Do Degree Days accurately describe rates of cotton development?

S.P. Milroy[1] and M.P. Bange[1]
CSIRO Plant Industry, Cotton Research Unit, Narrabri, NSW
CRC for Sustainable Cotton Production

Summary

Degree days are commonly used by industry and researchers to estimate expected crop development. This assumes that cotton's potential development is largely a function of temperature. Controlled environment studies show that the function currently used to calculate Degree Days does not accurately reflect the effect of high temperatures on development. Preliminary analysis of the data shows that the inclusion of an optimum temperature in the degree day function in addition to the base temperature of 12°C can make more consistent predictions of cotton development. Improving this function will enable better predictions of cotton development in a greater range of environments and seasons.

Introduction

The rate of crop development is controlled by temperature and the relationship is often described using the convenient concept of degree days (DD). This is essentially the average temperature on a given day minus a base temperature of 12 °C; the temperature at which development ceases. The present function used in the Australian cotton industry to derive DD12 is:

$$\text{Degree Days } (^\circ\text{C d}) = \frac{(\text{Tmax} - 12) + (\text{Tmin} - 12)}{2}$$

where Tmax and Tmin are daily maximum and minimum temperatures respectively. When Tmin is less than 12 °C, (Tmin - 12) is set to 0 (Constable and Shaw, 1988). Degree days can be accumulated over time to predict developmental phases or rates of cotton growth (eg. time to first square). In the cotton industry DD12 are used for a variety of purposes, such as comparing the performance of crops within and across seasons; nitrogen management (nutriLOGIC); pest management (entomoLOGIC); and the cotton crop simulations models OZCOT and CERCOT.

Since the DD12 function was derived from experiments which focused on the effects of early season development of cotton (Constable, 1976). The effects of low temperatures were the primary concern. Hence, this function describes the development of cotton ceasing when minimum air temperature drops below 12 °C. This minimum temperature for development is often referred to as the base temperature.

Recent studies into the effects of environment on crop development have highlighted some deficiencies in using this function to predict development. Constable and Shaw (1988) estimate that approximately 505 DD12 are required from sowing to first square. However, the measured DD12 for this period varied considerably (from 510 to 695 DD12) in a series of field experiments when calculated using the standard function (Table 1). Similarly, recent investigations of dry season cotton production in the Ord (North West Australia) where high daily temperatures are experienced early in crop growth have shown that the time to first square varied between 440 and 600 DD12 (Yeates pers comm). Such variation devalues the usefulness of DD12 in predicting development. Especially when very hot conditions can be expected.

Table 1: Degree days (base 12) calculated for the time to first square for cultivars S324 and L22 (there was no significant difference between cultivars).

Season	Sowing date	Degree Days (°C d)
1995/1996	10 October 1995	696
	20 November 1995	608
	5 December 1995	644
1996/1997	11 October 1996	510
1997/1998	16 October 1997	622

While variation in development can be caused by a number of environmental influences (such as waterlogging, pest attack, disease, cold shock), there is evidence to suggest that some of this variation may be caused by high daily temperatures. The DD12 function assumes that the rate of a process continues to increase as temperatures increase. However, at high temperatures many biological processes don't respond as markedly to temperature as they do at moderate temperatures.

Studies conducted by Wells (1994) have shown a tendency for the rate of progress toward first square to increase only gradually when average daily air temperatures exceed the mid twenties (Figure 1). Constable (1976) in his studies in early cotton crop development also indicated that there appeared to be a plateau in the rate of crop development when temperatures exceeded 23° C.

