



## Category: Research Article

# APSIM-Based Assessment of Rice Yield and Growth under Climate Change

\*<sup>1,2</sup>Liyanage, Anuga

\*<sup>1</sup>Department of Agricultural Biology, Faculty of Agriculture, University of Ruhuna, Sri Lanka, 81000

\*<sup>2</sup>Faculty of Agriculture and Food Systems, University of Melbourne, Australia

### ARTICLE DETAILS

#### Article History

Received: 04<sup>th</sup> October 2025  
Accepted: 03<sup>rd</sup> January 2026  
Published Online: 17<sup>th</sup> June 2026

#### Keywords

APSIM-Rice, increased temperature, rainfall change, rice productivity, Australia

#### \*Corresponding Author

Email: [anugaliyanage@gmail.com](mailto:anugaliyanage@gmail.com)

TP:071 8017621

### ABSTRACT

*Oryza sativa*, commonly known as rice, belongs to family Poacea is a staple food for the majority of the world's population. Australia produces 1.2 million tons of rice annually, which feeds about 40 million people everyday and is a staple food consumed by more than half of the world's population. According to future climate change projections, temperatures will rise and there will be less water available due to reduced rainfall. Regardless of the importance of rice to countrywide and worldwide food systems, there are limited location-specific evaluations of how predicted changes in temperature, rainfall, and CO<sub>2</sub> concentration will relate to effect rice yield across main Australian rice-growing regions.

This study employed the APSIM-Oryza crop simulation model to assess rice yield responses to future climate scenarios at two major Australian rice-growing regions: Griffith (New South Wales) and Kununurra (Western Australia in 2017). Amaroo, Langi, and Quest, which stand for late, mid, and early maturity varieties of rice, were utilized at Griffith. For the Kununurra region, only one rice variety (IR72) was utilized. In order to simulate the range of anticipated climatic changes for Australia over the next 60 years, five incremental temperature changes: 0 (base), +1, +2, +3, +4°C, five rainfall variations (+10, 0, -10, -20, and -30%) and 5 corresponded CO<sub>2</sub> concentrations (380, 435, 535, 640, and 750 ppm) were used. Results show that up to a 2°C temperature increase at Griffith, all types revealed an increase in yield, which may have been caused by the CO<sub>2</sub> fertilization effect. A study examining the responses of rice cultivars to temperature and precipitation changes in Griffith, New South Wales and Kununurra, Western Australia, found that all cultivars showed an increase in yield with increasing temperature up to 2°C. However, further increases resulted in a steady decline in yield, with the short-season variety 'Quest' least affected. Grain yield at Kununurra decreased steadily with a 4°C increase in temperature, shortened the cropping period, and reduced the yield index for all varieties. The study suggests that warmer temperatures may increase spikelet sterility, limiting rice production in Southeastern Australia.

## 1. Introduction

The human population has grown exponentially, reaching 8.2 billion people on the planet in 2024 (increasing at an annual rate of 80 million), and the projection for 2050 is 9.7 billion. A highest of 10.3 billion populations is expected in the mid of 2080s. The urban population is expected to double in the

next 20 years, increasing the demand for food, particularly for crops, meat, and forest products (Lam, 2025).

To meet this demand, significant increases in agricultural production are required. Rice, the staple food of over half of the world's population, is a critical agricultural practice which covers 154 million

hectares and supplies 21% of global human per capita energy and 15% of protein. It is a brilliant source of complex carbohydrates and energy, with modest protein content (IRRI fact sheet, 2009).

### 1.1. Global rice production

Rice farming is crucial for the global economy and livelihood of millions of rural poor, with one-fifth of the population relying on it. With nearly 523.9 million tons (milled basis) produced in 2023, rice is a versatile food that contributes to food security and political security in developing countries. However, low availability and higher prices of rice can cause social unrest. Climate change impacts are expected to worsen this situation, and a 60% increase in rice production is required by 2025 to meet population demands (Jena *et al.*, 2023).

