Effect of time of sowing on phenology of cereals grown in a temperate environment in south-eastern Australia

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Abstract

Research is currently being undertaken using crop simulation modelling to evaluate the potential for early sowing to achieve an increase in yield in the high rainfall zone of Australia. In Tasmania, this has required location specific validation of crop development for differing sowing times. A pot experiment was undertaken under ambient conditions in Hobart, Tasmania, where five wheat cultivars and a barley cultivar were sown monthly, from May to December, and crop development recorded weekly. Days after sowing and thermal time were measured to anthesis (GS61). Base temperatures for crop development in this environment were greater than 0˚C for time to anthesis but correction factors appear necessary to account for vernalisation and photoperiod responses in some cultivars. These phenological parameters will need to be incorporated into simulation model routines of crop growth and yield to test various phenological strategies of wheat and barley under local conditions. This information will be of use to crop physiologists undertaking comparative simulation modelling that includes temperate climates in both Australia and New Zealand.

Key Words

Photoperiod, simulation modelling, vernalisation, high rainfall zone

Introduction

The production environment of Tasmania, with its cool temperate climate and generally high (>600 mm) annual rainfall is distinct from much of mainland Australia. Research in this and other high rainfall zone (HRZ) regions in Australia aim to improve yield potential of grain crops. One potential strategy is to manipulate crop phenology through plant breeding to achieve an earlier sowing date while avoiding abiotic stresses around anthesis and during grain filling. Given a lack of adapted cereal cultivars, research efforts have focussed on the use of simulation approaches to evaluate the impact of early sowing dates on crop development and grain yield (Clough et al. 2008). However, simulation approaches are only as good as the underlying sub-models. Contemporary phenological models include basic thermal and photo-thermal behaviour (e.g. Angus et al. 1981), including vernalisation. Examples include the APSIM, CROPSYST and DSSAT suite of cropping systems models with differing stages of development included for various functional reasons. In the context of a changing climate a better understanding of crop phenology of existing winter cereals sown outside the typical sowing period is required to improve the analyses of the impacts and adaptation options available to maximise crop production and profitability in the HRZ.

Methods

Cultural details

Wheat cultivars included two spring (Bonnie Rock, early maturing; Sentinel, late maturing) and three winter (Mackellar, Revenue and Tennant) types, plus the barley cultivar, Gairdner. Seed were sown at a depth of 2 cm in 10 cm pots containing a commercial potting mix on the 17th day of each month in four replicates, commencing in April 2009. Seeds were not vernalised before sowing. Plants were grown in a shade house open to ambient air conditions with overhead irrigation in Hobart, Tasmania (42?50'S, 147?21'E). Air temperature was measured every hour above the plants using Tiny Tag data loggers. Daylength, that included civil twilight, was calculated for Hobart's longitude. Fertiliser and pesticides were applied as required. Phenological development of the main-stem was determined weekly using Zadoks decimal code for cereals.

The average days after sowing (DAS) to the start of anthesis (GS61) was interpolated from weekly data for each sowing date and cultivar combination. Daily cumulative thermal time and photoperiod were calculated for each sowing date. Regression analysis was used to determine the base temperature and photoperiod (i.e. intercept on the x-axis) of the six cereals.

Results and Discussion

Estimation of base temperatures and photoperiods

Increased temperature and photoperiod (arising from the different sowing times) decreased time to flowering. Spring-types Bonnie Rock, Gairdner and Sentinel had a linear relationship between development rate (1/DAS) and average temperature and photoperiod (Figure 1), whereas the relationship for winter-types Mackellar, Revenue and Tennant was quadratic. Previously, Angus et al. 1981 reported that the relationship between average temperature and photoperiod for cereals should be curvilinear with the rate of development showing diminishing returns at higher temperatures or longer photoperiods. This was the case for the winter-types, which had a base temperature and photoperiod of 12.1 ˚C and 9.1 hr (Table 2), with optima for crop development at around 17 ˚C and a 14 hrs (Figure 1). For the spring-types, however, this relationship was essentially linear, although there may be trend for the data to start to plateau above 20 ˚C (Figure 1a), which is consistent with published data (Angus et al. 1981; Gomez-Macpherson and Richards 1997). Otherwise, the average base temperatures and photoperiods for the spring types were 7.2 ˚C and 8.4 hr, respectively.

The base temperatures for crop development were higher than previously reported. For example, the base temperatures of 3.5 ˚C have been reported for spring wheat (Angus et al., 1981) and 6 ˚C for winter wheat (Penrose et al. 2003). Such differences have been noted elsewhere (Kirby et al. 1987) and are thought to be related to differences in cultivars and sites, or in this instance, pots. Nevertheless, base photoperiods shown here differed little between spring and winter types and are similar to published data (Angus et al. 1981; Penrose et al. 2003).

