Assessing the likelihood of the occurrence of low temperature damage in the NSW rice industry

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Abstract

Low temperature can limit production of rice (Oryza sativa L.) at high latitudes. This paper describes the extent of the low temperature damage which can arise mid-season during the panicle development phase. The occurrence of a low temperature problem was investigated across four seasons in field experiments at the Yanco Agricultural Institute (YAI). Plants were sown on 2 - 3 occasions in most seasons to increase the chance of exposure to low temperature during panicle development in late January. The number of engorged pollen grains per anther and spikelet sterility were measured. Historical temperature records were used for probability analysis in determining the probability of a low temperature problem.

Low minimum air temperature during microspore development and, at flowering, increased spikelet sterility. An average minimum air temperature of 13.8?C during microspore development in shallow-watered (8 cm) fields resulted in 25% spikelet sterility. The study of historical temperature records at YAI has shown that, in 45% of years, rice would be exposed to an average minimum temperature of < 17?C for 10 days during microspore development. This would be expected even when the crop is sown early in the season (early October). As the threshold temperature decreases from 17?C to 13?C the probability of damaging years decrease from 45% to 14% for early sown crops.

Key Words

Low temperature, Microspore development, Engorged pollen, Spikelet sterility

Introduction

Investigations (2,4) of low temperature damage in rice indicate that the microspore development stage, more specifically, the tetrad formation stage of pollen development, is most sensitive to low temperature. The research program undertaken in this study investigated low temperature effects on spikelet sterility of rice and their implications for the NSW rice industry.

Methods

Four field experiments were conducted at Yanco Agricultural Institute (YAI) (34?37’ S, 146?25’E) during the summers of 1996/97 (Exp 1), 1997/98 (Exp 2), 1998/99 (Exp 3) and 1999/00 (Exp 4). There were 1, 3, 2 and 2 sowing times in Exp 1, 2, 3 and 4, respectively (Table 1). Exp 4 included low and high sowing rates to investigate the effects of spikelet density on sterility. The mean minimum daily temperature was calculated for the period of microspore development for each sowing time in all four experiments. Mean minimum temperature during flowering was also determined for the period from 50% heading to 50% flowering for each sowing, in all experiments. In all instances, engorged pollen grain number, spikelet density, spikelet sterility and grain yield were recorded.

Results and Discussion

Seasonal variation experienced in the experimental program

Exposure to low temperatures during the critical stage of microspore development is weather dependent, a variable that cannot be controlled in field experiments. The recommended sowing window for cv. Amaroo based on the average weather pattern in the NSW rice growing area is 1 - 15 October (3). In the

present series of field experiments, microspore development occurred at around 20 - 30 January, when the crop was sown within the recommended sowing time; an exception was for the early-sowing in Exp 2 (Table 1). In all four seasons of the study, crops sown up to 17 October

Table 1: Microspore development periods, average minimum temperatures during microspore development (MTM) and flowering (MTF) for cv. Amaroo during four seasons of field experiments. (LR, low sowing rate; HR, high sowing rate)

Experiment and season	Date of sowing	Microspore development period	MTM (?C)	MTF (?C)
Exp. 1 (1996/97)	15 Oct	23 Jan - 30 Jan	18.8	na
Exp. 2 (1997/98)	2 Oct	8 Jan - 17 Jan	19.6	17.7
	17 Oct	22 Jan - 1 Feb	16.4	14.8
	30 Oct	22 Jan - 3 Feb	17.0	16.3
Exp. 3 (1998/99)	1 Oct	20 Jan - 2 Feb	20.0	19.3
	3 Nov	3 Feb - 14 Feb	22.7	21.0
Exp. 4 (1999/00)				
	2 Oct (LR)	20 Jan - 29 Jan	13.9	21.0
	2 Oct (HR)	20 Jan - 30 Jan	13.9	21.0
	3 Nov (LR)	29 Jan - 13 Feb	19.3	16.8
	3 Nov (HR)	1 Feb - 13 Feb	20.4	19.0

na; no data available

experienced a minimum temperature range of 13.9 - 20.0?C during microspore development, and 14.8 - 21.0?C during flowering (Table 1).