#### • Australian rice production

Despite taking up a comparatively small amount of rice land in Australia, rice cultivation is important to regional economies, where highly mechanized and irrigated systems sustain high productivity. (Australian Bureau of Agricultural, Resource Economics and Sciences, 2023). Australia's rice production, the ninth largest agricultural export, accounts for 0.2% of world rice production and over 4% of world trade. Still, water availability remains a limiting factor (Rice growers' Association of Australia, 2015). The country's average temperature is projected to increase (along with the higher CO<sub>2</sub> concentrations) from 1-2°C by 2030, and 1-6°C increase by 2070 (IPCC, 2023). Yet, the effects of climate change, for instance rising temperatures, transformed rainfall patterns, and rise in the frequency of extreme weather events, are posing a growing threat to sustainable rice production in Australia.

Uncertain climate changes will exacerbate stress factors for rice plants, including heat stress and drought stress. High temperatures can reduce rice plant height, tiller number, and total dry weight, reducing yield in most areas. Rice, a C3 grass, has variable temperature requirements across different growth stages, and deviation from optimal temperatures can alter physiological activities or direct the plant to a different developmental pathway (Singh *et al.*, 2021). High temperature tolerance can vary depending on the plant's developmental stage. It is projected that both direct and indirect effects of climate change will have a significant impact on crop growth, development, and yield of rice (van Oort & Zwart, 2018). Understanding of how rice-based systems will react to future climate scenarios is crucial to develop adaptation and mitigation

strategies to increase productivity, profitability, and environmental sustainability.

Process-based crop simulation models are effective instruments for investigating the intricate relationships among crop genotype, soil properties, climate variables, and management techniques. The Agricultural Production Systems Simulator (APSIM) is one of these that have been used extensively in Australia and around the world to evaluate mitigation strategies, support decision-making under uncertainty, and assess the effects of climate variability on crop productivity (Holzworth *et al.*, 2014). This study simulated the possible effects of climate change on rice production in two significant Australian rice-growing regions in Australia using the APSIM model.

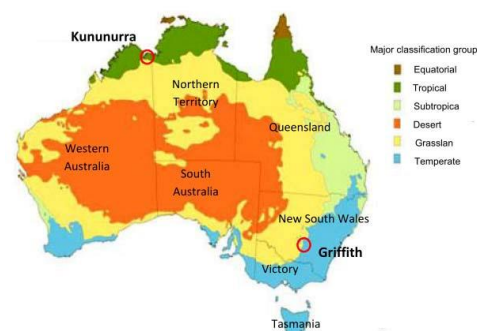
### 1.2. Objectives of this research

Using the APSIM model, simulate the effects of anticipated climate change scenarios on rice growth, development, and yield in key rice-growing regions of Australia.

- To evaluate the sensitivity of rice production to main climate variables such as temperature and CO<sub>2</sub> concentration under future climate scenarios.
- To identify the adaptive management practices in mitigating the adverse impacts of climate change on rice productivity.

## 2. Material and Methods

- **Site 01-Griffith (New South Wales, Riverina).**



Griffith is situated in the Riverina agricultural region of New South Wales, Australia. The Riverina's flat plains, warm to hot climate, and abundant irrigation water supply set it apart from other regions of Australia. One of Australia's most fruitful and agriculturally diverse provinces is now the Riverina. The vast majority of Australia's rice is produced in the

Riverina region. Griffith is 134 m above sea level. Latitude 34.25°S and longitude 146.07 °E are the coordinates of Griffith. Riverina is located in a hot, dry zone with chilly winters, according to the classification of Australia's climatic zones, which is based on temperature and humidity (Australia's Bureau of Meteorology 2021).

