Identifying the optimal flowering period for wheat in south eastern Australia: A simulation study

B.M. Flohr [1, A], J.R. Hunt[1, B], J.A. Kirkegaard[1, C], J.R. Evans[2]

[1] CSIRO, Agriculture Flagship, PO Box 1600, Canberra, ACT 2600, [A]bonnie.flohr@csiro.au, [B]james.hunt@csiro.au, [C]john.kirkegaard@csiro.au

[2] The Australian National University, Research School of Biology, Canberra, ACT 0200, john.evans@anu.edu.au

Abstract

Across the Australian wheat belt, the time at which wheat flowers is a critical determinant of yield. In all environments an optimal flowering period exists which is defined by decreasing frost risk, and increasing water and heat stress. Despite its critical importance, optimal flowering periods based upon simulated yield from long-term climate records have not been comprehensively quantified across Australia's cropping zone. In this study, the widely validated cropping systems model (APSIM-Wheat) was used to predict wheat yield, with reductions in yield applied for frost and heat damage based on air temperatures during sensitive periods. The APSIM-Manager was used to sow a crop on a fixed date at weekly intervals starting from the 1 April to the 15 July of each year. The relationship between flowering date and grain yield was established for 29 locations using 51 years (1963-2013) of climate records. The simulation experiments provided results on potential yields, yield reduction from frost and heat events and interactions with season and soil type. APSIM output for yield and flowering date was split by calculating the means of values between the 20th and 30th percentiles, 45th and 55th percentiles and 70th and 80th percentiles within each sowing date. The peaks of the percentile bands, representing the relationship between sowing date, flowering date and yield, were used to define the optimal flowering period in each location. Optimal flowering periods varied considerably across the Australian wheat belt. The optimal flowering period across all locations ranged between 13 August and 1 November, though the start and end dates, and duration of these periods varied greatly with location. Quantifying optimal flowering periods is vital to identify suitable genotype x sowing date combinations to maximise yield in different locations.

Keywords APSIM, frost, heat, optimal flowering period, simulated yield

Introduction

Infrequent rainfall events, high temperatures during grain fill and the risk of frost at flowering are three major environmental constraints to wheat yield in Australia (Gomez-Macpherson and Richards 1995). Flowering at the optimal period is critical to final grain yield, as it is immediately prior to and during anthesis that grain number is determined. It is also at this time that grain yield is most sensitive to stresses such as extreme high and low temperatures and water stress (Fuller *et al.* 2007; Tashiro and Wardlaw 1990). A combination of environmental factors (soil type, water availability, temperature) influence the start, end and duration of an optimal flowering period which varies greatly across the Australian wheat belt. In addition to the variability of Australian environment types, there is evidence of changing rainfall patterns (Cai *et al.* 2012), and predictions of further rainfall variability, occurrence of high-temperature events (Zheng *et al.* 2012) and harsher springs (Kirkegaard and Hunt 2010). Therefore the need to identify the optimal flowering periods for environments in the Australian wheat belt is clear.

Identifying the optimal flowering period for specific environments allows identification of suitable genotype (G) x management (M) combinations allowing yield to be maximised. In contrast to Zheng *et al.* (2012) who used air temperature records to analyse frost and heat patterns of the Australian wheat belt to calculate target flowering windows based on last frost days and first heat days in current and future climates, this study uses APSIM-Wheat to incorporate the effect of drought stress and radiation as well as temperature to define the optimal flowering period for locations in the south eastern Australia wheat belt.

Material and Methods

Site selection and crop simulation approach

Locations were selected to represent environments where wheat is grown in the southern cropping region of Australia, and based on the availability of accurate soil characterization from the APSoil database (Dalgliesh *et al.* 2009) and patched-point meteorological weather stations from the SILO database (Jeffery *et al.* 2001). The cropping systems model Agricultural Production Systems SIMulator (APSIM) version 7.6 was used to estimate the optimal flowering dates for wheat for locations in the south eastern cropping zone. APSIM is a model for wheat yield that has been extensively validated in numerous studies across southern Australia (Hochman *et al.* 2009), no further validation was undertaken here. The key APSIM modules used in the analysis were Wheat (crop growth and development) and Manager (specifying sowing rules). APSIM-Wheat calculates flowering date by accumulation of thermal time, calculated from the daily average of maximum and minimum air temperatures, and is adjusted by genetic and environmental factors (Ritchie and NeSmith 1991). The length of each phase between emergence and floral initiation is determined by thermal time, and cultivar- specific factors, photoperiod and vernalisation (Ritchie and NeSmith 1991).

