.4 shows both the observed trends in average minimum and maximum temperature in the Riverina over the rice growing period (Oct – April) between the years 1957 and 2005. Past observations show a pattern of higher average maximum temperatures associated with drought years (ie. less cloud cover) and lower average maximum temperatures associated with years of above average rainfall (ie. more cloud cover). Hence the temperature trends evident may be substantially a function of more drought years in the second half of the record compared with the first. Whilst a strong correlation exists between droughts and increased average maximum temperatures recent work by Nichols (2004) has demonstrated that over the last 50 years droughts have, on average, been hotter. We can find no published evidence to show trends observed by Peng et al (2004) are mirrored in Australian rice yields, however similar trends have been observed elsewhere in the world (Pathak and Ladha, *et al.* 2003). There may be different factors at play in different environments, however the observed IRRI trend suggests that further investigation may be warranted for projected Australian climate scenarios.

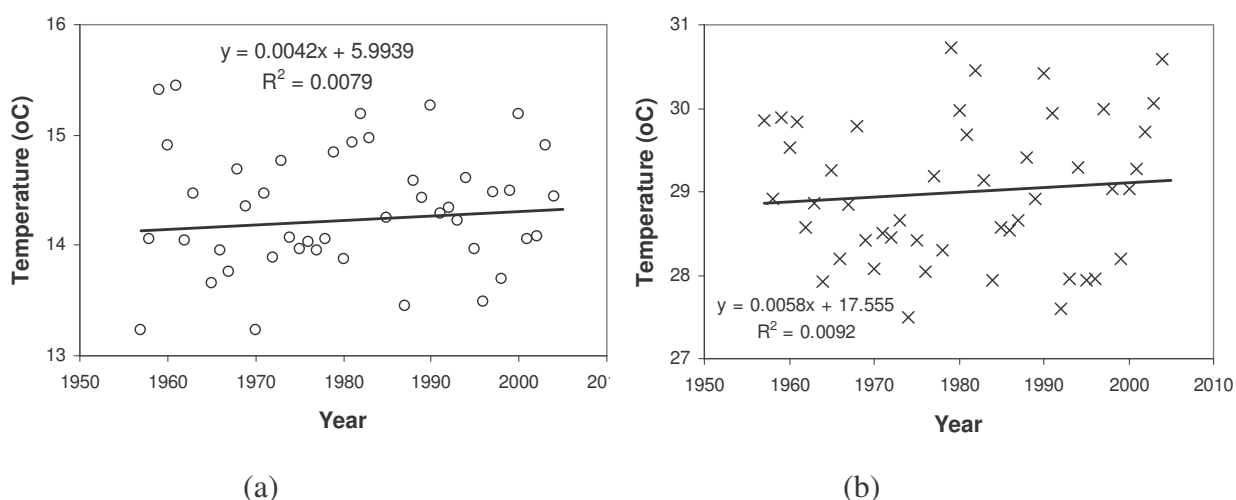


Figure 6.4: Trends in average (a) minimum and (b) maximum temperatures during rice season (Oct-April) at Coleambally (1957-2006).

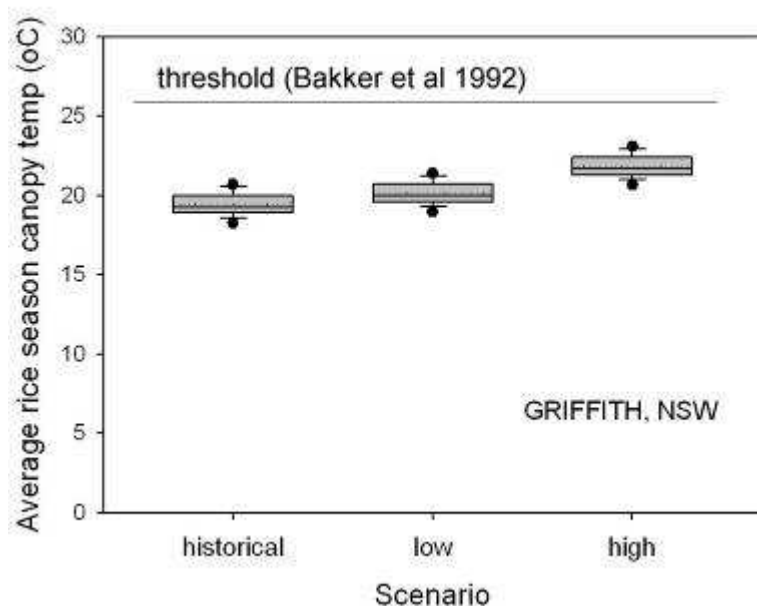


Figure 6.5: Average canopy temperature during rice growing season for Griffith under historical climate, and low/high climate change forcing scenarios using the HadleyC2 GCM (scenarios are IPCC b1 and a1f1), assuming a canopy cooling of at least 4 °C (Matsui et al 2007) applied to maximum daily temperatures. The threshold is average season temperature (Peng et al, 1995) above which a negative yield response could be expected.

There is general agreement that increased average temperatures will have a negative effect on rice yields internationally, with yield decreases due to temperatures alone (in isolation from CO₂ increases) estimated to range between 5 and 10% per 1°C rise in average season temperatures in some areas (Peng et al. 1995; Baker et al. 1992; Baker and Allen 1993). Peng et al (1995) suggested a negative yield response to increasing

average rice season temperatures above a threshold of 26 °C. In Australia, the range of average temperature during rice growing season is shown in Figure 6.5 for historical and high & low forcing climate change projections.

Australia and other temperate rice growing zones of the world may experience an increase in rice production with temperature, as climate changes increases average canopy temperatures which are currently below the 26 °C threshold (Peng *et al.* 1995). Note that this threshold was reported for indica varieties, and on the basis of no further information this analysis assumes it is the same for japonica varieties. As can be seen in Figure 6.5, if the average maximum daily temperatures are reduced according to the evaporative canopy cooling effect measured by Matsui *et al.* (2007) of 6 °C, Australian rice production seems a considerable way from experiencing yield reductions due to climate change effects. Figure 6.5 suggests that this would be the case even under the highest climate change forcing scenario for 2070, if the threshold suggested by Peng *et al.* (1995) applies. There is further evidence that some Australian varieties have other physiological features/characteristics conferring tolerance to high temperatures which may increase the thresholds (Matsui *et al.* 2007), however this is a research area in which information is limited and further work is warranted to define these mechanisms and ensure future varieties have equal or improved tolerance levels. Baker and Allen (1993) suggest potentially reduced evaporative cooling of the canopy under increased CO₂ scenarios. It is also unknown whether the canopy cooling effect detailed by Matsui *et al.* (2007) would apply to aerobic and AWD rice cultures, and the extent to which this would effect high temperature risk in this culture. There is evidence of a likely strong interaction between temperature and CO₂ which is discussed in the Combined Temperature and CO₂ Effects section below.

