FINAL REPORT

(due within 3 months on completion of project)

Part 1 - Summary Details

Cotton CRC Project Number: 1.4.08 (was 1.2.03)

Project Title: Optimal Production and Water Use of High Retention Cotton and other New Technologies

Project Commencement Date: 1/07/2006 **Project Completion Date:** 30/06/09

Cotton CRC Program: **The Farm.**

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Part 3 – Final Report Guide (due within 3 months on completion of project)

(The points below are to be used as a guideline when completing your final report.)

Background

1. Outline the background to the project.

This project focused on understanding then optimising the crop response to water when using new technologies, such as high retention Bollgard II varieties and changed application methods such as low deficit scheduling in pressurised irrigation systems.

The release of Bollgard II cotton varieties has required efficient water management of a plant that can produce very high yields with a main stem that is rarely tipped by insects and has very high early fruit retention. Hence a high boll load early in flowering can lead to premature cut-out and lower yields. The aim of our research was to tailor irrigation scheduling that could combine soil and plant based measurements of plant stress to optimise the yield and water use efficiency of these high retention varieties.

The growth response of lower fruit retention conventional cotton is well documented (Hearn 1996). Abundant water combined with high rates of nitrogen fertiliser will stimulate vegetative growth, particularly leaves, at the expense of fruit, which is often shed. Therefore, at intermediate water and nutrient availability, vegetative and fruit growth is balanced. Below this optimum, nutrient and or moisture stress may reduce fruit production. Hence, in south-eastern Australia scheduling furrow irrigation after 40 to 60 % of plant available moisture is removed from the soil has been shown to be optimal on grey vertisols (Constable and Hearn 1981, Cull et al. 1981). This variation in optimal plant available moisture is likely to be due to the effect of evaporative demand and adaptation to abiotic stress (Sadras and Milroy 1996). It is not known to what extent the higher yield potential and fruit retention will change the response of cotton to soil water deficit and evaporative demand.

This project also collaborated with the final year of ”Delivering science to agribusiness; smart approaches to cotton irrigation” (CSP164) objective 1 ‘Irrigation research for emerging crop management issues’, as Stephen Yeates was the second researcher and led this component of the project. Research underway on comparing irrigation scheduling of Bollgard II and conventional needed to be continued for at least one more season. In those experiments, we expected that a high boll load may limit root development of Bollgard II compared with conventional cotton. Initial results from these experiments differed slightly from our expectation because yield differences between conventional and Bollgard II were not due to greater rooting depth of conventional cotton but were due to differences in boll development between the varieties at the time of moisture stress. Further research covering wider seasonal variation was required to confirm this response and to permit accurate measurement of the water requirements of transgenic and conventional cotton.

This project also built on a completed study CSP161C ‘The physiology of high retention cotton crops’ which developed an understanding of the impact on yield, growth and partitioning in crops with a rapidly increasing fruit load using the same irrigation management as conventional crops. The project reported here assessed, in detail, the effects of the rapidly increasing fruit load in response to changed irrigation management. A collaborative PhD project with Marcelo Paytas (student) and Prof. Shu Fukai (University of Queensland) "Growth and yield affected by early water stress and nitrogen in high retention cotton" provided the opportunity to measure early water stress reliably using a rain-shelter facility at Gatton. Warren Conaty's PhD study (University of Sydney) was also closely linked to this project in the measurement of the growth response to crop factors using drip irrigation and in evaluating the value of BIOTIC sensors in the drip and furrow irrigation experiments conducted by this project.

Objectives

2. List the project objectives and the extent to which these have been achieved.

The final project objectives are listed below:

1. Compare the water use and crop response of Bollgard II and conventional cotton to water deficits at different growth stages in 1m and 30" systems.
2. Measure the crop response to different irrigation deficits and evaluate methods of measuring deficits.
3. Evaluate pressurised (tape) irrigation for management of growth and yield using irrigation scheduling.
4. Validation and enhancement of the OZCOT cotton growth model for Bollgard II response to water availability and new production scenarios in Central Queensland and the Burdekin.

There were several changes from the original proposal due to reduced water availability and funding cuts. All changes were negotiated with the Cotton CRC and CRDC. Objectives 1, 2 and 3 have been achieved while OZCOT validation has been achieved for Objective 4. The validation exercise identified the need for further research before model enhancement can occur. One objective of improving OZCOT so HydroLOGIC will better predict the water balance of Bollgard II varieties was discontinued when further development of HydroLOGIC was not supported in 2007.

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

Objective 1:

A 3rd season's replicated experiment, building on two conducted in an earlier project (CSP161C), was conducted at ACRI in 2006/2007 where the response of Bollgard II to water stress at different stages of development was compared with conventional cotton in a Sicot 71 background. A fully irrigated treatment (deficit commonly used on conventional) was compared with two water stress treatments, one at cut-out and the other at 14 days after cut-out. Measurements were: dry weight accumulation, partitioning, leaf area development, fruit retention, main-stem tipping, lint yield, fibre quality, soil water extraction, irrigation application efficiency and water volumes.

Comparisons were also made between Bollgard II and conventional varieties in 2007/08 and 2008/09 at Keytah near Moree using 75cm (30") systems. In 2007/08 a replicated experiment compared the water requirement and yield of Bollgard II and conventional. In this experiment yield, the water balance, plant growth and retention were measured. This trial was in collaboration with Janelle Montgomery (NSW DPI) who led the collection of water balance data and the staff at Keytah (Andrew Parks and Peter Gall). The plant growth and retention measurements were made by this project. In 2008/2009 a similar comparison was made except that varieties were in separate, adjacent fields.

New methodologies for disinfecting Fusarium wilt from plant samples that permitted leaf area to be measured were developed from the trials at Keytah. This involved transporting leaves in alcohol to ACRI then air drying and measuring leaf areas and dry weights.

