FINAL REPORT 2006

Part 1 - Summary Details

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

CRDC Project Number: **CSP161C**

Project Title: **Physiology of high retention cotton crops**

Project Commencement Date: 1-July-2003 **Project Completion Date:** 1-July-2006

Research Program: On Farm

Part 2 – Contact Details

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Part 3 – Final Report Guide (due 31 October 2006)

Background

This project aims to understand how the potentially high fruit retention of Bollgard II varieties interacts with plant growth and yield. Our previous research (CSP90C and CSP123C) has quantified the variability in growth and development between conventional cultivars which differ in their time to maturity and growth habit. As expected, the majority of variation appears to be dictated by the timing and rate of development of the fruit load and less by differences in the growth characteristics of the varieties. The enhanced efficacy of the Bollgard II cultivars has led to very high early fruit retention in some crops. Such high levels of retention and the subsequent early development of the fruit load may restrict plant development and yield potential. In particular, there is concern that high retention may limit maximum potential yield through early cut-out or result in a higher susceptibility to premature senescence. This may also be an issue for other Helicoverpa resistant cultivars.

Research by Hearn, Constable and others with conventional cotton varieties has shown that as the fruit load develops, the demand for carbon outstrips the canopies capacity to support it. Since the fruit that are already growing monopolise the carbon, no new leaves and hence no new fruiting sites are formed. This governs both the time of crop maturation and its yield potential. These traits are therefore a function of the balance between a cultivar's capacity to produce carbon and the timing and rate of development of the fruit load. A rapid and early development of the fruit load, such as in Bollgard II crops, may under some circumstances limit the potential to develop an adequate plant structure to support a high fruit load.

Related to the balance between plant size and fruit load, research into premature senescence by Dr Phil Wright (NSW Agriculture) has shown that cultivars which developed their fruit load rapidly had a higher susceptibility to premature senescence. This appears to be due to the high rate of potassium uptake required to support fruit development. Where the demand cannot be met by current uptake, the nutrient is removed from leaf tissue to the extent that it falls below critical levels for photosynthesis. When this occurs with young leaves, the classical symptoms of premature senescence are evident. The size of the leaf storage can to some extent buffer against excessive draw-down. The rapid and early development of the fruit load in Bollgard II crops may predispose the cultivars to the risk of premature senescence through the combination of relatively small plant size and the rapid increase in demand for nutrients by the fruit.

It is necessary to develop a quantitative understanding of the reproductive development of the new Bollgard II cultivars to provide a basis for developing optimised crop management strategies that will allow them to achieve appropriate yield, and avoid problems due to premature cut-out or premature senescence. Parameters derived from the experiments will also be incorporated into the OZCOT cotton crop simulation model by Mr David Johnston to ensure that it is capable of correctly simulating high retention crops and current cultivars. OZCOT is a research tool to integrate our research as well as being the 'engine' in HydroLOGIC.

Since the commencement of this project in 2003 commercial production of Bollgard II cotton has commenced and there is now data from replicated variety trials that lends support to the concerns described above (Table 1). However, it is also possible that the management of these trials was tailored to the conventional variety and not the Bollgard II, which supports the need for knowledge that can provide the basis for its management. Also, recent hot dry seasons have favoured late boll set in compensating crops.

Table 1: High retention (Bollgard II) yields using a Sicot 71 background when included in CSD replicated conventional variety trial 2005/2006.

CSD 05/06 Site	Yield (b/ha)	
	Bollgard II	Conventional
Wathagar	9.8	11.0
Moree RR	10.6	11.0
Moree Conv.*	9.9	11.2

Moree Conv. Comment - Sean Boland
'.. the retention of the conventional varieties …about 60%. The BollgardII® varieties were able to maintain their retention levels well above 90%.' 'The Sicot 71BR and Sicot 71B… varieties were about two weeks more advanced than all other varieties in the trial.'

Objectives

A. To develop a quantitative understanding of physiological process which may potentially limit yield in high retention crops such as Bollgard II cultivars.

This objective was largely achieved. High retention in the absence of early main-stem tipping combined with a lower leaf area index were characteristics of Bollgard II. As a result boll growth was earlier and often faster than conventional cotton. Potential yield could be less due to a lower pre boll growth plant size because harvest index was conservative and independent of retention or tipping.

B. To quantify the extent to which the component processes can be beneficially manipulated.

The results suggest a need for a larger plant either via breeding or management, although success is likely to be regional and be confined to warmer long season areas such as the Gwydir and Emerald, when water is not limiting.

As a result of this project, further research has been initiated into the effect of late season leaf health on the yield potential of high retention cotton (in collaboration with Lewis Wilson), manipulation of pre-flowering biomass using water and sowing date (PhD project funded by the Cotton CRC) and changes to irrigation scheduling tailored to high retention cotton (timing and deficits, Yeates new project).

C. To test that the OZCOT model is capable of properly simulating high retention crops.

Modifications to OZCOT variety parameter files describing fruit survival, boll size and lint percentage were mostly successful in simulating independent on-farm crops from the Gwydir and at ACRI. However, this exercise confirmed long known problems with the simulation of leaf area index (LAI) under certain growing conditions. Future research will focus on improving the simulation of LAI following high temperatures and moisture stress. The enhancement of OZCOT capabilities in simulating crop and soil water and fibre quality is ongoing.

Methods

Three categories of activity were conducted:

- Detailed growth analysis experiments at ACRI that quantified the effect of high retention using BollgardII and conventional cotton with the same genetic background (Sicot 289). Conducted in years 1 and 2.
- Additional physiological data was collected from water stress experiments (in collaboration with Dirk Richards) that compared Bollgard and conventional cotton when moisture stressed at different stages of flowering and boll development using a Sicot 71 background. Conducted in years 2 and 3.
- OZCOT modification from above experiments and validated using independent experiments at ACRI and at Keytah (Moree) conducted in year 3.

A. Detailed Growth Analysis Experiments

Two experiments were conducted at ACRI in years 1 and 2 using a Sicot 289 background.

Treatments:

- Conventional cotton
- Bollgard II to represent high retention cotton.
- Bollgard II with early flower removal. This was done to generate a Bollgard II crop with lower retention, and involved tri-weekly flower removal for 2 weeks from early flowering.

The cultural details of the experiments are shown in Table 2. For practical reasons the Bollgard II treatments were included in the insecticide sprays for the conventional treatment, which were applied according to EntomoLOGIC thresholds. This also helped to ensure high fruit retention in the Bollgard II treatments. The treatments were replicated 4 times and plots were 8 rows by 20m.

Measurements

Plant height, main-stem node number, fruit retention at first flower, last effective flower and at maturity, dry matter accumulation and partitioning, time of first square, first flower and first open boll, nodes above white flower (NAWF), photosynthesis, light interception, leaf N, crop maturity, lint yield, turn out and fibre quality.

Table 2: Cultural details of detailed growth analysis experiments.

Management details	2003/2004	2004/2005
Date sown	13 / 10 / 2003	27 / 10 / 2004
Fertiliser	147 kg/ha N as NH4	147 kg/ha N as NH4
Population	12 p / m of row	12 p / m of row
Irrigation	Pre 13/9/03, 18/11/03, 23/12/03, 8/1/04, 4/2/04, 12/2/04	Pre 27/9/04, 5/1/05, 21/1/05, 9/2/05, 23/2/05, 14/3/05.
Flower Removal	5/1/04 to 21/1/04	5/1/05 to 20/1/05
Insecticide treatments#	8	8
Picking	Machine	Machine

As required for conventional variety but applied to all varieties.