Cold temperature damage and frost risk

There is presently significant risk of low-temperature damage during the reproductive stage in rice under Australian conditions. Low minimum temperatures can lead to pollen sterility and low yield in high N status crops. Minimum temperatures less than 17-19 °C during panicle development are considered dangerous (Farrell *et al.*, 2006b). The development of semi-dwarf varieties allowed the effective use of deep floodwater levels as a management strategy during this period as a management strategy to minimise risk by inundating the developing panicles (Williams and Angus 1994). At critical times, paddy water may be 5-7 °C warmer than the ambient air conditions. The coldest temperature often occurs just before dawn. The temperature of the rice plant components exposed to the ambient air has been shown to be practically identical to ambient air temperatures at this time (Williams and Angus 1994). The probability of encountering such ambient air temperatures during flowering are around 20-25% in the Griffith area, for the most commonly-planted cultivar Amaroo (Farrell *et al.* 2006b). The degree to which projected climate change scenarios might impact that risk is shown in Figure 6.6 (Gaydon & Crimp, in prep). Figure 6.6 shows projected climate change (IPCC A1F1 scenario, 2070) is likely to reduce the risk of low temperature occurrence at rice flowering by roughly one third. Currently this risk is mediated by the use of increased water levels (20cm) over this period, however adaptive options such as aerobic rice (see section below under Adaptation Options) do not have this protection and the projection in this risk is relevant to deliberations on

this option. There is evidence that frost risk may increase with climate change in southern Australia, hence further analysis of this matter is recommended.

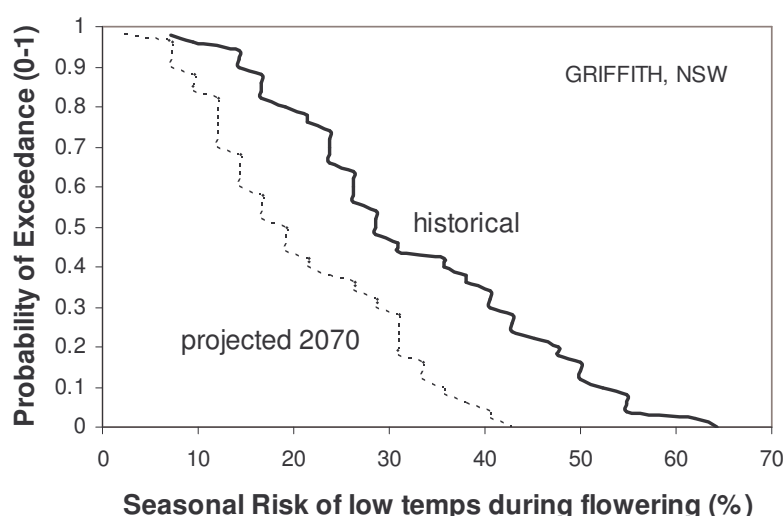


Figure 6.6: Risk of ambient temperatures below 15 °C during rice flowering time under historical and projected climate for Griffith, 2070 (general period of rice flowering is defined as 5th Jan – 15th Feb (Farrell *et al*, 2006b), however in any given year occurs over only five days). Risk per season is defined as the number of days per 5th Jan – 15th Feb period in which minimum temperature falls below 15°C. Warming projection developed using the HadleyCM2 GCM for a high forcing scenario (IPCC A1F1).

CO₂ fertilisation

Several free-air CO₂ enrichment (FACE) experiments have been conducted with rice, although none in Australia. Recent experiments in Japan and China using Japonica cultivars found that crop response to elevated CO₂ was associated with N uptake, and varied throughout the season (Kim *et al.* 2003; Yang *et al.* 2007). For CO₂ environments 200 ppm greater than ambient Kim *et al* (2003) recorded an average 15% increase in rice grain yield when N was in good supply, less for low N treatments. They found that green leaf area index response to increased CO₂ was positive during vegetative stages and negative after panicle initiation. This phenomenon was also observed in the Chinese experiments, with researchers suggesting that the recommended rates, proportions and timing of nitrogen application should be reconsidered under increased CO₂ to take full advantage of early uptake capacity and also facilitate subsequent N uptake (Yang *et al.* 2007). This study reported a rice grain yield increase of 13%. There is evidence from experiments in the Philippines that even higher CO₂ concentrations (300 ppm above ambient) can result in greater rice yield increases of (27%, (Ziska *et al.* 1997)). Note that mid-range projections of CO₂ in 2100 are about 350ppm higher than present. The implications of an increase in atmospheric CO₂ for rice production under Australian conditions are not known, however it would seem reasonable to assume similar potential rice yield increases as those observed in the Japanese and Chinese studies.

Combined Temperature and CO₂ Effects

Several studies have shown that high air temperatures can reduce grain yield even under CO₂ enrichment (Baker and Allen 1993; Ziska *et al.* 1997). There is also evidence to indicate that the relative enhancement of rice yields due to CO₂ fertilisation is gradually reduced with increases in air temperatures (Matsui *et al.* 1997), as the critical temperature for spikelet sterility is reduced.

It is difficult to make inferences on the implications for Australian rice production particularly as some studies have reported significant variance in the response of different cultivars to CO₂ fertilisation (Baker 2004; De Costa *et al.* 2007; Moya *et al.* 1998; Ziska *et al.* 1996). A modelling study covering a diverse range of agro-climatic zones in India, (Aggarwal and Mall 2002) found that climate change outcomes on rice grain yield were positive regardless of the uncertainties and climate change forcings, with average rice grain yield increases ranging from 1 – 38%. In contrast, negative trends in rice yields were found in a modelling study in India due to increases in minimum temperature and decreases in incident radiation (Pathak *et al.* 2003). This result was supported by observed data, and the researchers also suggested that these declining trends should be taken as an indication of a future problem in food security. Given the disparity in existing international studies, and the lack of published Australian studies it is difficult at this point to make any informed judgement on the combined effect of increased temperature and CO₂ concentrations on Australian rice production.