Objective 2:
A replicated experiment was conducted in each of 3 seasons from 2006 to 2009 at ACRI using furrow irrigation. Compared were four irrigation deficits 40, 60, 80 and 120 mm which equates to 20, 30, 40 and 60% of PAWC (plant available water content) for a soil with approximately 200mm of plant available water (See Table 1). Measured were: soil water extraction, ET, dry weight accumulation, partitioning, leaf area development, fruit retention, main-stem tipping, lint yield, fibre quality, soil water, irrigation application efficiency and water volumes and harvest box mapping. In the first two seasons an additional treatment was included where cotton was irrigated at a 60mm deficit until cut-out with 1 less irrigation after cut-out than the standard 60mm deficit treatment. In 2008/9 a treatment where no irrigation was applied until early flowering followed by irrigating at a 60mm deficit was included. This treatment was part of Marcelo Paytas' PhD studies at the University of Queensland that were supported by the Cotton Catchment Communities CRC.

Table 1: Deficit treatments and frequency of irrigation. NB deficit calculated as difference from drained upper limit.

Target Deficit (mm)*	Expected days between irrigations – no rain	Actual range of days between irrigations
35- 45	7	6 to 14
55- 65	10	8 to 24
75- 85	14	11 to 31
115 – 125	21	19 to 44

A simple method for determining a site specific crop factor (Kc) at any stage during the growing season was developed from these experiments. Kc was linearly proportional to canopy light interception (LI) where Kc = 1.2719*LI-0.0779, r^2=0.95 except when LI < 0.70 and irrigation or rain (≥ 15mm) occurred within 48 hours of measurement then Kc = 1. The soil water deficit could be accurately calculated from this and the ETo.,Thereby reducing the frequency of time consuming neutron probe measurements. In conjunction with the calculation of Kc described above, daily ETo was calculated from the ACRI meteorological station and added to the climate data on the Cotton Catchment Communities web site via the query data base (http://tools.cotton.crc.org.au/tools/acriweather/wx.aspx).

Objective 3:
Due to a shortage of land and water at ACRI, research into pressurised irrigation systems was conducted in collaboration with PhD student Warren Conaty. Five drip (surface)

irrigated treatments 25, 50, 75, 100, 125% of crop evapotranspiration (ETc) were compared over two seasons in 2007 to 2009. Daily ETc was calculated using a crop factor (Kc) as ETo*Kc. The crop factor was calculated from the relationship with light interception developed in Objective 2. Measurements taken for this project were lint yield, dry weight, partitioning, fruit retention and the position on the plant of pickable bolls was mapped at maturity.

Objective 4:
David Johnston (CSIRO) conducted most of the simulation analysis described below. The response of Bollgard II (Sicot 70BRF) to irrigation deficit was simulated for the three seasons of experiments and compared with observed yields, fruiting dynamics, leaf area index, water use and time to maturity. Simulations were run in OZCOT (stand–alone version) to assess its performance in modelling crop growth and water use. Crop growth was assessed against LAI development and maximum leaf area, fruiting site production, boll counts over time, open boll counts, seed cotton per boll and final lint yields (more detail is provided in Appendix 2).

We also tested the performance of OZCOT in more tropical environments where different humidity and cloudiness conditions could challenge its reliability as it was not developed for the environments. A similar validation exercise to that described above was conducted for the time of sowing date x yield study conducted at Emerald by Richard Sequeria (QDPI). The aim here was to evaluate the OZCOT model's capability to simulate the growth and yield of November and December sowings. The OZCOT model was also validated for the warm cloudy wet conditions that occur in the Burdekin using data from Paul Grundy's (QDPI) climate adaption experiments conducted at Ayr in 2008 and 2009.

Results

4. Detail and discuss the results for each objective including the statistical analysis of results.

Objective 1: Compare the water use and crop response of Bollgard II and conventional cotton to water deficits at different growth stages in 1m and 30"systems.

<u>i) The Final year of replicated Bollgard II vs conventional water use and stress response experiment</u> was conducted in collaboration with Dirk Richards at ACRI, where full irrigation (traditionally used for conventional) was compared with stress at first flower, mid flower, cut-out and post cut-out. As much of this work is contained in the final report of project (CSP164) by Dirk Richards in 2007 only key results are summarised here.

The irrigation water applied is shown in Table 2. Averaged over three years Bollgard II required 0.5 less ML ha of irrigation water than conventional cotton. The average lint yield was 10.1 and 9.2 b/ha for Bollgard II and conventional respectively. The difference in water requirement and lint yield between the varieties was explained by greater insect damage in conventional cotton. Prior to flowering caterpillar pests tipped the main stem on the conventional variety 5 to 20 times more frequently than in Bollgard II. Fruit retention was also significantly reduced by these pests in the conventional variety. The effect of this damage was to delay time to maturity and increase leaf area of the conventional variety, which, in turn, increased crop water use. An additional irrigation was required in 2004 / 2005 (Table 1).

Table 2: Total irrigation water applied (ML/ha) to replicated experiments at ACRI.

Season	Sicot 71BR	Sicot 71
2004 / 2005	6.9	7.8
2005 / 2006	5.7	6.1
2006 / 2007	6.3	6.5
Average	6.3	6.8

Bollgard II was more sensitive to water stress than conventional at cut-out. Yield was reduced by 36% and 17% in the Bollgard II and conventional varieties respectively after skipping an irrigation at this stage In other words a yield loss of 2.7% per day of stress for BGII compared to 1.2% per day for the conventional. This was an important finding at a time when growers were still adapting irrigation strategies for high retention Bollgard II varieties and when drought of necessitated stretching of irrigation intervals. Hence the message don't stress during flowering or grow conventional varieties instead was widely extended to industry.