B. Water stress experiments, comparing Bollgard II and conventional cotton for sensitivity to water stress.

These experiments were from CSP164, 'Delivering Science to Agribusiness' lead by Dirk Richards, where Stephen Yeates is the second researcher. This project focussed on the impact of moisture stress on the growth and recovery of high retention cotton, where as CSP164 focused on the water balance. Additional growth analysis data was collected from these experiments to provide information on the effect of water stress on the growth of high retention cotton and the fully irrigated treatments were used to provide growth analysis and OZCOT validation data for Sicot 71 B/BR. Large scale replicated experiments where conducted in years 2 and 3 of this project. Bollgard II and conventional cotton were compared when grown with full irrigation or with skipped irrigations and water stress imposed at different growth stages. Details on the methodology of these experiments and are in Appendix 1.

C. OZCOT modification for high retention cotton.

The experiments conducted in A an B above where used to provide data to modify the OZCOT model, where needed, to simulate the yield, fruiting dynamics and time to maturity of high retention Bollgard II varieties, Sicot 71B/BR and Sicot 289B/BR.

The approached used was to start with simple and obvious changes to the variety parameter files that could be expected to reflect high retention. These were fruiting site survival probability and boll size.

Three data sets were collected to provide data for validation of changes. Firstly, on-farm trials conducted with Andrew Parkes at Keytah near Moree (though the major objective of those trials was to compare Bollgard II with Conventional for water requirement and for irrigation scheduling optimisation of Bollgard II and link with similar research at ACRI in project CSP 164). Secondly, an experiment was conducted in 2005 / 2006 at ACRI and a complete data set collected. Finally, we also used data from the fully irrigated Sicot 289BR treatment in Mr James Neilson's water stress experiments at ACRI in 2004/2005 and 2005 / 2006.

Results

4.1. Objectives A and B

Where possible observations common to all experiments have been combined.

4.1.1. Early main-stem tipping and fruit retention of conventional and Bollgard II.

A common characteristic of Bollgard II cotton was the absence of main-stem tipping that typifies conventional cotton early in the season. Table 3 shows the difference in the proportion of plants tipped between Bollgard II and conventional cotton measured in this project. The absence of tipping has implications for leaf area development and the timing and rate of fruiting site production compared with conventional cotton. Research by Dr Tom Lei found early tipping increased yields of conventional and Ingard cotton in some seasons (see project report CSP 124C).

Table 3: The percentage of plants with their main-stem tipped for Bollgard II and Conventional cotton. Measurements taken at first flower. In brackets are standard errors. * = fully irrigated treatments only. Data is presented for experiments were there was no tipping due to hail.

Experiment	Bollgard II	Conventional
Growth Analysis 03/04	8 (2.6)	95 (5.0)
Growth Analysis 04/05	9 (2.1)	75 (6.9)
Water Stress 05/06*	3 (2.0)	62 (7.0)
Keytah 05/06	6 (4.1)	88 (12.5)

As expected the proportion of fruit retained was higher at first flower in Bollgard II compared with conventional cotton (Table 4). By the end of flowering (NAWF < 4.5) retention was similar to conventional suggesting that the higher early fruit load had caused shedding later in flowering. Removing flowers from Bollgard II (- flowers) was successful in generating an early retention that was intermediate to Bollgard II and Conventional in the growth analysis experiments.

Table 4: The percentage of fruit retained on all sites at first flower (FF) and last effective flower (LF). In brackets are standard errors.

Experiment	Bollgard II		Conventional		Bollgard II - flowers	
	FF	LF	FF	LF	FF	LF
Growth Analysis 03/04\	91 (2.7)	52 (4.9)	72 (3.2)	52 (2.1)	84 (4.9)	48.4 (4.3)
Growth Analysis 04/05	86 (2.0)	75 (2.5)	70 (2.6)	68 (0.7)	78 (2.2)	72 (1.7)
Water Stress 05/06*	86 (1.8)	68 ()	60 (4.2)	56(x.x)	_	_
Keytah 05/06	95 (0.2)	71 ()	87 (1.6)	73(x.x)	_	_

4.1.2. Plant growth and partitioning - detailed growth analysis experiments.

A key objective of this project was to quantify the processes that may limit yield in high retention cotton. The growth analysis study was designed to generate different retentions, hence fruit loads early in flowering and determine whether carbon supply or nitrogen (nutrient) supply could be limiting when retention is high.

Figure 1 shows, for two seasons, canopy dry weight changes with time and the proportion contained in bolls. Several key observations can be made from Figure1:

- While canopy dry weight increase was unaffected by fruit retention or tipping for most of the growing season or about 150 days after sowing (DAS), the proportion of that weight that was present in bolls was greater in the Bollgard II due to the high early retention and absence of tipping.

- Bollgard II had the highest proportion of bolls for most of the post flowering period while conventional cotton had the lowest, due to the combined effects of tipping and lower retention, and the Bollgard II with early flower removal was intermediate.

- Bolls contributed the same final proportion of canopy dry weight irrespective of retention and tipping. Although the conventional cotton and flower removal treatments took longer to reach maximum boll weight and had a slightly higher canopy dry weight when this occurred.

The above points would suggest that yield potential of the lower retention treatments is potentially higher than the Bollgard II. Although this assumes that pickable lint is produced in the same proportions from the later grown bolls.

A further question that arises from Figure 1 is whether a higher canopy weight at first flower will compensate for higher retention. Table 5 shows that there was a considerable range of canopy dry weights at first flower measured in all the experiments conducted in this study. This range may suggest that manipulation of pre-flowering biomass may be possible using alternative husbandry options, such as earlier irrigation or greater protection from early pests such as thrips. However, temperature may be a limitation in cooler growing regions. Also the 100 g difference observed here is less than 10 % of the final dry weight of a high yielding crop and hence may only translate into a small yield increase.

