Simulated wheat phenology is improved when local temperature is used

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Abstract

Grain yield is affected by the timing of environmental stress. An accurate phenological model is important for simulations of yield and management procedures. Phenological models rely, in part or completely, on the accumulation of heat; thus if temperature is measured more accurately then the accuracy that phenology is simulated should be improved. Wheat (cv Gladuis and Axe) was grown in large well irrigated pots at six locations across a transect from Adelaide to Orroroo. Local temperature was monitored using Tinytag dataloggers at 1.2 m height. Phenology was assessed from sowing until early grain fill using destructive sampling and timelapse photography. The observed phenology was compared to phenology simulated by APSIM using either local temperature or regional (SILO) temperature. Local daily maximum and minimum temperature differed from that obtained from the Patched Point Data climate files from SILO. Simulated phenology more closely match observed phenology when local temperature was used compared to when regional temperature was used. This suggests temperature data input to the phenology model can contribute to errors in simulated phenology, and that locally measured temperature data performed more accurately than regional data. This then implies inputs of more accurate temperature data into the model would lead to improved accuracy of not only simulated phenology but also yield and would therefore allow greater understanding of the risks to production as a consequence of management practices or impacts of weather and climate.

Key words

Wheat, phenology, flowering, temperature

Introduction

Projected future climate for South Australia's cropping region indicate a warmer and potentially drier future. Projections from global circulation models (GCMs) and recent historical observations indicate daily minimum temperatures are increasing more than daily maximum temperatures, such that the diurnal temperature range has declined as the daily mean temperature has increased (e.g. Brazagna *et a*l. 2003). Such a climate is likely to affect the agronomy, yield and risk of exposure to adverse weather conditions at sensitive stages of crop development.

Simulation models such as APSIM (Agricultural production Systems Simulator) have been used to compare production under historic and projected future climates. A requirement of a robust agronomic simulation model is a well-developed phenological model, and provision of accurate climate data (most importantly temperature data for wheat phenology until the completion of flowering as other phenological drivers such as photoperiod can be calculated with high accuracy). Temperature data used in simulation modelling is usually obtained for a local meteorological station as observed data or interpolated data, but there will always be a difference between the meteorological station and the paddock. The first objective was to characterise the error in simulating wheat phenology when using temperature data obtained from a meteorological station compared to when using temperature measurements collected in the field where the wheat was grown.

An approach to evaluate the performance of the agronomic model under future warmer climates is to examine locations that differ in current climate, and use spatial analogues, or space as a proxy for time, to examine projected future climate change. By examining an already hot location an indication of what a cooler location may evolve into in a future warmer climate will be obtained. This approach has a long standing in ecological studies and more recently in agricultural systems. However, different locations rarely differ only in daily mean temperature and/or daily diurnal temperature range so that useful comparisons cannot always be made. This is especially the case in South Australia where sites closer to the coast have a much more narrow diurnal range than inland sites. It is therefore important that the simulation model can provide accurate simulations of phenology in these conditions. Phenological development of wheat is related to daily mean temperature, but the effect of daily diurnal temperature range on the phenological development of wheat has been questioned. For example Slafer and Rawson (1995) show phenology is independent of daily diurnal temperature range while Chauhan *et al*. (2005) provide contrasting evidence when using similar daily mean temperature (19°C in Slafer and Rawson, 1995, 18°C in Chauhan et al., 2005) and daily diurnal temperature range (0 to 14°C in Slafer and Rawson, 1995; and 0 to 12°C in Chauhan *et al*., 2005). An additional objective of this research was to establish if phenology of wheat is affected by the daily diurnal temperature range independently of mean temperature and if the vernalisation - photoperiod and thermal time model used by APSIM accurately predicted phenology of wheat under these conditions.

Methods

Phenology data can be collected by careful observation of farmer's paddocks or trial sites such as NVT (National Variety Trials). A challenge of studying phenology across a transect is variation in emergence due to differences in both soil type and climate (autumn rainfall and temperature) across sites.

A field experiment in 2011 involved sowing cv Axe and cv Gladius at Roseworthy (34.52°S, 138.68°E, 47m ASL) and Waite Institute (34.97°S, 138.97°E, 103m ASL) on 30th June. Plants were harvested periodically and assessed for phenological development using the Zadok scale. At each site a temperature datalogger (Tinytag plus2 TGP-4500) was positioned at 1.2m height. The dataloggers were placed in radiation shields consisting of eight circular plastic rings of which two were solid enclosures and the remaining six formed an internal cavity of 8 cm height and 11.5 cm diameter (831 cm^3). Temperature was logged hourly and this was used to determine daily maximum and minimum temperature.