Crop management set up

To determine the optimal flowering period for different sites in the southern cropping region of Australia, simulations were run using 51 years (1963- 2013) of climate data. All simulated crops were sown at 150 plants/m^2, at a depth of 30 mm, and a row spacing of 300 mm. The cultivar parameters selected represented spring wheat of a mid-fast maturity such as is predominantly grown in SE Australia (e.g. Scout, Spitfire, Trojan etc.). This was based on the APSIM base cultivar with vernalisation sensitivity of 1.5 and photoperiod sensitivity of 3.0. The APSIM-Manager was used to sow a crop on a fixed date at weekly intervals starting from the 1 April until the 15 July of each year. Nitrogen was applied as NO_3 with a fertilizer rule, which was maintained above 100 kg/ha in the top three layers of the soil throughout the season such that N did not limit yield. In the simulation, the crop received 15 mm of rainfall at sowing so that it would emerge shortly after it was sown. APSIM assumes crops are grown free of weeds and disease. A reduction for frost and heat damage based on air temperature obtained from patched point meteorological weather stations was applied as per Bell *et al.* (2015). Within APSIM, yield reductions were cumulative for multiple events that occurred during the sensitive stages of plant growth. The combination of management rules and frost and heat rules ensure that the optimal flowering period for each site was calculated solely by the drought pattern, temperature and radiation of an environment. The output used in the analysis was annual grain yield modified for frost and heat damage at different sowing dates and the corresponding flowering dates. The output was split by calculating the means of values between the 20th and 30th percentiles, 45th and 55th percentiles and 70th and 80th percentiles for each sowing date. The peaks of the percentile bands, representing the relationship between sowing date, flowering date and yield, were used to define the optimal flowering period for each location.

Results and Discussions

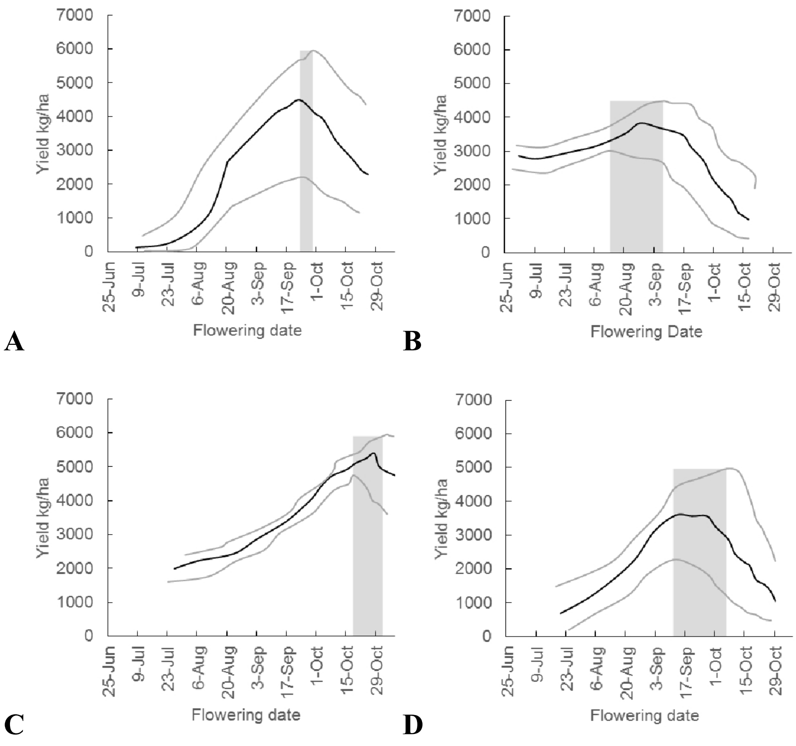

Figure 1: The optimal flowering period of wheat determined by APSIM simulation for A) Dubbo, NSW B) Minnipa, SA C) Inverleigh, VIC D) Urana, NSW. Grey lines represent potential yield for 20-30 and 70-80

percentile bands and the black line represents the 45-55 percentile band. Grey columns are the estimated optimal flowering period defined between peak of 20-30 and 70-80 percentile bands over the 51 year simulation (1963-2013).

