Effect of temperature on the rate of early fruiting developmental processes of cotton

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ABSTRACT

Degree days are commonly used within the Australian cotton industry to estimate expected crop development during early season growth. This assumes that cotton's early potential development is largely a function of temperature. Information collected on crop development over a range of field and controlled environment studies shows that the function currently used to calculate degree days does not fully reflect the effect of very high or low temperatures on development. More complex functions are available which can better represent the effect of temperature on cotton development as seen in the experimental data. Refining this function will enable better predictions of cotton development in a greater range of environments and seasons; which is important for the geographically expanding cotton industry.

KEY WORDS

Base temperature, degree days, development, cotton; *Gossypium hirsutum*, squaring.

INTRODUCTION

Within the cotton industry, the rate of cotton development is widely described as a function of degree days. The degree day approach is based on the near linearity of the response of a rate to temperature over the range most likely to be encountered by a given species in the field. The function used for cotton in Australia, degree days with base 12?C, was developed by Constable and Shaw (4) based on experiments conducted by Constable (2). The function is used in protocols for nutrient monitoring and simulation modelling for on-farm decision support.

Constable's experiments concentrated mainly on the rate of early development at Narrabri, NSW, and therefore on the effect of low temperatures on development. However, Constable indicated that a plateau in the rate of development might have occurred at around 25^{O}C. More recently, Reddy *et al.* (8) working in a controlled environment reported a decline in development rate at temperatures above approximately 25^{O}C. Consistent with these findings, inflated thermal durations for the time to the appearance of the first square (flower bud) have been found for cotton sown under high temperatures in the field in Kununurra, WA (S. Yeates, CSIRO, unpublished data) and Narrabri, NSW (A.T. Wells, CSIRO, unpublished data).

An alternative approach to degree days is to describe the rate of a process, or the rate of progress toward a developmental stage, directly as a function of temperature (5). This allows non-linear functions to more accurately reflect the variation in rate over a wider range of temperatures. With the continued expansion of the cotton industry into more extreme environments, there is a need to modify the current temperature response to account for the non-linearity of the response at both high and low temperatures.

In the research presented here, our aim was to explore temperature response functions to describe (i) the duration of the period between sowing and the appearance of the first square and (ii) the initial rate of production of fruiting sites. Fruiting sites are the nodes on the branches at which a square is produced although the fruiting form may or may-not have been shed at the time of counting. Two approaches were used. Firstly, data were collated from four field experiments conducted under a range of temperature environments. Secondly, to extend the range of temperatures available and to avoid possible extraneous effects on development, a controlled environment study was conducted.

MATERIALS AND METHODS

Controlled environment study

A series of experiments was conducted in a temperature controlled glasshouse under natural light conditions. In the first experiment (sown October 7 1996) day/night temperatures varied sinusoidally between maxima and minima of: 12/20, 18/26, 21/29, 23/31 and 28/32?C. In the second experiment (sown October 23 1998), the temperature regimes were 15/23, 20/28, 24/32?C and in the third experiment (sown October 11 1999) 15/23, 20/28, 24/32, 26/34^{O}C. Nine plants of cultivar Siokra L22 were grown singularly in 9L pots spaced at nine plants m^{-2}. This density was similar to that used in commercial practice, although in the field cotton is grown on a 1m row spacing. Pots received a basal N-P-K slow release fertiliser and Hoagland's solution was applied twice weekly. Pots were trickle irrigated daily. Pest control requirements were small, however two to three insecticidal sprays were required to control spider mites and aphids, and predatory mites were released.

Observations were made on an individual plant basis. Plants were inspected three times per week. It was possible to estimate accurately the date of events occurring on intermediate days. The date of appearance of the first square was recorded together with the node number at which it occurred. The appearance of a square was defined as the date when the subtending leaf unfolded (3). The rate of development between sowing and the appearance of the first square was calculated as the inverse of the duration of the period between the two events. From first square until one week after the opening of the first flower, the date of appearance of each fruiting site was recorded for all positions on all sympodia.

Determining the rate of fruiting in cotton is complicated by two factors. Firstly, as the plant develops, the number of fruiting branches (exserted at each mainstem node) increases and thus the number of terminals producing fruiting sites are increased. This leads to a quadratic pattern of fruit production over time during early reproductive development (6). The rate was therefore determined from the slope of the regression of the square root of the cumulative number of fruiting sites against time in days. Secondly, the rate of fruiting declines in response to an increasing fruit load (6,7). To avoid this feedback, the rate was assessed only up to the time of the first open flower

Collated field data

In the field trials, the date of sowing and of first square production were obtained along with daily maximum and minimum temperatures for the location. From these data the duration of the period between the two events was calculated and the rate of development derived as the inverse of that duration. The experiments used are listed in Table 1. Squaring rate was calculated from experiments in which the production of fruiting sites on individual plants was monitored prior to the first flower opening.

Table 1. Field experiments used in collating data from a range of temperature regimes for estimating the rate of development to the appearance of the first square and the initial rate of site production.

Location	Date of Experiment	Source	Time of first square	Rate of site production
Narrabri	1972-74	Constable (2)	*	
Narrabri	1994-98	Bange and Milroy (1)	*	
Narrabri	1990-92	Wells (previously unpublished)		*
Kununurra	1995-97	Yeates (previously unpublished)	*	

RESULTS

The data from the field experiments indicate that the duration of the period from sowing to first square decreased with increasing temperature and thus the rate of development increased (Fig. 1). The linear regression through the data was significant ($P<0.001$, $R^2=0.62$, $n=91$) and a quadratic or exponential regression did not improve the fit significantly. In spite of this, the data from the experiments grown in Kununurra indicate little response of development rate to temperatures above approximately 25?C and the data of Constable (2) showed a relatively high response at lower temperatures. This suggests curvature in the overall response although no statistical improvement was found. The slope of the overall linear regression was less than that through the data of Constable (.0016 cf .0021) and the base temperature was lower (9.1^{O}C cf 11.0?C). Because of the long extrapolation required to the *x* axis, small variations in the data cause large shifts in the estimated base temperature.

