Frost risk in New South Wales wheat belt

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Abstract

Frost damage to wheat crops is a major climatic risk for farmers in NSW. Farmers are faced with decisions on choice of sowing date and variety to minimise the frost risk at the critical time of flowering. We analysed frost risk in the NSW wheat belt using 2?C in the Stevenson screen as the critical temperature for frost damage to flowering wheat. The dates with a probability of a frost event less than or equal to 20%, 10% and 5% were estimated. The average dates for last frost were positively related to latitude and altitude. The dates for frost risk probability of 20%, 10% and 5% may be delayed by a week if the latitude is increased by 1.5, 1.4 and 1.2?S, respectively. Every 76 m increase in altitude delayed the dates of frost risk by one week. The information may be used as an aid by farmers and advisers.

Key Words

Frost probability, frost temperature, wheat, climate variability

Introduction

Frost damage to wheat crops is one of main climatic risks for farmers in NSW. Farmers are faced with decisions on choice of sowing date and variety to minimise the frost risk at the critical crop stage around flowering. However, if the crop is sown late, crop yield is generally low (6). Early flowering in the absence of frosts produces higher yields as the grain filling occurs during more favourable temperatures and potentially less drought stress. Therefore, sowing time and variety choice are the variables farmers have to optimise flowering time with a minimum risk of frost and high yield potential.

The critical temperature for frost damage to a wheat crop varies with stage of crop development (4, 8). During vegetative stages, plants are not affected by frost in the Australian wheat belt (8). Before stem elongation, the critical temperature for frost damage to wheat can be as low as -8?C, while the critical temperature for frost damage to the crop at stem elongation is -4?C (4). The most susceptible stage for frost damage is at flowering. At this stage, critical temperature is reported as -2 to -2.5?C (4). In this study, we analysed the historical climatic data and estimated the frost risk in the NSW wheat belt.

Methods

Minimum temperature data were obtained from MetAccess (2). Sites with a minimum of 30 years of records for minimum temperature were selected. A total of 38 sites were selected within the NSW wheat belt. The minimum temperature causing damage was taken as -2?C (4). Because air temperature recorded at meteorology stations can be greater than those of crops in the field (temperature sensors are often located at post offices) minimum temperature below 2.0?C recorded in the Stevenson screen is often used as critical temperature for frost (3, 5). However, minimum temperature of ≤1.3?C (9) or ≤2.2?C (4) have been used as critical frost temperatures. Thus, the critical temperature for a frost event is defined as a temperature of ≤2?C in the screen in this study. Because the frequency is calculated based on mostly 30-40 years of records, fluctuations in frequency curves are often observed. In order to reduce the impact of the fluctuations, the initial frost probability is smoothed by a 14 day moving average. This technique makes long term trends of a time series clearer. The 20%, 10% and 5% frost risk means that occurrence of a frost event after that day is 1 in 5 years, 1 in 10 years and 1 in 20 years, respectively.

Table 1.The dates of last frost for probability that is less or equate to 20%, 10% and 5% in NSW wheat belt.

Site no & Name ?	Lat (^oS)	Alt (m)	No years	FRP 20%	FRP 10%	FRP 5%
Northern						
1 Mungidi	28.98	160	31	18-Aug	31-Aug	08-Sep
2 Moree	29.48	212	38	28-Aug	13-Sep	28-Sep
3 Collarenabri	29.55	145	34	30-Aug	10-Sep	28-Sep
4 Brewarrina	29.97	115	37	08-Aug	29-Aug	01-Sep
5 Walgett	30.02	131	36	12-Aug	31-Aug	08-Sep
6 Narrabri	30.33	212	40	31-Aug	20-Sep	01-Oct
7 Barraba	30.38	500	36	06-Oct	18-Oct	31-Oct
8 Coonamble	30.98	180	37	25-Aug	07-Sep	16-Sep
9 Gunnedah	30.98	306	37	04-Aug	28-Aug	08-Sep
10 Tamworth	31.08	400	45	03-Sep	24-Sep	04-Oct
11 Coonabarabran	31.25	505	45	03-Oct	18-Oct	29-Oct
12 Quiridi	31.50	390	37	27-Sep	06-Oct	12-Oct
Mean				31-Aug	16-Sep	27-Sep
Central						
13 Nyngan	31.53	13	32	24-Aug	02-Sep	12-Sep
14 Trangie1	32.00	215	33	12-Sep	01-Oct	07-Oct