Where water is limited, stretching irrigations after cut-out had less impact on yield of Bollgard II than conventional because crop water use drops off significantly at this time.. From the additional treatment in the deficit experiments (see methods Objective 2) we found by applying 1 irrigation between the normal 2 irrigations, yield was reduced by 10 to 18 % if there was no rainfall and as little as 0 to 9 % if good timely rain fell after this final irrigation (>40mm). In these experiments the irrigation after cut-out was stretched to 21 days; it is possible that if the irrigation interval was only 14 days, then the yield reductions would have been even less.

ii) Water use, growth and yield of Bollgard v Conventional at Keytah in 30" beds 2007/08 and 2008/09.

The report for the 2007/08 season is in Appendix 2. Key findings relevant to this project are:

- Water balance comparisons are very sensitive to field variability hence replication is essential to gain meaning full results from on-farm evaluations.
- The difference in water requirement and yield between Bollgard II and conventional versions of the same variety could be explained by the *Helicoverpa* damage on plant morphology. That is, if the proportion of plants tipped early in growth and the fruit retention are similar then the yield and water use will also be similar. This was the case in 2007/08.

The trial in 2008/9 collected additional data on the relationship between Helicoverpa damage and water use / yield differences between Bollgard II and conventional. Due to technical issues with the Mace meters a water balance had not been calculated and a report for this trial could not be completed at the time of writing.

iii) Summary of Bollgard II v Conventional variety comparisons for water use and yield 2005 to 2009.

Combining the comparisons made in previous projects (CSP164, CSP161C) with this project over the past 5 seasons the severity, type and timing of *Helicoverpa* damage to the conventional variety could be related its effect on plant morphology which permits prediction of WUE and yield differences to the Bollgard II variety (Table 3).

Table 3: The impact of the type, severity and timing of *Helicoverpa* damage to a conventional variety on the likely water use, yield and WUE differences from a Bollgard II variety.

Insect damage to conventional	Effect of damage on plant morphology	Performance of conventional compared with Bollgard II		
		Water use	**Yield**	**WUE**
Pre squaring tip damage	High early tipping + High retention	~=	+	+
Pre squaring tip damage and early square removal	High early tipping + lower early retention	+	~=	-
Tip damage and fruit removal up to late flowering	High late tipping % + low cut-out retention	+	-	-
Low pest pressure.	Low tipping < (40%) + similar retention to BG	=	=	=

Objective 2: Measure the crop response to different irrigation deficits and evaluate methods of measuring deficits.

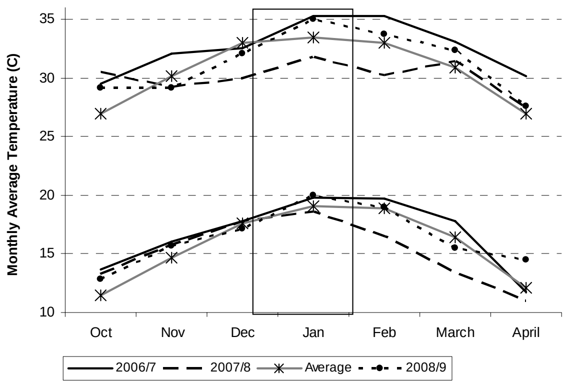
i) Irrigation deficit Experiments

Climatic conditions:

Monthly rainfall, temperatures and potential evapotranspiration (ETo) for the three seasons are presented in Table 4 and Fig. 1. The 2006/7 season was hotter and drier than average particularly during flowering and boll filling (December to March), which was reflected in the highest ETo during this period. 2007/8 was the most favourable for cotton growth receiving above average rainfall for November to March and maximum temperature near the 30°C photosynthetic optimal for the flowering period. The 2008/9 season was hot and dry in the flowering period of January and early February but wetter up to early flowering. Seasonal ETo was 955mm, 799mm and 860mm for 2006/7, 2007/8 and 2008/9 respectively.

Table 4: Monthly rainfall (mm). * = calculated from sowing.

Month	2006/7	2007/8	2008/9	Long term average
Oct*	10	25	3	
Nov	42	78	121	*58*
Dec	12	96	126	*66*
Jan	22	90	15	*83*
Feb	51	70	84	*64*
Mar	40	6	5	*57*
April	0	2	61	*39*
Total Nov to Mar	162	341	351	*328*



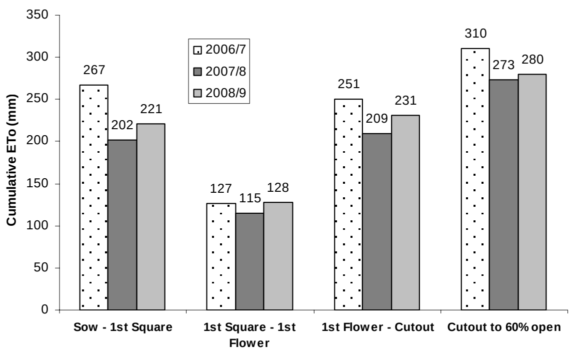


Fig. 1: Mean monthly maximum and minimum and long term average temperatures where the rectangle marks the flowering period. Cumulative potential evapotranspiration (ETo) for key growth phases.

Lint yield, total biomass and leaf area:

The response of lint yield to irrigation deficit was seasonal (Fig. 2). Not surprisingly the yield decline at the largest deficit was greatest in 2006/7 when evaporative demand was highest and in-crop rainfall during flowering was lowest, while lint yield was least sensitive to deficit in 2007/8 when evaporative demand was lower and in-crop rainfall highest. Generally Bollgard II produced consistently higher yields at smaller deficits (35 to 54mm) during flowering. However when irrigated at a 35 mm deficit lint was yield probably reduced in 2007/ 08 and 2008/9 by rainfall coinciding with irrigation, which highlights a risk with this strategy.

The response of lint yield and total biomass to irrigation deficit was similar (Fig. 2) indicating that partitioning to bolls was not affected by water availability in these experiments. Fruit retention of the Bollgard II varieties used in these experiments was very high at first flower (89-98%) and early tipping very low (<10%) ensuring a high boll demand early in flowering to compete with vegetative growth, hence rank growth was not observed in the frequently irrigated treatments.