Table 1: Summary of the predicted optimal flowering period for an early-mid spring wheat, simulated peak median of frost-heat adjusted yield and corresponding sowing date over 51 years (1963-2013), for 29 locations.

Location	Annual rainfall (mm)	Optimal flowering period		Length of flowering period (days)	Peak median value of frost-heat adjusted yield (kg/ha)	Coinciding sowing date to peak median
		Open	Close			
Waikerie (SA)	258	19-Aug	2-Sep	14	1679	29-Apr
Walpeup (VIC)	331	12-Sep	14-Sep	2	3707	29-Apr
Mathoura (NSW)	360	14-Sep	21-Sep	7	1855	29-Apr
Urana (NSW)	441	11-Sep	6-Oct	25	3583	29-Apr
Longerenong (VIC)	413	3-Sep	8-Oct	35	2906	6-May
Merriwagga (NSW)	356	5-Sep	12-Sep	7	2621	6-May
Nyngan (NSW)	441	17-Aug	28-Aug	11	2162	6-May
Hopetoun (VIC)	342	2-Sep	23-Sep	21	1762	6-May
Kerang (VIC)	356	1-Sep	26-Sep	25	3485	6-May
Lameroo (SA)	385	3-Sep	24-Sep	21	3443	6-May
Tottenham (NSW)	471	6-Sep	8-Sep	2	3322	6-May
Yarrawonga (VIC)	509	24-Sep	5-Oct	11	4068	6-May
Minnipa (SA)	343	13-Aug	7-Sep	25	3827	6-May
Lock (SA)	390	3-Sep	10-Sep	7	3506	6-May
Swan Hill (VIC)	344	17-Sep	1-Oct	14	4037	13-May
Charlton (VIC)	403	22-Sep	6-Oct	14	3265	13-May
Temora (NSW)	510	2-Oct	10-Oct	8	3366	13-May
Condobolin (NSW)	437	25-Sep	1-Oct	6	2149	13-May
Bogan Gate (NSW)	495	5- Sep	2-Oct	27	4309	13-May
Hart (SA)	458	24-Sep	29-Sep	5	4737	20-May
Cleve (SA)	400	28-Aug	16-Sep	19	3984	20-May
Dubbo (NSW)	591	23-Sep	29-Sep	6	4494	20-May
Trangie (NSW)	492	19-Sep	25-Sep	6	5256	20-May
Saddleworth (SA)	493	13-Sep	25-Sep	12	4130	27-May
Bordertown (SA)	479	2-Oct	6-Oct	4	4076	27-May
Cummins (SA)	428	14-Sep	27-Sep	13	4316	27-May
Cootamundra (NSW)	618	9-Oct	25-Oct	16	5087	27-May
Maitland (SA)	502	24-Sep	7-Oct	13	5288	3-Jun
Inverleigh (VIC)	553	18-Oct	1-Nov	14	5400	1-Jul

Chenu *et al.* (2013) illustrated the large variability in rainfall and temperature patterns that wheat crops experience in Australia. Correspondingly, our simulation study shows that the optimal flowering period differs for each environment in the Australian wheat belt. For each of the 29 locations (Table 1) analysed, we have identified a flowering period for an early-mid spring wheat that generated the highest yields over 51 seasons in each environment. The locations ranged from marginal rainfall and light textured soil types such as in Walpeup VIC and Waikerie SA, to high rainfall and heavy textured soil types such as in Dubbo NSW and Temora NSW. The highest peak median yield was in Inverleigh VIC, of 5400 kg/ha. The lowest yielding location was Waikerie, of 1635 kg/ha. High annual rainfall often reflects a cooler growing season in the southern grain-growing region. Higher rainfall and cool growing seasons can also translate into higher yield, and later optimal flowering periods (Table 1).

The optimal flowering period for a wheat of mid-fast maturity, across all locations ranged between 13 August and 1 November. However, the start and end dates varied greatly across the wheat belt with substantial variation in duration of these periods. The earliest flowering start date was at Minnipa SA. The latest flowering start date was Inverleigh. The degree of incline or decline of the percentile curves before or after the optimum for a location illustrates if an optimal flowering period is influenced by frost or drought in an environment. For example, Minnipa percentiles have a gentle incline showing that frost is less of a determinant on flowering period, but heat and water stress (drought) play a larger role as shown by the sharp decline after peak yield is reached (Figure 1B). In comparison, in locations Inverleigh and Dubbo, frost or sub-optimal radiation plays a large role in determining flowering period, as seen by the sharp incline of the percentiles (Figures 1A and 1C).