1.2. Summary of Climate Change Impacts

The largest impact from projected climatic change on Australian rice production is likely to be from reduced supply of irrigation water. Projected reductions in Murray-Darling stream-flows of 16-25% by 2050 and 16-48% by 2100 are likely to result in similar levels of reduction in rice production, under current production and water use systems. A key question relates to the projected increase in variability of water supplies, how often significant rice plantings will be possible, and hence how this will affect the cost/benefits of maintaining current rice production infrastructure. Farming systems changes in response to a reduced and more variable water supply (ie changed rotations, irrigations methods, crops, layouts etc) could see additional reductions in rice production, however the costs/benefits of various adaptation options are currently unknown and this is a major research area for irrigated farming in the Riverina. The impacts on rice yields in the Australian situation from projected CO₂ fertilisation and changes in temperature are much more uncertain, and require further research. It would appear that yield reductions due to extreme high temperatures presents a possible risk, given the current high ambient temperatures during rice microspore and the likelihood of increased temperature extremes in combination with potentially reduced evaporative cooling of the canopy under increased CO₂ scenarios. It is unlikely that increases in average temperatures over the growing period will present significant production risk, as considerable buffer already exists between current average temperatures and the reported average temperature thresholds for incurring yield losses. Increased temperatures associated with climate change may reduce the risk of low temperature damage during microspore –one of the largest limitations to rice production in Australia currently.

1.3. Current Options for Dealing with Climate Variability

Cropping Area Modification

The process of irrigating crops is in itself an option for dealing with climate variability. When rainfall is less forthcoming, extra irrigation water is applied to meet the deficit. Similarly, less irrigation water is required in seasons with higher on-farm rainfall. Hot, dry growing seasons result in increased water demand, and historical climate variability in the rice-growing districts has been characterised by significant variance in seasonal water requirements to produce a rice crop. There are existing options for managing this variability in water demand. When calculating areas for sowing to rice, farmers often employ a small 'buffer' in their calculations to account for the possibility of encountering greater than average evaporative demand in the coming season. For example, if a farm has a historical average water requirement of 12 MI/ha to produce a rice crop, the farmer may utilise a figure of 14-15 MI/ha in calculating the area serviceable from his irrigation water allocation. Hence,

$$1000 \text{ MI allocation} / 14 \text{ MI/ha} = 71.5 \text{ ha}$$

In this example, the farmer would conclude they cannot sow any more rice than 71.5 ha. In this way, if the season water demand runs higher than average, he will only be short of water on the most extreme of years. If the demand runs to average levels then he will have excess water, which can be used elsewhere or used as 'carry-over' for the subsequent winter crop or following years summer crop. Alternatively growers might adopt a strategy of sequential sowing, increasing over the planting window as progressive allocation increases are made and are anticipated into the future.

Purchase/sale of Water on Open Market

Water can be bought and sold on the open market, and represents an option for managing situations in which a growers encounters water shortages due to climatic variability (for example see <http://www.waterfind.com.au/>).

Investment in more efficient irrigation technology

The majority of the other crops in the rice-growing districts are irrigated using surface irrigation methods (furrow, border-check bays) which may be inefficient on light-textured soils (Watson and Drysdale 2006) - although growers are moving to use higher flows and modified layouts to improve efficiency. With increasing pressure on decreasing water supplies, and likelihood of increased variability, some growers are now considering investment in more water efficient irrigation methods (pressurised systems, lateral move, subsurface drip) for non-rice crops on non-rice soils. For rice crops, shallow standing water is still necessary hence this potential adaptation does not apply, and improved surface application techniques/layouts are being pursued actively by growers (North 2007). However savings on other parts of the farm have the potential to affect water available for rice. All of the more efficient irrigation technologies require considerable initial investment and the cost-benefits are largely unknown. This represents a major research need in the Riverina irrigation districts, particularly as a function of soil type, climate-change scenario, water pricing scenarios, and crop price scenarios.

Flexible rotations

In managing variability in water supply, rice farmers have a high degree of inbuilt flexibility in their farming systems in comparison with operations based on permanent plantings such as grapes, fruit trees etc. If water allocations are reduced, response strategies include:

- Reduce rice area sown (but still maximising potential rice areas with the limited water available) and leave larger areas of the farm in summer fallow. Generally, farmers will still aim to maximise their rice areas (see table 1.1, Introduction, for reasons) in accordance with available water. Spring watering of winter crops if rainfall is insufficient provided winter crop prices allow for good profit per hectare or megalitre.
- Reducing rice areas sown even further, and also sow other less water-intensive summer crops (e.g. soybean).
- Take the primary focus off rice, and plan to divert available water to subsequent winter cereals and pulses which require only supplementary irrigation in most/many seasons.
- Sow no rice, and plan to hold the limited water allocation for potential sale later in the season when other more adventurous growers run out, and the water price is high.

The cost-benefits of each of these approaches are unknown, and represent a research need with the irrigated farming community.

Sowing winter crops directly after rice

During the rice phase of rotations, the soil is flooded until shortly before the crop matures in April, and hence effectively has a full profile of stored moisture at harvest. Growing winter crops immediately after rice harvest (direct-drilling) minimises the impact of climatic variability on the subsequent crop by providing a soil water buffer against the likelihood of a dry winter. Also, if not followed by a winter crop, the rice field will usually lie fallow over the winter until the next rice crop (depending on the rotation). In addition to increasing the grower's production, the planting of a sod-sown winter crop creates the capacity in the profile to capture winter rainfall instead of losing it as runoff or deep percolation (Humphreys et al. 2006).

Nutrient management adjustment

The MaNage Rice decision support software provides the farmer with guidance in determining nitrogen application rates (Angus et al. 1996; Williams et al. 1996) and is a key tool in managing climate variability for individual crops. The software allows the grower to download weather data, and conduct an analysis of various N management strategies as a function of sowing date, seasonal conditions, variety and water depth, based on assessment of N uptake at panicle initiation. It functions in much the same way as the Yield Prophet[®] software (Hunt et al. 2006) which aims to assist the farmer in better tailoring fertiliser requirements to individual seasons, and hence managing risk associated with climate variability. MaNage Rice is a product of CSIRO and NSW Department of Primary Industries and in the past updates were sent to all rice farm businesses on a CD.