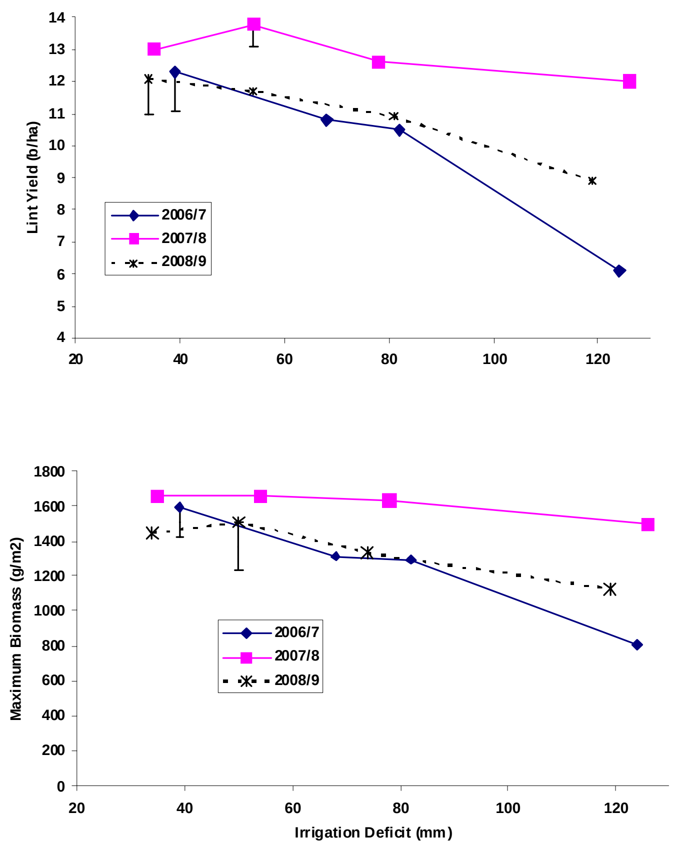


Fig. 2: The effect of season and irrigation deficit on lint yield and maximum biomass. NB Irrigation was applied to refill 100% of the deficit. Bars are $LSD_{0.05}$. NB there were significant differences between replications in all seasons.

Lint yield differences could be explained by the contribution of bolls from later pollinated flowers located toward the 'top' of the plant that came from fruiting sites grown mostly after first flower (Table 5). That is P1 and P2 bolls nearer the top of the plant and vegetative branch bolls. Only in the extreme stress situation observed in 2006/7 where a large irrigation deficit (126mm) was combined with high temperatures, low in-crop rainfall and large evaporative demand was yield from the 'bottom' of the plant significantly less over three seasons.

Hence for Bollgard II plants during flowering, irrigation should be scheduled on the basis of plant stress to ensure vegetative growth is not suppressed in preference to boll growth as would occur during water stress.

Table 5: The impact of irrigation deficit or PAWC (average of 3 seasons) on lint yield produced in the bottom and top sections of the plant, where Bottom is P1 bolls on 1st 8 fruiting branches (FB) + P2 bolls on 1st 4 FB and Top = bolls from rest of the plant.

		2006/7		2007/8		2008/9	
PAWC	Deficit	Bottom	Top	Bottom	Top	Bottom	Top
0.80	32-39	6.3	6.0	5.7	7.3	4.9	7.2
0.68	50-68	6.3	4.4	6.4	7.4	5.6	6.1
0.55	74-82	6.3	4.2	5.9	6.7	5.5	5.4
0.45	119-126	4.2	1.9	6.2	5.8	5.0	3.9
	$lsd_{0.05}$	1.38	1.16	Ns	1.11	ns	0.71

Leaf area development was strongly changed by season and irrigation deficit (Fig. 3). Where deficits exceeded 75 mm, seasonal differences that affected early LAI persisted for the life of the crop and LAI appeared to be inversely proportional to evaporative demand. Where irrigation was applied at deficits < 65mm, LAI recovered in the intermediate evaporative demand season 2008/9; the greater moisture availability allowing leaf expansion to continue. This data suggests that varying deficit in response to evaporative demand can contribute to optimising leaf area development.