The range of the annual mean maximum temperature is 23–25.5°C. Between 1961 and 1990, the average monthly rainfall was 393.7 mm, with the maximum being 703.3 mm and the lowest being 148.8 mm. Griffith experiences extremely chilly winter nights, much like the other locations in the hot, dry zone (Australia's Bureau of Meteorology, 2021).

• **Site 2-Western Australia, Kununurra**

The second site selected for this research is in the Kununurra region of Western Australia. Kununurra is 47 m above sea level. Latitude 15.78°S and longitude 128.74° E are the coordinates of Kununurra. Based on temperature and humidity, Australia's climate zone classification places the Kununurra region in the hot, humid summer zone. (Bureau of Meteorology Australia, 2021).

The average monthly high temperature in Kununurra is approximately 35°C. The annual maximum temperature typically falls between 34 and 36°C. The annual rainfall average is about 800 mm per month, with the highest recorded at 1400 mm and the lowest at 435 mm (Australia's Bureau of Meteorology, 2021).

• **Modeling Process**

To investigate the production responses of Australian lowland rice to climate change (temperature, rainfall, and increasing carbon dioxide concentration) in two different climatic zones, two selected locations in the Riverina (New South Wales) and Kununurra (Western Australia) were simulated independently using the Agricultural Production Systems Simulator APSIM-Oryza model (Holzworth *et al.*, 2014). The following traits were modelled for three rice varieties-Langi, Amaroo, and Quest-grown in New South Wales, Australia's main rice-growing region.

**Langi**-Semi-dwarf long grain,

soft cooking

**Amaroo** -Semi-dwarf medium grain,

high yielding

**Quest** -New semi dwarf medium grain,

short season variety

A single high-yielding rice variety (IR72) suitable for the Kununurra region was used for the simulation.

• **Climate scenarios**

Baseline climate data for the Griffith and Kununurra sites (January 1, 1960 to December 31, 2000) were obtained from the SILO database Australia (Jeffery *et al.*, 2001). Based on climate data from 1960 to 2000 and the anticipated climate changes throughout Southern and Western Australia, 25 future climate scenarios were developed for each rice variety (using various combinations of temperature, CO<sub>2</sub>, and rainfall). For each rice variety, 25 future climatic scenarios were simulated using the APSIM–Oryza model, which combined incremental temperature changes of 0, +1, +2, +3, +4°C, and rainfall variations of +10, 0, -10, -20, and -30%. As the temperature rose, the variations in atmospheric CO<sub>2</sub> concentrations were taken into consideration as the equivalent values. 380, 435, 535, 640, and 750 parts per million of CO<sub>2</sub> were utilized in accordance with the 0, +1, +2, +3, +4°C increase of temperature respectively as illustrated in table 1 below.

Table 1: Various temperature, CO<sub>2</sub> and rainfall variations used for simulations

	Temperature Change (°C)	CO <sub>2</sub> (ppm)	Rainfall change (%)
1	0	380	+10
2	+1	435	0
3	+2	535	-10
4	+3	640	-20
5	+4	750	-30

APSIM requires three primary climate inputs for these simulations. Higher CO<sub>2</sub> concentration, rainfall, and temperature were used. Simple changes in temperature and rainfall amounts were expressed using daily temperature and rainfall data spanning 40 years, from 1960 to 2000.

As input parameters for these models, daily climate data spanning 40 years from 1960 to 2000 was used, including rainfall (mm), maximum and minimum temperatures (°C), radiation (MJ/m<sup>2</sup>), and vapor pressure deficit (KPa). Additional input factors were the bulk density, saturated water retention characteristics, and soil texture of the soil profile.

Table 2 below shows how each rice variety was simulated using 25 rainfall and temperature combinations (25 distinct scenarios) based on these

factors. There were 100 simulations for each of the four types of rice. Each rice variety's productivity was replicated at each location with a 50 mm ponding depth and no restrictions on soil nutrients. The output frequencies were calibrated as daily out puts and at harvest out puts for these simulations.