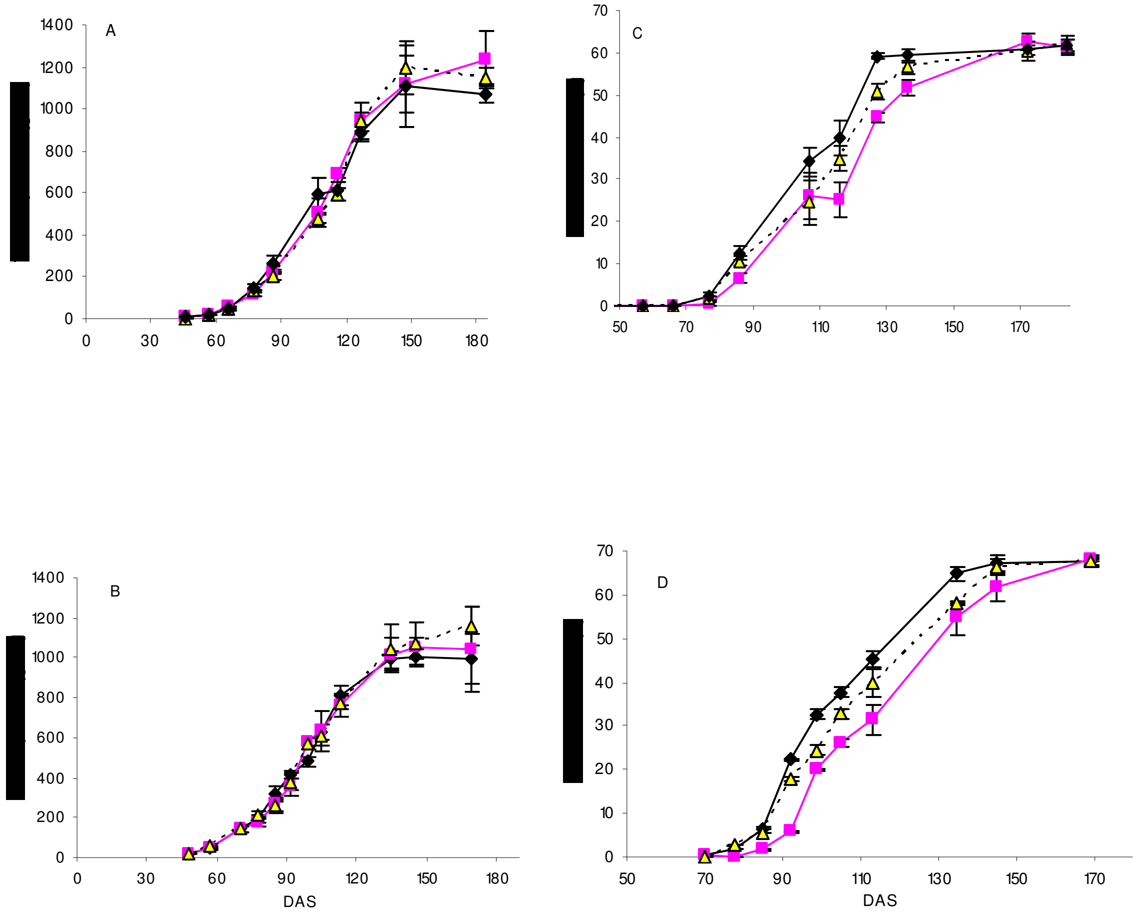

Figure 1: Canopy dry weight accumulation in A) 2003 / 2004 and B) 2004 / 2005 and the proportion of the canopy dry weight that is bolls at each sampling date in C) 2003 / 2004 and D) 2004 / 2005. Where: △- = Bollgard II with fruit removal, ♦ = Bollgard II, ■ = Conventional. Bars are standard errors.

Table 5: The range of measured dry weights (g/m^2) near 1st flower. * = Fully irrigated treatments

Experiment	Bollgard II	Conventional	Bollgard II - flowers
Growth Analysis 03/04	149	117	136
Growth Analysis 04/05	141	141	142
Water Stress 04/05*	182	156	
Water Stress 05/06*	115	126	
Keytah 05/06*	210	247	

Maximum leaf area index (LAI) was less for Bollgard II, which had higher retention and was not tipped out (Figure 2). This is consistent with a higher earlier fruit load preventing later fruiting site production hence production of further leaf area. There was a greater difference between conventional and Bollgard II cotton for the variety Sicot 71BR which is a smaller plant than Sicot 289BR.

Leaf photosynthesis in the lower part of the canopy was generally not affected by fruit retention nor was leaf nitrogen concentration (Figure 3). This data suggests that carbon demand not nutrient supply was the major factor affecting the growth of cotton when fruit retention is high.

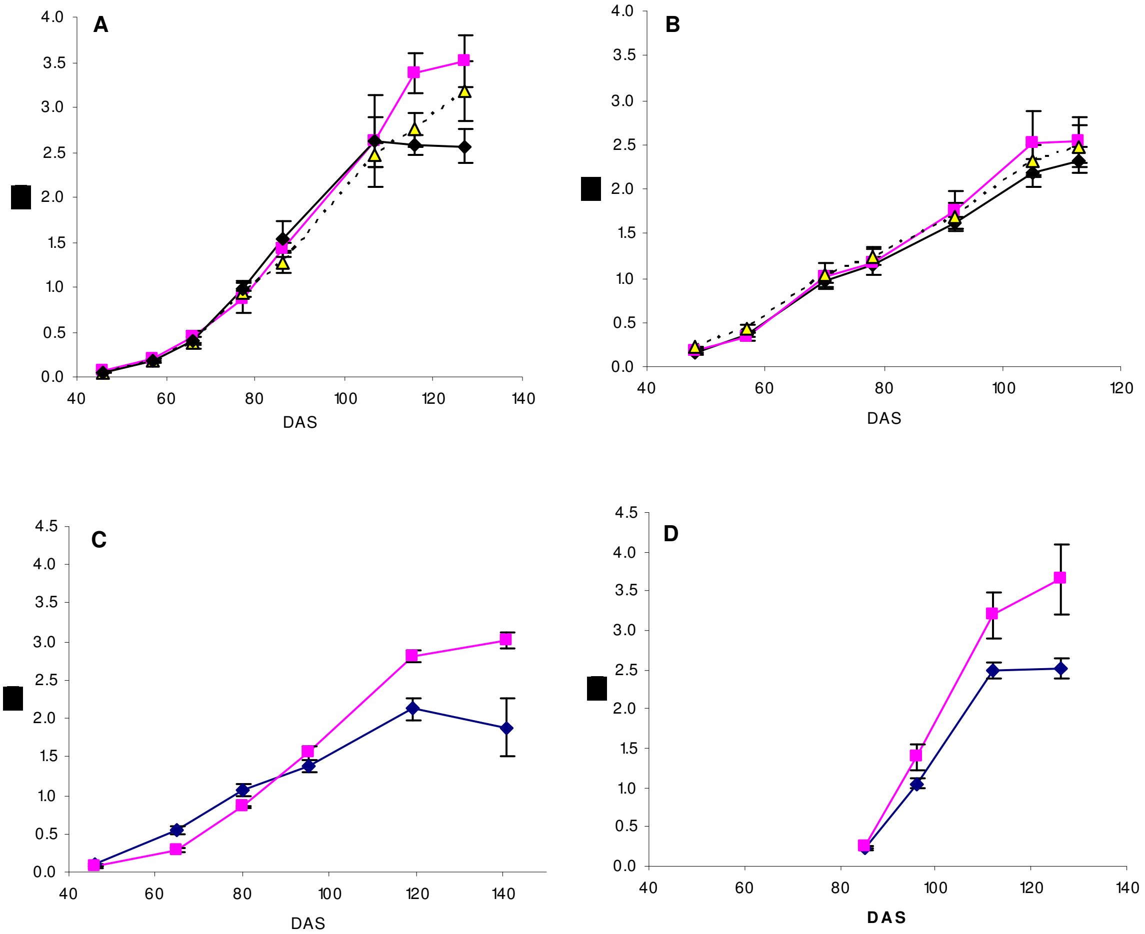

Figure 2: Progress to maximum leaf area index (LAI) as affected by early fruit retention and main-stem tipping. A) and B) are for the detailed growth analysis experiments in 03/04 and 04/05 respectively and C) and D) are fully irrigated treatments in the water stress experiments in 04/05 and 05/06 respectively. Where: - △ = Bollgard II with fruit removal, ♦ = Bollgard II, ■ = Conventional. Bars are standard errors.

