



## Annual, Progress and Final Reports

# REPORTS

### *Part 1 - Summary Details*

*Please use your TAB key to complete Parts 1 & 2.*

**CRDC Project Number:** **CSP140C**

**Annual Report:**  Due 30-September

**Progress Report:**  Due 31-January

**Final Report:**  Due 30-September 2004

(or within 3 months of completion of project)

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**Project Title:** The Impact of Temperature Extremes on Cotton  
Performance

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**Project Commencement Date:** 01/07/2001 **Project Completion Date:** 30/06/2004

**Research Program:** 4 Farming Systems

### *Part 2 – Contact Details*

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**Administrator:** Ms Jo Cain (Administration Manager)

**Organisation:** CSIRO Plant Industry

**Postal Address:** CSIRO Cotton Research Unit Locked Bag 59 Narrabri

**Ph:** 02 67991500 **Fax:** 02 67 931186 **E-mail:** Jo.Cain@csiro.au

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**Principal Researcher:** Dr Michael Bange (Principal Research Scientist)

**Organisation:** CSIRO Plant Industry

**Postal Address:** CSIRO Cotton Research Unit Locked Bag 59 Narrabri

**Ph:** 02 67991500 **Fax:** 02 67 931186 **E-mail:** Michael.Bange@csiro.au

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**Supervisor:** Dr Greg Constable (Cotton Research Unit Program Leader)

**Organisation:** CSIRO Plant Industry

**Postal Address:** CSIRO Cotton Research Unit Locked Bag 59 Narrabri

**Ph:** 02 67991500 **Fax:** 02 67 931186 **E-mail:** Greg.Constable@csiro.au

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**Other (please specify)** Ms Jane Caton (Technical Officer)

**Organisation:** CSIRO Plant Industry

**Postal Address:** CSIRO Cotton Research Unit Locked Bag 59 Narrabri

**Ph:** 02 67991500 **Fax:** 02 67 931186 **E-mail:** Jane.Caton@csiro.au

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**Signature of Research Provider Representative:** \_\_\_\_\_

## ***Final Report 'The Impact of Temperature Extremes on Cotton Performance'***

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### **1. Project Background**

Temperature plays a critical and fundamental role in the growth and development of cotton. Cool starts to seasons in southern regions have again highlighted of the problems of cold shock and slow crop development rates at low temperature. Low temperatures after sowing increase the time to emergence and reduce seedling vigour often leading to poor establishment, poor early growth and increased risk of seedling diseases. The timing of crop maturity, yield and fibre quality may also be affected. There has also been evidence to suggest that high crop temperatures may negatively impact on crop development.

Much of our current understanding of the impacts of cold temperature on cotton crop growth and development is based on experimental work undertaken by Dr Greg Constable in the early 70's with cultivars quite different than those used commercially today. It was from these experiments that, the base temperature (12°C) used in estimating crop development was derived, and the definition of a cold shock (<11°C) was formulated. Dr Constable acknowledged even at the time there was considerable extrapolation of the information to derive these values the lowest mean daily temperature tested was 18°C. His work on cooler temperatures also focussed on early season crop development, as was the need at the time in the Namoi Valley. No specific experimentation on the effects of low temperature has occurred in Australia since then. In addition there has been no definitive attempt to better understand and quantify the effects of temperature extremes on cotton growth and development at other stages and subsequent impact on crop yield (especially with current varieties and agronomic practices, particularly early season insect protection).

Recent research has highlighted problems with the use of day degree function (DD12) to predict crop growth. Constable estimated that approximately 505 DD12 were required for development from sowing to first square. However, in recent studies the measured DD12 for this period varied considerably (from 510 to 695 DD12) across experiments even with the same cultivar. 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 duration from sowing to first square varied between 440 and 600 DD12 (S.Yeates pers comm). Such variation devalues the usefulness of DD12 in predicting development and highlights deficiencies with the current function. In particular recent research by Drs Milroy and Bange suggests that part of the problem with the DD12 function is that it does not account for an optimum temperature beyond which crop development does not increase and adverse affects may occur.

These issues highlight our lack of quantitative description of the impacts of extreme temperatures on crop growth and development. This has also impeded our capacity to explore management opportunities to improve crop yield and profitability (both from a genetic and agronomic perspective) under such temperature extremes. These factors take on greater importance with the expansion of the industry into regions to the north and to the south which has increased the range and duration of hot and cold temperature to which the crop may be exposed. It has posed additional and different types of questions about the effects of temperature on crop growth, for example, the effects of cold night temperatures followed with hot daytime temperatures (as in the Ord at different crop growth stages).

This project will aim to cover three main research components:

- 1.) Develop refined analysis of the impact of temperature extremes on cotton performance.
- 2.) To use information to develop a more functional decision support tools which will enable research and management to be done more accurately in scenarios where extremes of temperature are likely.
- 3.) Utilise this understanding to assist with the development of field management packages of sowing strategies with adapted genotypes,

## **2. Project Methodology**

This project will have a strong focus on field experiments in a range of climates and where necessary complementary studies under controlled conditions will also be conducted. Sowing date experiments in locations such as Kununurra, Emerald, Bourke, Narrabri, Breeza and Hillston will create very diverse temperature combinations. An important element of this project will be to work with other researchers to collect information from trials spread through the cotton growing regions, including those in northern Australian.

Genotypes used in this study will include current commercial cultivars as well as genotypes known for their potential adaptation to extreme environments. Some screening of genotypes for cold and heat tolerance will occur in this project, but breeding new cultivars will be part of the CSIRO breeding program. New cultivars take at least eight years to develop. Measurements will include accurate recording crop developmental stages, daily climate variables, crop growth rates, fruit development, crop maturity, yield and quality. This will allow us to:

- i) Derive field based temperature response functions for a range of key developmental processes including: time to 1st square, square production rate, and fruit development.
- ii) To directly measure the cold shock threshold for the first time and its impact.
- iii) Determine whether the importance of cold shock is the same throughout development.
- iv) Quantify the losses incurred by frost throughout crop development.
- v) Quantify the losses due to night respiration under high temperature conditions.
- vi) Quantify the genetic variation within existing commercial cultivars and explore potential genotypes for better adaptation to temperature.

## **3. Project Objectives**

### **Year 1**

- 1) Complete day degree function for a single cultivar.
- 2) Compile field data to test evaluate day degree function for different cultivars.
- 3) Conduct sowing time experiments with different cultivars in a number of regions to collect data.
- 4) Begin initial investigations into cold shock impacts on crop growth and development.

## **Year 2**

- 1) Conduct experiments exploring the impacts of cold shock on crop growth and development' exploring different cold temperatures, duration and number of cold shocks.
- 2) Conduct sowing time experiments with different cultivars in a number of regions to collect data.
- 3) Begin initial experiments on the impact of frost on crop growth and development.

## **Year 3**

- 1) Conduct more detailed experiments on the impact of frost on crop growth and development.
- 2) Attempt to quantify the losses due to night respiration under high temperature conditions.
- 3) Conduct sowing time experiments with different cultivars in a number of regions to collect data.
- 4) Prepare a final report

## Summary of Project Outcomes

A brief outline of the major results and outcomes from this project is given below. Research outcomes will be discussed under relevant broad objective headings. Where research has been published the appropriate reference in the list of publications is given.

### Crop Development with Extreme Temperatures

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. Refining these functions will enable better predictions of cotton development in a greater range of environments and seasons; which is important for the geographically expanding cotton industry.

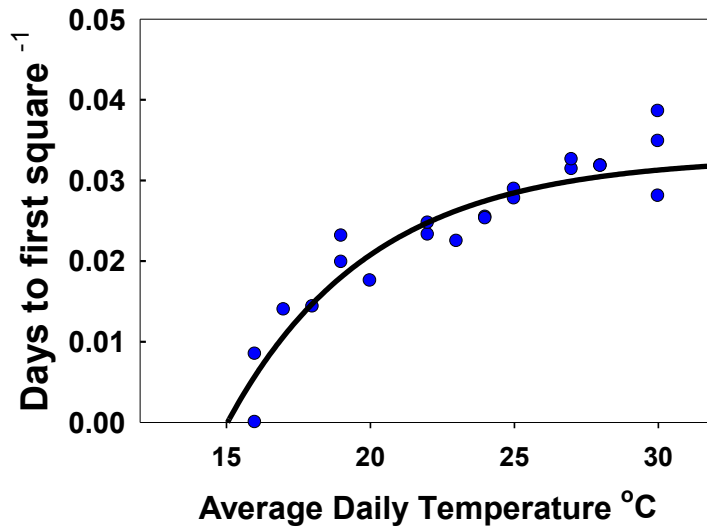
Results of investigations of cotton crop development for each of the developmental stage are discussed individually below. In some cases the responses measured in controlled environment studies are compared with field measurements. We will then use these function to improve estimates of crop development in OZCOT and other decision support tools (eg. SILO day degree calculator).