In the controlled environment experiment, the rate of development to first square increased with temperature (Fig. 1), but in contrast to the field data, the response showed a significant curvature. The data was well described by an exponential rise to a maximum function:

Rate = -0.9134+0.9474(1-exp(-0.2135*Temp) ($R^2=0.90$; $P<0.001$).

At high temperatures, a maximum rate of 0.034 was approached and the rate fell to zero at an average temperature of around 15^{O}C. The curve fitted to the controlled environment data lay at the upper edge of the field data.

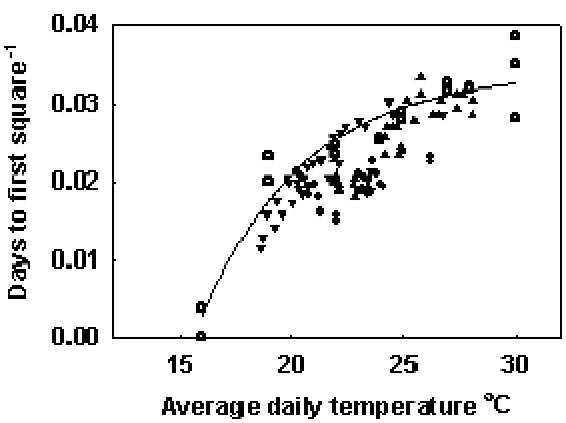

Figure. 1: Rate of development toward the production of first square in field trials (solid points) and controlled environment (open points), as a function of average temperature. Bange and Milroy (1), ●; Constable (2), ▼; Yeates, ▲. The curve represents the regression through the controlled environment data ○.

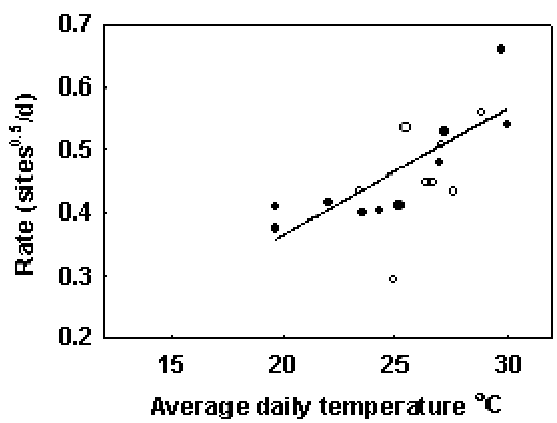

Figure. 2: Rate of production of squares in field trials of Wells (open symbols) and controlled environment (closed symbols) as a function of average temperature. The line is the linear regression through the controlled environment data.

In the controlled environment experiment, the shape of the response of fruiting rate to average temperature was unexpected (Fig. 2). The rate remained approximately constant at approximately 0.4 over the range of 19 to 26^{O}C and above this temperature the rate was found to increase. There was no clear indication of the response to temperature flattening at high temperatures. A linear regression through the data indicated an increasing rate with temperature and a base temperature around 2^{O}C. The field data was variable but lay reasonably well around the controlled environment data.

DISCUSSION

The data confirms the limitations of the degree day approach when used to describe early cotton development under a wide range of temperatures and also indicates that the responses are not necessarily transferable between processes.

The controlled environment data indicate that the rate of development to first square does not respond linearly to temperatures over the range used. This range of temperatures reflects the range of environments within which cotton is now grown in Australia. The results are consistent with those of Constable (2) who suggested a plateau in the response at about 25^{O}C. This shape of response explains the higher estimates of the thermal duration to first square found for cotton sown in high temperatures (A.T. Wells unpublished data and S. Yeates unpublished data). At higher temperatures the rate of development does not actually proceed faster but the estimated degree day accumulation each day is inflated by the linear extrapolation of the function.

Although the field data are highly variable, there is an indication of the same curvature as seen in the phytotron. The use of more refined analyses to account for the daily temperature conditions rather than using the average temperatures between two events might remove some of this noise. Other factors will also contribute to this variation, however. Cold shock early in crop growth or insect damage to the apical meristem can delay the appearance of the first square (4) and thus reduce the apparent rate of development. The fact that the curve fitted to the controlled environment data lies at the upper edge of the scatter of field data suggests that it represents a maximal rate of development with other factors reducing the estimated rate for individual field observations.

Similarly, drought stress and insect damage can alter the rate of fruit production (7,9). These effects would have increased the variability seen in the field data and rendered it more difficult to detect any curvature in the response to temperature. The shape of the phytotron response is unexpected and suggests the possibility of some sort of homeostasis in the fruiting rate over a range of temperatures. Additional data are currently being collected in a further phytotron experiment to confirm this response. Particular emphasis is being given to temperatures below 19^{O}C.

The responses derived from this research will be important for monitoring crop development in the field against expected progress and for application in simulation models. Research is continuing to examine other developmental processes and to assess differences between cultivars.

CONCLUSIONS

For controlled environment data, the response of the rate of development to first square in cotton was well described by an exponential rise to a maximum function. This appears to represent a potential rate that was approached by the field grown crops. The temperature response functions for development to first square and the initial rate of site production differed.

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