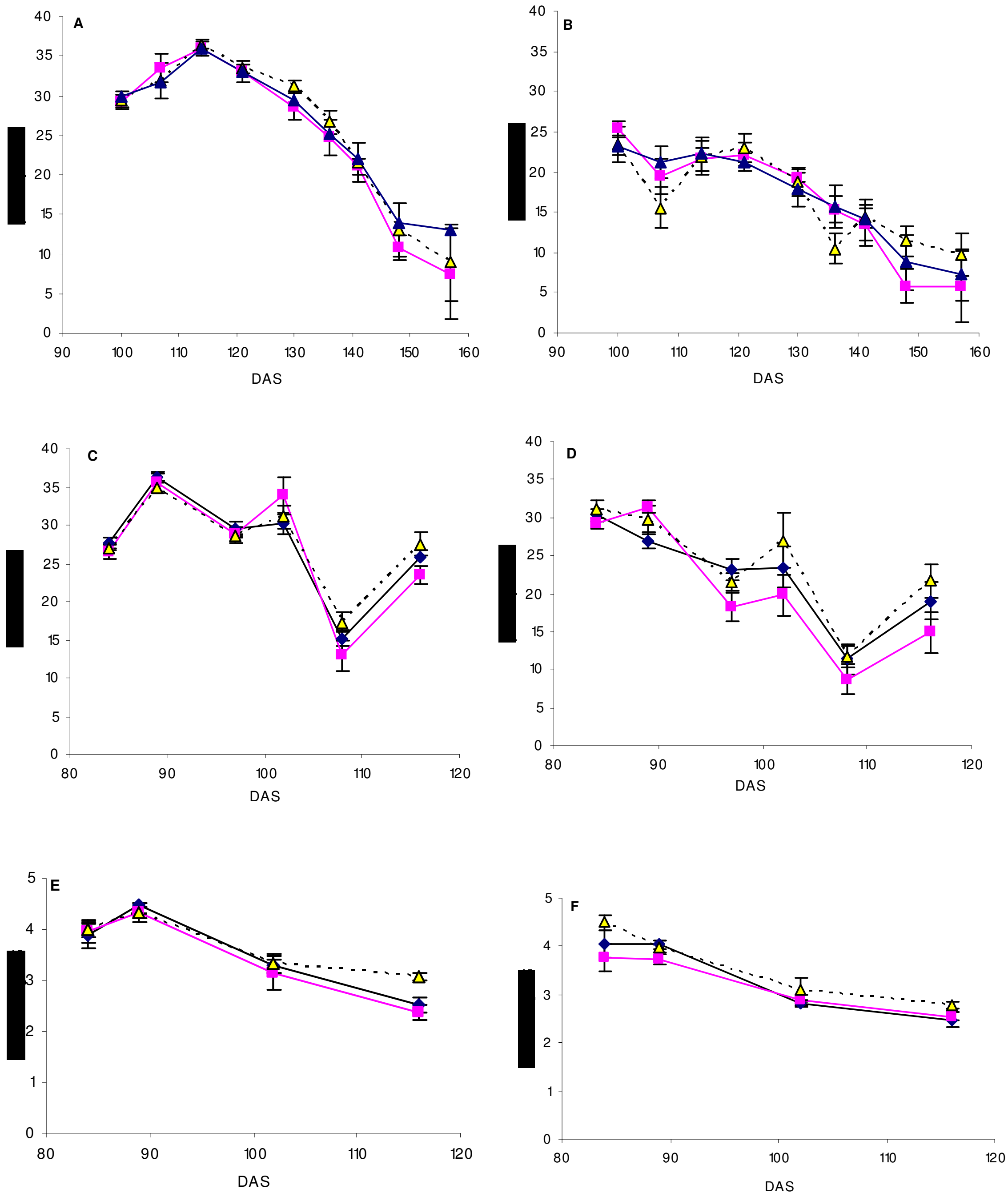

Figure 3: Photosynthesis for: A) main stem leaf 4 03/04; B) 1st fruiting position leaf on fruiting branch 3 03/04; C) min-stem leaf 3 04/05; D) 1st fruiting position leaf on fruiting branch 3 04/05. Leaf N % for: 0405 E) main-stem leaf 4; F) 1st fruiting position leaf on fruiting branch 3. Where: △- = Bollgard II with fruit removal, ♦ = Bollgard II, ■ = Conventional. Bars are standard errors.

4.1.3. Yield and maturity

The lint yields and number of days to maturity for the experiments described previously are shown in Table 6. Yields were not reduced by high retention, although there was no attempt to adjust management for the different fruiting patterns. In the 04/05 growth analysis experiment and the 05/06 water stress experiment the yield of the conventional variety was reduced by late insect damage. Maturity reflected retention but later maturity was not related to higher yield.

Table 6: Yield (b/ha) and days to maturity (60% bolls open). Where ns = not significant, *=P<0.05 and ** = P<0.01 using least significant difference test.

Experiment	Bollgard II		Conventional		Bollgard II - flowers		Significance	
	Yield	Maturity	Yield	Maturity	Yield	Maturity	Yield	Maturity
Growth Analysis 03/04	9.6	158	9.6	165	9.4	166	ns	*
Growth Analysis 04/05	10.5	152	10.2	159	11.0	161	ns	*
Water Stress 04/05*	9.5	173	9.1	196			ns	**
Water Stress 05/06*	9.6	176	8.5	179			**	ns
Keytah 05/06*	11.0	148	11.4	148			ns	ns

4.1.4. Determinacy.

Determinacy is defined as the extent to which vegetative growth ends abruptly. That is, there is a low likelihood of new flushes of leaves and fruiting sites, which may or may not contribute to final yield. Across all the experiments in this study where vegetative and reproductive growth was measured over time Bollgard II was found to be determinant compared to conventional using the same variety background. The termination of fruit numbers coincided with the end of leaf growth, which also coincided with NAWF falling below 4.5. Conventional cotton was not consistent in these relationships.

An interesting finding from the examination of determinacy was the low proportion of final boll weight produced, about 40%, when leaf growth terminated and boll numbers were at their maximum (Fig. 4). When a greater range of experiments were compared the results were similar with 30 to 56% of yield produced when vegetative growth terminated in Bollgard II (Table 7). The variability in the conventional variety reflected its greater indeterminacy using these definitions (Table 7).

The results shown in Figure 4 and Table 7, suggest that for Bollgard II up to 50 to 70% of final boll weigh is reliant on photosynthesis from aging leaves or translocation of stored carbon. Concurrent research by Dr. Lewis Wilson evaluating simulated insect damage to leaves near the top of the plant has shown that yields can be reduced, although these results require further research for confirmation. We propose to collaboration with Lewis to further evaluate the importance of leaf function to yield in high retention cotton.