Although microspore development commenced at the same time of the year when the crop was sown early in Exp 3 and Exp 4, plants in Exp 4 encountered a 6.1?C lower average minimum temperature during the microspore development period (Table 1). This result demonstrated that the recommended sowing window may not necessarily avoid low temperature damage during microspore development. When the crop was sown between 1 and 15 October, exposure of microspore development to temperatures of < 14?C occurred in one season out of four. Flowering, on the other hand, was exposed to warmer conditions (17 - 21?C) when the crop was sown very early (2 October). When the crop was sown after 15 October, flowering was exposed to low temperatures (< 17?C) in Exp 2 and, in particular, the low density crop in Exp 4. In Exp 3, the mean temperature was higher (21?C) during flowering. Late-sowing, however, increased the risk of exposure to low temperature at flowering; flowering in two out of three seasons (Exp 2 and Exp 4) was exposed to < 17?C when the crop was sown late.

When low temperature did occur in Exp 2 and Exp 4, spikelet sterility was significantly correlated with the minimum temperature during microspore development in Exp 4 ($r = -0.496^{*}$), but in Exp 2 it was significantly correlated with minimum temperature during flowering ($r = -0.790^{**}$). In Exp 4, there was a significant combined effect of average minimum temperature (?C) during microspore development (x_1) and during flowering (x_2) on spikelet sterility (y). The model, $y = 59.8 – 1.40x_1 – 0.91x_2$ ($r = 0.609^{**}$), showed that sterility was more sensitive to minimum temperature during microspore development. However, in the same season (Exp 4) an average minimum air temperature of 13.8?C during microspore development in shallow-watered (8 cm) fields resulted in 25% spikelet sterility. Combined analysis of field data showed that variation in spikelet sterility over three seasons (Exp 2, Exp 3 and Exp 4) was largely explained by spikelet density ($r = 0.553^{**}$) followed by the number of engorged pollen grains per anther ($r = -0.493^{**}$) (Table 2). Although minimum temperature during microspore development did not significantly correlate with sterility, stepwise regression of independent variables against sterility showed that the combined effect of spikelet density (m^{-2}) (x_1) and minimum temperature (?C) during microspore development (x_2) explained 46% the variation in spikelet sterility (%) (y). The model was:

$y = 20.9 + 0.0020x_1 – 0.69x_2$ ($r = 0.680^{**}$)

Increased spikelet density increased grain yield over three seasons' experiments (Exp 2, Exp 3 and Exp 4) ($r = 0.922^{**}$) (Table 2). Stepwise regression of independent variables shown in Table 3 against grain yield showed that spikelet density (m^{-2}) (x_1) and spikelet sterility (%) (x_2) explained 87% the variation in grain yield (g m^{-2}) (y). The equation for the model was:

$y = 210.9 + 0.016x_1 - 9.52\ x_2$ ($r = 0.933^{**}$)

Table 2: Correlation coefficients for linear regressions of components of sterility against grain yield and correlation matrix of spikelet sterility and sterility components for cv. Amaroo across three seasons of field experiments (Experiment 1 data have not been included) at Yanco Agricultural Institute. (MTM, minimum temperature during microspore; MTF, minimum temperature during flowering)

	Grain yield (g m^{-2})	Spikelet sterility (%)	Spikelet density (number m^{-2})	Engorged pollen (grains $anther^{-1}$)	MTM (?C)	MTF (?C)
Grain yield (g m^{-2})	1.000					
Spikelet sterility	0.366ns	1.000				

(%)						
Spikelet density (number m^{-2})	0.922**	0.553**	1.000			
Engorged pollen (grains $nther^{-1}$)	-0.089ns	-0.493**	-0.257ns	1.000		
MTM (?C)	0.207ns	-0.332ns	0.118ns	0.235ns	1.000	
MTF (?C)	-0.434*	-0.244ns	-0.372*	-0.264ns	-0.092ns	1.000

**$p < 0.01$; *$p < 0.05$; ns, not significant; n = 30 (12, 6 and 12 treatments in Experiments 2, 3 and 4 respectively). No engorged pollen number and MTF data was available for Experiment 1.