This work has been published in Australian agronomy proceedings (Bange and Milroy 2001) and information presented in Bange and Milroy (2002) in Australian cotton conference proceedings.

### *Time of first square*

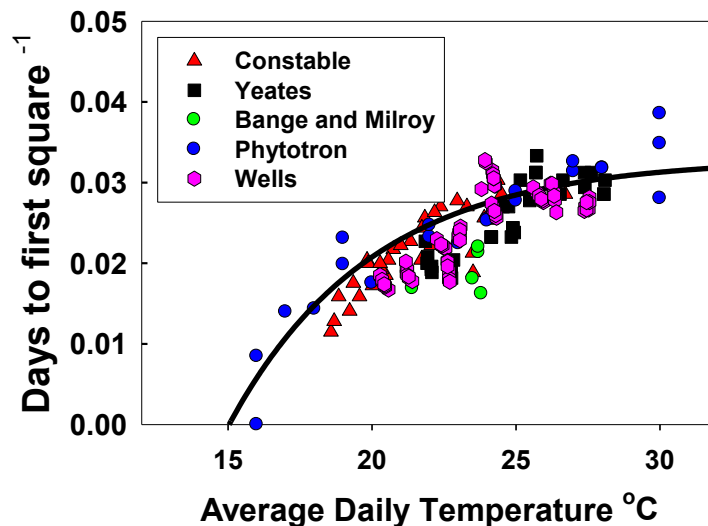
Data collated from a number of experiments conducted in the Phytotron (controlled environment glasshouse) in Canberra have been used to develop a more robust function that describes the rate of crop development to first square. Measurements of crop development were taken from plants grown in average daily temperatures ranging from 16 to 32 degrees Celsius. The function is:

Rate of progress to first square ( $d^{-1}$ ) =  $-0.30 \times (1 - \exp(-0.20 \times (\text{average temperature} - 15.03)))$  ( $R^2 = 0.83$ )



**Figure 1:** Rate of crop development to first square versus average daily temperature (Cultivars L22 and S324).

This function more accurately accounts for the effects of high temperatures on crop development and gives a better estimate of the base temperature where crop development ceases (little development measured below approximately 15 °C) (Figure 1). Note that this function has only been derived for the cotton development period from sowing to first square.



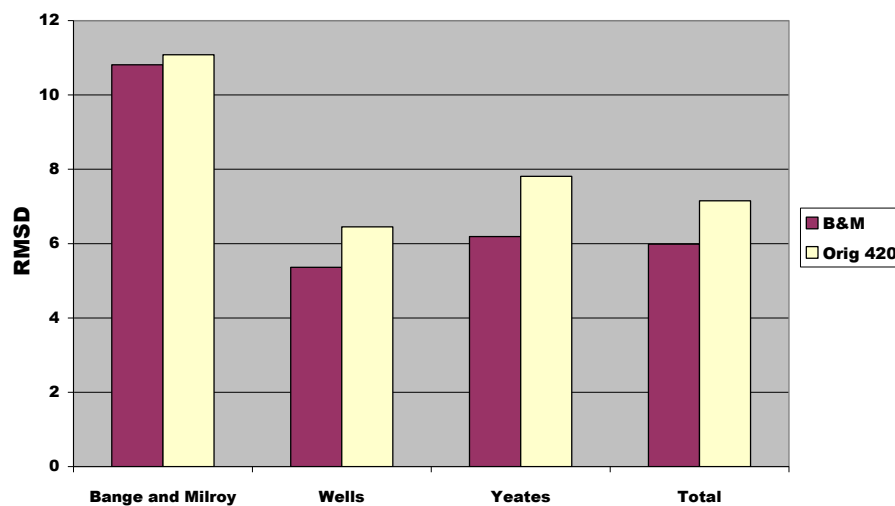
**Figure 2:** Function used to predict time of first square versus average daily temperature plotted with data collected from the field in Narrabri and Kununurra.

Data was then collected from a number of different experiments conducted in Narrabri and Kununurra using a range of different cultivars. Although the field data are highly variable, there is an indication of the same curvature as seen in the controlled environment studies. Other factors will also contribute to this variation, however. Water stress or insect damage to the apical meristem can delay the appearance of the first square 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.

Using independent field datasets the ability of the new function predict timing of first square compared with the existing day degree function of using a base temperature of 12 °C was tested. Using the day degree function to predict first square requires day degrees to accumulate to a 420 target and account for cold shocks which delay development by adding 5.2 day degrees to target when minimum temperature falls below 11°C.

Overall the new function was better in its ability to predict time of first square compared with the existing day degree function. This was indicated by the lower root mean square deviation (RMSD) shown in Figure 3. RMSD is a measure used to indicate and compare variation from the actual measured values when different methodologies are used to make predictions. A lower RMSD means the performance of a model to simulate the measured yields is better than a previous effort. It is important to note that the new function did not require a day degree target to be specified, nor did it need to account for cold shocks.

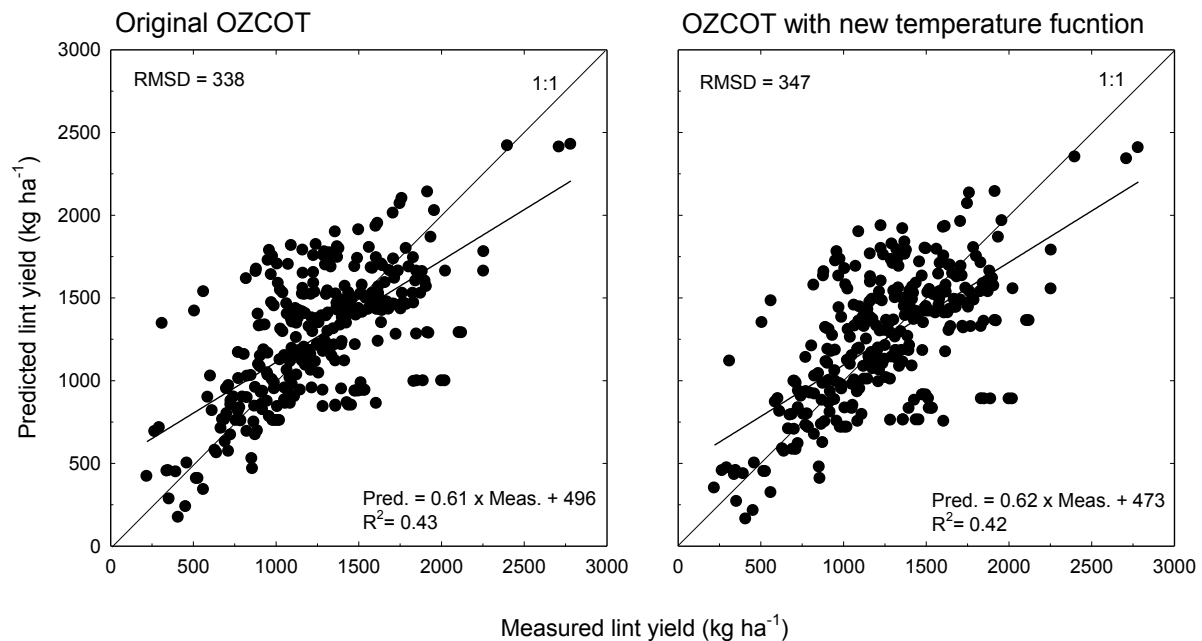


**Figure 3:** A comparison of RMSD (a measure of variation from the actual measured values once predictions are made) between using the existing day degree function used in the Australian cotton industry with a target of 420 day degrees and the function derived by Bange and Milroy (2001). RMSD – Root mean square deviation.

### ***OZCOT performance with temperature rate function (first square)***

The performance of the temperature rate function was tested in the OZCOT crop simulation model to predict cotton yields. To assess model performance, simulated lint yield was plotted against the measured (observed) (Figure 4). The fitted line to the simulated versus observed yields analysis was used to identify bias, that is whether there are problems in simulating yields when measured yields are high or low. The coefficient of determination ( $R^2$ ) of this regression described the degree to which the data is clustered around a straight line. In addition a statistical measure RMSD (Root mean square deviation) was also used to quantify these comparisons. A lower RMSD means the performance of a model to simulate the measured yields is better than a previous effort.