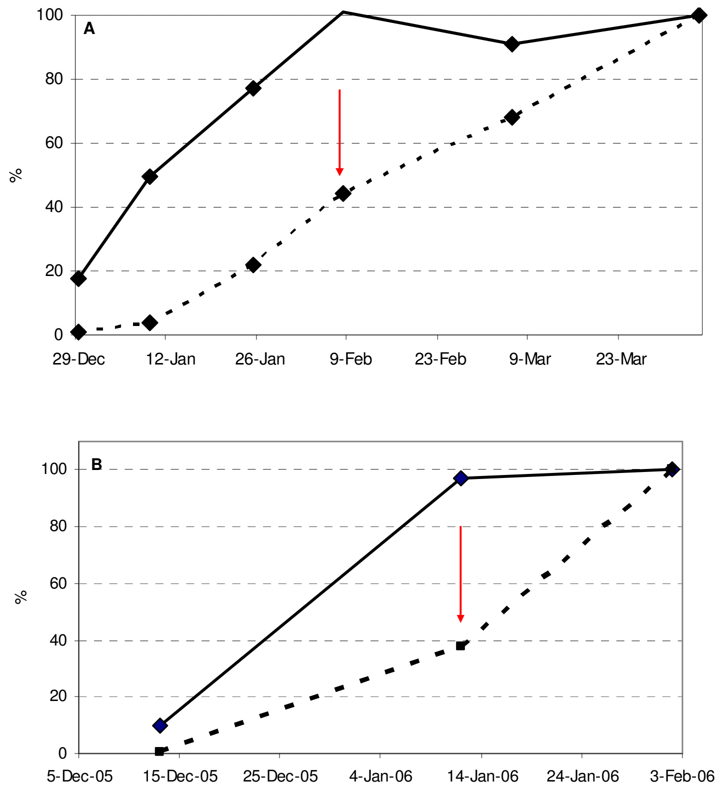

Figure 4: The proportion of final boll number (solid line) and boll weight (dashed line) for fully irrigated treatments using Sicot 71BR A) ACRI water experiment 05/06 , B) Keytah water trial 05/06. The arrow shows the relative boll weight at maximum boll number, which was when vegetative growth has ceased.

Table 7: The proportion of final boll dry weight at the time of maximum boll numbers and cessation of leaf growth for Bollgard II and conventional cotton.

Experiment	Bollgard Yield (b/ha)	% final boll dry weight at max boll number, and when leaf growth terminates.	
		Bollgard	Conventional
Growth Analysis 03/04#	9.6	30	22 to 29
Growth Analysis 04/05#	10.5	35	26
OZCOT validation 05/06#	9.9	56	38 to 44
Keytah 05/06*	11.0	38	45
Water stress 04/05*	9.5	47	28 to 63
Water stress 05/06*	9.6	44	28

Sicot 289 background *Sicot 71 Background

4.1.5. Water Stress

This project also focussed on the obtaining physiological explanations for the effect of water stress on the growth and yield of high retention cotton. The more rapid boll growth and greater determinacy of Bollgard II has meant greater yield losses due to stress toward the end of flowering (Tables 8 and 9). The high boll load on a similar sized plant prevented compensation when the water stress was relieved. The significance of the 36 % yield loss when stressed near last effective flower is highlighted by the fact the stress only lasted about 10 days. This result has important implications for the management of Bollgard II when retention is high.

Table 8: Percentage yield loss relative to fully irrigated Bollgard II and conventional cotton due to skipping irrigations at different growth stages. * Rain during stress period.

	2004/2005		2005/2006		Average	
	Bollgard	Conventional	Bollgard	Conventional	Bollgard	Conventional
First Flower	22	18	24	25	**23**	**21**
Peak Flower	2*	0*	24	2	**13**	**1**
Last effective Flower	32	14	41	19	**36**	**17**
10 days post last flower			4	0	**4***	**0***

Table 9: The relative boll number and weight of Bollgard compared with conventional cotton when moisture stressed at different growth stages after previously being fully irrigated.

		Timing of water stress (Bollgard II)			
		First Flower	Mid Flower	Last Effective Flower	Skip last 2 irrigat
Relative Boll No. (BG/Con)	2005	1.0	3.2	**3.1**	_
	2006	2.4	1.3	**1.5**	1.4
Relative Boll weight. (BG/Con)	2005	1.0	2.5	**3.7**	_
	2006	1.5	1.0	**1.9**	2.3

4.2. *OZCOT modification for high retention cotton.*

Objective C

4.2.1 Variety Parameters

Changes to variety parameters were deemed necessary based on data collected from the experiments described above. The changes to the variety parameters from the conventional equivalent variety that were required to simulate the varieties Sicot 289B and Sicot 71B are summarised in Table 10. The change to 90% fruit survival was based on the average shown in Table 3, (although in validating this value, sensitivity to 86 and 95 % was simulated). Boll size changes were based on observed data and data from breeder's variety comparisons during 2004 to 2006 (a high and median value was tested for each variety). Similarly the lint percentage of Sicot 71BR was changed.

Table 10: New OZCOT variety parameters derived for Bollgard II.

Variety		Fruit survival (%)	Seed cotton / boll (g)	Lint (%)
Sicot 71	Conventional	80	5.2	42
	Bollgard II R	90	5.0	40
Sicot 189/ 289	Conventional	80	4.7	42
	Bollgard II R	90	4.5	42

4.2.2. Validation of new variety parameters

As described in the methods, these were only for crops to provide independent for validation and three of these crops were grown in 2005 / 2006. To increase the data set and to include a wider range of seasons, all other experiments were also simulated using the new parameters. Further validation will be conducted when new data becomes available.

Figure 5 shows that yield at Keytah using two different irrigation schedules could be accurately predicted. Similarly, accurate yield predictions were made for growth analysis experiments and the crop of Sicot 289BR at ACRI in 2004/2005. The greatest deviations from observed occurred in the 2005/2006 season at ACRI and in the water experiments at ACRI. There are two reasons for these differences: First the soil in the water experiment has different hydraulic properties than typical cotton soils. We expect future enhancements of OZCOT, using components from the APSIM model, to solve this problem; Second, the hot dry conditions of the 2005/2006 season resulted in an under prediction of leaf area index (LAI), which is linked to fruit number and yield.

The capacity of the new variety parameters to simulate fruiting dynamics and LAI was also extensively tested. Figure 6 is an example of this testing for the Sicot 289BR validation experiment of 2005/ 2006. While square number was accurately predicted, green bolls and LAI were poorly simulated. The model failed to predict the crops recovery from a low leaf area at early flowering that coincided with hot dry weather. The need to improve OZCOT's capacity to simulate LAI has been highlighted by this analysis. Errors in the simulation of LAI are unlikely to reduce the accuracy of HydroLOGIC, as LAI data is usually provided from field observations as the season progresses.

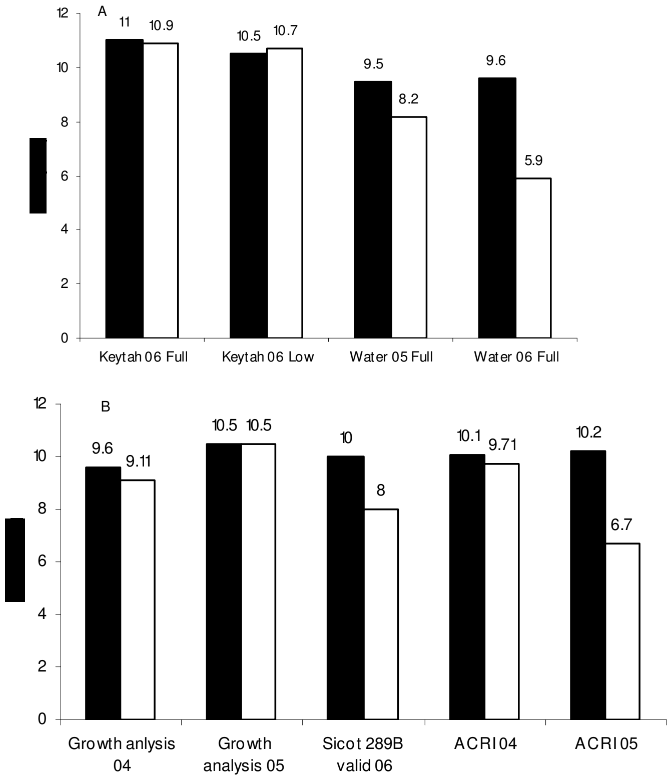

Figure 5: Observed (black column) v simulated (white column) yield using OZCOT modified for high retention Bollgard II varieties A) Sicot 71, B) Sicot 289B.

