The Cost of Low Temperature to the NSW Rice Industry

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Abstract

The Riverina region, located in south eastern Australia is among the highest yielding rice-growing regions in the world. This is due primarily to high levels of solar radiation and a cooler grain filling period. However, low temperature during reproductive development (between panicle initiation and flowering) sometimes limits achieving consistently high yields in this region. To ultimately increase the level of cold tolerance of commercial Australian rice varieties, the Cooperative Research Centre for Sustainable Rice Production is pursuing a multi-faceted approach to understand the mechanisms present at the plant, organ, cell, protein and genetic level. A yield model was developed for the Australian rice industry to estimate the extent of low temperature damage from 1955 to 1999. Genotypic parameters for the model were developed for the variety Amaroo, using the last 13 years of yield and meteorological data. The long-term yield potential of the rice industry was estimated at 9.7 t/ha/year. The mean yield reduction due to low temperature was estimated to be 0.68 t/ha/year, which is equivalent to $20 million a year. The benefit of improving the cold tolerance of commercial varieties was estimated by reducing the threshold temperature in 1?C steps for 4?C. The model was used to simulate yield for 45 years. For each degree reduction in the threshold temperature, the average loss due to low temperature was halved, with a 4^{o}C reduction predicting little cold damage.

Key words

Rice, low temperature, cold tolerance, sterility.

Introduction

The occurrence of low night temperatures during reproductive development in rice is one of the major yield-limiting factors of rice growing in New South Wales (NSW), where the majority of Australia’s rice is grown. Low temperature induced spikelet sterility is one of the major constraints to achieving consistently high yields in the NSW rice industry (Heenan, 1984; Williams and Angus, 1994). All Australian rice farms are fully irrigated, have high adoption levels of technology, and successfully control pests and have no major diseases. Low temperature problems occur during establishment (October-November) and again at the reproductive stage (late January-early February). Low temperature at the reproductive stage disrupts pollen development causing spikelet sterility, which reduces grain yield (Peterson et al, 1974; Satake, 1976). At panicle initiation approximately half of Australia’s farmers increase their water level (> 20 cm) to protect the developing panicle from low air temperature. The Australian commercial varieties begin to suffer low temperature damage when the minimum temperature is approximately 17?C for at least three consecutive nights during the critical young microspore stage.

Material and Methods

Model

Amaroo has been the most widely grown commercial variety in Australia since its release in 1987. Amaroo is a long duration variety of good grain quality with a high yield potential up to 14 t/ha. The average yields of Amaroo over the last 13 years were investigated in relation to temperature and radiation levels throughout the season (Table 1).

A model was devised that assumed yield potential was a function of accumulated radiation for a pre-defined period of time. Yields were then estimated by subtracting an amount of yield based on mid-season cold weather damage (Equation 1).

Equation 1: The yield model used a total of nine parameters

$$Yld = (K1 * \sum_{day2}^{day1} SR) - (K2 * \sum_{day4}^{day3} T_{\min} \leq T_{Crit})$$

Table 1. Nine different parameters were used in the yield model with five parameters being optimised

Symbol	Parameters	Optimised
K1	efficiency of conversion of radiation into yield	yes
day 1	time of planting	no
day 2	time of physiological maturity	no
K2	sensitivity to low temperature	yes
day 3	start of cold sensitive stage	yes
day 4	end of cold sensitive stage	yes
T_{Crit}	a threshold minimum temperature for cold damage	yes
SR	daily solar radiation data	no
T_{min}	daily minimum temperatures respectively	no

This model used an optimiser to fit five parameters (Table 1) based on 13 years of Amaroo yields. All weather data is from Griffith CSIRO meteorological station.

Results

Model development

The parameters in Table 3 predicted the average yields (? 0.4 t/ha) of Amaroo (Table). This model predicts that industry yield potential in the last 13 years was 9.7 t/ha, with cold damage reducing yields by an average of 0.9 t/ha. Yearly variation was more due to low temperature loss than variation in potential yield.

Table 2. Estimated values to predict industry performance of Amaroo.

Parameter	Value	Units
Day1	5-Oct	
Day2	22-Mar	
Day3	22-Jan	
Day4	5-Feb	
K1	2.28	t/ha/1000MJ
K2	0.18	t/ha/^{o}C<T_{Crit}
T_{Crit}	12.0	^{o}C

Table 3: Observed and simulated grain yield for Amaroo over the last 13 years.