While the inclusion of the new temperature function did not improve the models ability to simulate lint yield it did not change predictions to any great degree. This is highlighted the similar  $R^2$  and RMSD. To fully test the robustness of the function it will require testing the model with data taken from crops that have been grown in a greater range of temperatures. The sowing time data collected in this study will assist this analysis.



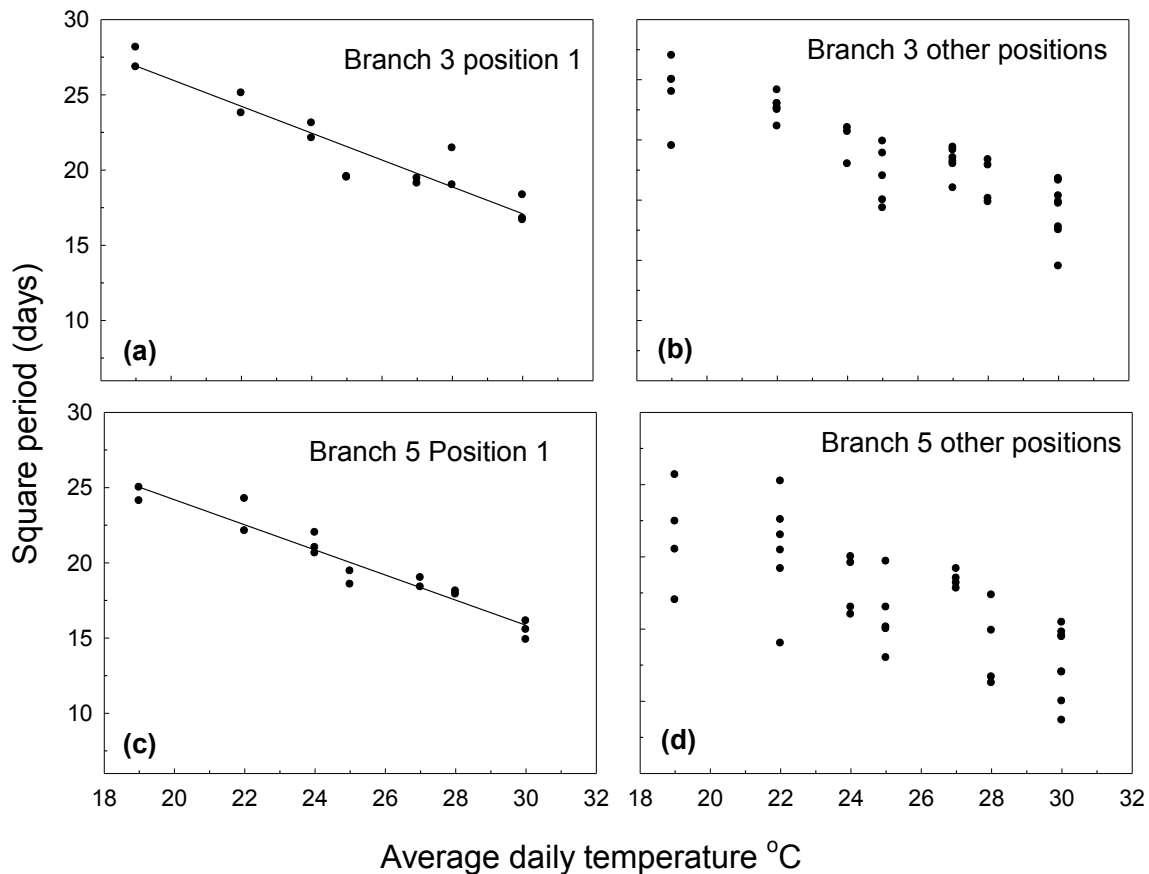
**Figure 4:** Predicted lint yields versus measured lint yields comparing the predictions using the original OZCOT simulation and with the inclusion of the temperature rate function derived in this study. Measured data includes studies conducted in Narrabri and Emerald.

### *Square Period (square to flower)*

In the controlled environment experiments, square period declined with increasing temperature (Fig. 5). Unlike the rate of development to first square, the function relating the rate of development of fruiting forms to temperature showed no curvature over the range of temperatures available in this study.

Square period also varied with location on the plant (Fig. 4). The square period on the third fruiting branch was significantly greater than on the fifth fruiting branch (Fig. 4a). Similarly, square period was significantly shorter with higher position number on the branch (Fig. 4b). For both effects, while the average duration varied, the effect of temperature was not different. That is, the intercept parameter of the response function varied with position but not the slope parameter.

When data was reanalysed to explore the rate of development in response to average daily temperature it showed that there again was no curvilinear response especially at the higher temperatures. When the data was linearly extrapolated it approximated that the lower base temperature (that is the temperature at which no development occurs) was it was in the range of 0 to 6°C. It is most likely that this is not actual base temperature and that there is a rapid decline (or curvilinear) response to temperature at the lower temperatures which has not been measured in this study.



**Figure 5:** Square period (time from square to flowering) versus average daily temperature for (a) fruiting branch 3 position 1, (b) branch 3 other positions, (c), fruiting branch 5 position 1, and branch 3 other positions.

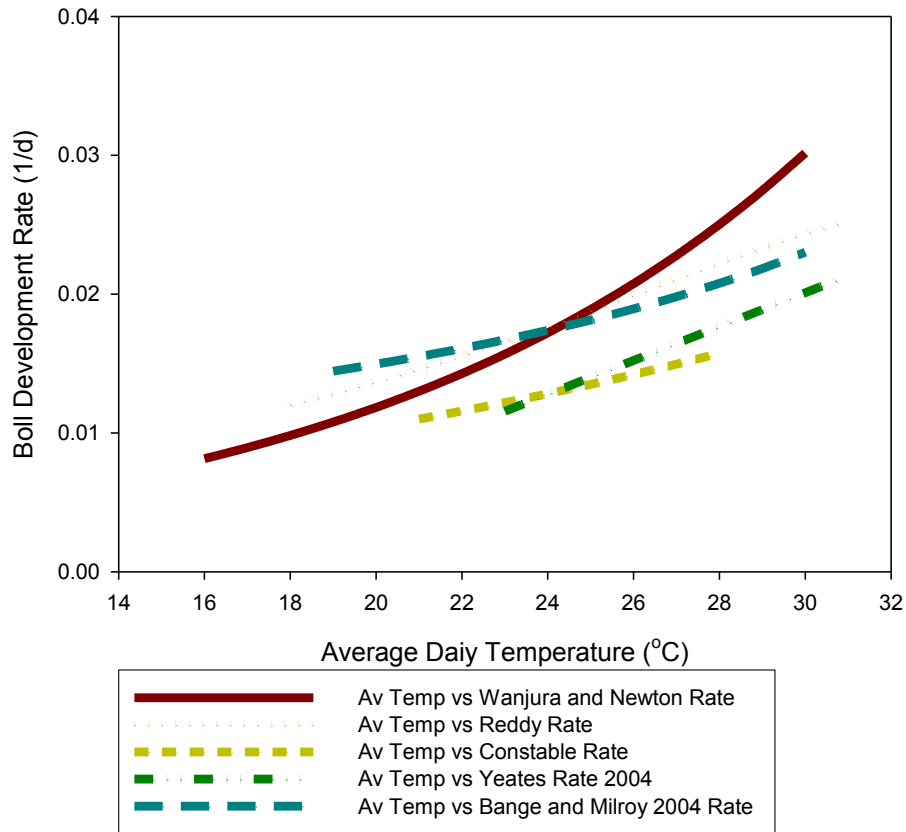
### ***Boll Period***

As for square period, boll period declined linearly with increasing temperature in the controlled environment. However, it did not differ significantly with location on the plant; either branch number or position on the branch. Again there was no difference between the cultivars in the rate of development at any given temperature. In addition when compared with the rate of development of the first square there was no reduction in the rate at higher average temperatures. Boll period (d) could be described as function of average temperature (°C) as follows:

$$\text{Boll period} = 114.61 (\pm 4.63) - 2.35 (\pm 0.182) * T_{av} \quad (R^2=0.76; P<0.001)$$

Compared with other published data the function developed was similar to that of others generated in glasshouses (Reddy, Wanjura and Newton) but slightly higher than that of both Constable and Yeates taken from field data. These other studies also confirm that there appears to be no reduction in the rate of development of boll period at high average daily temperatures.

The ability of this function to predict boll period for field studies compared with existing relationships still needs to be validated.



**Figure 5:** Comparison of published and the results generated in this study of the rate of boll development versus average daily temperature. Responses are plotted only over the range of temperatures in which measurements were made.