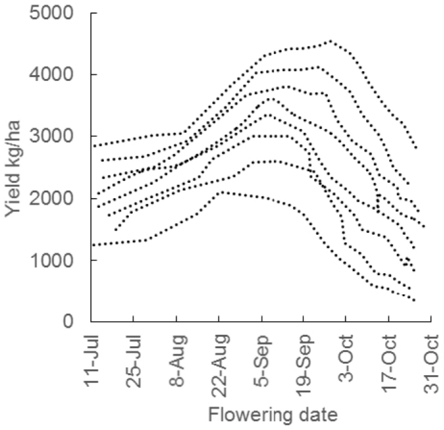

Figure 2: The flowering period for Lameroo, South Australia, split into percentile bands. Dotted lines represent the average of yield and flowering date values within each sowing date between the 10th-20th, 20th-30th, 30th-40th, 40th-50th, 50th-60th, 60th-70th, 70th-80th and 80th -90th percentile bands, for simulated 51 years (1963-2013).

When APSIM output for yield and flowering date is separated into percentile bands (Figure 2), it reveals how optimal flowering date can change from season to season. In a practical sense, given seasonal conditions are unknown at sowing, wheat producers should aim for the peak median flowering date and its corresponding sowing date as this is a reasonable estimate of an appropriate flowering date under the most likely conditions based on historic weather data (Table 1).

Conclusion

Changing rainfall patterns and increasingly variable weather during spring makes achieving timely flowering of wheat crops increasingly critical to yield and farm profitability (Kirkegaard and Hunt 2010). Now that optimal flowering periods have been identified, different G x M strategies can be evaluated in order to achieve these optimal flowering dates in different locations under current and future climates.

References

Bell LW, Lilley JM, Hunt JR, Kirkegaard JA (2015) Optimising grain yield and grazing potential of crops across Australia's high-rainfall zone: a simulation analysis. 1. Wheat. *Crop and Pasture Science* **66**(4), 332-348.

Cai W, Cowan T, Thatcher M (2012) Rainfall reductions over Southern Hemisphere semi-arid regions: the role of subtropical dry zone expansion.

Chenu K, Deihimfard R, Chapman SC (2013) Large-scale characterization of drought pattern: a continent-wide modelling approach applied to the Australian wheatbelt spatial and temporal trends. *New Phytologist* **198**(3), 801-820.

Dalgliesh NP, Foale MA, McCown RL (2009) Re-inventing model-based decision support with Australian dryland farmers. 2. Pragmatic provision of soil information for paddock-specific simulation and farmer decision making. *Crop & Pasture Science* **60**(11), 1031-1043.

Fuller MP, Fuller AM, Kaniouras S, Christophers J, Fredericks T (2007) The freezing characteristics of wheat at ear emergence. *European Journal of Agronomy* **26**(4), 435-441.

Gomez-Macpherson H, Richards RA (1995) Effect of sowing time on yield and agronomic characteristics of wheat in south-eastern australia. *Australian Journal of Agricultural Research* **46**(7), 1381-1399.

Hochman Z, Holzworth D, Hunt JR (2009) Potential to improve on-farm wheat yield and WUE in Australia. *Crop & Pasture Science* **60**(8), 708-716.

Jeffery S, Carter J, Moodie K, Beswick AR. (2001) Using spatial interpolation to construct a comprehensive archive of Australian climate data. . *Environmental Modelling & Software* **16**, 309-330.

Kirkegaard JA, Hunt JR (2010) Increasing productivity by matching farming system management and genotype in water-limited environments. *J Exp Bot* **61**(15), 4129-43.

Ritchie JT, NeSmith DS (1991) Temperature and Crop Development. In 'Modeling plant and soil systems Agronomy 31.' (Eds J Hanks and J. T. Ritchie.) pp. 5-29)

Tashiro T, Wardlaw IF (1990) The effect of high-temperature at different stages of ripening on grain set, grain weight and grain dimensions in the semi dwarf wheat banks. *Annals of Botany* **65**(1), 51-61.

Zheng BY, Chenu K, Dreccer MF, Chapman SC (2012) Breeding for the future: what are the potential impacts of future frost and heat events on sowing and flowering time requirements for Australian bread wheat (Triticum aestivium) varieties? *Global Change Biology* **18**(9), 2899-2914.