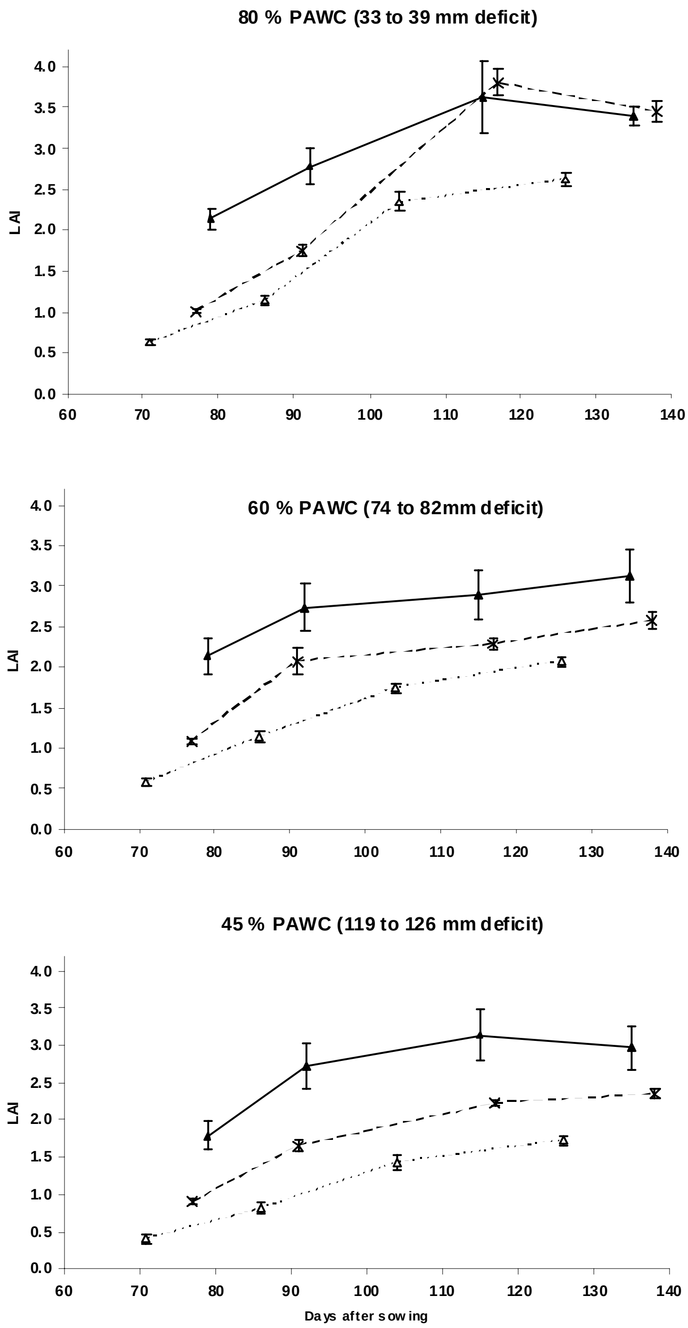


Fig. 3: The effect growing season and irrigation at different PAWC (Plant Available Water Content) or soil water deficits (calculated from DUL) on leaf area index (LAI) development from sowing. Where 2006/7 ---Δ-----, 2007/8 solid line, 2008/9 - -*- -. Bars are standard errors. NB the 50 to 68 mm deficit had a similar response to the 33-39 mm deficit hence is not presented.

Fibre quality.

Fibre length was only significantly reduced when irrigating at > 100 mm deficit or 0.45 of PAWC and seasons where evaporative demand was high during flowering and boll growth (Table 6). Fibre strength was resilient and was only significantly reduced at the 124mm deficit in the hot dry 2006/7 season. Micronaire was significantly changed by irrigation deficit within seasons but there was also a between season influence. Micronaire increased with irrigation deficit in the 2006/7 and 2008/9 seasons that were hotter and drier during flowering and warmer post cut-out. Hence a lower boll load combined with higher temperatures may have increased micronaire in the drier treatments. The lack of a consistent response to irrigation deficit in 2007/8 reflects mild temperatures and a low frequency of plant stress due to moisture.

Table 6: The effect of irrigation deficit from 1st flower to 14 days after cut-out on fibre quality.

Season	Deficit	Length (in)	Strength (g/tx)	Micronaire
	39	1.17	30.6	4.98
2006/7	68	1.15	29.7	5.18
Sicot71BR	82	1.16	29.6	5.38
	124	1.11	28.6	5.60
	$Lsd_{0.05}$	0.022	1.45	0.198
	35	1.20	29.5	4.00
2007/8	54	1.21	29.9	3.70
Sicot70BRF	79	1.22	30.3	3.90
	126	1.20	30.1	4.10
	$Lsd_{0.05}$	ns	ns	0.199
	33	1.19	30.1	4.15
2008/9	50	1.18	29.3	4.40
Sicot70BRF	74	1.17	31.0	4.50
	119	1.14	30.3	4.70
	$Lsd_{0.05}$	0.027	ns	0.16

Irrigation application efficiency and WUE.

Measuring the water balance for each deficit proved challenging due to several technical issues. Hence it was not possible to collect a complete data set for all irrigations of all plots. Measurement of water off the field using in-furrow flumes was frequently confounded by blockages due to trash and water breaking through the furrows (breakouts). Breakouts were most common where deficits were smaller due to wetter soil and more frequent running of water eroding the bed walls. The methodology of placing 2 flumes in the furrows of the centre rotabuck of each plot, although proving an accurate measurement of the water applied and tail water for that rotabuck, assumed even water run times for the entire plot. This was not always the case in these fields. The irrigation application efficiency, that is (water on – water off)/water on, were calculated for plots were high quality data was collected. The objective was to achieve 100% deficit replacement at each irrigation event so that all treatments were at the same soil moisture content following irrigation.

Figure 4 shows for the paddocks used in these experiments and the supply infrastructure associated with these paddocks, irrigation application efficiency increased in proportion to soil water deficit. This response is consistent with furrow irrigation studies conducted elsewhere on clay soils with similar infiltration properties (e.g. Muchow and Wood 1981). For deficits > 60mm efficiencies between 80 and 90% were achieved with good management, however for deficits < 40mm the efficacy averaged only 53% and exceeded 60% on only one occasion. When refilling small deficits small errors in judging timing the end of water application or estimation of the flow time to the end of the field can contribute a greater proportion of the total water applied than when refilling a larger deficit.

The efficiency of a furrow irrigation system is a function of the field, the irrigation distribution system associated with the field and the human capacity of the farm. Hence, the important practical consideration from the response in Figure 4 is the need for each grower to be aware of the irrigation application efficiency of each field and whether the farm has the capacity to measure and optimise application efficiency across a range of irrigation deficits. Good knowledge of tail water return losses is assumed here.

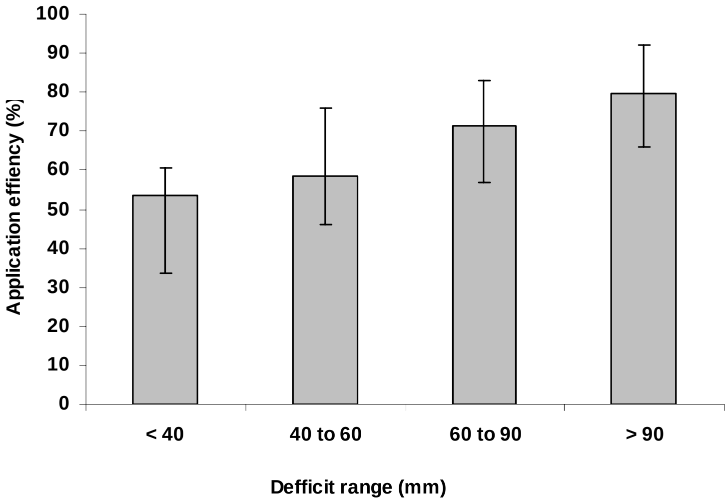


Fig. 4: Irrigation application efficiency ((water on – water off)/water on) was proportional to deficit. Bars show the highest and lowest efficiency measured.