### *Other experiments*

Two further experiments were conducted in the Canberra Phytotron (controlled environment) to provide additional data to confirm results previously presented. The first experiment was to explore the impact of cold temperatures on boll period and fibre development. The second experiment varied the average daily temperature ranging from 16 to 34°C for different developmental phases. This experiment was conducted to test the robustness of the functions measured above with a different and more recent cultivar (Sicala V3i). The data from these experiments is still to be included in the analyses described above.

## **The Impact of Extreme Cold Temperatures on Cotton Growth and Development**

Low temperatures after sowing increase the time to emergence and reduce cotton seedling vigour often leading to poor establishment, poor early growth and increased risk of seedling diseases). Much of our current understanding of the impacts of temperature on cotton crop growth and development in Australia is based on experimental work undertaken in the early 1970's by Constable (1976) with cultivars quite different to those used commercially today. It was from these experiments that the current day degree function used in estimating crop development for cotton in Australia, was derived using a base temperature of 12°C (Constable and Shaw 1988).

To improve the accuracy of prediction using this function, it was postulated that early in crop growth there may be instances where chilling injury (cold shock) could delay crop development. A definition of a cold shock was then derived from a simple iterative procedure that minimized the coefficient of variation in the prediction of time to flowering. A cold shock was thus defined as where minimum daily temperatures are < 11°C and each event extends the duration to flowering by 5.2 day degrees (Hearn and Constable 1984). In some cotton producing regions in Australia early in cotton growth the number of cold shocks can as frequent as 40 (period 15th Sep. to 30 Nov.). The distribution of cold shocks is often associated with cold front weather patterns moving through eastern Australia during this period. This can sometimes happen once, or result in a sequence of cold nights together or spaced over longer periods.

Studies as part of this project were initiated to quantify the effects of periods of extreme cold temperature on crop growth and development. The studies were essentially divided into three parts. The first was a series of studies explored the impact of short term exposure on early growth of cotton. The second series of studies explored longer durations of cold exposure and at later stages of development. A separate smaller study also explored the impact of cold temperature exposure on cotton tissue viability.

These activities utilised the cold room, leaf photosynthesis machine (including attachment for leaf fluorescence) supported by the CRDC.

### ***Short term cold exposure early cotton growth***

The aim of this work was to empirically assess impacts of short term exposure of cold shock on pre flower development of cotton plants. Cotton seedlings were grown in controlled temperature glasshouses (six experiments). Plants were transferred to cold chambers ranging from 5 to 22°C during the night period for durations from 3 to 10 d. Negative impacts were not seen until plants had been exposed to at least 10 nights at 10°C, or for at least 5 nights at 5°C. When differences were generated it did not delay development to first square any more than 4 d, nor was the effect consistent. These differences translated into delays to first flower, but had little effect on plant morphology, or dry weight measured soon after flowering. In one experiment a significant reduction in leaf photosynthesis was measured at two times of day on the day after cold shock at 5°C.

While there is some indication of the existence of a chilling effect caused by low night temperatures, the results show little indication of a consistent or general cold shock (unless treatment was severe) impacting crop growth and development when imposed between the four leaf stage and flowering. The persistence of the use a cold shock to adjust estimates of crop development may be perpetuated by inadequacies of the base temperature of 12°C used in the calculation of day degree used in the Australian cotton industry (Constable and Shaw

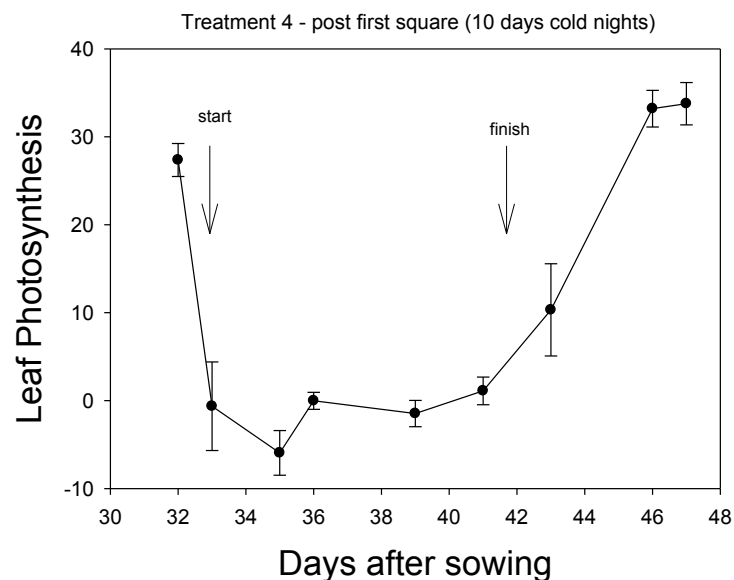
1988). In the studies presented we have shown that the base temperature for Australian cultivars is probably closer to 15 than 12°C. Although the derivation cannot be sourced, 15°C is a value similar to that quoted generally in cotton literature; especially in the US (derivation cannot be sourced). This may account for many instances where predictions in crop development are earlier than observed, and the observed delay attributed to cold shocks. This outcome also serves to highlight there is an opportunity to improve the functions used in the industry used to predict crop development.

This work is presented in more detail in the paper published in Australian Journal by Bange and Milroy (2004) and is contained in the appendix of this report.

### ***Longer cold exposure on cotton growth***

To build on the activities presented previously on the impact of severe cold night temperatures we conducted a further eight pot experiments that extended the duration of cold night exposure as well as varying the time when cotton was exposed (Table 1). The results have generally shown that these extended periods of cold night temperatures do reduce growth and extend plant development.

We have explored the reasons for these reductions by measuring leaf photosynthesis and assessing the leaf function (using a leaf fluorometer). An example of the response of leaf photosynthesis to cold night temperatures is shown in Figure 6. The data show considerable reductions in photosynthesis but with significant recovery within 5 days.



**Figure 6:** Example of the response of leaf photosynthesis before during and after application of cold treatment (4°C for 10 days).

We intend to finalise the analysis of these experiments, publish these results in a referred journal and disseminate these results to industry.

**Table 1:** List of experiments exploring the impact of long durations of cold night temperatures on cotton growth and development. Experiments were conducted using glasshouses and cold room facilities at ACRI.

Experiment Name	Night Temperature	Description
Cold Shock 6	Cold Room 4° C	5 or 10 Consecutive nights 2 Trts. prior to squaring (5 nights & 10 nights) 2 Trts. post squaring (5 nights & 10 nights)
Cold Shock 7	Cold Room 4° C	5 or 10 Consecutive nights 2 Trts. prior to squaring (5 nights & 10 nights) 2 Trts. post squaring (5 nights & 10 nights)
Cold Development 1	Cold Room 10° C	10, 20, 30 or 40 Consecutive nights Each treatment starts at 4 leaf stage Trt 5 has 10 nights in 10 nights out, & 10 nights in
Cold Development 2	Cold Room 10° C	10, 20 or 30 Consecutive nights Each treatment starts at first flower. Trt 5 has 10 nights in 10 nights out, & 10 nights in
Cold Development 3	Cold Room 10° C	0, 20, 30 & 40 Consecutive nights Each treatment starts at first flower. Trt 5 has 10 nights in 10 nights out, & 10 nights in
Cold Development 4	Cold Room 11° C	10, 20, 30 or 40 Consecutive nights Each treatment starts at 4 leaf stage Trt 5 has 10 nights in 10 nights out, & 10 nights in
Cold Development 5	Cold Room 10° C	10, 20, 30 & 40 Consecutive nights Each treatment starts at first flower.
Cold Development 6	Cold Room 10° C	10, 20, 30 or 40 Consecutive nights Each treatment starts at 4 leaf stage Trt 5 has 10 nights in 10 nights out, & 10 nights in
Cold Development 7	Cold Room 10° C	10, 20, 30 & 40 Consecutive nights Each treatment starts at first flower. Trt 5 has 10 nights in 10 nights out, & 10 nights in

### *Impact of cold temperatures on cotton tissue viability*

Building on the previous studies, aiming to quantify the effects of cold temperature on growth and development we investigated the effects of cold temperatures on the viability of cotton leaf tissue. The hypothesis tested was that exposure to 10 °C for 10 or 20 nights does

not affect tissue viability; and that this lack of impact of cold on cotton growth and development is because cold temperatures around 10 °C treatment is not affecting tissue function and survival. This part of the project was assisted by Angela McDowell and Daniel Tan from Sydney University supported by a Cotton CRC summer scholarship.