Therefore, spikelet sterility which was determined by both spikelet density and minimum temperature during microspore development, appeared to be a determinant of grain yield.

Examination of historical temperature records

The likelihood of occurrence of low temperature damage in rice plants depends on the time that low temperature is experienced relative to the reproductive development stage. Microspore development should take place in the middle of summer to minimise the possibility of exposure to periods of low temperature. Early-sowing as a practice to reduce spikelet sterility caused by low temperature during microspore development or flowering, is based on the average weather pattern of the rice growing region of the Murray Valley in NSW.

Calculations were made of the probability of occurrence of mean minimum temperature below 13?C (used in glasshouse experiments in conjunction with these field experiments), 15?C (the estimated threshold temperature for cv. Amaroo (1)) and 17?C (the estimated threshold temperature for cultivars tolerant of low temperature (4)). This was done by first computing the mean and standard deviation for each 10-day period between October and March using 42 years' (1959 to 2001) of temperature data. Subsequently, the probability of occurrence of a temperature below a particular threshold temperature, was estimated. The results of analysis showed that as the season progresses beyond mid-February, the chance of receiving damaging minimum temperatures, during a period of 10 days, increases (Fig. 1). The results indicated that in 14% of years, rice would be exposed to a minimum temperature < 13?C for 10 days during microspore development in late January for crops sown early in the season. In the present study of early-sowing over four seasons, microspore development was exposed to temperatures lower than 14?C only once (Exp 4). From Exp 4, it appeared that minimum temperatures of 15?C during microspore development caused 18% sterility. When the crop is sown early and microspore development takes place in late January, the probability of minimum temperature below 15?C for 10 days would be 28% (Fig. 1). Although microspore development in the late-sown crop coincides with the time of the lowest probability (12%) of a low temperature of 13?C, the probability of flowering being exposed to a temperature of < 13?C would be 14% of years. It appears that sowing up to end of October had a similar probability of receiving injurious low temperature during