The rigorous analysis of the growth and development of high retention BollgardII cotton has identified possible constraints to yield compared with conventional cotton. The importance of larger plant size at flowering and avoidance of water stress late in flowering are immediate outcomes for industry. In the longer term additional research questions arising such as breeding for a large plant, measuring the contribution of upper leaves and improved scheduling of irrigation will have positive outcomes for yield and water use efficiency.

The data provided had been used to modify and validate the OZCOT model. This will allow more accurate prediction of yield in Bollgard II crops. This will be beneficial both for strategic studies using OZCOT to simulate long term trends in yields and tactical applications such as in HydroLOGIC.

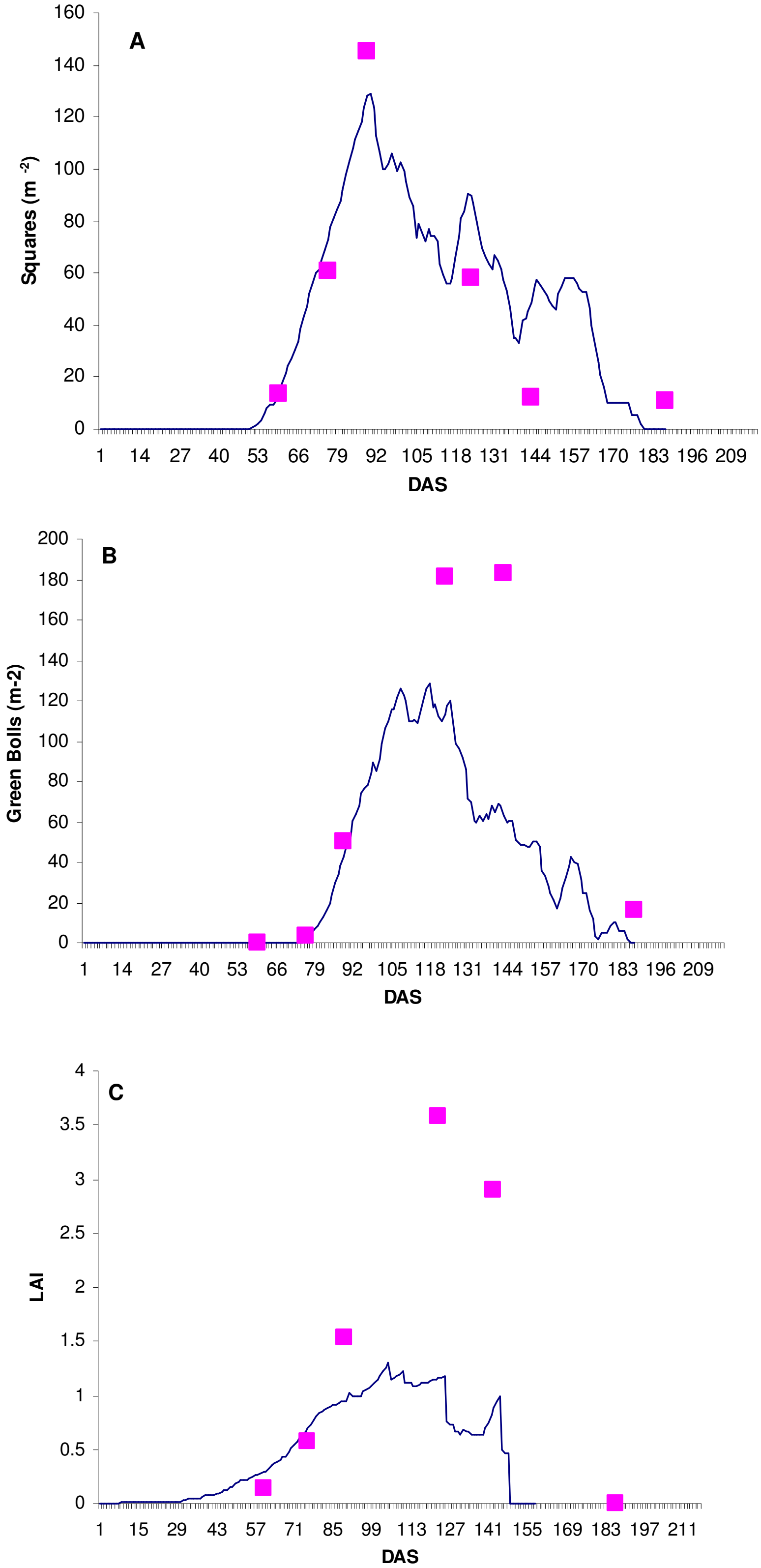

Figure 6: Observed (■) vs predicted (line), A) square number; B) green boll number and c) leaf area index for Sicot 289B in 2005 / 2006 validation experiment at ACRI.

1. **Please describe any:-**
   a) **technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);**

   Modification of OZCOT for high retention Bollgard II varieties Sicot 289BR and Sicot 71BR

   Progress toward more effective management of current Bollgard II varieties and significant effort and success in passing the message onto growers.

   b) **other information developed from research (eg discoveries in methodology, equipment design, etc.); and**

   Plant removal in Fusarium regions – conducting research of this nature in regions where a Fusarium protocol for bring plant material into ACRI is required is extremely difficult and limits the capacity for detailed physiological research in these areas. There is a need for facilities to process and dry plant samples in regions like the Gwydir.

   c) **required changes to the Intellectual Property register. -** Unlikely

Conclusion

2. **Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?**

7.1. Summary of conclusions:

- High retention in the absence of early main-stem tipping combined with a lower leaf area index were characteristics of Bollgard II. As a result, boll growth was earlier and often faster than conventional cotton.
- Potential yield could be less due to smaller plants because harvest index was conservative and independent of retention or tipping. However, yield increases are likely to be confined to regions with a long growing season.
- Leaf nitrogen and photosynthesis on leaves lower in the canopy was not affected by retention, suggesting that carbon demand from bolls was the major cause of growth differences due to high retention in these experiments.
- Due to the rapid increase in boll growth, Bollgard II was more determinate than conventional cotton, hence less capable of recovering from water or other stress late in flowering.
- The greater determinacy of Bollgard II meant that leaf production consistently terminated when approximately 40% of final boll weight had grown, hence the crop was reliant on aging leaves and translocation to complete development of the remaining 60%. Research is now measuring the contribution of older leaves to yield in Bollgard II crops.
- The variety parameters (fruit survival, seed cotton per boll and lint percentage) for the modification of OZCOT to simulate Bollgard II varieties were measured and validated. However this work identified the need for improved simulation of Leaf Area Index in high retention cotton.

7.2. Likely impacts of this research:

- Options for increasing yield in high retention cotton were identified from this research. These include increase plant size via managing for a larger plant either at first flower or at maturity and breeding for a larger plant. The former option would involve changes to water management and possibly early insect management to increase early leaf area. Research in 2006/2007 is evaluating water management options.
- The need to monitor fruit load and avoid moisture stress late in flowering of Bollgard II varieties was identified from this research.
- The OZCOT model and HydroLOGIC will be modified to improve the simulation high retention Bollgard II varieties Sicot 71BR and Sicot 289BR.