Water Management

Low minimum temperatures (<15-18°C) during the reproductive stage in rice can cause catastrophic damage to crops, particularly those with high N status (Williams and Angus 1994). One consequence of the historically variable climate in the Riverina is that low temperatures are occasionally encountered during this brief (5 day) period in the rice life cycle (see Figure 6.6). Due to plant-to-plant variation the five days at risk for a single plant equates to roughly a 10-14 day risk period for an individual crop. A management adaptation to this climate variability which allows growers to maintain high N-status (and hence potentially high yielding) rice crops is establishment and maintenance of increased depth over the critical danger period. The normal ponded water depth is often approximately 50-100 mm deep, however the depth is increased to around 200mm for two weeks, before returning to 50-100 mm for the remainder of the ponded period. The developing microspores are submerged or partially submerged to avoided low air minimum temperatures, using the thermal mass of the water as protection. High N applications have been shown to lead to high rice yields provided the microspores are protected from low temperatures in this manner (Williams and Angus 1994). This was a scientific development of truly massive impact in the Australian rice industry, is an integral component in the successful 'RiceCheck' recommendations (Lacy 1994) and the technology has had roughly 60% uptake by growers. The remaining 40% of growers encountered a range of difficulties including inability of system channel flow capacity to meet crop demand (sometimes out of farmer control).

Stubble retention

Stubble retention for the purposes of soil moisture conservation is a widespread technique used to manage climate variability during non-rice phases in the rice-growing districts, however rice stubble is usually burnt prior to sowing of subsequent crops due to mechanical difficulties involved in sowing into the high-density biomass. Options are being researched to overcome this, such as the "Happy Seeder" (Sidhu *et al.*, 2007). It is likely that climate change will drive continued changes in residue management practices over Australia as growers seek to conserve soil moisture and modify greenhouse gas emissions (Howden and O'Leary 1997).

1.4. Adaptation Options for Dealing with Climate Change

Altering varieties, planting times, nitrogen management and irrigation management to better match the new environments experienced under climate change is likely to increase yields compared to a non-action scenario. This can be viewed as the benefits of adaptation. When summarised over a large number of studies globally, the benefits of adaptation increase significantly with increasing levels of change (Figure 6.7). However, a similar analysis in wheat-based cropping systems suggests that there are limits to the benefits from management adaptations without making more fundamental system changes (Howden *et al.* 2007). In that case, the benefits were largely found with only a 2 to 3°C increase in temperature and the associated changes in rainfall and CO₂. Rice systems appear to have a greater range of adaptive response with this being found up to 5°C. Many of the studies on which this analysis is based assume continuing availability of irrigation water. When options for fine-tuning the underlying rice-based system have been exhausted with high levels of climate change, there will be a need to adopt more systemic change such as moving to intermittently-irrigated systems or dryland systems. As stated by Humphreys *et al.* (2006), there is limited scope for further significant increase in irrigation or input water productivity by reducing water application under the current Australian rice farming system, and future savings must come from implementation of alternative, lower water-use systems with greater water productivity.

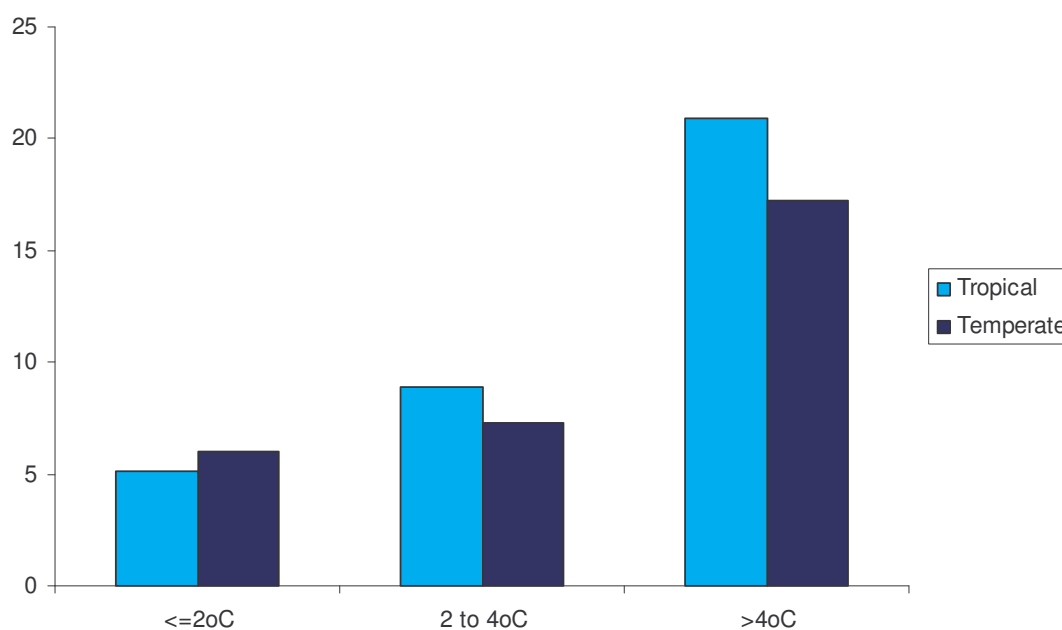


Figure 6.7: Mean benefit of adapting rice systems to impact of temperature and rainfall changes calculated as the difference between % yield changes with and without adaptation. Values are means for tropical and temperate systems. The mean benefit of adapting was not significantly different for temperate and tropical systems. Data sources are listed in Figure 5.2 of (Easterling *et al.* 2007). The temperature changes have associated changes in rainfall and CO₂ that vary between sites, scenarios and publications.

Reductions and increased variability in irrigation water supply are likely to represent the greatest challenge to the Australian rice industry from projected climate change. Hence water use efficiency measures in existing systems figure strongly in consideration of current options for dealing with the threat, in addition to future prospects for alternative systems. Options are considered below, firstly looking at potential water productivity improvements in existing systems, and secondly looking at a range of new ideas and potential modifications to systems which may hold the promise of enhancements to whole farm water productivity.

Better definition of rice-suitable soils

Historical methods of classifying rice-suitable soils depended on single-point paddock sampling. Groundwater recharge below ponded rice fields can be significant contributor to rising groundwater levels leading to soil and water salinisation. Reduced groundwater recharge is essential for sustainable rice-based, irrigated farming systems in southern Australia both from a groundwater/ salinity and a water productivity viewpoint. Until recently a soil was deemed as suitable for rice production if 1 soil profile per 4 ha contained 2 metres or more of continuous medium or heavy clay textured material. However it has been demonstrated that clay content alone is a poor predictor of groundwater recharge (Beecher *et al.* 2002). Electromagnetic induction surveys of rice fields can show variation in soil physico-chemical properties across rice fields. This allows the delineation of distinctly different areas of a field based on EM readings and allows accurate targeting of soil sampling and measurements. Current rice soil suitability criteria incorporates electromagnetic surveying and measurement of soil exchangeable sodium percentage (a measure of soil sodicity) enabling soils with potentially high percolation characteristics to be removed from rice growing. Consequently, there is significant potential to further increase water productivity through reduced water use in rice production through more accurate determination of the least permeable soils using the revised rice soil suitability criteria. This technology has had varied adoption at this point – in some jurisdictions electromagnetic surveying has been widespread whilst sodicity assessment is being adopted gradually. The approach has been adopted in principle by all authorities regulating rice land suitability. Rice water-use is closely monitored and paddocks with high consumption are reassessed for suitability.