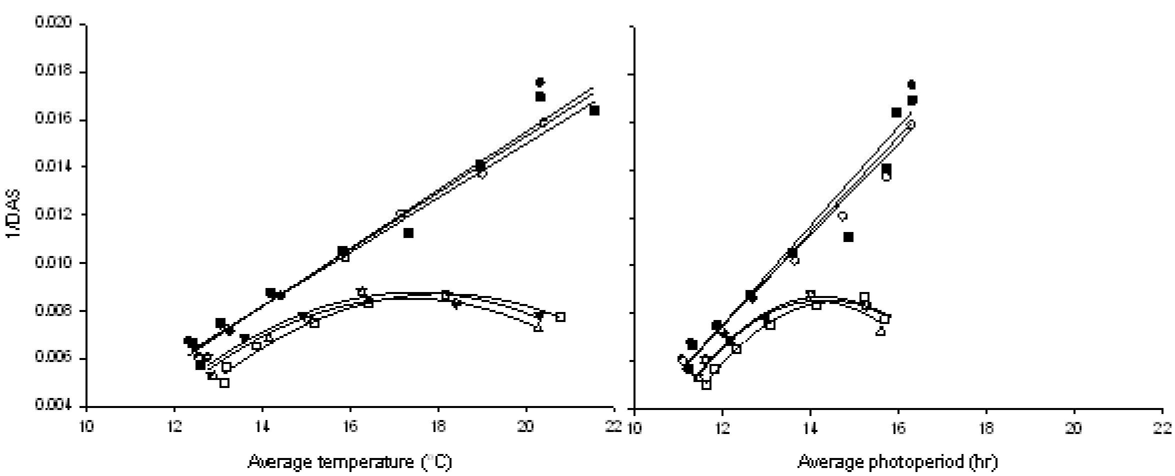

Figure 1. Relationship between development rate and A) average temperature; and B) average photoperiod, from sowing to anthesis for cereals sown between April and November in Hobart. Symbols: l) Bonnie Rock; m) Gairdner; n) Sentinel; ?)Tennant; q) Mackellar; and r) Revenue.

Table 1. Regression equations describing the relationship between development rate vs. temperature from sowing to anthesis for cereals sown between April to November in Hobart. Relationships are based on linear [1/DAS = α + βτ] or quadratic [1/DAS = $ατ^2$ + βτ + γ], where symbols α, β and γ are constants and τ (the x-intercept) is the base temperature. The SE is in parentheses.

Cultivar	α	β	γ	τ (˚C)	r^2
Bonnie Rock	$-8.90e^{-3}$ ($1.22e^{-3}$)	$1.22e^{-3}$ ($8.94e^{-5}$)	-	7.4	0.97
Gairdner	$-7.70e^{-3}$ ($6.25e^{-4}$)	$1.13e^{-3}$ ($3.76e^{-5}$)	-	7.0	0.97
Sentinel	$-8.90e^{-3}$ ($1.47e^{-3}$)	$1.22e^{-3}$ ($8.94e^{-4}$)	-	7.2	0.94
Mackellar	$-3.22e^{-2}$ ($6.98e^{-3}$)	$4.81e^{-3}$ ($8.64e^{-4}$)	$-1.37e^{-4}$ ($2.64e^{-5}$)	11.7	0.96
Revenue	$-3.49e^{-2}$ ($7.81e^{-3}$)	$5.01e^{-3}$ ($9.75e^{-4}$)	$-1.44e^{-4}$ ($2.97e^{-5}$)	11.7	0.91
Tennant	$-3.60e^{-3}$ ($4.64e^{-4}$)	$4.95e^{-3}$ ($5.67e^{-4}$)	$-1.37e^{-4}$ ($1.69e^{-4}$)	13.0	0.97

Table 2. Regression equations describing the relationship between development rate vs. photoperiod from sowing to at anthesis for cereals sown between April to November in Hobart. Relationships are based on linear [1/DAS = α + βλ] or quadratic [1/DAS = $αλ^2$ + βλ + γ], where symbols α, β and γ are constants and λ (the x-intercept) is the base photoperiod. The SE is in parentheses.

Cultivar	α	β	γ	λ (hr)	r^2
Bonnie Rock	$-1.73e^{-2}$ ($2.23e^{-3}$)	$2.07e^{-3}$ ($1.62e^{-4}$)	-	8.8	0.96
Gairdner	$-1.53e^{-2}$ ($1.73e^{-3}$)	$1.90e^{-3}$ ($1.25e^{-4}$)	-	8.1	0.97
Sentinel	$-1.63e^{-2}$ ($2.36e^{-3}$)	$1.98e^{-3}$ ($1.70e^{-4}$)	-	8.3	0.95
Mackellar	$-7.38e^{-2}$ ($7.64e^{-3}$)	$11.5e^{-3}$ ($1.14e^{-3}$)	$-4.05e^{-4}$ ($4.21e^{-5}$)	9.3	0.98
Revenue	$-7.83e^{-2}$ ($1.66e^{-2}$)	$1.22e^{-2}$ ($2.48e^{-3}$)	$-4.32e^{-4}$ ($9.19e^{-5}$)	8.5	0.93
Tennant	$-7.61e^{-2}$ ($1.14e^{-2}$)	$1.16e^{-2}$ ($1.69e^{-3}$)	$-3.99e^{-4}$ ($6.19e^{-5}$)	9.6	0.97

Crop simulation modelling of time of anthesis in Tasmania

Phenological data reported in this paper were used to parameterise cultivar-specific data for Mackellar wheat and Gardiner barley in APSIM, namely for vernalisation and photoperiod sensitivity, thermal time from grain filling to maturity and the phyllochron (Table 3). These changes reduced the RMSE from 8.5 to 5.4 days and therefore increased the confidence in the modelled outputs for the relationship between sowing and flowering date in Tasmania (Figure 2), which has been provided to farmers as a Fact Sheet (Riffkin et al. 2010). Base temperature in APSIM is presently set to 0 ˚C for wheat. It may be worthwhile to consider changing this value and underlying function in APSIM to be more representative of cereal development.