These experiments tested whether exposure to 10 °C for 10 and 20 nights affected tissue viability. Experiments were conducted using plants grown in the glasshouse at the 14-node stage and plants grown outdoors at the 7-node stage. Simple tissue viability tests using 2,3,5-triphenyl tetrazolium chloride TTC and relative electrical conductivity (REC) were conducted following treatments. Leaf photosynthesis and chlorophyll fluorescence were also measured to determine whether there were changes in photosynthetic function. Plants treated with cold shock at 10 °C for 10 and 20 nights did not show any significant impact on tissue viability or cell membrane integrity in the TTC and REC tests, respectively. Photosynthesis and chlorophyll fluorescence levels fell slightly in the 20 night treatment compared to the control, but recovered quickly outdoors at the end of the 20 nights. There was no evidence in the data that exposure to 10 °C for 10 and 20 nights will reduce cotton tissue viability or plant growth. The outcome of this work helps to support the lack of effect of cold shock (chilling injury) on early growth of cotton found in the previous studies.

This work is presented in more detail in the paper published in Australian Cotton Conference proceedings by McDowell (2004) and is contained in the appendix of this report. This work also contributed the honours thesis of Angela McDowell.

### **Assessment of cultivars for cold tolerance**

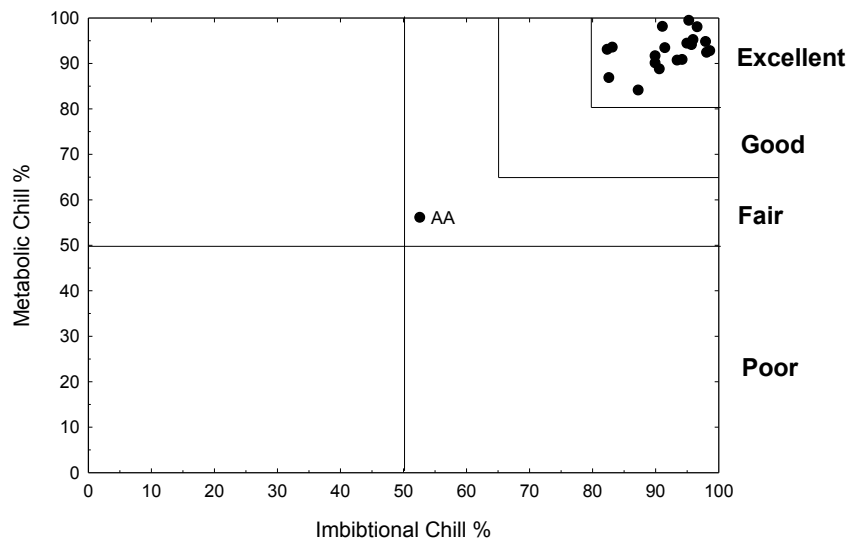
The objective of these studies was to explore methodologies developed in the United States to assist screening of cultivars for their ability to withstand cold temperatures during seedling growth. Two tests were evaluated, the metabolic chill and imbibitional chill tests. The two tests are summarised below:

Metabolic chill test – Seedlings planted in sand boxes and grown in a growth room 18°C for 21 d. The metabolic chill percentage was calculated from the emergence at the end of the 21 d period.

Imbibitional chill test – Seed was soaked in 5° C water and exposed to 5°C for six hours and then grown in a growth room at 30 °C for 14 d and the emergence recorded.

We used genotypes that were used in the studies conducted in the US (DP50, Sure Grow 125, Altex Atlas and DP5690), Australian varieties (Sicot 189, Sicala 40 and Siokra 102) and others (Lumian, Chirpan, and Fergana). A plot of the metabolic chill % versus the imbibitional chill % is used to define whether genotypes have capacity for tolerance against early cold temperatures (Figure 7). Genotypes that have better tolerance have higher values of both metabolic chill and imbibitional chill germination percentages.

The results showed that that most genotypes with the exception of Altex Atlas fell in the excellent range for cold tolerance. We expected that the more of the US genotypes would have fallen in the fair to poor range as had been measured in the US. We are repeating the experiments to confirm the results.



**Figure 7:** A plot of metabolic chill germination % versus imbibitional chill % as a measure of genotypes early tolerance to cold conditions.

### Impact of frost on seedling cotton survival

There is limited knowledge on the impacts of frosts (<2°C Screen temperature) on survival and the subsequent growth cotton. The chances of frost can occur in most regions at the start of the crop or at the end. In the OZCOT crop simulation model if a frost occurs early in the crop simulation is terminated, or towards the end of the crop immature bolls are forced open prematurely. The model's reaction to frost may well be an over-reaction. Some field observations (although circumstantial) suggest that there is some ability for the crop to survive frost and continue to grow.

Two series of experiments were conducted. The first series explored the survival of seedlings shortly after exposure to frost conditions. The second series of experiments explored the impact of frost later in crop growth.

#### Early frost

The impact of early frost was explored by exposing growing seedlings (cotyledon and 3-4 true leaves) to one night of cold temperatures. We conducted 12 different experiments with treatments replicated 3 to 5 times. In experiments where we placed cotton plants outside from a glasshouse the results showed that survival of seedlings measured 7d after the exposure to the cold nights at both the cotyledon and 3-4 true leaf stage when returned to optimal growth conditions was favourable (Table 2). Minimum night temperatures ranged from -3.1 to 4.6 °C at ground level.

We then exposed seedlings (cotyledon stage) to one night of continuous extreme cold temperatures for the duration of the night (12 h) in a cold room. In these experiments we were able to reduce survival 7d after the exposure to the cold nights when returned to optimal growth conditions (Table 3). When comparing the results with the experiments that put seedlings outside it showed that the duration of exposure and the degree of temperature have

an impact on survival. To fully understand these results we will also need to explore the interaction with relative humidity.

**Table 2:** The survival of cotton seedlings 7 d after exposure to one night cold temperature (outside).

Growth Stage	Minimum Night Temperature (Ground Temperature) °C	% Survival
Cotyledons	-2.7	100
Cotyledons	-1.8	100
Cotyledons	-0.1	100
Cotyledons	3.5	100
Cotyledons	4.6	100
3-4 true leaf	-3.1	100
3-4 true leaf	1.1	100
3-4 true leaf	2.7	100

**Table 3:** The survival of cotton seedlings (cotyledons) 7 d after exposure to one night cold temperature (cold room).

Average Night Temperature	% Survival
-0.6	98.8
-2.3	61.9
-3.1	6.2

### Late frost

A further experiment was conducted to explore the impacts and symptoms of frost at other stages of crop development. Plants were exposed to two consecutive nights of extreme cold temperatures and then grown to maturity in favourable conditions in the glasshouse. The treatments in this experiment were:

- Control (no frost treatment)
- Frost at 4 leaf stage (when all plants reached 4 leaf stage)
- Frost at squaring (when all plants reached first square)
- Frost at flowering (when all plants reached first flower)
- Frost during boll opening (when all plants have one boll open)

The results of this experiment are yet to be analysed.

### **Sowing Time and Temperature Effects on Cotton Growth and Yield**

One of the most important agronomic considerations for growers to optimise yield and quality is to select an appropriate sowing time for a crop of cotton. Choosing the best time of sowing in a particular region can often be difficult, as it is a decision that must strike a balance between sowing too early and enduring problems associated with cold weather or sowing too late and losing potential yield. Sowing too early when cold weather can be predominant slows crop growth often leading to poor establishment, poor early growth and exposes the crop to many seedling diseases. Sowing when conditions are warmer reduces the risk of poorer establishment because the crop grows more vigorously. Sowing too late however, will reduce season length and will reduce yield.

During this project seven field experiments (Table 4) that varied the time of sowing were conducted. The purpose of these experiments was to:

- Collect field data of crop responses to temperature as supporting evidence for other data collected in this study.
- Examine the response of cotton growth and yield to sowing time and relate differences to the temperature.
- Collect data for validation of the OZCOT crop simulation model for both yield and quality.
- Examine the effect of Ingard® and Bollgard II ® on yield of cotton with different sowing times.