Piping water on-farm

Rice farms generally convey water around the property in open earth-lined channels and incur both seepage and evaporation losses of water as a result. Research into on-farm channel seepage losses has been performed on nine Riverina rice farms previously identified with seepage problems (Akbar and Khan 2005; Khan *et al.* 2007; Khan *et al.* 2005). The farms had a total of 32.2 km of unlined channels and 7.5 km of drains. Seepage losses were generally between 1 and 2%, with one farm losing 4% of allocated water due to particular soil conditions. For a large rice farm with a licensed allocation of 1400 ML, it was shown that combined losses could be > 60 ML/year – representing 4-5% of the farm's available water. Options to reduce these losses include lining or piping of channels, however there are significant practical limitations relating to the need to move large volumes of water and the energy costs of doing so. This attitude could change however with potential increase in water costs, and from this perspective is worthy of further consideration.

Piping water in the district, or lining supply channels

Over 42 GL/yr of water is lost from 500 km of channels as seepage, in addition to 12.5 GL/yr through evaporation from channel water (Akbar and Khan 2005). Seepage occurs primarily through “hot spots”, that is where channels/drains cross coarse textured highly permeable materials. Potentially some 100 GL of water in the Murrumbidgee Irrigation Area and 105 GL in the Coleambally Irrigation Area (with potentially equivalent savings in the Murray Valley Irrigation Districts) can be saved each year through smarter and more integrated scheme to on-farm management. This represents roughly 16% of total water in these schemes so is a significant saving, however capital investment in improvements required to achieve these savings are large (\$500-\$4000 per ML water saved, depending on local conditions) (Akbar and Khan 2005; Khan *et al.* 2007; Khan *et al.* 2005).

Whole farm planning

Through currently available technology, electromagnetic surveys of whole-farm soil characteristics is possible. This has the potential to allow more efficient design of farm layouts to (for example) avoid inclusion of old stream-beds in rice bays, and hence to reduce drainage losses in irrigated rice production. Greater understanding of variation of soil type in a spatial sense also allows similar soil types to be grouped together in management zones, leading to increased efficiency in a range of processes from fertiliser utilisation to drainage of water. The need for improved surface irrigation layouts that allow for the incorporation of the widest range of cropping options along with infrastructure (on farm drainage recycling facilities, investigated and evaluated soil suitability, large capacity supply and drainage facilities) to allow for large irrigation water volumes- and subsequently fast irrigation and drainage times are likely to be important adaptations – these strategies align with Land And Water Management Plans- but have been constrained in current adoption due to financial limitations during current drought conditions.

Raised beds in bays

Raised beds within irrigation bays have been suggested as a means of increasing water productivity in Riverina rice-based operations. In a north Queensland study in the 1990s, 32% water saving was demonstrated through the use of raised beds and saturated soil culture, over traditional flooding practice. No significant reduction in yield was recorded (Borrell *et al.* 1997). In more recent experiments in the Riverina, however, such water productivity benefits have not been demonstrable. High yielding rice crops can be successfully grown on raised beds, but when beds were ponded after panicle initiation for the required cold-temperature protection, there was no measured water saving compared with rice grown on a conventional flat layout (Beecher *et al.* 2006). The authors concluded that on Riverina rice-suitable soils, until ponded water is no longer required (for low temperature protection for current varieties, weed control etc), there is little scope for saving water while maintaining yield on suitable rice soil through the use of beds. The major difference with the study of Borrell *et al.* (1997) was the degree of permeability of the soils. The Queensland soil used in the experiments would not be classified as a rice-suitable soil under Riverina guidelines due to higher levels of internal drainage. With growing interest in aerobic rice

cultivars which may be more suited to higher permeability soils (see section below on aerobic rice) raised beds may offer water productivity gains. There are likely to be increase flexibility and cropping.

Beds within terraced, bankless channel systems are being adopted in the Murrumbidgee Irrigation, Coleambally Irrigation, Murray Valley and by riparian and groundwater irrigators. A range of crops are being grown under variations of this style of layout including rice, wheat, maize, cotton, fababeans, chickpeas, barley and sunflowers. The area of adoption is not large at this stage but considerable attention is being focussed on to the performance of these commercial fields by other irrigators. Surveyors and designers are generating and installing irrigation designs based on these concepts in the rice growing areas of southern New South Wales. Some growers are using relatively expensive designs in terms of structures and piping to achieve terraces/steps between bays in commercial situations but consider the labour saving benefits worthwhile. The ongoing adoption of terraced zero graded bankless channel rice layouts, including raised beds, appears likely given the increased cropping choice and flexibility and the significantly reduced labour requirement made possible by this type of layout. The adoption of these layouts will be constrained to locations where existing land grades allow creation of zero graded layouts with appropriate terrace widths (land forming costs not being excessive) and steps to allow adequate drainage and to where access to large irrigation flows are available in order to achieve satisfactory short duration water on/water off times for crops other than rice. There may be significant improvements to be made where pastures are grown in rotation with rice in flat layouts by increasing irrigation flow rates and reducing water on/water off times.

The potential of these irrigation layouts fits with grower and grains industry desires to increase crop flexibility and yield potential e.g. crops after and in rotation with rice, fababeans, soybeans, canola, wheat and barley. The layouts would link to precision agriculture concepts – compaction control, tramlining, machinery efficiencies and uniform or varied input application.

Irrigation Scheduling

Water savings may be available from more efficient scheduling of irrigation for crops in rotation with rice. Irrigation scheduling aims to apply the required amount to the crop at critical times, and minimise losses through runoff and deep percolation, whilst maximising crop production. A study in California found that optimal irrigation required less (48-63%) water than what local growers referred to as ‘full’ irrigation. This also reduced both the deep percolation and runoff losses and caused a 31-43% increase in the application efficiency, and a 32-54% increase in net return (Raghuwanshi and Wallender 1998). There appears to be considerable scope within existing Australian irrigated rice-based farming systems to irrigate non-rice crops more efficiently and hence potentially divert more water for rice enterprises. This could include investment in more efficient irrigation technology (see below), in addition to more targeted application of irrigation water.