15 Dundoo	32.02	388	37	28-Sep	09-Oct	25-Oct
16 Dubbo	32.22	275	43	05-Sep	28-Sep	06-Oct
17 Wellington	32.52	394	36	30-Aug	21-Sep	05-Oct
18 Mudgee	32.55	471	40	01-Oct	12-Oct	30-Oct
19 Peak hill	32.72	267	37	19-Aug	31-Aug	27-Sep
20 Condobolin	33.08	199	35	28-Sep	06-Oct	12-Oct
21 Parkes	33.13	330	32	23-Aug	04-Sep	21-Sep
22 L Cargelligo	33.27	169	34	30-Aug	10-Sep	30-Sep
23 Forbes	33.38	240	45	20-Sep	04-Oct	12-Oct
24 Cowra	33.80	380	37	24-Aug	03-Sep	04-Oct
25 Hillston	33.83	122	45	27-Aug	19-Sep	26-Sep
26 Grenfell	33.90	384	34	02-Sep	28-Sep	05-Oct
27 West Wyalong	33.93	245	37	02-Sep	29-Sep	05-Oct
Mean				**05-Sep**	**21-Sep**	**05-Oct**
Southern						
28 Young	34.25	380	34	10-Oct	01-Nov	14-Nov
29 Griffith	34.30	126	37	05-Sep	30-Sep	12-Oct
30 Temora	34.40	270	37	03-Oct	15-Oct	30-Oct
31 Hay	34.52	93	45	09-Aug	05-Sep	22-Sep

32 Balranald	34.63	61	33	26-Aug	17-Sep	26-Sep
33 Cootamundra	34.63	318	39	01-Oct	12-Oct	25-Oct
34 Narranddera	34.72	160	32	12-Sep	05-Oct	11-Oct
35 Wagga Wagga	35.12	220	60	26-Sep	09-Oct	29-Oct
36 Deniliqu	35.55	93	39	23-Aug	22-Sep	03-Oct
37 Tocumwal	35.80	114	31	26-Aug	11-Sep	27-Sep
38 Albury	36.10	184	37	09-Aug	30-Aug	26-Sep
Mean	**?**	**?**	**?**	**07-Sep**	**27-Sep**	**12-Oct**

Linear regression was used to quantify the effect of latitude and altitude on the date at various frost risk probabilities. In order to allow the model to be applied at low latitude and high altitude that are not covered by the selected sites in NSW wheat belt, a few lower latitude and higher altitude sites other than in the NSW wheat belt are included. They are St George, (lat. 28.02?S , alt. 201 m), Dalby (lat. 27.17?S, alt. 344 m) and Toowoomba (24.58?S, alt. 675 m) from Queensland, and Tumut (35.33?S, alt. 305 m) and Yass (34.83?S, alt. 520 m) from New South Wales. The NSW wheat belt sites are listed in Table 1. The model was also presented by estimating frost risk from the model for points on a GIS map with known location and altitude

Results

Table 1 shows the dates for the occurrence of last frost for the 20%, 10% and 5% probabilities. NSW wheat belt was arbitrarily divided into three regions with a latitude range: northern ≤ 31.5?S; 31.5?S < central ≤ 34?S; southern > 34.0?S. The dates of frost probability in northern region, at 20%, 10% and 5% were 31 August, 16 September and 27 September, respectively. This compares with the southern region where the respective dates were 7 September, 27 September and 12 October. There was about one week delay for each frost probability from northern to central and from central to southern region.

Altitude had a large effect on the frost occurrence. Within the same region, the latest frost risk dates all corresponded with the highest altitude. The highest altitude was 500 m at Barraba in northern, 471 m at Mudgee in central and 380 m at Young in the southern region. They had 5% frost probability of 31 October, 30 October and 14 November, respectively. The site with the lowest altitude had the earliest dates for 5% frost probability in northern and central regions. However, in southern region, the lowest altitude was 61 m at Balranald, which had a 5% frost risk date of 26 September. The earliest date for this event in this region is 22 September at Hay

To quantify the effect of latitude and altitude, we used the linear regression of day of year (DOY) at a defined frost risk probability as a function of latitude and

altitude:

$$D_{\alpha} = a + b\Lambda + c\Delta \quad (1)$$

Where D_{α} is the DOY at α % FRP, Λ is the latitude (?S), and Δ is the altitude (m). The results were

$$D_{20} = 70.82 + 4.746\Lambda + 0.092\Delta, \quad R^2=0.45, \ (2)$$

$$D_{10} = 81.40 + 5.008\Lambda + 0.089\Delta, \quad R^2=0.54, \ (3)$$

$$D_{5} = 64.87 + 5.863\Lambda + 0.092\Delta, \quad R^2=0.65, \ (4)$$

All coefficients were significantly different from zero ($p<0.001$).