In 2012 plants were grown at a central location (Waite Institute) before the pots were transferred to experimental sites. 120 pots (14 litre; height 26 cm, diameter between 22 to 28 cm) were each filled with 9 kg soil (hydrated blend of 1 sand: 0.9 unhydrated coco peat by volume). Pots were placed in a bird proof netted area on 4th June 2012 and watered to field capacity. On the 6th June 2012, eight seeds of either cv. Axe, a very early maturing variety or cv. Gladius, an early-mid maturing variety were sown into each of 60 pots at a depth of 3 cm. Pots were watered to field capacity immediately after sowing. Irrigation to field capacity was also provided 3, 7, 14 and 19 days after sowing. Pots were randomly allocated to each of six groups each containing 10 pots sown with each variety. Between the 25th and 26th June 2012 five randomly selected groups of the 20 pots (10 pots containing each variety) were moved to each of five additional experimental locations (Roseworthy, Port Germein 32.95°S, 138.00°E, 49m ASL, Orroroo 32.73°S, 138.62°E, 430m ASL, Lenswood lower valley 34.95°S, 138.82°E, 399m ASL, and Lenswood upper valley 34.93°S, 138.80°E, 471m ASL where we expect a smaller daily diurnal temperature range). The remaining 10 pots of each variety remained at Waite Institute. These locations were selected as the historic (1957-2011) long term averages cover a range of high and low daily mean temperature and high and low daily diurnal temperature range during the growing season (1 April to 31 October) (Table 1).

Table 1. Historic long term (1957-2011) averages of daily mean temperature (°C) and daily diurnal temperature range (°C) during the growing season (1 April to 31 October) for the experimental locations.

Location	Station	Elevation (m)	Daily mean temperature	Daily diurnal temperature range
Lenswood	23801	480	11.4	8.0
Orroroo	19032	428	11.7	12.3
Port Germein	19037	4	14.9	11.2
Roseworthy	23020	68	13.3	10.8
Waite	23031	115	13.3	8.4

The pots remained at the experimental locations until the experiment ended. During the experimental period the pots received regular irrigation to supplement rainfall. Sampling frequency was increased from every 3 weeks until early August then every 2 weeks up until mid-September and then weekly until flowering was completed. One plant was randomly selected for destructive sampling from 5 of the 10 pots at each location. Selection of pots for sampling was approximately random although some bias was introduced to ensure similar number of plants remained in each pot. The harvested plants were assessed for phenological development using the Zadok scale.

Because phenology could not be measured daily timelapse cameras (Wingscapes TimelapseCam8.0 http://www.wingscapes.com/timelapse-cameras/timelapsecam8) were used. Images were obtained hourly during daylight hours. To obtain images of sufficient resolution for analysis only a limited number of plants were monitored at each location.

Patched Point Data climate files were obtained from SILO (http://www.longpaddock.qld.gov.au/silo/) for locations close to each experimental location. This unadulterated climate file was designated Regional climate. A new climate file, designated Local climate, was generated for each of experimental location by substituting daily maximum and minimum temperatures collected from the dataloggers.

Wheat phenology was simulated using the APSIM V7.4 using the Regional climate and the Local climate as inputs. We used mean bias (MB), the root mean square error of prediction (RMSEP) and the Nash-Sutcliffe coefficient (also referred to as modelling efficiency) to compare the observed with simulated phenology.

Results

Temperature measured by dataloggers positioned at the experimental location differed to that obtained from SILO (Table 2). The RMSEP were about 1°C for mean daily temperature and usually slightly more than this for diurnal range in temperature. Distance and elevation differences between the SILO stations and the experimental locations contributed to the observed differences in temperature. Temperature measurements at Lenswood (upper valley and lower valley) showed the most dramatic effect of meso-site on meso-climate. These sites are 1km apart but with an elevation difference of 72m which resulted in changes to the diurnal range in temperature.

Table 2. Mean daily temperature (°C) and average diurnal range in temperature (°C) of Local climate measured using Tinytag dataloggers and Regional climate (obtained from SILO), and the root mean square error (RMSE) of these differences for period from date of sowing to just after completion of 'flowering' at each location. The 2012 experiments used potted plants while the 2011 experiments used field grown plants.

	Local climate		Regional climate		RMSE	
Location	Mean	Diurnal	Mean	Diurnal	Mean	Diurnal
2011 in field						
Roseworthy	13.1	13.6	12.2	12.9	1.1	1.2
Waite	13.6	9.1	12.8	9.3	1.2	1.3
2012 in pots						
Lenswood Lower valley	10.1	10.3	10.9	8.7	1.1	2.5
Lenswood Upper valley	10.4	8.9	10.9	8.7	0.8	1.3
Orroroo	11.3	13.6	10.4	12.2	1.4	2.2
Port Germein	12.9	11.9	11.8	11.6	1.6	1.7
Roseworthy	12.1	10.7	11.1	11.8	1.3	1.7
Waite	12.3	8.4	11.4	8.2	1.3	1.4

Figure 1 shows two examples of the improved match between observed and simulated phenology when paddock level data was used. There were instances when use of Regional climate more closely matched observed phenology (Table 3). Regional climate had similar RMSEP for both cultivars and when calculated for the period from sowing to flowering or only near flowering. Local climate was a better predictor of phenology than regional climate near flowering than of phenology from sowing to flowering (Table 3). This can be seen by the reduction in RMSEP (average of the eight occasions), the increase in the average difference in prediction, and the number of occasions when Local climate improved the simulation (i.e. RMSEP was reduced).