Combine and Sodsowing of rice

Combine and sodsowing of rice allows the possibility of delaying introduction of standing water, with the aim of reducing water loss through evaporation and drainage (Tabbal *et al.* 2002). An ancillary benefit in Australian rice systems is a decreased risk of duck damage to the young crop compared with crops established by aerially-sowing into standing water. Water savings have been reported however further research is required to understand the process on a range of soil types. Drilling rice presents problems in the heavy clay sodic soils such as those in the Murray valley where drilled rice has difficulty breaking through drying surface layers, due to the rice plant's weak emergence capacity.

Breeding

- *increased yields to increase WUE.*

Average field water productivity of the total NSW rice crop roughly doubled over the period 1980–2000 (Humphreys *et al.* 2006). This was largely due to increased yields from new cultivars, overcoming restraints due to cold temperature damage, weed control, higher N rates, land forming etc, and water use savings from industry-regulated restrictions on allowable rice soils. The rice industry in Australia continues to invest in cultivar development to deliver increased yields from less water as a means of increasing water productivity further.

- *Varieties to reduce ponded evaporation*

Simpson *et al.* (1992) found that for evapotranspiration from aerially-sown rice, 40% on average is due to evaporation from the ponded water surface, and the remaining 60% from the rice plants themselves. Early in the season all of the loss was evaporation from the water surface. In mid-December two thirds was via the plants, increasing to 90% in mid-January. Development of new varieties with optimum sowing dates which move ponded periods outside peak evaporation periods may represent another option for incremental gains in water productivity (Humphreys *et al.* 2005).

- *shorter season varieties*

Water use in ponded rice culture can potentially be reduced by the development of varieties with shorter crop duration (up to 10%) (Reinke *et al.* 1994), however there is some evidence that shorter durations will also result in less yield and hence reduced WUE (Williams *et al.* 1999). The length of the vegetative period is reduced for short-season varieties, thus limiting the time for sufficient biomass production to support high yield. Provided there are no limitations to growth during the foreshortened vegetative phase, short-season types have been shown to have similar yield potential to current long-season types. In recent times, however, by focusing on seedling vigour and early growth shorter duration varieties with high yield potential have been developed (Reinke *et al.* 2004). An associated benefit of shorter season rice varieties from a farming systems perspective is that they may facilitate earlier establishment of following winter crops, hence leading to higher yields and better system WUE (Humphreys *et al.* 2005). Continuing development of shorter season, higher WUE conventionally-irrigated rice cultivars is warranted, however significant industry interest in the Riverina is currently focussed on breeding and selection of aerobic and alternate wet-and-dry cultivars for the longer term (see section below) as a response to climate change in the region.

Aerobic and AWD rice

It has been suggested there is limited scope for further significant increase in irrigation or input water productivity through reduction in water use in current rice farming systems in Australia, and future savings must come from changing to alternative, lower water use practices, which are currently under investigation (Humphreys *et al.* 2006). These include the potential for aerobic rice culture in Australia. There is published evidence from overseas that aerobic rice culture has the potential to increase water productivity over conventionally-irrigated rice – by 32–88% (Bouman *et al.* 2007; Bouman *et al.* 2005). Water losses are constrained by treating the rice like any other irrigated crop such as wheat or maize – once soil moisture has decreased to a specified level irrigation is then applied to bring the soil moisture content in the root zone up to field capacity. Ideally, the amount of irrigation required should match the evaporation from the soil surface and transpiration from the crop. The potential water-use reduction at the paddock level is large, especially in soils with higher drainage rates. In addition to drainage below the root zone declining, the concept is that evaporation decreases since there is no free water surface. Research in Australia on intermittent watering using existing rice cultivars showed that saturating the rice root zone with flooding every 7 days throughout the season reduced water use by 60%, but the negative effect on yields was dramatic (1–2 t/ha compared with 9 t/ha for conventional ponded culture) (Heenan and Thompson 1984). Grain quality was also negatively affected. Experiments were also performed in the Riverina with sprinkler irrigation (Humphreys *et al.* 1989) and although water-use was reduced by 30-70%, yields declined by an even larger amount, resulting in decreased water productivity. These past experiences in Australia suggest a critical issue when considered alongside more positive reports (Bouman *et al.* 2005) is the importance of cultivars selected for their aerobic potential. Ideal aerobic rice cultivars combine the drought-resistant characteristics of upland varieties with the high-yielding characteristics of irrigated varieties (Lafitte *et al.* 2002). Chinese breeders have produced aerobic rice varieties with an estimated yield potential of 6–7 t ha. There are currently steps underway to trial some of these varieties in Australian conditions.

A major issue which will affect success of new aerobic rice cultivars in Riverina growing conditions is tolerance to low temperatures during microspore. As previously discussed, Australian varieties are protected from this risk by a water depth to 20cm. Such an option is not available in aerobic rice culture, and the reliance must come back onto genetic tolerance. It is possible that the best suited soils to aerobic rice production in Australia are the more freely draining soils currently not suitable for rice under ponded culture (due to high drainage losses). If this is the case, then another potential method of addressing the cold temperature constraints in the Riverina is to relocate aerobic rice production further north to warmer climatic conditions hence mitigating low temperature risk. Another outstanding issue for aerobic rice in the Riverina is weed control. In addition to providing water supply and low temperature protection to irrigated rice, it would be expected that aerobic rice would require conventional weed control and hence result in increased chemicals in these systems.

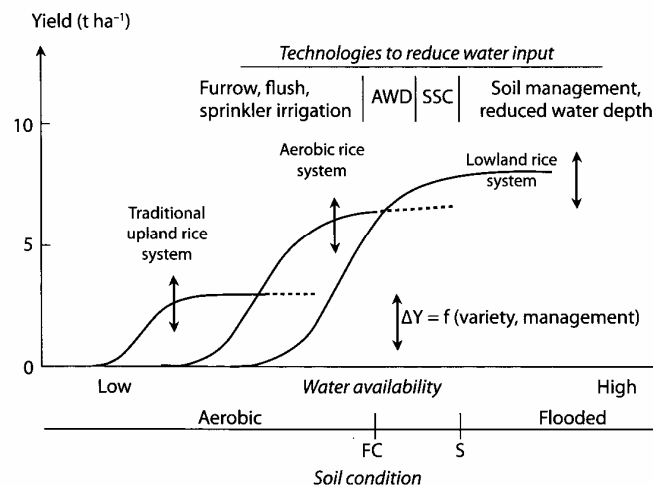


Figure 6.8: Schematic presentation of yield responses to water availability and soil conditions in different rice production systems and their respective technologies to reduce water inputs. (Bouman et al. 2007). AWD = alternate wetting and drying, SSC = saturated soil culture, FC = field capacity, S = saturation point, $\Delta Y = f(\text{variety, management})$ in yield.