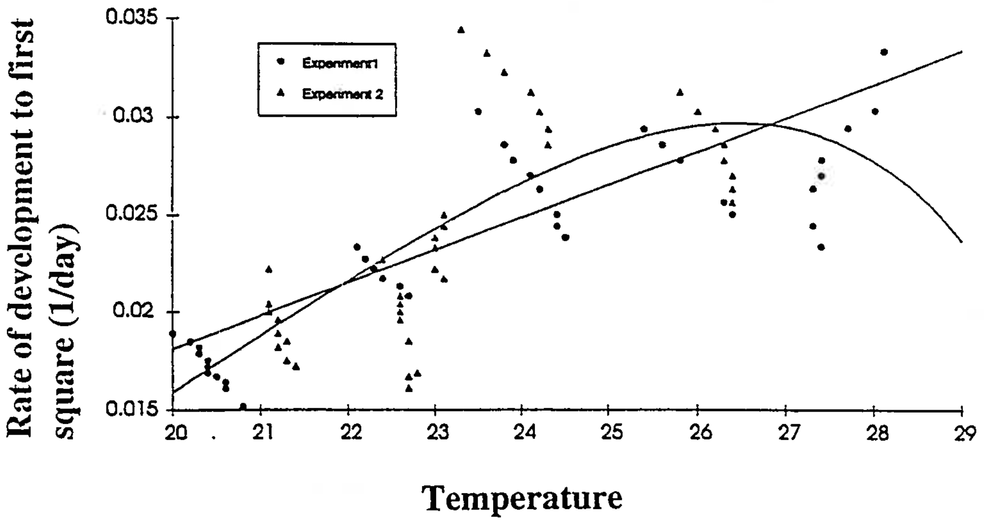

Figure 1. The rate of development to first square versus average daily air temperature (Wells, 1994).

Little work has been conducted to determine the effects of high temperature on the development of cotton. This paper outlines results from continuing studies to develop new functions that can be used to calculate DD that will account for both low and high temperature effects on cotton development.

Experimental Methods

To quantify the response of cotton development to temperature, specifically the time to first square and squaring rate, an experiment was conducted in a controlled temperature glasshouse under natural light. A short season (Siokra S324) and a long season (Siokra L22) cotton cultivar were sown on October 7 1996. Nine plants of each cultivar were grown under each of five maximum/minimum temperature regimes: 12/20, 18/26, 21/29, 23/31 28/32 °C (daily means of 16, 22, 25, 27 and 30 °C respectively).

Plants were observed three times per week and the date of appearance of the first square was recorded. The appearance of a square was defined as the date when the subtending leaf unfolded (Constable, 1991). From the appearance of the first square until one week after the opening of the first flower, the date of appearance of each square/site (sites analogous to new square production) was recorded for cultivar S324. This provides an estimate of the potential rate of squaring before the effects of increasing boll load could be expected to slow the rate of square production. Degree Days (DD12) were calculated using the function presented previously.

Results and Discussion

Rate of development calculated using the present cotton industry function (DD12) appeared to decrease as average daily temperature increased, in other words the apparent duration to first square in DD12 for both cultivars increased as average temperature increased (Figure 2). Degree Days to first square for cultivar S324 increased from 356 DD12 at 22 °C average daily temperature to 415 DD12 at 30 °C. This means that the DD12 calculation may not be adequately allowing for high temperatures. A better function would give similar estimates of developmental rate at all temperatures. A similar response was seen for cultivar L22, only the calculated DD12 were greater for each average temperature. No squares were produced in the 16 °C average daily temperature treatment in the experimental period.

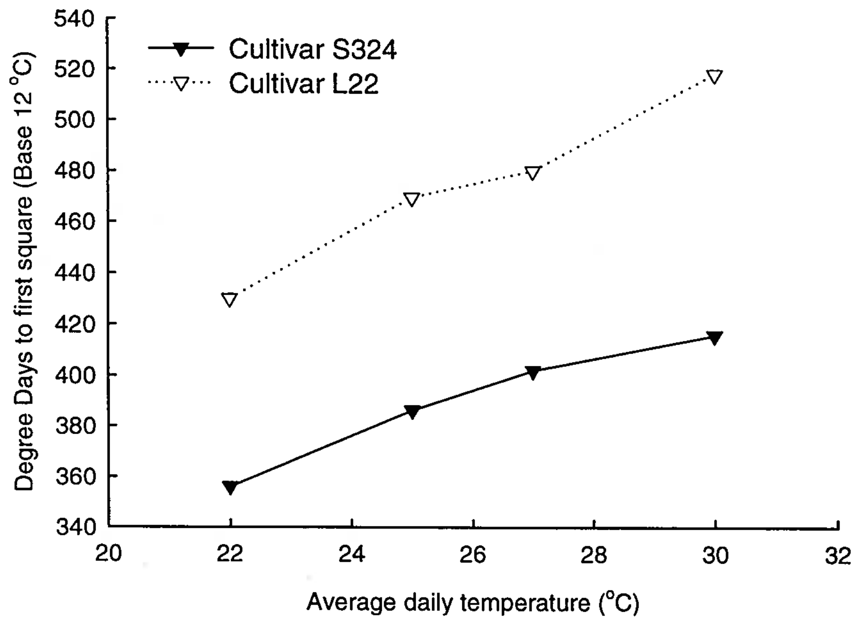

Figure 2. Degree Days (calculated using present industry function) to first square versus daily average temperature (°C) for cultivars S324 and L22.