The calculation of many WUE indices from these experiments was marginalised because application efficiencies were farm / paddock specific. The WUE per mega litre of ETc is least affected by irrigation distribution specifics and is presented in Table 7. The smaller deficits had generally higher WUE in the 2006/7 and 2008/9 seasons where in-crop rainfall was lowest and evaporative demand highest; yield was the major contributor to WUE in this situation. Irrigation at larger deficits improved WUE in 2007/8 where in-crop rainfall was greater and evaporative demand lower.

Table 7: The effect of irrigation deficit on WUE (B/ML ETc).

Deficit	WUE (bales / ML ETc)		
	2006/07	2007/08	2008/09
32 – 39	1.61	1.65	1.58
50 – 68	1.57	1.79	1.57
72 – 82	1.49	1.69	1.55
109 – 124	1.03	1.64	1.37

Development of methods of deficit measurement.

As described in the methodology a simple method for determining a site specific crop factor (Kc) at any stage during the growing season was developed from water extraction data collected in the 2006/7 season. When combined with ETo calculated from the meteorological station on site the soil water deficit could be accurately calculated from this and the daily ETo, reducing the frequency of time consuming neutron probe measurement. Soil water measurements were required after significant rainfall events. This method of soil water deficit calculation accurately predicted observed irrigation deficit for 44 irrigation events in 2007/8 and 2008/9 r^2=0.85 slope = 1.006.

Conclusions – Irrigation Deficit experiments

- There is no one threshold soil water deficit that can optimise yield and WUE in all seasons.
- Varying the soil water deficit trigger in response to plant / climate measures of water stress should improve the efficiency of irrigation water use and permit more effective use of in-crop rainfall.
- Due to the high boll load during flowering Bollgard II responded to deficits less than than previously reported for conventional cotton with lower fruit retention. Smaller deficits helped maintain vegetative growth in early flowering and due to the high boll load, vegetative and reproductive growth was balanced in the Bollgard II variety.

ii) The effect of irrigation on early growth.

Attempts to exclude rain prior to flowering on small areas within the deficit experiments using plastic sheeting between the rows was not successful due to wind ripping up the sheeting (see Plate A). The Gatton, rain shelter experiments found yield reductions of 14 to 35% where irrigation was not applied between 1st square and 1st flower and full irrigation followed the stress period. The full details of the Gatton studies will be published in Marcelo Paytas' PhD and report to the Cotton CRC.

Plate A: Wind damage to plastic sheeting used to exclude early rain at ACRI. Note this method of water exclusion has proven successful when used after flowering when plants are taller.

Interestingly in the deficit experiments conducted at ACRI, where no rain fell between 1st square and 1st flower in December 2006, irrigation increased plant biomass and leaf area development at first flower while height and node development were more tolerant to water stress (Table 5). This data suggests that the traditional method of monitoring early growth based on plant height and node number may not provide sufficient sensitivity to early season water stress and alternative plant measurements - possibly based on leaf area or leaf temperature should be evaluated.

Table 5: The percentage reduction in plant growth at first flower where there was no rain or irrigation between 1st square and 1st flower compared with irrigation. * = significantly different ($p<0.05$).

Plant growth measurement	**% of irrigated**
Nodes	95
Height	83
Height : Node	88
Dry weight	72*
Leaf Area	64*

Objective 3: Evaluate pressurised (tape) irrigation for management of growth and yield using irrigation scheduling.

Cotton growth and partitioning in response to the frequent application of different volumes of irrigation water (fractions of ETc) from pressurised drip tape was seasonal (Fig. 4). Total biomass increased with the volume of water applied in both seasons. Whereas lint yields were only increased in proportion to water volume in 2008/9 being maximised at 50 to 75% of ETc in 2007/08. This response is different to furrow irrigation for the same seasons at this site where the response of biomass and lint yield was similar within a season (Fig. 2).

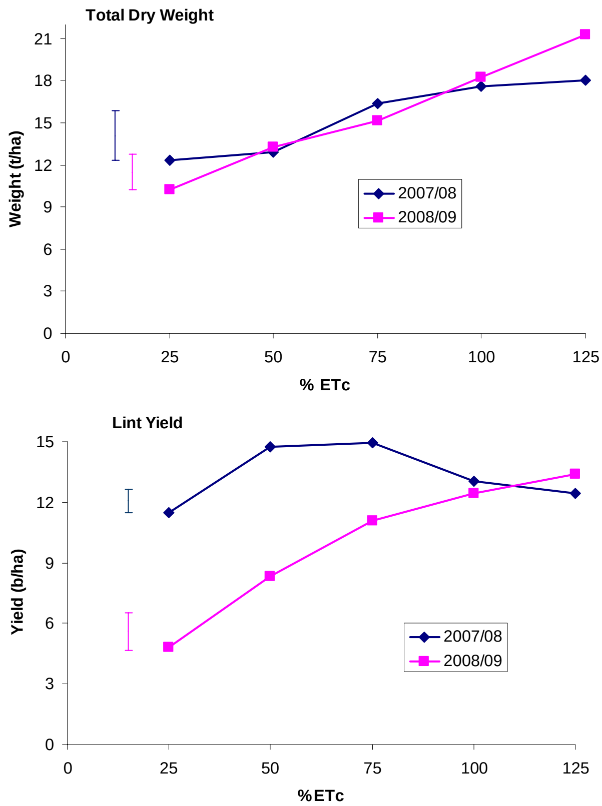


Fig 4: The effect of irrigation at different proportions of Etc on total biomass and lint yield for 2007/08 and 2008/09 growing seasons. Bars are $lsd_{0.05}$ with the upper and lower bar for 2007/08 and 2008/09 respectively.

