Assessment of individual fruit maturation (boll) period in modern cotton systems

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Abstract

Important knowledge used in cotton management is to understand the period from when the last fruit has flowered (defined as the last effective flower (LEF) or 'cutout') to when it is mature ready for harvest (last effective boll). The timing of cutout has important implications for both yield and quality. In estimating cutout date across regions historical climate data is used to calculate the timing of the LEF from a response of boll period to temperature and this is used to back-calculate this period in time from a pre-determined end of season harvest date. The current boll period temperature response used within the industry was developed from cultivars used in the 1980's and there are concerns that it may no longer be relevant today. Using boll period collected in recent years the current industry response and a more recent response from tropical Australia were tested for their accuracy by comparing measured versus observed data. The results showed that the current industry response was reasonable ($r^2 = 0.64$), while the tropical response captured the temperature effects but had an average bias of being 13 d later. New functions improved predictability especially when the nodal position was included ($r^2 = 0.73$). However, all functions had a slight and similar bias towards underestimating the boll period at higher nodal positions which are more relevant to the period of LEF. The results suggested that substitution of a new function into decision tools to estimate LEF seems unwarranted, without further data collection.

Keywords

Gossypium hirsutum, temperature, nodes, decision support.

Introduction

Cotton *(Gossypium hirsutum* L.) is a perennial grown as an annual in Australian cotton systems. Unlike annual cultivated species where the length reproductive period from flowering to maturity is determined by temperature and/or daylength; the length of reproductive period in cotton is determined by the availability of resources for new growth of fruit (Hearn 1994). The time when available resources being generated for assimilation equals the demand by the fruit is defined as 'cutout' and is when no new fruit is being produced. The timing of cutout is important in cotton systems as it affects the maturity of the crop ready for harvest, and non-optimal timing for a region will reduce both yield and quality. Too early will reduce yield as it shortens the period of reproductive growth, while being too late affects quality as maturing fruit can be immature at harvest time lowering quality. Delays in maturity can also lead to crops being rain affected at harvest (Bange et al. 2009).

Important knowledge used across the Australian industry to assist in timing cutout is to understand the period from when the last fruit has flowered (defined as the last effective flower (LEF) to when it is mature ready for harvest. This fruit maturation period is for an individual fruit and is commonly referred to as a boll period. Across regions historical climate data is used to estimate the timing of cutout using a boll period of this LEF calculated from a temperature response back calculated in time from either a pre-determined harvest date, or the date of occurrence of first frost for the winter period (≤ 2ºC minimum) (www.cottassist.com.au).

The temperature response used to generate this boll period of the LEF was developed by Constable (1991) from experiments conducted from 1983 to 1986 on cultivars no longer used within the industry today. As the Australian cotton industry expands into regions with shorter season lengths the need for confidence in the boll period of the LEF becomes more necessary. This study aims to assess the function of Constable (1991) and a more recent one of Yeates et al. (2010) in estimating boll periods of a cultivar representing those used within industry today. Using the data collected in this study a new function of boll period related to temperature was developed.

Methods

A fully irrigated field experiment that had two planting times (5 Oct and 12 Nov 2012) was undertaken at the Australian Cotton Research Institute, Narrabri, NSW, Australia. The Bollgard II® cultivar Sicot 71BRF (CSIRO) was grown according to current production methods. To assess the effect of temperature on individual fruit maturation (boll) periods, white flowers (one day old) were tagged across all nodes and positions each day from the time of appearance of the first flower until the crops ceased producing flowers (cutout). At the end of the season each individual fruit (boll) that remained on the plant was monitored to identify the time when it matured. Fruit were mature (open bolls) once two sutures had split. Prior to harvest the dates of flowering and maturity of each individual fruit was recorded as well as its nodal position (counting cotyledonary node as zero). In each planting there were three replications and in each plot 15 plants were monitored. The experiment used a randomised complete block design with each plot 10 m long by 8 m (4 rows) wide. Air temperature surrounding the crop was recorded at a fully serviced weather station located within 2 km of the experiment. A total of 806 bolls were measured in this study.

The first objective of this study was to assess and compare the performance of existing functions on predicting boll periods for this experiment using functions developed by Constable (1991) (Equations 1 and 2), and more recently those developed by Yeates et al. (2010) for tropical Australia (Equation 3). The functions are outlined below:

$$\ln(BP) = 5.39 - 0.0512 \times T_{mean} \qquad \text{Equation 1}$$

$$\ln(BP) = 5.52 - 0.0538 \times T_{mean} - 0.0066 \times Node \qquad \text{Equation 2}$$

$$BP = 1/(0.00122 \times T_{mean} - 0.0165) \qquad \text{Equation 3}$$

Where BP is boll period in days; T_{mean} is the mean temperature of the period between flowering and a mature fruit in centigrade; and Node is the mainstem node number.