Table 2: Combination of 25 different climate scenarios:T-atmospheric temperature-Rain fall change

Temperature Change °C	
% RF	0
10	T0,R10 T1,R10 T2,R10 T3,R10 T4, R10
0	T0,R0 T1,R0 T2,R0 T3,R0 T4,R0
-10	T0,R-10 T1,R-10 T2,R-10 T3,R-10 T4,R-10
-20	T0,R-20 T1,R-20 T2,R-20 T3,R-20 T4,R-20
-30	T0,R-30 T1,R-30 T2,R-30 T3,R-30 T4,R-30

The APSIM model was validated using observed field data from past rice production trials carried out in significant Australian rice-growing regions in order to guarantee the accuracy of simulation outputs. Comparing simulated outputs with matching observed data the process of validation was done. Standard statistical indices such as Nash–Sutcliffe Efficiency (NSE), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) were used to assess the model's performance.

The significance of variations across climate scenarios and management approaches was assessed using statistical tools (ANOVA).

Crop growth parameters (Crop Growth Rate, or GCR) and yield components (rice yield, spikelet fertility factor, and crop duration) were measured over a period of 40 years in each of 25 climate scenarios. The information gathered includes variations from the climate baseline scenario as well as averages over a 40-year period.

Crop growth and the rice leaf area index are examples of output variables that are computed as the daily averages for 40 years during the entire crop year (beginning on the first day following the crop's emergence).

### 3. Results and Discussion

#### Results

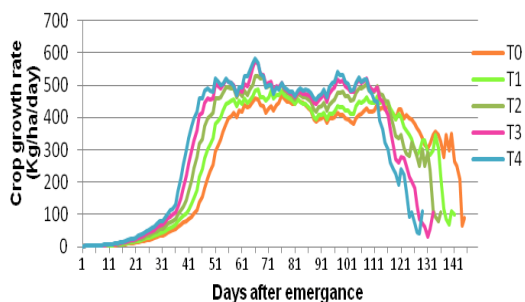
- Effect of temperature, CO<sub>2</sub> increase and Rainfall decrease on growth parameters of rice

#### Crop growth rate (Kg/ha/day)

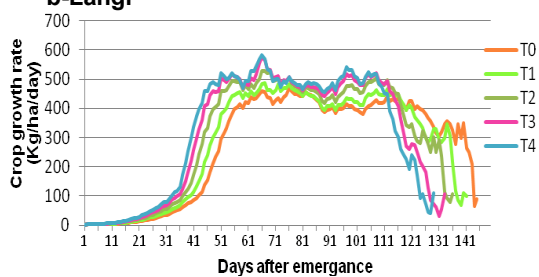
Griffith is located in Australia's New South Wales, namely in the Riverina agricultural region. Riverina is different from other parts of Australia because of its flat plains, warm to hot climate, and ample supply of irrigation water. Riverina has become one of Australia's most productive and agriculturally varied regions. Riverina produces the great majority of Australia's rice. The elevation of Griffith is 134 meters above sea level. Griffith is located at latitude 34.25°S and longitude 146.07°E. Riverina is located in a hot, dry zone with chilly winters, according to the Bureau of Meteorology Australia's 2021 classification of Australia's climatic zones, which is based on temperature and humidity.

The range of the annual mean maximum temperature is 23–25.5°C. Between 1961 and 1990, the average monthly rainfall was 393.7 mm, with the maximum being 703.3 mm and the lowest being 148.8 mm. Griffith experiences extremely chilly winter nights, much like the other locations in the hot, dry zone (Australia's, Bureau of Meteorology 2021).