These results imply in a climate where evaporative demand and in-crop rainfall are highly variable (i.e. 75% of Australian irrigated cotton) within and between seasons the crop factor (irrigation volume) should be changed in response to the plants growth to achieve the optimum balance of vegetative and reproductive growth.

Objective 4: Validation and enhancement of the OZCOT cotton growth model for Bollgard II response to water availability and new production scenarios in Central Queensland and the Burdekin.

i) Enhancement of OZCOT for compatibility with common modelling protocols and integration of APSIM soil water and soil N modules.

To date, David Johnston's efforts have produced a Cotton component (re-coded in C#, a modern programming language) that is compatible with both the APSIM and AusFarm simulation environments. It is running in the CSIRO Plant Industry simulation environment (namely 'AusFarm'). It is yet to be validated in, and integrated into, the APSIM environment. Some test validations have been done with the component using the APSIM SoilWat2 and SoilN components in the AusFarm environment. Validation testing will be completed when he has finished developing '**AussieCot',** a new application interface that will make running cotton specific simulations fairly intuitive (due for beta release in early 2010). This simulation environment will allow the new Cotton component to use the APSIM Soils database, APSIM SoilWat2, SoilN2 and Irrigate components without complicated setup requirements. These components are more complex that those currently used in OZCOT, and may allow it to simulate cotton growth and yield more reliably across a wider range of osil types and climates. These developments will allow OZCOT to use the more advanced APSIM components, while also ensuring that advances in the core science of the cotton growth model (the core of OZCOT) are made available in the one and only cotton component that all major Australian crop modeling systems use. This will ensure consistency in OZCOT and help with version control.

ii) **The performance of the OZCOT model for simulating irrigation deficit experiments at ACRI conducted between 2006/7 and 2008/9. Report by David Johnston and Stephen Yeates.**

Summary (see appendix 2 for the detailed report)**:**

The following comments are a summary of observations made of the performance of the model using these various settings for the model.

<u>Prediction of Yield</u>

Broad generalisation: OZCOT under predicted in high yielding crops and over predicted in low yielding crops (Fig. 5). There was a poor correlation between observed and predicted when all data was combined.

Crops in good conditions (mild- warm climate and well irrigated) had yield under predicted which was proportional to the under prediction of the number of bolls and, similarly, the under prediction of the number of fruiting sites produced. Under prediction of sites → under prediction of yield. Reducing the water logging effect and boosting nitrogen improved the situation slightly (Fig 5).

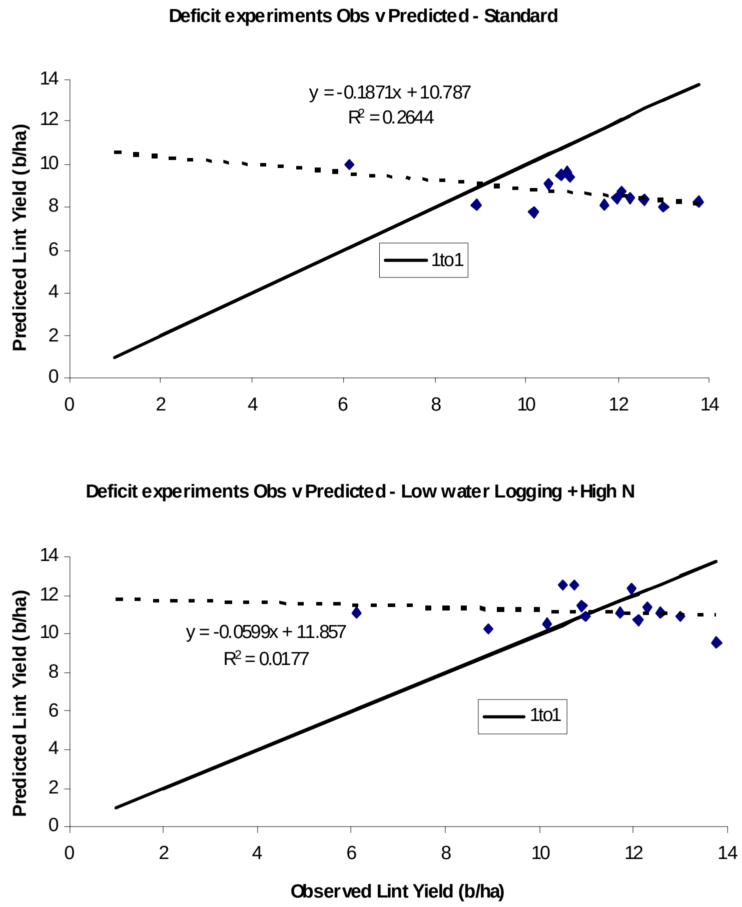


Fig. 5: Observed v OZCOT predicted yields for irrigation deficit experiments. 1 to 1 line is shown.

Fig. 6 shows the deviation from observed for each treatment. Crops in hot dry conditions had yield over predicted, some by > 50%. This was proportional to the over prediction in boll numbers, while site numbers were predicted fairly accurately.
Sites OK, but too many bolls → too high yield: shedding too low.
Changes to water logging trigger had an effect, but water logging should not have happened at all in the actual experiments, so adjustment should not be necessary.

Model responsiveness to nitrogen in very dry trials also raises some questions about simulation of nitrogen dynamics in the model.

Boll size, as represented by the varietal parameter 'Seed Cotton/Boll' was varied from the default of 5.0 to 5.5 and 5.8. While some differences were noted, the error in total yield generally was such that fine adjustments in this parameter were effectively meaningless. Simulations that did produce yields closer to the mark indicate that a review of the default boll size from the current 5.0 to 5.5 may be warranted.