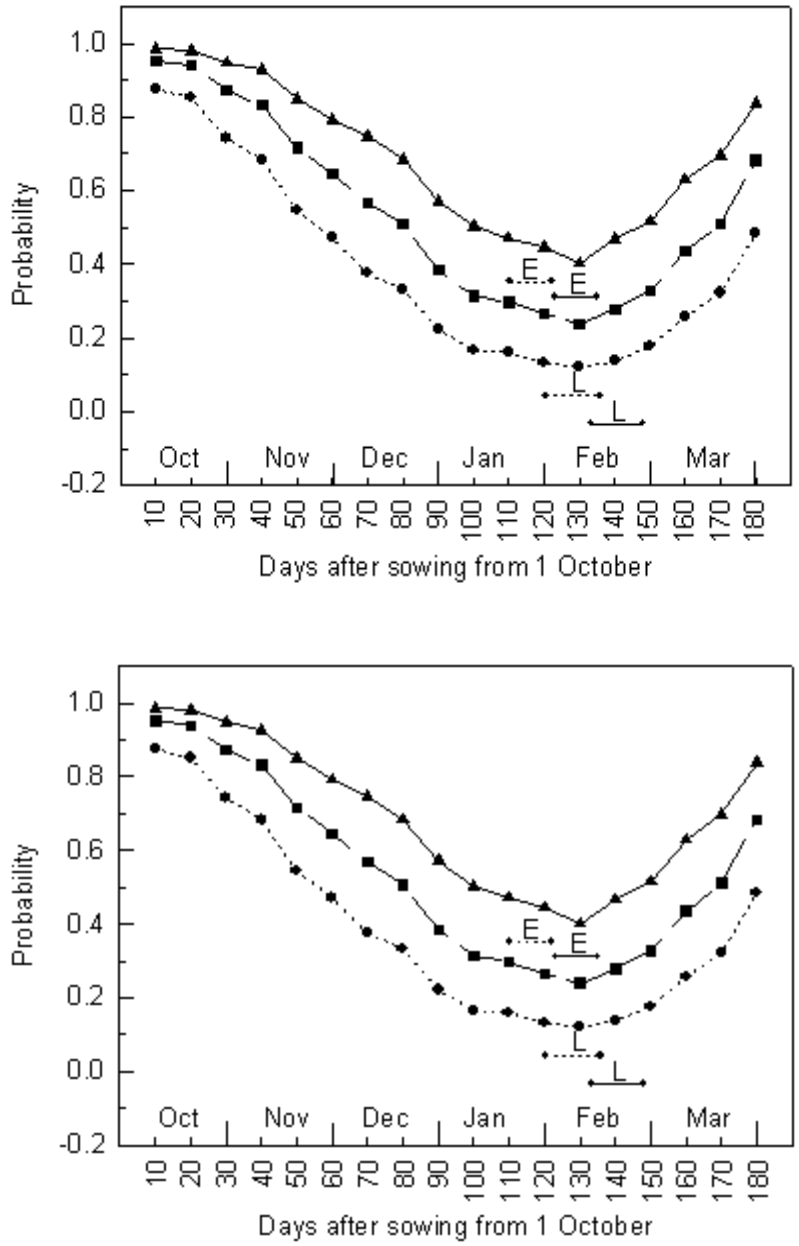

Fig. 1: The probability of the occurrence of mean minimum temperature below 17?C (▲), 15?C (■) and 13?C (●) over periods of 10 days from October to March at Yanco Agricultural Institute. Minimum temperature data for 42 seasons (1959 to 2001) were used. Horizontal dotted bars show the period of microspore development whereas horizontal solid bars show the flowering period across four season experiments (E, early-sowing; L, late-sowing). (Temperature data source: NSW Agriculture, 2001.)

microspore development. On the other hand, an average minimum temperature of 17?C during flowering caused about 16% spikelet sterility in Exp 2 (r = -0.794**) and in the late-sowing in Exp 4 (r = -0.713**). The probability of minimum temperature for 10 days below 17?C during flowering in the early-sowing is 40% of years. This increased to 48% when the crop is sown late.

Developing a cultivar with low threshold temperature for microspore development appears to be very important, for as the threshold temperature decreases from 17?C to 13?C the probability of damaging years decreases from 45% to 14% for early sown crops.

Early-sowing within the recommended sowing window for cv. Amaroo in order to avoid low temperature damage during flowering does not, however, necessarily avoid damage during the microspore development stage. On the other hand, flowering time in the early sown crop in most seasons coincided with the microspore development period of the late sown crop (i.e. early February) (Fig. 1). There is > 40% chance of having a temperature < 17?C during early February where flowering and microspore development occurs in early- and late-sowing crops, respectively. This emphasises the need to develop low temperature tolerant cultivars, as the risk of low temperature exists during both microspore development and flowering, regardless of sowing time.

References

(1) Farrell, T. C., Williams, R. L., and Fukai, S. (2001) Proceedings of the 10th Australian Agronomy Conference, Hobart (www.regional.org.au/au/asa/2001/).

(2) Heenan, D. P. (1984) Aust. J. Exp. Agric., 34: 917-919.

(3) NSW Agriculture. (1999). Ricecheck Recommendations: NSW Agriculture and the RIRDC Rice Research Development Committee, pp 20.

(4) Satake, T. (1969) Japanese Agricultural Research Quarterly, 4: 5-10.