The model was compared with dates of frost risk probability, which were estimated from climatic data, to examine the agreement of the regression (Figure 1). The latitude and altitude account for the 45%, 54% and 65% of total variation. This suggested a large proportion of variation is due to other local factors. There was a greater dispersion between fitted values and measured values at 20%, indicating the model performed worse in the high frost risk probability than low risk probability. This also can be seen from the coefficient of determination (R^2): the lower the frost risk probability, the higher the value of R^2.

The reasons for these big deviations are unknown. The unknown factors may include rainfall, position in the landscape and the position of weather station relative to buildings etc. Loss (1989) reported that for two recording sites about 400 m apart, 4?C differences in minimum temperatures were recorded. In our studies, using the combined data of three Albury sites (Albury Airport, lat. 36.07 ?S, alt.165 m; Albury Grammar School, 36.07 ?S, 183 m and Albury Pumping Station, 36.08 ?S, 182 m), the dates for 20%, 10%, and 5% risk were 31, 35, 18 days later than the reported in Table 1 (for Hume Reservoir, 36.1°S, alt. 184 m). The dates for the respective frost risk probability were 5 days earlier, the same and 5 days later than that predicted by Eqs, 2, 3, and 4, respectively. This was compared with 38 days, 36 days and 24 days overestimated, using the data of Hume Reservoir, for 20%, 10% and 5% risk, respectively. The temperature data recorded at Hume Reservoir may be warmer than nearby recording stations as the micro-environment may be different due to the body of water in the reservoir. Estimation using data from Hume reservoir gave earlier dates than other sites nearby. Simulating two sites near Wagga Wagga shows that Soil Con. Services (lat. 35.13, alt. 222 m) were, respectively, 7, 11 and 17 days' earlier than that at Wagga Wagga AMO. The differences at Wagga Wagga and the Albury example show the importance that locality can have on frost. Users should be aware of the limitations of the model.

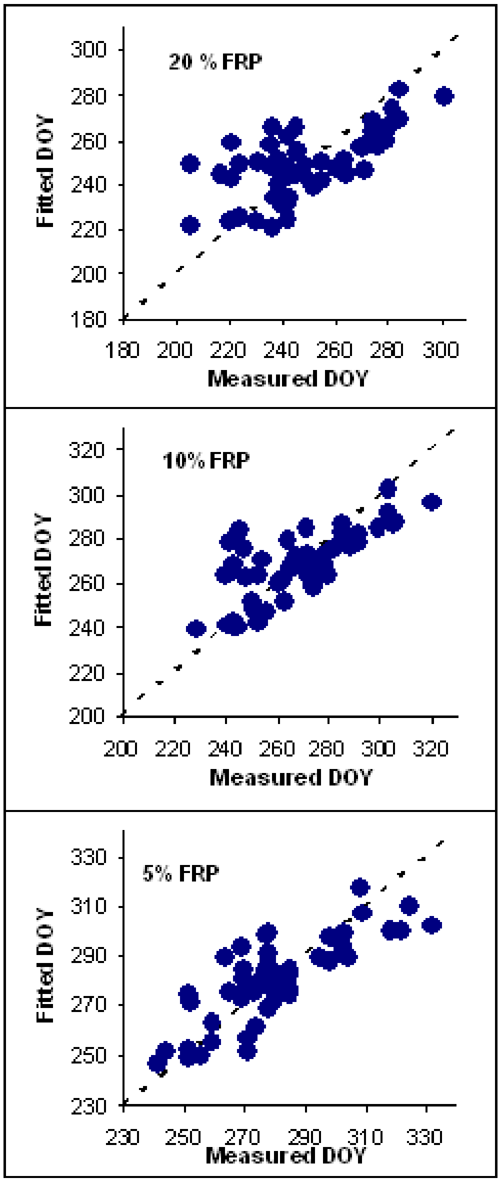


Figure 1. Comparison of day of year (DOY) at 20%, 10% and 5% frost risk probability (FRP) determined by climatic data (measured DOY) and calculated DOY by Eqs. 2, 3 and 4 (fitted DOY)