AWD refers to *alternate wet and dry* culture, also aimed at reducing evaporation and deep drainage losses, but not to the extent of aerobic rice. For current Australian rice varieties, there is no yield loss with intermittent irrigation for the first 10–11 weeks, offering the opportunity to save irrigation water and increase water productivity immediately (Humphreys 2006). Following the intermittent irrigation phase management proceeds as for normal irrigated rice, providing the low temperature protection with increased water depth at the critical stage. Water use saving of 10–15% may be possible for no appreciable loss in yield. Saturated soil culture (SSC) or very shallow water (Bouman and Tuong 2001) is another option, reducing hydraulic head, drainage losses, and there is evidence that it can increase water productivity. Figure 6.8 clearly shows a succession of options for reducing water use in rice production systems and general consequent trends in yield.

In summary the AWD technology presents the most immediate option for the Australian situation, although it offers only modest increases in water productivity and limits rice production to existing rice-suitable soils. Aerobic culture offers the promise of significantly enhanced water productivity benefits, together with the potential for expansion in geographical range of production. There is a need for further research into suitability of existing international aerobic cultivars for Australian conditions and variety of soils, including issues relating to water productivity, irrigation and fertiliser management, weed control, and low temperature sensitivity.

New farm layouts

A potential strategy is to intensively irrigate a smaller area of the farm as close as possible to the water supply source, and consider the remainder dryland, thereby minimising losses from channel conveyancing systems. This may work best in conjunction with new irrigation technologies (see below). Similarly the lowest

percolation soils could be selected for an intensive rice rotation in lasered terraces best suited to rice with separate new layouts used for non rice rotations.

Investment in more efficient irrigation technology

With increasing pressure on decreasing water supplies, and likelihood of increased variability, some growers are now considering investment in more water efficient irrigation methods (pressurised systems, lateral move, centre pivot, subsurface drip) as a means of watering non-rice crops on lighter-textured soil. Water savings benefits from more efficient irrigation technology in the Riverina range between 16-35% for cereals, 15% for soybeans, and 7% for maize (Khan *et al*, 2005). Lateral move systems cost roughly \$1500/ha, and centre-pivot systems \$2000-\$2500/ha (Khan *et al*. 2005). Centre-pivot and lateral move irrigation systems have low labour requirements (Raine and Foley 2002), which needs to be accounted for in any economic analysis. All these systems require considerable initial investment and the cost-benefits are largely unknown, representing a major research need in the Riverina irrigation districts, particularly as a function of soil type, climate-change scenario, water pricing scenarios, and crop price scenarios. Obviously, pressurised irrigation systems are not an option for existing rice growing systems, however on non-rice areas of the farm (lighter soils) represent an option for increasing water productivity and hence could influence rice production via affect on available water.

New crops, rotations and priorities for water

With climate change projections suggesting a future reduced and more variable water supply, some Riverina irrigators are questioning previous priorities for water and asking questions such as:

- What do optimal irrigation water priorities look like if my farm is no longer to be a fully-irrigated enterprise? Is it better to partially-irrigate everything or plan to intensively irrigate a small portion of the farm with the remainder dryland?
- How does a small intensively irrigated area of vegetables, maybe under a sub-surface drip irrigation system compare with conventional rice production?
- How would aerobic rice (if found to be viable) affect water priorities on farm, and impact on other crops, rotations, weed control, diseases etc?
- With reduced water, what is the optimal combination of livestock and cropping?
- Is water better diverted to winter crops as first priority due to their need for supplemental irrigation only, and should rice be considered an option only in years with high allocation?
- How would alternative rice production systems (aerobic & AWD) affect the water equation?

These are all very valid questions for which there is an absence of research answers at present, particularly under a changing climate.

1.5. Costs and Benefits

AWD Rice Culture

The costs of implementing AWD culture are minimal as no new infrastructure is required, and 10-15% savings are potentially available.

Piping/lining channels

Capital investment in improvements required to achieve these savings are large (\$500-\$4000 per ML water saved, depending on local conditions) (Khan *et al.* 2007; Khan *et al.* 2005). In view of potential earnings from irrigation water from rice and wheat (105 and 75 \$/ML respectively), a pay-back period in the range of 6 – 53 years is estimated.

Investment in more efficient irrigation technology

Lateral move systems cost roughly \$1500/ha, and centre-pivot systems \$2000-\$2500/ha (Khan *et al.* 2005). Potential benefits are likely to depend heavily on soil type, enterprise mix, water and commodity process, and irrigators considering investments of this type feel they do not have access to enough information on these. This represents an urgent knowledge gap in adaptation of Riverina irrigated farming systems.

1.6. Knowledge Gaps and Priorities

Use of Seasonal Climate Forecasts

With projected increases in water supply variability, there is a growing need for effective and targeted seasonal climate forecasting to assist in early planning of farm operations from expectations of the coming season's water supply and demand. Limited research has been conducted into how this information should best be used in irrigated farming system management, yet potential benefits are large.

Aerobic and AWD Rice in Australia

There is evidence that aerobic rice represents an option to increase water productivity whilst maintaining production of rice which supports numerous regional towns and industries in the Riverina. There are numerous unknowns:

- Regional and physical applicability of aerobic rice.
- Potential impact on water productivity as a function of soil type and region.
- Optimal irrigation, weed control and fertilisation strategies.
- Potential of internationally-available aerobic rice cultivars with cold tolerance to allow the shift away from the current irrigated rice system in Australia.
- Most important traits associated with adaptation to aerobic conditions in Australia – an understanding of these is critical to facilitate potential further breeding efforts.

Cost-benefits of investment in more efficient irrigation technologies

Growers throughout the Riverina need to include cost-benefit analysis of investment in efficient irrigation technologies into their planning for the future, however there is a real and significant lack of understanding relating to the water productivity gains achievable from investment in different irrigation technologies (lateral move, centre pivot, subsurface drip) under a changing climate (Sam North, NSW DPI, Deniliquin, *pers comms*). These gains are likely to vary greatly as a function of soil type, potential future water pricing, commodity prices etc.