Measurements included:

- plant establishment
- time of first square, first flower and 60% bolls open
- yield, yield components (boll size and number) and fibre quality traits
- final retention values
- light interception at flowering
- Temperature at experiment sites

**Table 4.** List of field sowing time experiments conducted as part of this project.

Trial Name	Location	Design	Sowing Dates	Cultivars
Establishment Trial 01/02	ACRI	RCBD	10/09/01	Sicala V2i
		6 sowing dates	20/09/01	
		1 cultivars	2/10/01	
			18/10/01	
			30/10/01	
			17/12/01	
Breeza - Time of Sowing 01/02	Breeza	RCBD*	25/09/01	Siokra S101i
	Camilleri's	4 sowing dates	5/10/01	Sicala V3i
	Jangaree	2 cultivars	16/10/01	
			30/10/01	
Breeza – Time of Sowing 02/03	Breeza	RCBD	25/09/02	Siokra S101i
	P. Morgan's	3 sowing dates	16/10/02	Sicala V3i
	Battery Hill	2 cultivars	18/11/02	
Hillston Time of Sowing 02/03	Hillston	RCBD	27/09/02	Sicala 40i
	Lachlan	3 sowing dates	24/10/02	Siokra V16i
	Farms	3 cultivars	27/11/02	Pima S-7
Breeza – Time of Sowing 03/04	Breeza	RCBD	26/9/03	Sicala 43
	P. Morgan's	3 sowing dates	14/10/03	Sicala 43
	Battery Hill	2 cultivars	4/11/03	equivalent CSX 404
ACRI – Time of Sowing 02/03	ACRI	RCBD	24/09/02	Sicot 189
		3 sowing dates	15/10/02	Sicot 289B
		4 cultivars	11/11/02	Sicala 40
				Sicala 40B
Development/Time of Sowing 03/04	ACRI	RCBD	13/10/03	189RR
		3 sowing dates	5/11/03	Sicot 289BR
		2 cultivars	28/11/03	
Development/Time of Sowing 04/05	ACRI	RCBD	6/10/04	189RR
		3 sowing dates	22/10/04	Sicot 289BR
		2 cultivars	10/11/04	

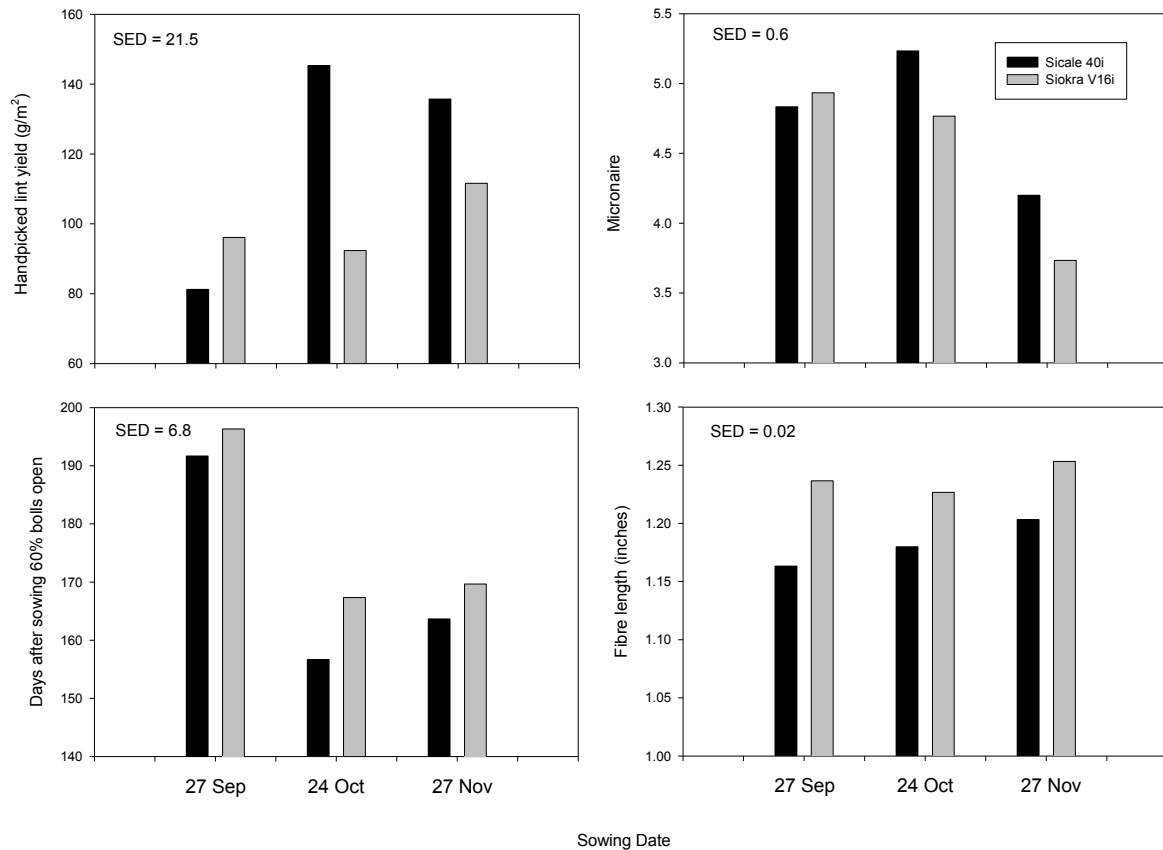
\* RCBD – Randomised complete block design

Much of this data is yet to be analysed fully. Some of the work summarised to date is presented below:

#### Hillston Sowing Time

A field experiment conducted at in Hillston (Lachlan Farms) during the 2002/03 season explored the impact of sowing time and temperature on growth and development of cotton of two varieties (Sicala 40i and Siokra V-16i) differing in their maturity and a Pima cotton variety (S-7). In this particular year the early and late sowing considerably reduced yield (Figure 8). Yield was reduced through a lower boll set and small boll size in the early sowing and poor ginout % in the late sowing. A sowing in late October maximised yield and allowed

the crop to avoid the problems with cold temperatures, promote early vigour, and maximise season length thus allowing bolls and fibre to develop. The use of Sicala 40i an earlier maturing variety also improved yield by being able to set its bolls earlier and allow fibre to develop to more optimal conditions. Sicala 40i also offset the effects of the late sowing; highlighting the opportunity to use earlier varieties when sowing is delayed.

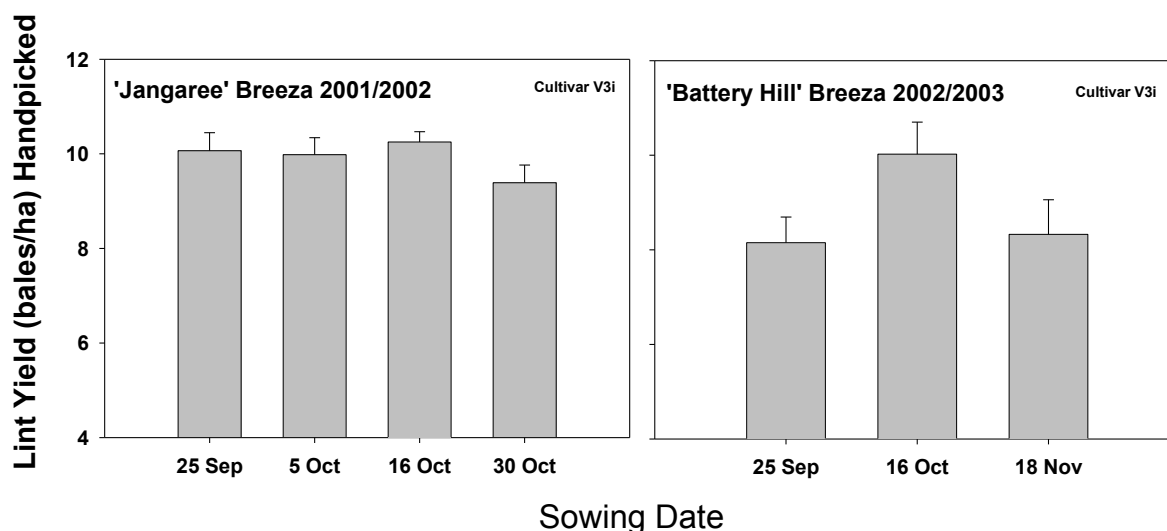


**Figure 8:** Average yield, 60% maturity, fibre length and micronaire for Sicala 40i and Siokra V-16i for each of the sowing treatments. SED is the standard error of the difference of means for the comparison between sowing and cultivar combined.

This work is presented in more detail in an Australian cotton conference proceedings by Bange et al. (2004) attached to this report.

### Breeza Sowing Time

Results of two sowing time field experiments conducted at Breeza in the 2001/02 and 2002/03 cotton seasons showed different response of yield to sowing time (Figure 9). In both seasons however, it showed that the numerically highest yields were those when the crop was sown on the 16<sup>th</sup> October. In all experiments we also included a shorter season variety, and as expected these varieties were able to offset to some degree the reduction of yield through later sowings with later maturing varieties.



**Figure 9:** The impact of sowing time on lint yield at Breeza.

Outcomes from these experiments have been included in the local CottonTales extension publication discussing the impacts of sowing time. An example is included in the appendix of this report.