The second objective of this study was to develop a function that related boll period (days) to average temperature during the boll period. The form of the function chosen was that used by Constable (1991; Equation 1) that related ln(BP) to average temperature using a linear response. As in Constable (1991) a second response was also developed including the nodal position of the fruit (Equation 2). Linear and stepwise regression analyses were performed using GENSTAT V16. All data was combined across all planting times as there was no significant effect of planting time when added as a factor in the regression analyses.

To assess relationship performance in predicting boll period, predicted boll periods were plotted against the measured (observed) bolls periods. Accuracy of the predictions was quantified using the root mean square deviation (RMSD) between a number (n) of predicted (P) and observed (O) paired results (Steele and Torrie 1987):

$$RMSD = [(O - P)^2/n]^{0.5}$$

RMSD represents a mean weighted difference between predicted and observed data. The linear regression of predicted versus observed results was used to quantify bias, and the coefficient of determination (r^2) of this regression described the degree to which the data clustered around a straight line.

Results and Discussion

Boll periods in this study experienced average temperatures ranging from 26.9 to 22.4 ºC (Figure 1) resulting in periods ranging from 47 to 77 d in length. When Equation 1 (the current function used within the Australian industry to predict boll period (Constable 1991)) was applied to the observed data there was reasonably good prediction of boll period (r^2 = 0.66; RMSD = 3.18 d). When node position was included in the function (Equation 2) there was significant improvement in the prediction of boll period (r^2 = 0.72; RMSD = 2.86 d). The lines of best fit in both these comparison (Figure 2a and b) showed positive intercepts and slopes less than 1.0 indicating a bias to underestimate boll periods when they were longer. Overall, the predictions were reasonable given the significant changes in cultivars used in the industry today compared to that used by Constable (1991). With the data used here in this study there appears to be no substantial effect of plant breeding on boll period since the 1980’s.

Using the more recent function (Equation 3) published by Yeates et al. (2010) resulted in a much poorer prediction in boll period (r^2 = 0.62; RMSD = 13.86 d) (Figure 2c). Across the whole dataset boll period was consistently over predicted by an average of 13 d up to maximum of 30 d. In investigating the approach of Yeates et al. (2010) in more detail, it was most likely the methodology used was the reason for differences and introducing the bias. In their study it appears that boll period of each individual boll was not used in the analysis but rather a median boll period for a cohort of bolls.

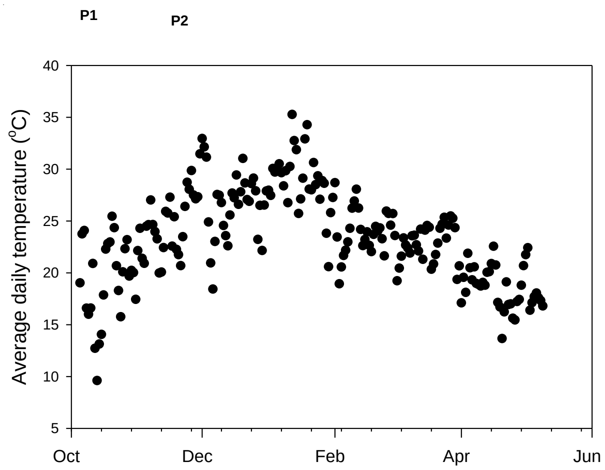

Figure 1. Average daily temperature conditions experienced during the experiment. The arrows designate the planting time. (P1 – first planting, P2 –second planting).

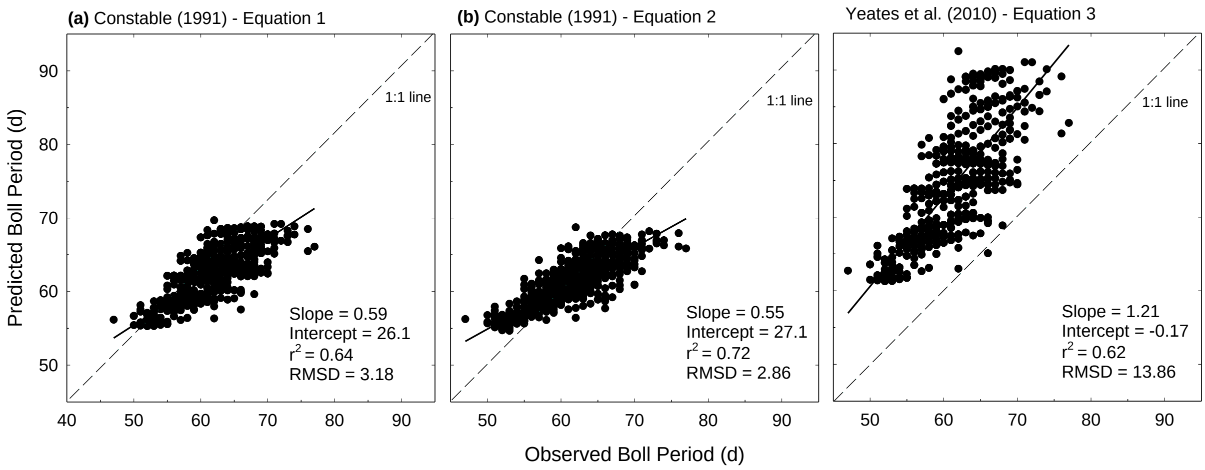

Figure 2. Predicted boll period using Equations 1 to 3 versus observed boll period measured in this study. Solid line is the line of best fit. Dotted line is the 1:1 line.