Table 3. Summary of the original and revised APSIM phenological parameters for wheat cv. Mackellar and barley cv. Gairdner.

	Vernalisation sensitivity	Photoperiod sensitivity	Thermal time (start grain fill to maturity) (^{o}Cd)	Phyllochron (^{o}Cd)
Original APSIM Mackellar wheat	3.9	4.30	580	90
Revised Mackellar wheat	3.2	3.50	750	110
Original APSIM Gairdner barley	1.0	3.50	580	40
Revised Gairdner barley	1.5	4.05	650	50

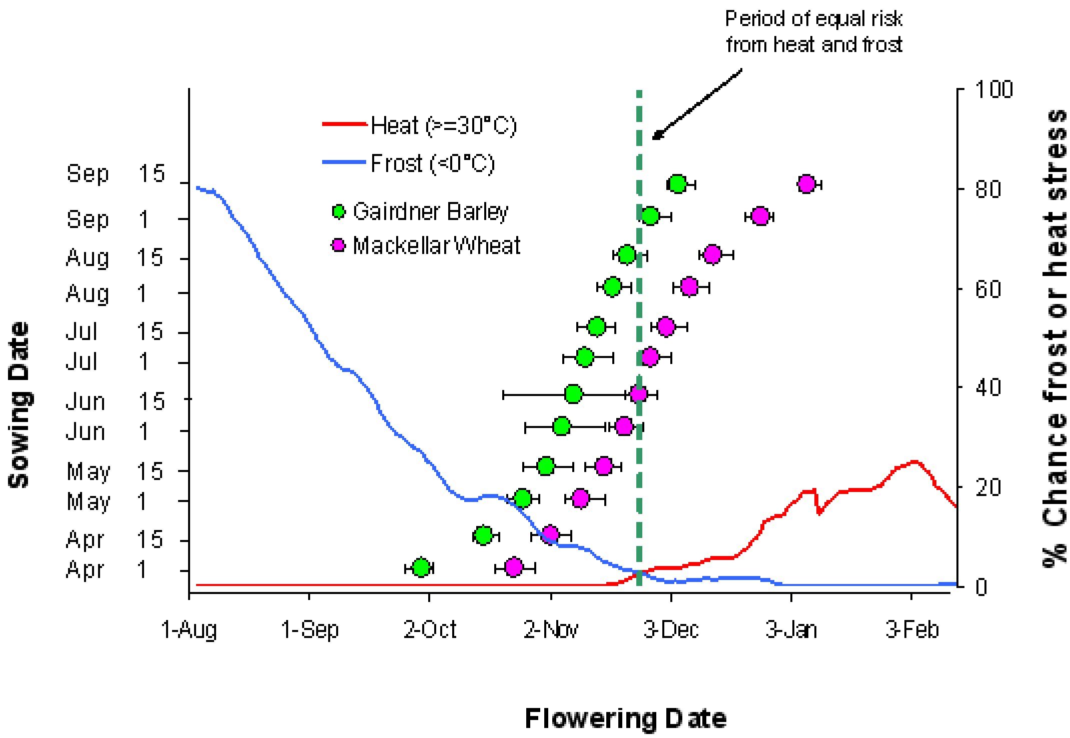

Figure 2. Anthesis date for Gairdner barley and Mackellar wheat sown on the 1st and 15th of each month at Perth, Tasmania. Simulations were run using 120 years of climate data. The circles represent median values and the bars show the range. Climatic risk at flowering is shown by the blue line (frost) and red line (heat) (Riffkin et al., 2010).

Adjustment of the APSIM parameters is a quick way to achieve satisfactory performance of simulated time to anthesis at any location but it does not help the larger problem of simulating this response across experimental sites or into new locations. Nor does it address the issue that base temperature, photoperiod and vernalisation interact to modulate crop development (Liu 2007). This problem is not unique to the APSIM suite of models but all similar approaches have struggled with phenological parameter determination (e.g. Boote et al. 2003).

Conclusion

Data reported here highlight a potential need for location-specific phenological data, particular in instances when crop simulation modelling is being applied to cropping situations beyond the typical sowing dates. In particularly, it appears that the base temperature for both spring and winter wheat produced in Tasmania may be relatively high. An implication is that crop simulation modelling of cereal production in Tasmania and other temperate climates may underestimate the duration of key phenological stages of development, indicating a need for better parameterisation in these phenological functions in the models. Furthermore, there is a need to pursue the ultimate goal of developing a universal phenology model to assist in crop modelling analyses across new locations in the context of a changing climate.

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