Extension Opportunities

3. 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.

In the original proposal a key process for dissemination of outcomes from this research was to be via the farming systems scientist's project (Grant Roberts). This position has been vacant since April 2005 and the extension plan has required modification:

8.1. Indirect extension
Incorporate research findings into HydroLODGIC and OZCOT.

8.2. Direct extension
There has been a lot of interest in Bollgard II as it is a new technology that represents a new opportunity and may require a change in management. Hence, there has already been significant direct dissemination to consultants, growers who have good physiological knowledge and the skills to interpret this information when presented in a technical form and make management adaptations. In addition to continued face to face communication and media interviews there will be at least one Cotton Grower article.

9. A. **List the publications arising from the research project and/or a publication plan.**
(NB: Where possible, please provide a copy of any publication/s)

Scientific publications are planned.

Update of grower information on management of Bollgard II.

Cotton Grower Article.

B. **Have you developed any online resources and what is the website address?**

No

Appendix 1 – 2006 Australian Cotton Conference Paper

Progress in evaluating the moisture stress response of Bollgard II® compared with conventional cotton

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CSIRO Plant Industry, ACRI, Narrabri and Cotton Catchment Communities CRC

Key Points

- Bollgard®II accumulated yield faster than conventional cotton due to higher retention combined with a very low proportion of tipped plants. This meant that late in flowering and at cut-out Bollgard®II was less able to compensate for water stress equal to a depletion of ≥120mm of soil water (≥ 58% plant available soil water) and yields were lower relative to conventional cotton stressed at the same time.
- Yields and soil water extraction of Bollgard®II and conventional cotton were the same when moisture stress occurred at early flowering.
- With full irrigation, that is soil water deficits of 44 to 83 mm, Bollgard®II had the same yield or higher yield than conventional cotton but matured earlier due to more rapid boll setting.
- Future research will aim to optimise irrigation scheduling of Bollgard®II for yield and water use efficiency.

Introduction

Prior to introduction of Bollgard®II varieties there was a concern that the water requirements and irrigation scheduling may differ from conventional varieties. One hypothesis was that a Bollgard®II plant with higher early fruit load and less likelihood of tipping, might be smaller at the start of flowering and might have a smaller root system during the peak flowering and boll filling period. If that was true, Bollgard®II may require a different irrigation schedule.

Experiments were initiated to clarify and quantify any differences in plant water demand between conventional and Bollgard®II varieties, and to begin formulating management guidelines if required. We describe in this paper progress with the following objectives:

- Determining the sensitivity of Bollgard®II is to soil moisture stress at different plant development stages.
- Relating fruit retention patterns to plant water extraction and yield.

The irrigation water use efficiency of Bollgard®II and conventional cotton is presented in an accompanying paper (Richards et al., these proceedings).

Methods

Two experiments were conducted, using furrow irrigation at ACRI, Myall Vale in 2004 / 2005 and 2005 / 2006. The Bollgard®II variety Sicot 71BR and its conventional equivalent were planted on the 25-26th October 2004 and 3-4th October 2005 with an established plant stand of 12-14 plants / m of row. There were 3 replications of each irrigation treatment for each variety. Plot size was 24 rows by the length of the field, which, was 600m in 04/05 and 500m in 05/06. Insect pest management decisions were made using CottonLOGIC thresholds for each variety. Full irrigation was compared with skipping the first, second and third irrigations. In 05/06 an additional treatment of skipping the final 2 irrigations was included (Table 1).

Table 1: Irrigation treatments (NT = not tested)

Treatments	Date when irrigation skipped	
	2004 / 2005	**2005 / 2006**
Full irrigation	None	None
Skip 1st irrigation	6-Jan	29-Dec
Skip 2nd irrigation	21-Jan	9-Jan
Skip 3rd irrigation	4-Feb	27-Jan
Skip final 2 irrigations	NT	8-Feb and 6-March

Results

Tipping and fruit retention

The most obvious early season difference was the greater main-stem tipping and lower total fruit retention of conventional cotton. At first flower tipping of the conventional variety was 5 to 20 times more frequent than in Bollgard®II. Fruit retention (all sites) at first flower was 89% in Bollgard®II compared with 62% in conventional cotton. Hence, boll numbers and boll weight increased at a faster rate in Bollgard II®, resulting in earlier maturity.

Growth stage and relative boll load at time of water stress.

Water stress at the first and second irrigations coincided with early flowering and mid-flowering in both varieties (Table 2). However, by the third and later irrigations Bollgard®II had a higher fruit load and the growth stages were different (Table 2). The third irrigation coincided with last effective flower or cut-out in Bollgard®II and late flowering in the Conventional. In 05/06 the conventional cotton was at cut-out about the time of the fourth irrigation or 12 days later than the Bollgard®II. The relative boll number reflected the rapid fruiting in the Bollgard®II and after the first irrigation was between 1.3 and 3.2 times that of the conventional cotton (Table 2).

Soil water deficits and relative yield.

In both seasons there was no difference in soil water extraction between the varieties up to cut-out in Bollgard®II 04/05 and up to 14 days after first flowering in 05/06 (Table 3). In 05/06 there was greater soil water extraction by the conventional during the cut-out stress due to a greater leaf area.

Where no irrigation was made post cut-out in 05/06, the Bollgard®II extracted more soil water with a higher yield than the conventional. This yield difference was to the Bollgard®II being at a later stage of development when the irrigations were skipped, so it required less water to complete growth.

Table 2: Details of crop growth stage and relative boll number of Bollgard®II (BG) compared with Conventional (Con) when water stress was imposed. The rainfall during stress periods is also shown.

		Irrigation Skipped			
		First	**Second**	**Third**	**Fourth and Fifth**
Growth Stage	04/05	1st Flower	Early Flowering	Cut-out BG	–
	05/06	Early flowering	Mid flower	Cut-out BG	Boll fill

Relative Boll No. (BG/Con)	04/05 05/06	1.0 2.4	3.2 1.3	3.1 1.5	_ 1.4
Rain during stress (mm)	04/05 05/06	6.4 0	41 48	46 65	- 102

There were four consistent trends in relative yields shown in Table 3:

1. Under full irrigation the Bollgard®II yield was greater than the conventional.
2. Water stress at first flower did not affect yield of Bollgard®II compared with the conventional.
3. When the third irrigation was skipped at cut-out of the Bollgard®II yield was much lower than the conventional (83%). It seems the conventional was able to compensate for the water stress due to it not having completed flowering.
4. Lower relative yields of Bollgard®II at or prior to cut-out were associated with soil water deficits around 120mm or extraction of at least 58% of plant available water.