Year	Observedyyield (t/ha)	Simulated yield (t/ha)	Error (t/ha)	Yield potential (t/ha)	Cold loss (t/ha)	Sum radiation (100MJ)	Sum cold damage (^{o}C days)
1987	6.6	7.4	0.8	9.9	2.5	4.3	13.8
1988	8.1	7.9	-0.2	10.4	2.4	4.5	13.6
1989	8.8	9.0	0.2	9.5	0.5	4.2	3.0
1990	9.1	8.4	-0.7	9.6	1.2	4.2	6.5
1991	9.8	9.7	-0.2	10.2	0.5	4.5	2.8
1992	9.5	8.5	-1.0	9.4	0.9	4.1	4.7
1993	8.3	8.8	0.5	8.8	0.0	3.9	0.0
1994	8.8	8.8	-0.1	9.2	0.4	4.0	2.5
1995	9.5	9.4	-0.1	9.9	0.6	4.4	3.1

1996	6.7	7.1	0.4	9.5	2.4	4.2	13.5
1997	9.0	10.0	0.9	10.0	0.0	4.4	0.0
1998	9.6	9.6	0.0	9.8	0.2	4.3	1.0
1999	9.7	9.7	0.0	9.7	0.0	4.3	0.0
MEAN	8.73	8.78	0.05	9.67	0.89	4.24	4.93

Long term simulation

The distributions of yield loss due to low temperature also changes dramatically with the lowering of the threshold temperature (Figure 1). The model was used for the years 1955 to 1999 using the parameters from the Amaroo data. The average yield loss across these 45 years was 0.68 t/ha, with 24% of years having no cold damage. In 11% of years there was a yield reduction of more than 2.2 t/ha. These years were 1957, 1965, 1987, 1988 and 1996, which is approximately a once per decade event. The reduction of the critical threshold from 12?C to 11^{o}C increases the years with no cold damage from 24% to 36%, and reduces the largest yield loss from 2.5 t/ha to 1.6 t/ha.