As expected, a fit of the same functions used by Constable (1991) to the observed data used in this study improved prediction of boll period (r^2 = 0.64; RMSD = 3.04 d) (Equation 4; Figure 3a). This function was still not as accurate in predicting boll period when nodal position was accounted for (r^2 = 0.73; RMSD = 2.62 d) (Equation 5; Figure 3b). A larger magnitude in improvement was attained compared with Constable (1991) where r^2 was improved from 0.55 to 0.61 and this is most likely attributed to the significant node by temperature interaction which was included and not reported by Constable (1991).

$$\ln(BP) = 5.55 - 0.0583 \times T_{mean} \qquad \text{Equation 4.}$$

$$\ln(BP) = 6.88 - 0.0107 \times T_{mean} - 0.0867 \times Node + 0.0032 \times Node.T_{mean} \qquad \text{Equation 5.}$$

Similar biases for slopes and intercepts were found for the fitted functions generated in this study (Figure 3) as for those predictions using the functions by Constable (1991) (Figure 2a and b). This has important implications for estimates of boll periods at the end of the cotton season where they are used to estimate the time of last effective boll for harvest preparation. In general boll periods at the end of the season are longer due to cooler temperatures, although the higher nodes shorten the period. However, the effect of temperature on boll period is far greater than that of node position (Equations 1 - 5). To establish what impact these biases had on estimates of boll periods of these higher nodes which occur at the end of the season, comparisons of the RMSD were made on only observed data ≥18 nodes using the current industry function (Equation 1) and the most accurate function (Equation 5). The difference of the RMSD for this comparison and limited dataset (n = 35) was small. RMSD for Equation 1 was 3.66 d compared to 3.42 d for Equation 5 the new function based on this dataset.

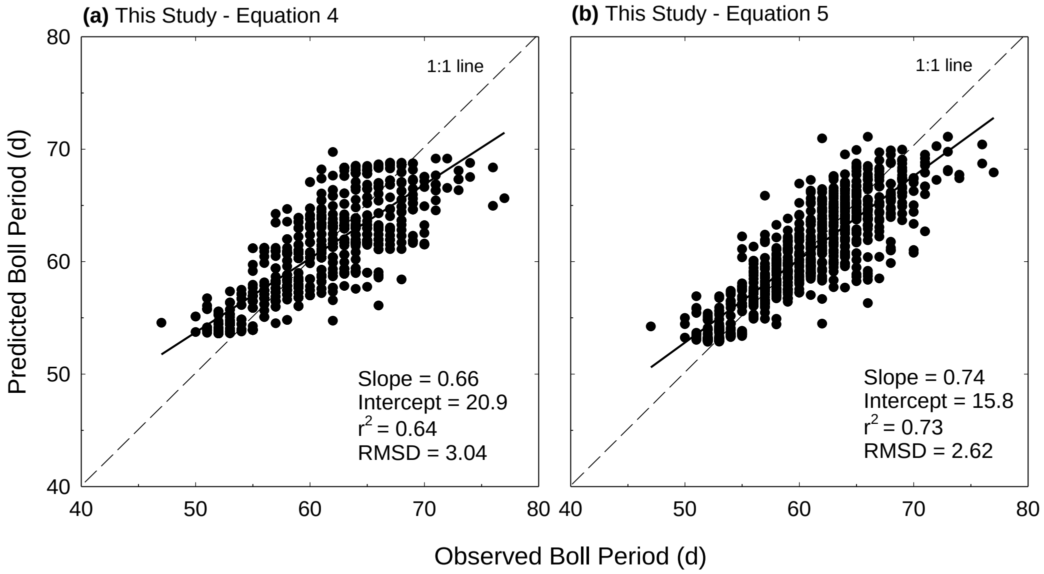

Figure 3. Predicted boll period using Equations 4 to 5 (generated from data measured in this study) versus observed boll period measured in this study. Solid line is the line of best fit. Dotted line is the 1:1 line.

Conclusions

While the dataset is limited for higher nodes in this study, there was not strong evidence to suggest that the current function used by the industry (Equation 1; Constable 1991) was substantially different to generate great concern relating to potential inaccuracies. Substitution of a new function into decision support tools estimating boll period (last effective flower to last effective boll at harvest) seems unwarranted without further data collection, and analysis of boll period at higher nodes especially at cooler temperatures.

Acknowledgments

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