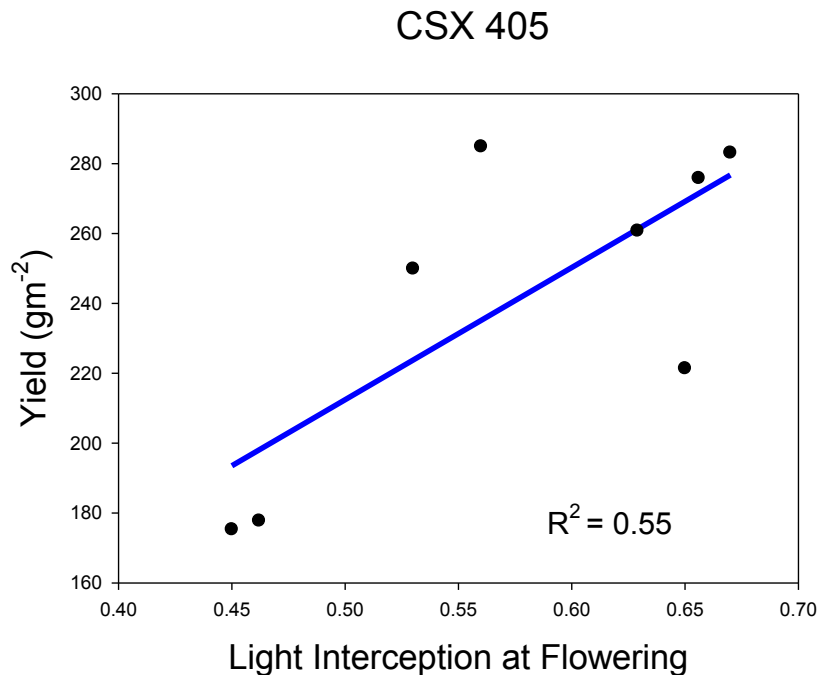
#### Narrabri Sowing Time (Bollgard II)

Increased fruit retention can lead to earlier crop maturity and earlier maturity can also reduce crop yield. It is speculated that the higher fruit retention that can be achieved with Bollgard II cultivars could potentially shorten the time to maturity and thus impact on yield. In terms of agronomy if this earlier maturity is the case then how could this be exploited in terms of crop management? One idea is that the crop could be sown later and gives greater flexibility for sowing time and gain advantages associated with a shorter growing season without significantly impacting on yield.

Later sowing of crops that have the potential for high fruit retention should enable increased plant size before the onset of fruit growth (thus supporting more fruit). This is achieved by growing a vigorous crop (including increased leaf expansion) prior to flowering and increasing the node at which first fruiting branch occurs.

To test the theory that a greater plant size will contribute to higher yields of Bollgard II we measured the amount of light interception of the crop around flowering for different sowing times as a surrogate to measuring the amount of leaf area. In 2002/03 season we were able to get a significant positive linear response of lint yield to the degree of light interception by the crop at flowering (Figure 10). The higher light interception values recorded were associated with the later sowing times. Information from three seasons from 2002 will be combined to complete this analysis.

The treatments in these experiments will also be used to collect data on distribution of fibre quality through the plant and to establish the relative difference between conventional and high retention crops (eg. Bollgard II).

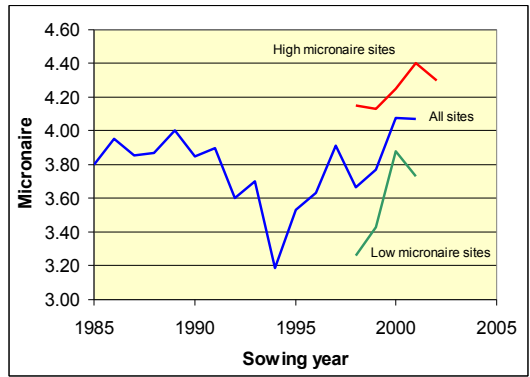


**Figure 10.** Response of lint yield of Bollgard II (CSX405) to light interception at flowering.

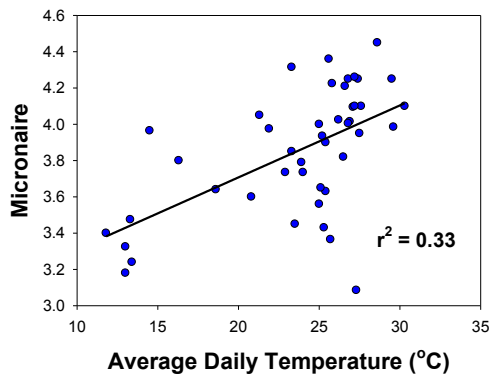
### Fibre Quality and Temperature

In recent years spinners have complained about the high micronaire, short fibre and high neps of Australian cotton. Some are suggesting that the increasing micronaire is related to problems associated with varieties. The CSIRO breeding team have shown that increasing micronaire (seasons 1999 – 2000) was associated with seasonal effects, not change in varieties (Figure 11). In an attempt to establish the effect of temperature on fibre quality traits we approximated for each of the trials located in each region and year the time when fibres were thickening which impacts on final micronaire. The analysis showed that approximately a third of the increase in micronaire in these seasons was related simply to the high temperatures experienced during boll filling (Figure 12). Given that we had not accounted for any other stresses or differences in management practices that may have contributed to differences in micronaire this strongly suggests that temperature was a main factor in causing increases in micronaire in this analysis.

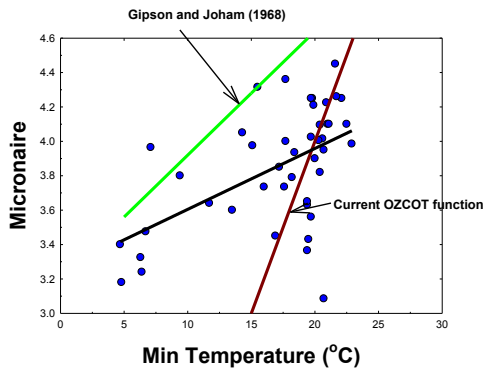
The other finding from this analysis shows that our current understanding of the impact of temperature on micronaire may be limited. When we plotted the response of micronaire to minimum temperature it was different from that used in the OZCOT crop simulation model and that quoted in the literature (Figure 13). Improving this relationship is a subject of a current CRDC study into the climate and agronomic impacts on fibre quality.



**Figure 11:** Measured HVI micronaire of the old control varieties DP16 and Namcala in the last 18 cotton seasons to 2001/02. Mean of up to 13 sites each season including Emerald, Biloela, Theodore, Brookstead, Boggabilla, St George, Collarenabri, Moree, Bourke, Merah North, Myall Vale, Breeza, Warren and Hillston. Emerald data for 2002/03 data is also shown.



**Figure 12:** The response of micronaire to average daily temperature during fibre thickening of control varieties DP16 and Namcala used in CSIRO breeding programme from season 1999 to season 2000.



**Figure 13:** Current responses of micronaire to minimum daily temperature during fibre thickening.

The results of these analyses have been presented at numerous industry forums with discussions on fibre quality issues.

## Other Research

This project supported resources for a number of projects conducted in Northern Australia. In collaboration with Brian Duggan and Nerrylie Gaff we conducted two field experiments that explored the impact of night temperature on fibre quality traits. We modified night temperature by placing tents over the crops at different stages of fibre development. The tents increased the night temperature and unexpectedly reduced fibre quality. Results from this study are presented in the CRDC final report 'Refining crop agronomy for dry season production in NW Australia'.

This project also provided support for the purchase of sensors to explore the impacts of high relative humidity on fibre quality of cotton around harvest. This work was carried out by Steve Yeates in Kununurra.

## 4. Provide a conclusion as to research outcomes compared with objectives. What are the "take home messages"?

Some current significant take home messages were:

- The results of studies that varied temperatures from very cool to very hot highlighted that at different stages of development that the response to temperature varied.
- A temperature response function produced in this study predicted timing of first square as well as a day degree accumulation without the use of cold shock adjustments and day degree targets.
- The base temperature for early cotton growth is more likely to be around 15°C. This agrees with the US literature, although the source of this value cannot be found.
- Cold shocks appear to be an anomaly associated with use of the current day degree function that uses a base temperature of 12°C.
- Cotton is relatively resilient to cold night temperatures as shown by the controlled environment experiments that found:
  - o Short term impacts of cold night temperatures having little impact on cotton growth and development even at temperatures as low as 4°C.
  - o In long periods (10-20 nights) of cold night temperatures (around 10°C) cotton tissue does not appear to be damaged.
  - o Cotton photosynthesis rebounds rapidly once cold night temperatures are removed.
  - o Exposing cotton seedlings to a single night of frost conditions had little or no impact on survival.
- Our understanding of the quantitative impacts of temperature on micronaire is limited and warrants further research.