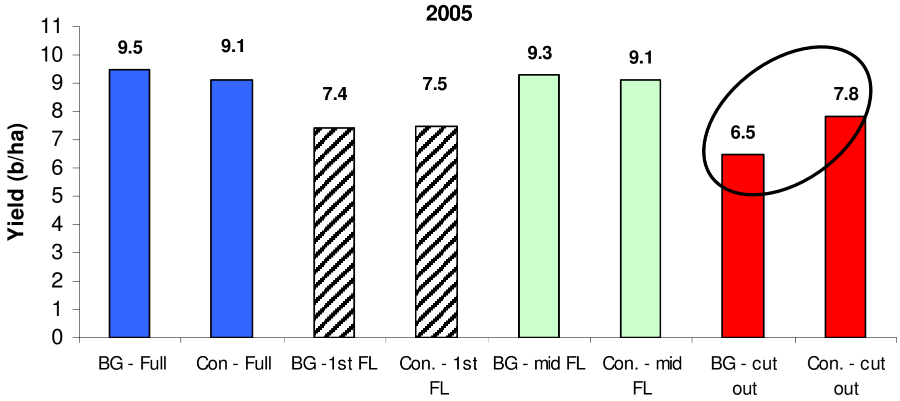
Table 3: Soil water deficits of stress treatments compared with full irrigation and yield of Bollgard®II relative to conventional for each stress treatment. NB the plant available soil water was measured as 207mm to 120cm.

Timing of water stress	2004 / 2005			2005 / 2006		
	Soil Water Deficit (mm)		Relative Yield (BG/Con %)	Soil Water Deficit (mm)		Relative Yield (BG/Con %)
	BollgardII®	Conventional		BollgardII®	Conventional	
Full Irrigation#	44	50	104	83	78	112
First Flower	79	77	99	104	113	115
Mid Flower	94	91	103	126	120	89
Cut-out*	121	118	83	121	145	82
Skip last 2 irrigations	_	_	_	187	165	108

Soil water deficit is average of irrigations skipped * Bollgard NAWF < 4.5, Conventional NAWF > 5.4.

Lint Yield.

The lint yields for each treatment are shown in Fig. 1. Lint yield of Bollgard®II was the more variable than conventional being the highest when fully irrigated and the lowest when stressed at cut-out. The significantly lower yield in the fully irrigated conventional in 05/06 was due to *Helicoverpa* caterpillars that could not be sprayed for a 10 day period during mid-January due to poor weather. In both seasons Bollgard®II was most sensitive to water stress at cut-out.



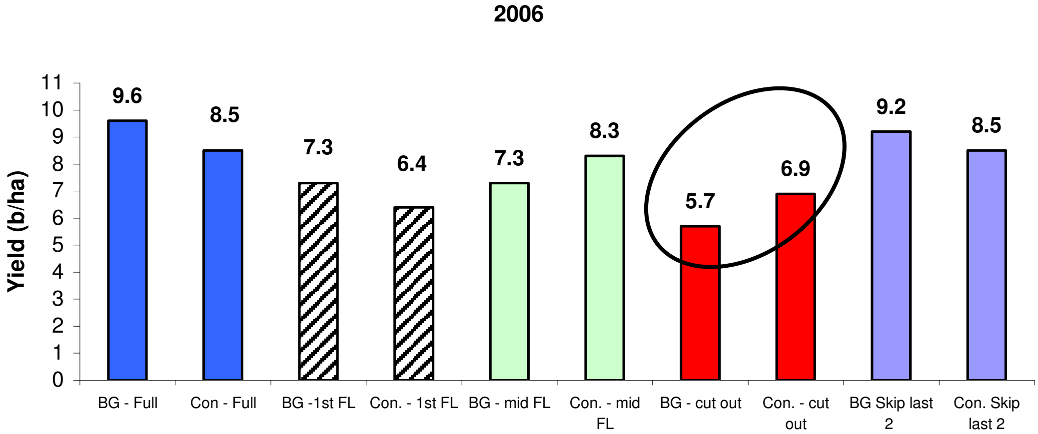


Fig. 1: Machine picked lint yields for different stress treatments. Where $lsd_{0.05}$ 2005 = 0.86, and 2006=0.71. Circled is the yield difference for stress near cut-out for Bollgard II®.

Fibre quality differences.

In 04/05 significant differences were found for fibre length and micronaire (Table 4). Stress at or near cut-out significantly reduced fibre length, while earlier stress had no effect. The conventional cotton had lower micronaire than Bollgard®II with full irrigation and when water stress occurred in early flowering. When stressed late in flowering, micronaire was higher in the conventional and equal to Bollgard II®. The micronaire of Bollgard®II was not affected by moisture stress during flowering or at cut-out. The difference between the fully irrigated Bollgard®II and the conventional for fibre length and micronaire could be partly explained by fibre development occurring under different temperatures, due to later fruiting in the conventional variety.

Table 4: Significant fibre quality differences in 04/05, length and micronaire.

Timing of water stress	**Length (in)**		**Micronaire**	
	Bollgard®II	**Conventional**	**Bollgard®II**	**Conventional**
Full Irrigation	1.140	1.158	4.65	4.33
First Flower	1.143	1.168	4.60	4.53
Mid Flower	1.142	1.167	4.76	4.36

Cut-out	1.113	1.115	4.78	4.76
$lsd_{0.05}$	0.027		0.27	

Conclusions

- Bollgard®II accumulated yield faster than conventional cotton due to higher retention combined with a very low proportion of tipped plants. This meant that late in flowering and at cut-out Bollgard®II was less able to compensate for water stress equal to a depletion of ≥120mm of soil water (≥ 58% plant available soil water) and yields were lower relative to conventional cotton stressed at the same time.

- Bollgard®II showed similar sensitivity to water stress in early flowering and soil water extraction was the same as conventional cotton.

- In 04/05 fibre length was only reduced by stress at cut-out, which occurred for Bollgard®II and conventional cotton. Micronaire of Bollgard®II was not affected by water stress during flowering or cut-out. Although under full irrigation the conventional variety had lower micronaire than Bollgard®II.

Part 4 – Final Report Executive Summary

The Physiology of High Retention Cotton- Research identifies options that may increase yield and water use efficiency of high retention Bollgard II cotton.

Options for increasing yield and water use efficiency in high retention Bollgard II cotton were identified from research that studied the growth and development of Bollgard II and conventional cotton varieties. Options include increase plant size via managing for a larger plant either at first flower or at maturity, breeding for a larger plant and avoiding water stress late in flowering. The former option would involve changes to early water management and possibly early insect management to increase early leaf area.

A further outcome of this research is changes to the OZCOT model and HydroLOGIC irrigation support tool which will assist growers with management decisions when growing the Bollgard II varieties Sicot 71BR and Sicot 289BR.

This research found that high fruit retention in the absence of early main-stem tipping combined with a lower leaf area index late in flowering were characteristics of Bollgard II. As a result, boll growth was earlier and often faster than conventional cotton. Potential yield could be less due to smaller plants in Bollgard II crop with high retention because harvest index (the ratio of boll weight to total plant weight) was the same as conventional cotton However, yield differences are likely to be confined to regions with a long growing season and full irrigation, where the later fruit set and larger plant size of conventional or lower retention crops will allow them to mature a bigger crop.

The need to monitor fruit load and avoid moisture stress late in flowering of Bollgard II varieties was identified from this research. Due to the rapid increase in boll growth, Bollgard II was more determinate than conventional cotton, hence less capable of recovering from water or other stress late in flowering.

Leaf nitrogen and photosynthesis on leaves lower in the canopy was not affected by high retention, suggesting that rapid boll growth was the major cause of growth differences due to high retention in these experiments.

Future research identified from this project includes, optimal water management of Bollgard II including options to increase early plant size, the contribution of upper leaves to yield in high retention cotton and further enhancements to OZCOT that will improve simulation of crop water use and requirements, and ultimately lead to an improved HydroLOGIC DSS.

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