Better water productivity from new farming systems

Rice farmers are involved in a wide range of agricultural industries in addition to rice. In a future with projected reductions in average water supply, increased demand, and a likelihood of increased variability of supply, there is a lack of knowledge in both the farming and research communities on how current farming systems compare with a wide range of potential modified systems. Questions needing to be answered include:

- What might the optimal rotations and farm layouts look like with less water in a changed climate?
- At what point in terms of allocation reductions does it become uneconomic to maintain the existing bays and surface irrigation infrastructure?
- Does potential investment in new irrigation technology change the picture for optimum enterprise mixes under a changed climate?

These are only a small selection of whole-of-farm scale questions which need urgent research attention from the perspective of adapting irrigated farming systems in the Riverina to climatic change.

1.7. Summary of adaptation options

The rice industry has been highly successful in increasing water productivity over its history, and must continue to do so in adapting to climatic change. In consideration of adaptive options, several categories exist as detailed in Table 6.1. Under *Easily Implemented*, the table lists the technologies and options which are available now, and which offer demonstrable benefits in all or some situations. Combine or sodsowing of rice represents an opportunity for water savings through delaying the application of permanent or ponded water. Its application is limited on the heavy sodic clay soils of the Murray Valley due to problems with seedling emergence, however in combination with delayed flooding (ie no permanent water for drill sown crops until just prior to panicle initiation) it may present an option for 10-15% savings in rice water use for no appreciable loss of yield (Humphries *et al.* 2006). The cost of implementing this option is minimal for suitable soils, subject to the grower's access to suitable drilling equipment. Research and development into other different AWD water-management strategies (different wetting and drying regimes, and associated effect on

practices such as fertilisation, weed control) is also considered high priority, specifically relating to costs (reduced production etc) and benefits (water savings).

Table 6.1: Adaptation options summary table (highest priority is 1, lowest priority is 3)

Adaptation option	Priority
<i>Easily Implemented</i>	
Combine and sodsowing of rice	1
Alternate wet-and-dry rice culture	1
Better definition of rice-suitable soils	1
Irrigation scheduling	2
<i>Potentially implementable after further R&D</i>	
Aerobic rice evaluation	1
New AWD water management practices	1
Seasonal climate forecasts	1
Consideration of new crops, rotations, priorities for water	1
Conventional breeding for shorter season varieties, increased yields	2
<i>Requiring major investment</i>	
Investment in more efficient irrigation technology	2
Whole farm planning	2
Piping water on-farm	3
Piping water in district	3
Raised beds in bays	2

The technology for implementing enhanced identification of rice-suitable soils is currently available. There is significant potential to further increase water productivity through reduced water use in rice production through more accurate determination of the least permeable soils using the revised rice soil suitability criteria (Beecher *et al.* 2002). This technology has had varied adoption at this point – in some Riverina jurisdictions electromagnetic surveying has been widespread whilst sodicity assessment is being adopted gradually. The approach has been adopted in principle by all authorities regulating rice land suitability, and it is suggested that this should progress as a high priority. Similarly, the technology for more effective irrigation scheduling (timing and quantity) for non-rice crops in rice based farming systems is also available, however it has been listed as priority 2 due to the limited flexibility of many existing irrigation systems (e.g. flood irrigation in bays) in applying the exact the amount water required by the crop. This technology is most suited following investment in high efficiency irrigation systems such as drip, centre pivot and lateral move machines on suitable soils. High flow / bed layouts could present a better option for applying more targeted water amounts to non-rice crops on heavy rice-suitable soils.

Under the adaptation options (Table 6.1) which may be viable after further R&D, investigations into the potential for aerobic rice in Australian systems is considered high priority, after demonstrated substantial increases in water productivity (32–88% (Bouman *et al.* 2007; Bouman *et al.* 2005)) from overseas trials using specially adapted aerobic cultivars. Several subsequent years in the same experiment yielded variable results, indicating a need for research to observe longer term effects in Australian conditions. Previous experiments in Australia have centred on growing traditional flooded varieties aerobically, and proved fruitless (Heenan and Thompson 1984; Humphreys *et al.* 1989). Australian trials with international aerobically-adapted cultivars are considered high priority for the Australian rice industry. A major issue which will affect success of new aerobic rice cultivars in Riverina growing conditions will be tolerance to low temperatures during microspore. It is possible that the best suited soils for aerobic rice production in Australia are the more freely draining soils currently not suitable for rice under ponded culture (due to high drainage losses). If this is the case, then another potential method of addressing the cold temperature constraints of the Riverina would be to relocate aerobic rice production further north to warmer climatic conditions hence mitigating low temperature risk. This would also move into summer-dominant rainfall locations meaning a higher proportion of in-season rainfall and decreased demand for irrigation water. Weed control costs in aerobic rice culture are also an unknown quantity for the Australian rice industry, as are issues relating to optimal fertilisation and irrigation regimes. In summary, although various forms of AWD technology presents the most immediate option for the Australian situation, it offers only modest increases in water productivity and limits rice production to existing rice-suitable soils. Aerobic culture offers the promise of significantly enhanced water productivity benefits, together with the potential for expansion in geographical range of production. Additionally, the removal of other constraints of a flooded system (e.g. vertebrate pests - birds - which have caused problems in previous Northern Australian rice ventures), may also be an advantage with aerobic rice. It should be noted that issues related to disease risks in more northern locations would need to be targeted in research.

The use of seasonal climate forecasts in irrigated systems to aid in water and crop management decisions is listed as high priority due to the projected increases in future climatic variability, and the continuing effort being applied in scientific circles to improve climate/weather forecast skill (Macintosh *et al.* 2007). Accurate forecasts would assist in early planning of farm operations from expectations of the coming season's water supply and demand. Limited research has been conducted into how this information should best be used in irrigated farming system management, yet preliminary studies suggest benefits may be substantial (Gaydon *et al.* 2006). Rice-growing irrigators in the Riverina are already experimenting with new crop options (for example cotton) and priorities for water (for example allocating available irrigation water to winter crops rather than rice) a process influenced by low allocations in recent years, but also by available \$ returns from other crops during drought conditions. This process will continue, however would benefit from dedicated R&D involving farmer participation and simulation modelling, which would allow consideration of various scenarios of water availability, climate change, water and commodity prices etc..

The rice industry in Australia continues to invest in fully-ponded cultivar development to deliver increased yields from less water as a means of further increasing water productivity. At this point, potentially greater gains in water productivity are offered by AWD and aerobic rice, hence this ongoing development has been allocated a priority of 2 to recognise the greater urgency for R&D in the areas – AWD and aerobic rice.

Due to the current drought conditions, and consequent financial implications for many rice-growers, the adaptation options requiring significant financial investment have all been prioritised 2-3. These priorities may vary considerably between farmers, depending on both their financial position and potential benefits to their operations from these investments.

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