## **5. Detail how your research has addressed the Corporation's three Outputs - Economic, Environmental and Social?**

This project addressed all outputs prescribed by the CRDC. Better understanding and improvement of the day degree function for example will assist with crop management directly, as well as through the decision support tools CottonLOGIC and crop simulation models. CottonLOGIC assists with BMP, while crop simulation is used to characterise risk of agronomic production as well as being used to assess production potential for new regions. Crop simulation is also being used to develop information for land and water management plans as well as being used by growers to improve their WUE. Better understanding of different genotypic responses to extreme temperature will also assist directly with agronomic practice as well as plant breeding.

## **6. Provide a summary of the project ensuring the following areas are addressed:**

- a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.)**
- b) other information developed from research (eg discoveries in methodology, equipment design, etc.)**
- c) are changes to the Intellectual Property register required?**

Not Applicable

## **7. Detail a plan for the activities or other steps that may be taken:**

- (a) to further develop or to exploit the project technology.**
- (b) for the future presentation and dissemination of the project outcomes.**
- (c) for future research.**

As mentioned previously throughout the document much research is yet to be analysed. It is our intention to continue with these analyses, publish results in scientific journals and disseminate our findings widely in industry publications. Ultimately we will use this data to improve current decision support tools (eg. CRC day degree calculator) and the OZCOT crop simulation model to assist with predictions in crop development.

A project titled 'Enhancing cotton crop management for improved fibre quality' has been supported by the CRDC and builds on the understanding of the impacts of temperature on cotton growth generated by this study. Background to the project follows:

In recent years there have been complaints of Australian cotton quality raised by spinners for high micronaire, short fibre and high neps. Some are suggesting that the increasing micronaire is related to problems associated with varieties. A recent analysis also showed that 30% of the increase in micronaire in these seasons was related simply to the high temperatures experienced during boll filling.

Confusion relating to these issues highlights our lack of understanding of the impacts of management and environment on fibre development. This has impeded our capacity to explore alternative management opportunities to improve profitability (both from a yield and fibre quality perspective). Meaningful descriptions of the effects of management and environment on cotton fibre quality are needed. Only then can the genetic, crop management and environmental sources of fibre quality variability be quantified and modulated to produce the high-quality cotton fibre demanded by a modern textile industry and ultimately the consumer.

CSIRO Plant Industry has fibre quality as one of our major focus subjects for plant breeding and for agronomic management. This project will be aimed at strengthening/enhancing the cotton research efforts in delivering initiatives that focus on management aspects of fibre quality (other than breeding and processing). This project aims to fill a gap that exists in developing management strategies in the field that optimise cotton fibre properties. The specific aims are:

1. Initiate targeted research to improve the understanding of the effects of different climate, plant and management factors on fibre properties.
2. Utilise agronomy and physiology research tools such as OZCOT simulation to develop guidelines to assist in the management of cotton to optimise yield and fibre quality.
3. Strengthen agronomic research to meet the needs of the 'Fibre to Fabric' initiative.

## **8. Publications arising from the research project**

Publications follow this report.

### ***Journal Articles***

1. Bange, M.P. and Milroy, S.P. (2004). Impact of Short Term Exposure to Cold Night Temperatures on Early Development of Cotton (*Gossypium hirsutum* L.). *Australian Journal of Agricultural Research* 55(6): 655-664.

### ***Refereed Conference Papers***

2. Bange, M.P. and Milroy, S.P. (2001). Effect of temperature on the rate of early fruiting developmental processes of cotton. Proceedings of the 10th Australian Agronomy Conference, Hobart, TAS. 2001. <http://www.regional.org.au/au/asa/2001/1/d/bange.htm>

3. Bange, M.P. and Milroy, S.P. (2003). Cold shock in early growth of cotton. Proceedings of the 11th Australian Agronomy Conference, Geelong, VIC. 2003. <http://www.regional.org.au/au/asa/2003/c/5/bange.htm>

### ***Conference Papers***

4. Bange, M.P. and Milroy, S.P. (2002). Temperature extremes and cotton performance. In Proc. 11<sup>th</sup> Aust. Cotton Conf. 13-15 August, Brisbane, Aust. The Aust. Cotton Growers Research Organisation, pp. 477-481.

5. Bange, M.P. and Milroy, S.P. (2004). Impact of 'cold shock' on early development of cotton. In Proc. 12th Aust. Cotton Conf. 10-12 August, Gold Coast Aust. The Aust. Cotton Growers Research Organisation, pp. 433-439.

6. Bange, M.P., Brown, E. Caton, J. and Roche, R. (2004). Sowing time, variety and temperature effects on crop growth and development in the Hillston region. In Proc. 12th Aust. Cotton Conf. 10-12 August, Gold Coast Aust. The Aust. Cotton Growers Research Organisation, pp. 441-447.

7. McDowell, A.J., Bange, M.P. and Tan, D.K.Y. (2004). Cold shock at 10 °C for 10 and 20 nights does not reduce cotton tissue viability. In Proc. 12th Aust. Cotton Conf. 10-12 August, Gold Coast Aust. The Aust. Cotton Growers Research Organisation, pp.747-756.

### ***Grower Magazine Articles***

8. Richards, D.Q., Bange, M.P., and Milroy, S.P. (2002). A season of two halves: 2001-02 weather in review. 23(3) The Australian Cottongrower pp.28-34.

### ***Others***

Cotton Tales Upper Namoi Valley (2003). Results of planting date trials. Issue 2 (03/04).

There is considerable data yet to be analysed and it is envisaged that more formal and industry publications will be forthcoming.

**9. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community.**

Day degrees are commonly used by industry and researchers to estimate expected crop development. One of the first aims of this project was to improve this function so that it is applicable over a greater range of temperatures and crop growth stages and to current cultivars. Using outcomes generated in this study we will improve the ability to predict crop development of crops within and across seasons. It will also have flow-on effects through improving nitrogen management with NutriLOGIC, pest management with EntomoLOGIC, and enhance the cotton crop simulation model OZCOT by providing better information on the crops' response to temperature.

We will also seek to improve the following information from using information generated from this study to:

- Generate a better understanding of crop establishment with the potential to develop tool for predicting better time for crop establishment when link to weather forecasts (used in California US).
- Collecting data to generate a better understanding of crop establishment
- Further enhance the replant calculator
- Reassess general rules of thumb eg. Last effective flower
- Development of a new database collating long term analyses of crop development durations using a new degree function and incorporating seasonal climate forecasts (e.g. SOI) delivered via CottonLOGIC and the Internet.
- Continue to identifying crop germplasm for breeding for tolerance to extreme temperatures.

## ***Final Report Executive Summary***

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Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

Temperature plays a critical and complicated role in the growth and development of cotton. The cool starts to the last three seasons in southern regions have again highlighted of the problems of cold shock and slow crop development rates at low temperature. Low temperatures after sowing increase the time to emergence and reduce seedling vigour often leading to poor establishment, poor early growth and increased risk of seedling diseases. The timing of crop maturity, yield and fibre quality may also be affected. There has also been evidence to suggest that high crop temperatures may negatively impact on crop development.

Much of our current understanding of the impacts of cold temperature on cotton crop growth and development is based on experimental work undertaken by Dr Greg Constable in the early 70's with cultivars quite different than those used commercially today. It was from these experiments that, the base temperature (12°C) used in estimating crop development was derived, and the definition of a cold shock (<11°C) was formulated. Dr Constable acknowledged even at the time there was considerable extrapolation of the information to derive these values the lowest daily temperature tested was 18°C. His work on cooler temperatures also focussed on early season crop development, as was the need at the time in the Namoi Valley. No specific experimentation on the effects of low temperature has occurred in Australia since then. In addition there has been no definitive attempt to better understand and quantify the effects of temperature extremes on cotton growth and development at other stages and subsequent impact on crop yield (especially with current varieties and agronomic practices, particularly early season insect protection).

This project aimed to cover three main research components:

- 1) Develop refined understanding of the impact of temperature extremes on cotton performance.
- 2) To use information to develop a more functional decision support tools which will enable research and management to be done more accurately in scenarios where extremes of temperature are likely.
- 3) Utilise this understanding to assist with the development of field management packages of sowing strategies with adapted genotypes,

Some significant findings were:

- The results of studies that varied temperatures from very cool to very hot highlighted that at different stages of development that the response to temperature varied.
- A temperature response function produced in this study predicted timing of first square as well as a day degree accumulation without the use of cold shock adjustments.
- The base temperature for early cotton growth is more likely to be around 15°C. This agrees with the US literature although the source of this value can not be found.
- Cold shocks appear to be an anomaly associated with use of the current day degree function that uses a base temperature of 12°C.
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