Figure 2.
Estimation of the dates
for 20% frost risk probability
in NSW wheat belt

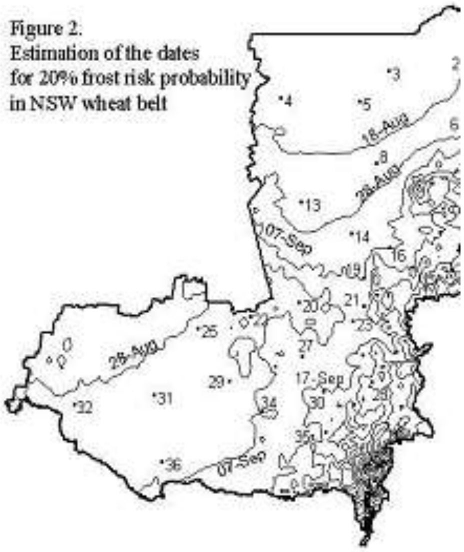


Figure 3.
Estimation of the dates
for 10% frost risk probability
in NSW wheat belt

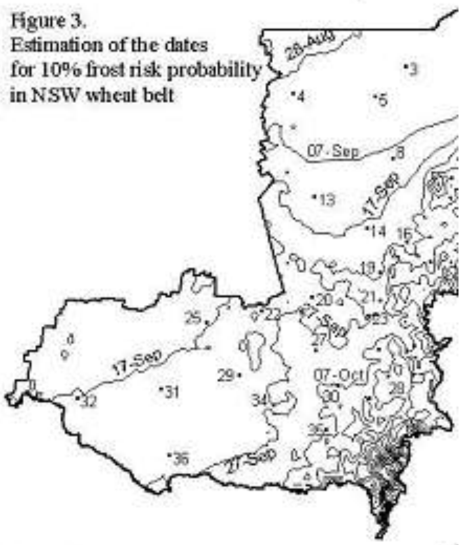
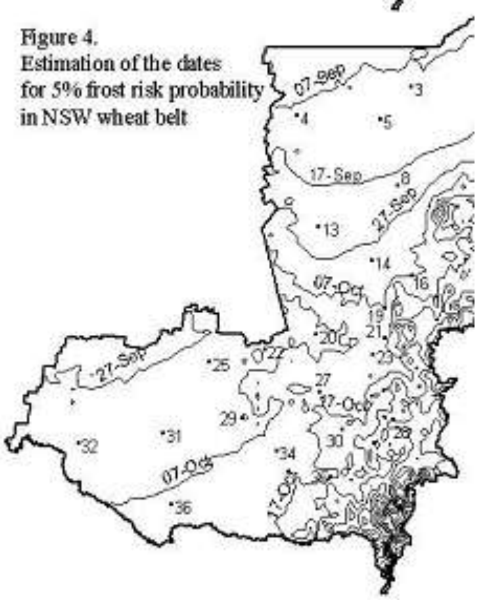


Figure 4.
Estimation of the dates
for 5% frost risk probability
in NSW wheat belt



One-degree of latitude increase delayed the dates for frost risk by 4.7, 5.0 and 5.9 days at 20%, 10% and 5%, respectively. Increase in latitude of 1.5, 1.4, 1.2?S delayed frost risk date by a week for 20%, 10% and 5% frost probability. Every 100 m increase in altitude will gave a delay of about 9 days for all three frost risk probabilities. Thus, if the altitude has 76 m higher than a reference location, the expected date for a frost risk will be a week later. The frost risk we have defined is present in Figs 2, 3, and 4 by interpreting the models (Eqs 2, 3, and 4) using a digitised map with known altitude. The figures give an overview of the general frost risk in the NSW wheat belt. DOY is presented as a date on a line and towns are numbered as for Table 1. Variation in dates for any frost risk probability is much greater in the eastern than in western part of the wheat belt indicated by dense lines alone the eastern side of the wheat belt.

The date for 10% frost risk was 9 October at Wagga Wagga. Plant breeders have traditionally used a targeted flowering date of 10 October for selecting varieties for this region.

Conclusion

Frost risk for flowering wheat crops in NSW has been broadly described; altitude and latitude have a major effect on the probability of frost. Local effects can be important but are not included in the model

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