The mean bias showed similar results for RMSEP. The Nash-Sutcliffe coefficient was typically above 0.9 with increases of less than 0.05 when Local climate was used, suggesting that predictions of phenology were accurate when Regional climate was used with only small improvements when Local climate was used.

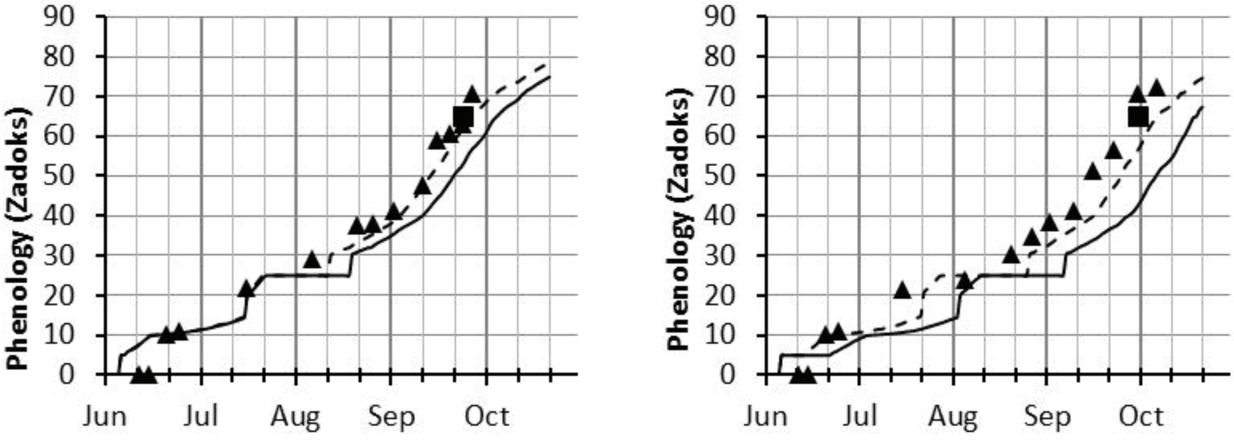

Figure 1. Phenology of wheat cv gladius grown at Waite (left) and Orroroo (right). The observed data from destructive sampling (triangle) and by a timelapse camera (square). Phenology simulated by APSIM using Regional (SILO) climate (solid line) and using Local (Tinytag) climate (dashed line).

Table 3. The average root mean square error of prediction (RMSEP) (in days) of phenology when Regional climate or Local climate were used in APSIM simulations for the eight comparisons (*i.e.* locations and years). The difference in RMSEP between the two climate inputs is shown along with the range in parenthesis and the number of occasions when use of Local climate improved (*i.e.* reduced) RMSEP (maximum of eight occasions).

	Regional climate	Local climate	Difference in RMSEP	Occasions improved
Sowing to Flowering				
Axe	8	7	1 (-2 to 3)	5
Gladius	9	7	2 (-1 to 5)	5
Flowering (Z51 to71)				
Axe	7	4	3 (-5 to 7)	6
Gladius	10	6	4 (-4 to 8)	7

There was no relationship between mean daily temperature and the diurnal range in temperature (r = 0.4), which allows their use as covariates in determining their influence on ability to predict phenology. The predictive accuracy of the APSIM phenology model increased (as measured by a declining RMSEP) with increasing mean daily temperature for phenology from sowing to flowering of cv Axe. Diurnal range in temperature, different measuring periods (i.e. near flowering), or any relationships with cv Gladius were significant. This implies the APSIM phenology model is not biased according to mean temperature or diurnal range in temperature, which in turn implies the phenology model can be used equally well to simulate phenology over a larger or smaller range in mean and diurnal temperatures. As these variables are most likely to change in future warming climates, this suggests spatial analogues which have temperature characteristics of the desired location in a future climate can be used with a high level of certainty to examine projected future climate change.

Conclusions

The simple thermal-photoperiod model of phenology used by APSIM is robust and shows no bias towards mean temperature or diurnal range in temperature making it useful for space-for-time approaches to explore impacts of future warming climates. However, the model generally predicts phenology more accurately when temperature measurements more truly reflect those at the experimental location.

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