A- Quest



b-Langi



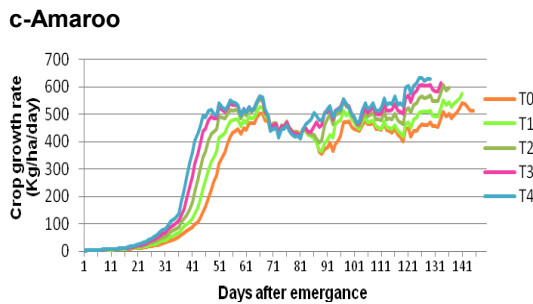


Figure 1: Crop growth rate (Kg/ha/day) of different rice varieties

When the temperature rose above the base temperature, the rice types used in this study showed a moderate increase in growth rate. The crop growth rate displays a similar pattern in each of the aforementioned graphs. The crop's growth rate mounted quickly until 50–60 days after emergence, after which it decreased as the crop grows. Crop growth rates at base temperature (T0 in Figure 1 above) are lower than those at higher temperatures.

- **Effect of temperature and CO<sub>2</sub> increase on yield components of rice**

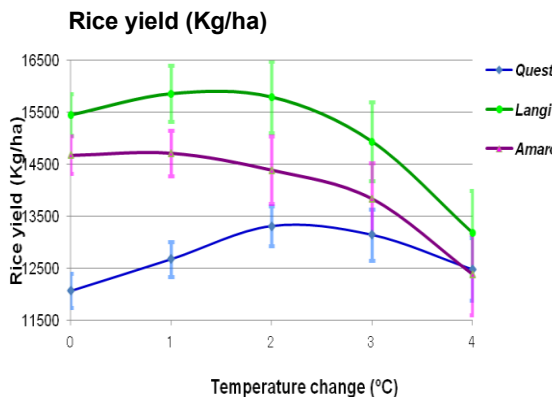


Figure 2: Variation of rice yield in Riverina rice varieties with different climate scenarios

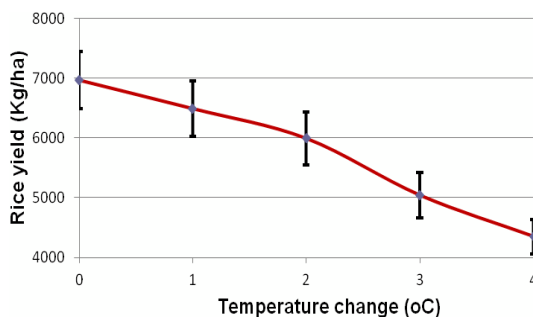


Figure 3: Variation of rice yield in Kununurra rice variety (IR72) with different climate scenarios

Figure 2 shows a steady rise in yield up to a temperature increase of 1–2°C, after which the yield decreases as the temperature and CO<sub>2</sub> concentrations rise further. For the types "Amaroo," "Langji," and "Quest," the average yield changes as a result of temperature increases up to 4°C were -15.6%, -14.7%, and +3.4%, respectively, in comparison to the base temperature. Significant yield differences were observed (<0.05) in variety Quest. Overall yield reductions were anticipated in Amaroo and Langji, whereas an overall yield gain was anticipated in Quest.

In contrast to Riverina, the estimated average rice yield of Western Australia's Kununurra region (shown in figure 3) gradually decreases as air temperature and CO<sub>2</sub> concentrations rise. At Kununurra, grain yields gradually decreased from 6.97 t/ha at base temperature to 4.35 t/ha after a 4°C temperature increase. The yield decreased significantly by 37.1% when the temperature was raised by 4°C above room temperature and the CO<sub>2</sub> level was raised by 750 ppm.