After first square the rate of site production can be described by the squaring constant. The constant indicates the rate of square production as a function of temperature. It is a characteristic of the cultivar and should be constant across temperatures. Cultivars with a greater squaring constant have a higher rate of square production. The squaring constant for cultivar S324 calculated using the conventional DD12 function decreased as average temperatures increased (Figure 3). So again it would appear that the function did not adequately reflect the effects of high temperature.

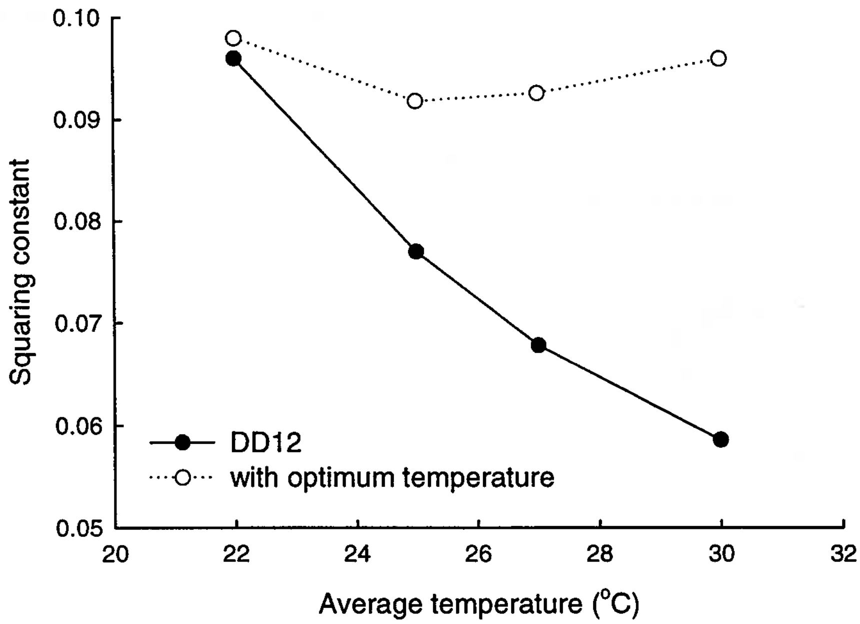

Figure 3. Squaring rate for cultivar S324 versus daily average air temperature (°C) calculated using the present cotton industry function (DD12) as well as a function that includes an optimum temperature.

These results demonstrate that the present function to calculate DD does not account for the effects of high daily temperatures. The addition of an optimum temperature in the DD function, in the same way as a base temperature of 12 °C, may allow for more consistent predictions of developmental rates. Figure 3 shows that a more reliable squaring constant can be estimated when an optimum temperature is included in the DD function. The functions are still being explored, particularly for the development to first square.

Improving the function that calculates DD by including an optimum temperature will enable better prediction of cotton development in a greater range of environments and seasons. Continuing work is concentrating on developing the response over a greater range of temperatures and for different developmental processes in cotton growth, as well allowing for differences between cultivars. The new temperature functions are also being tested using field grown crops.

References

Constable, G.A. (1991). Mapping the production and survival of fruit on field-grown cotton. *Agron. J.* **83**: 374-378.

Constable, G.A. (1976). Temperature effects on early field development of cotton. *Aust. J. Exp. Agric. Anim. Husb.* **16**: 905-910.

Constable, G.A. and Shaw, A.J. (1988). Temperature requirements of cotton. Agfact P5.3.5. New South Wales Agriculture and Fisheries.

Wells, A.T. (1994) Estimating parameters for the OZCOT cotton crop model for a range of cotton cultivars by field measurement. Master of Engineering Thesis, University of Southern Queensland, Toowoomba.

Acknowledgements

This research is funded by the Cotton Research and Development Corporation. We wish to thank Jennifer Price and Chris Stonehouse for conducting the glasshouse trial.