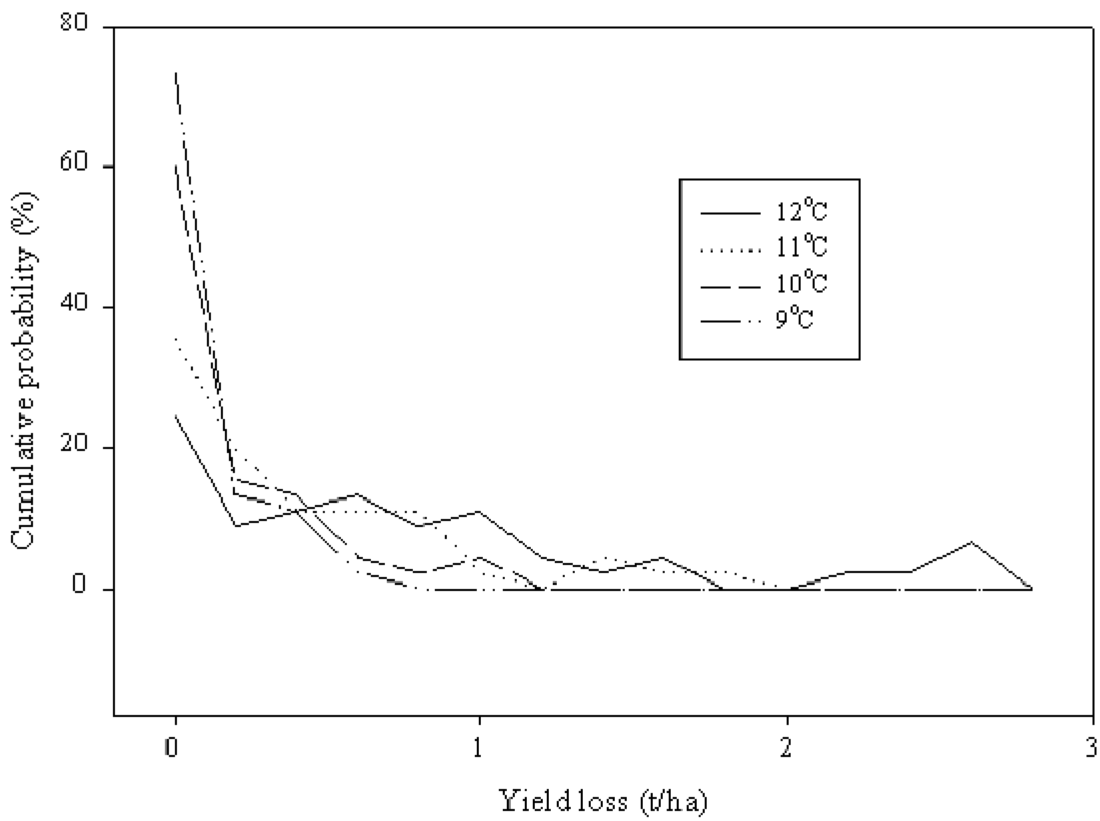

Figure 1. Distribution of average yield loss for a range of threshold temperatures for the NSW rice industry. The initial long-term simulation was based on T_{Crit}=12?C

Additional simulations were run with a range of threshold temperatures. The threshold temperature was reduced by one-degree intervals from the standard 12?C down to 9?C. Mean yield loss reduced by more than half for each degree reduction in threshold temperature.

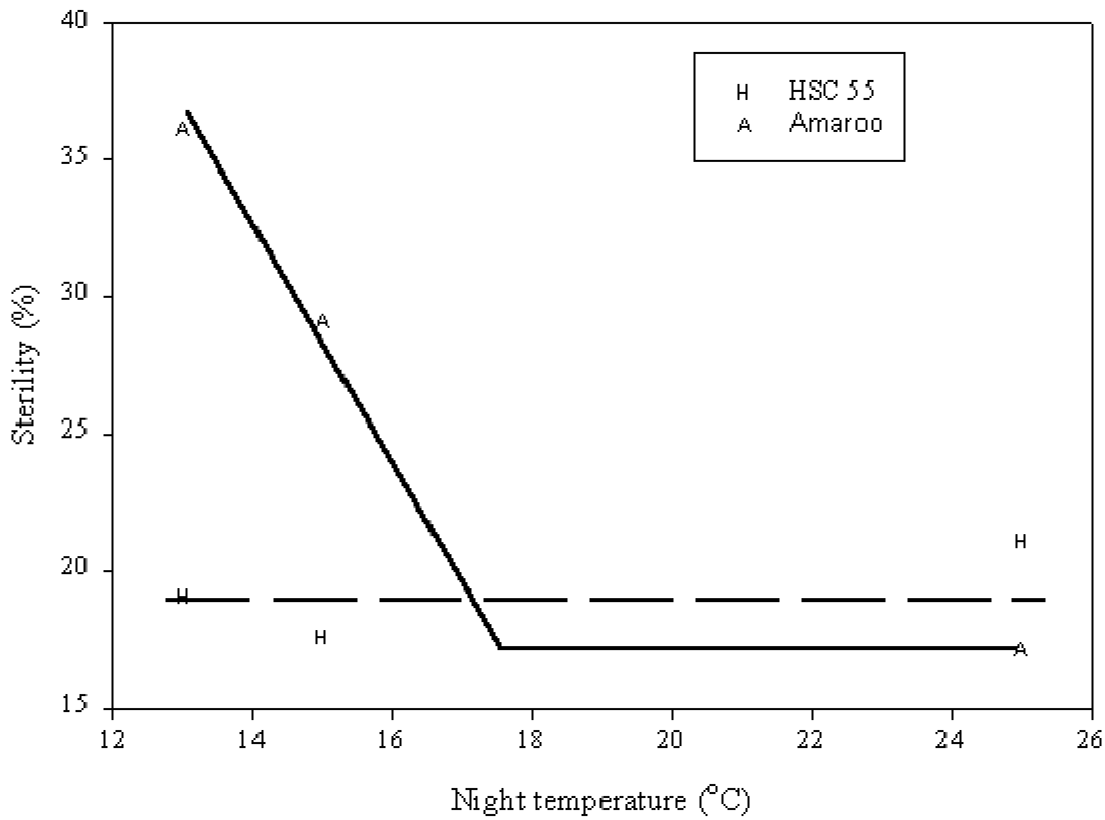

Figure 2. Percent sterility of Amaroo and HSC 55 at three night temperatures in controlled rooms

Table 3. Mean yield loss with a range of threshold temperatures.