- **Crop season/duration (days)**

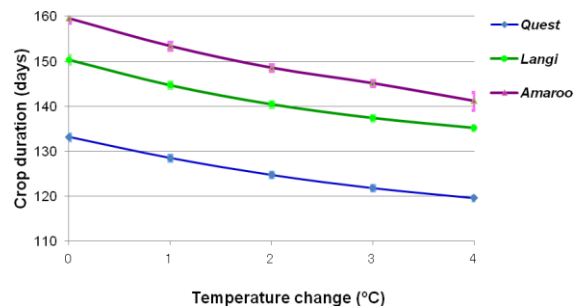


Figure 4: Changes in crop duration with the temperature increase in Riverina

The effects of ambient temperature on crop season length (crop duration) are shown in Figure 4. It is evident that an increase in temperature significantly shortened the crop's growth. For all three types, the length of the crop gradually decreased as the temperature increased. In all kinds, the production season was shortened by an average of 14–18 days due to temperature increases. The var Amaroo' (18 days) had the largest decrease. The lengthy maturity kind is "Amaroo" (18 days), which is followed by medium maturity "Quest" (14 days) and "Langji" (15 days) are short-term varieties.

## Discussion

The study's prediction of a progressive increase in crop growth rate (shown in figure 1) was caused by the combined effects of rising temperatures and elevated CO<sub>2</sub> concentrations. The higher CO<sub>2</sub> concentration is expected to improve both the net absorption rate and the rate of photosynthesis (Krishnan *et al.*, 2007). Thus, higher CO<sub>2</sub> concentrations were discovered to be the cause of rice's faster growth rate. Similar findings were made by Kimbal *et al.* (2002), who discovered that doubling the CO<sub>2</sub> concentration increased the pace of rice growth by 30%. Ishii *et al.* (2011) found that higher temperatures during rice vegetative growth accelerated crop growth.

The higher rate of photosynthesis and above ground dry matter may be the primary causes of this. All rice cultivars have shorter crop durations as a result of temperature effects and increased CO<sub>2</sub> growth acceleration.

The combined effects of rising temperatures and CO<sub>2</sub> concentrations are advantageous in the Riverina region, where the average maximum monthly temperature ranges from 23 to 25.5°C. This is because rising temperatures up to 2°C improve yield (figure 2). Similar findings were made by Baker *et al.* (2005), who discovered that a 32% increase in rice yield was caused by an increase in CO<sub>2</sub> content from 330 to 660 μmol CO<sub>2</sub> /mol in the atmosphere. This is mostly because of the CO<sub>2</sub> fertilization impact and the combined effect of slightly rising temperatures. The development of rice plants can be accelerated by increased canopy photosynthesis and a higher rate of net absorption, both of which are explained by higher CO<sub>2</sub> concentrations. Greater tillering, more panicles yielding grains, and growth responses are all brought on by increasing CO<sub>2</sub> concentrations (Krishnan *et al.*, 2007).

However, up to 2 °C above the ambient temperature, an increase in rice yield is seen because of the CO<sub>2</sub> fertilization effect. McGrath *et al.*, (2013). After 2°C, further temperature increases led to a reduction in Riverina production. Similarly, Ziska *et al.* (1997) and Hussain *et al.*, (2020) shown that greater temperatures can reduce rice yields even at higher CO<sub>2</sub> concentrations (due to the CO<sub>2</sub> enrichment effect). According to Kudeyarov *et al.* (2006), the effect of CO<sub>2</sub> fertilization can gradually diminish as the temperature of the atmosphere rises significantly. Similar findings were reported by Matthews and Wassmann (2003), who found that rising temperatures can lower rice yields and rising CO<sub>2</sub> concentrations can boost them.

Up to 2°C above the ambient temperature, a rise in rice output is seen as a result of the CO<sub>2</sub> fertilization effect. De Vries *et al.* (1990) used the MACROS crop simulation model, and their findings showed that a doubling of the CO<sub>2</sub> concentration would raise yield by 10-15%, though this increase would be recompensed by the increasing temperature effects. Correspondingly, in this study in var. Quest, rice yield augmented by +3.4% with the combined effect CO<sub>2</sub> and temperature increase in Riverina region.

Variety IR72's yield response to the same range of temperature and CO<sub>2</sub> variations differs from that of the Riverina rice varieties when the Kununurra region (Figure 3). As CO<sub>2</sub> levels rise and temperatures fluctuate, Figure 3 illustrates the significant yield drop as a percentage, reaching 37.1%. These findings supported those of Bachelet D (1995) and Matthews & Wassmann (2003), who demonstrated that rice yield decreased at higher temperatures.

The main cause of this is the variation in weather in these climatic zones. The Riverina is in a hot, dry zone with cold winters, and its mean maximum temperature is 23–25.5°C, which is relatively low compared to the ideal temperature of 28°C for rice growth (Prasad *et al.*, 2006). As a result, any additional temperature increase can increase rice yields because of the combined effect of CO<sub>2</sub> enrichment (up to 28°C).

However, a decrease in rice output might be seen if the temperature rises over the crop's ideal temperature (Prasad *et al.*, 2006). According to the Australian Bureau of Meteorology, the Kununurra region is in a hot, muggy summer zone. The annual mean maximum temperature ranges from 34 to 36 degrees Celsius, which is far higher than the ideal temperature for rice growth. Extremely high temperatures can significantly reduce rice productivity in areas with hot climates and temperatures that are at or above the ideal range for rice cultivation (Easterling *et al.*, 2007). This is mostly because the higher temperatures cause spikelet sterility (Kim *et al.*, 2003; Ohe *et al.*, 2007). Likewise, in this study, additional temperature increases had a negative impact on rice yield and caused it to fall. In the Kununurra region, var. IR72 showed a very substantial yield reduction (37.1%) (Figure 3).

According to Goswami *et al.*, (2006), spikelets are extremely sensitive to temperature changes in areas with temperatures around 33°C, and a 10°C fluctuation could significantly reduce rice yield. The primary cause of the drop-in spikelet fertility among several cultivars at higher temperatures was a combination of decreased pollen production and

reduced pollen reception (Prasad *et al.*, 2006). According to Shah *et al.* (2011), high temperatures right before or during anthesis are extremely detrimental and can cause rice and most other crops to produce fewer seeds.

Since these processes are extremely sensitive to temperature, higher temperatures during reproductive development interfere with anther dehiscence, pollen shedding, pollen grain germination on rice plant stigma, and pollen tube elongation (Fahad *et al.*, 2018). Poor spikelet fertility in rice is caused by the aforementioned causes. Less filled grains, lower grain weight per panicle and a decline in the harvest index can all be consequences of low spikelet fertility (Prasad *et al.*, 2006).

#### 4. Conclusion

The study's overall findings show that rising air temperatures and CO<sub>2</sub> concentrations have had a detrimental impact on future rice output in Australia's two study zones (the Kununurra and Riverina regions). Due to the hot and dry climate in the Kununurra region towards the end of this century, these effects are expected to be more severe for rice farmed there than in the Riverina region. Compared to the Riverina region's colder Mediterranean environment, yield losses will be more pronounced in the tropical north. Crop growth rate is expected to rise but crop length decreases in higher temperatures when crop growth characteristics are considered.

According to the results, short-season cultivars like var. Quest can withstand the effects of high temperatures and yield well under pressure. By shortening the crop length, short-season cultivars may compensate for yield losses in warmer climates.

According to the results, short-season cultivars like var. Quest can withstand the effects of high temperatures and yield well under pressure. By shortening the crop length, short-season cultivars may compensate for yield losses in warmer climates.

In order to deal with the effects of rising temperatures in the future, future rice breeding methods should concentrate on creating short-season types with increased spikelet fertility.

To reduce the effects of future climate change on rice production, early growth (shorter season) cultivars with improved water usage efficiency and high yield potential may be introduced. Another adaptive strategy is to change the planting dates so that the reproductive stage is not exposed to periods of higher temperatures.

#### Acknowledgement

Dr. K.B. Dassanayaka and Dr. B.R. Cullen- Faculty of Agriculture and Food Systems, University of Melbourne, Australia for expert advice.

The SILO data base for providing baseline climate data of two regions in Australia

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