Threshold Temperature (°C)	Mean yield loss (t/ha)
12	0.68
11	0.34
10	0.15
9	0.05

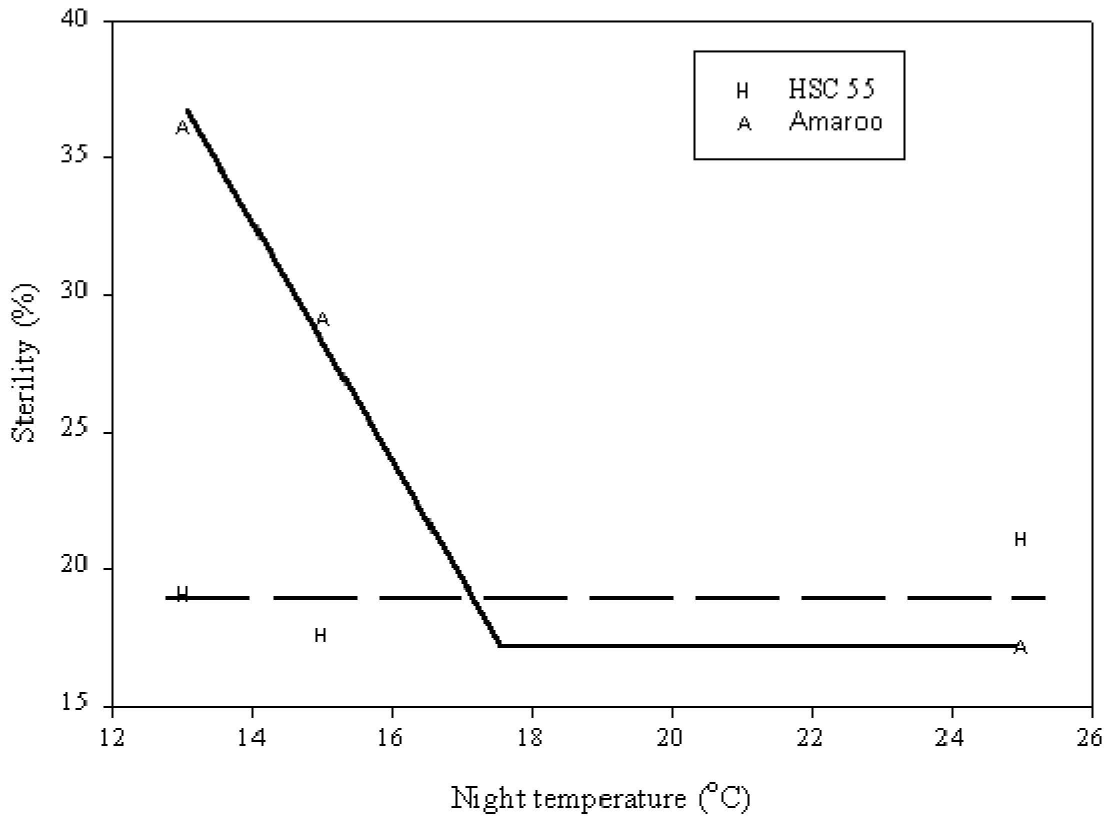

Figure 2. Percent sterility of Amaroo and HSC 55 at three night temperatures in controlled rooms.

Available genetic material

Recent testing of new germplasm in two glasshouse experiments has demonstrated the superior cold tolerance of some introduced, lines compared to the widely grown variety Amaroo. At night temperatures of 13?C, the sterility of HSC55 was unaffected when compared to that at the higher temperatures (Figure 2).

However, Amaroo showed a significant increase in sterility at temperatures of 15?C and lower. From this data, it appears that the threshold temperature for low temperature damage of HSC55 is at least 3?C lower than Amaroo, and possibly much lower. Confirmation of this tolerance in the field is in progress.

Conclusion

Incremental changes (such as one degree) in increasing the cold tolerance of Australian rice varieties can have dramatic increases in rice sustainability and profitability. New genetic material is available that has been proven in the glasshouse to have a threshold temperature at least 3?C lower than Amaroo. If this increased cold tolerance is confirmed in the field, incorporation of this level of tolerance must become a high priority of the NSW rice-breeding program.

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