While simulation of yield in wetter treatments was improved by limiting water logging, yields in driest trials (06/07 – 126 mm) were adversely affected by reducing water logging and boosting nitrogen.

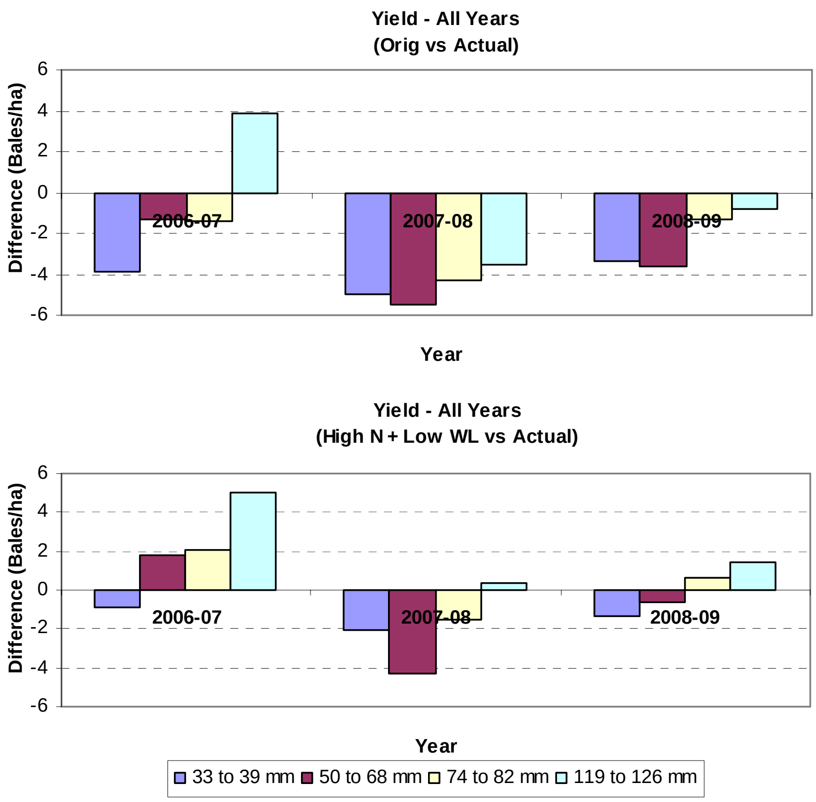


Fig. 6: Deviation of predicted from observed lint yield for deficit experiments for original model settings and with increased N and water logging trigger value lowered.

<u>Prediction of LAI development</u>

For larger deficits, OZCOT over predicted the LAI. The worst prediction observed was for the 119-126 mm treatment in 2006-07, the hot dry year. LAI was over predicted for deficits for the early part of the 2006-07 season, but most significantly for the drier treatments. LAI was generally reasonable, both in development timing and maximum LAI predicted for the moderate trials in both 2007-08 and 2008-09. LAI prediction for the smallest deficits was improved by reducing water logging and boosting nitrogen.

Some unusual fluctuations were predicted in the smaller deficits with LAI ending up being a little on the low side. Reducing the water logging effect (WatLogC = 0.87 → 0.95) and adding some extra Nitrogen (92kg → 150kg N applied) significantly helped to limit the fluctuations and allowed the model to simulate a recovery to close to observed LAI values. This effect was consistent for the smaller (wetter) deficits for both 2007-08 and 2008-09.

<u>Prediction of Site numbers</u>

Site development was predicted most accurately for the larger deficits, with smaller deficits having delayed development (approx 20 days by mid 2008-09 season), and/or too few sites (150 – 200 per metre too few in 2007-08 35 mm deficit). Reduced water logging improved the predication of the total number, especially in the smaller deficits, but the delay was still evident. Adding extra Nitrogen and reducing the water logging can result in an 'over shoot' of the total site number. Reduced water logging improved prediction of site numbers in smaller deficit treatments.

Prediction of Boll numbers

Boll numbers followed the pattern observed for site numbers. The largest deficit (119-126 mm) varied from this pattern in that site numbers were reasonable, while boll numbers were over predicted as was yield. This may indicate that insufficient shedding occurs in very dry conditions. Boll numbers were over predicted for the driest treatments (119-126 mm deficit).

Discussion Points:
Based on the observations and analysis of the model performance as outlined above, the following points should be discussed and remedial actions considered and appraised:

a) Nitrogen Uptake in OZCOT
Nitrogen uptake needs to be boosted beyond the 240 kg mark to achieve the yields observed. This is consistent with new varieties performing beyond the point where 240kg of N is sufficient.

Currently the published paper describing OZCOT (Hearn 1994) refers to a routine called UPTAKN_MAX – this is not in the OZCOT model – and this is stated to be set at 240 kg ha^{-1} based on work by Basinski *et al.* (1975). OZCOT does not limit the initial Uptake N pool, but does use the 240 kg ha-1 limit to apportion out the effective addition that fertilizer applications make to the pool.
Ian Rochester has new figures that could be used, the equations re-worked and documentation amended. The size of this pool does affect the calculation of the VNSTRS (Veg N Stress factor) which in turn can affect the Fruiting Site Production and LAIGEN (note p262 of Hearn 1994).

This issue needs to be re-evaluated in light of the fact that the new Cotton component will be using APSIM SoilN. How the core OZCOT model integrates with SoilN needs to be reviewed to assess whether any part of the current problem will remain when simulations are run in AussieCot or in ASPIM with the new Cotton component.

b) Water Logging
Water Logging appears to have too great an effect when left at the default level (WatLogC = 0.87). Simulated results indicate a better fit at about WatLogC = 0.95.

The 33 to 29 mm deficit treatment had the greatest the under-prediction of site production and boll retention.
Limiting the effect of water logging in one of the small deficit treatments in the wettest year (2007/8) significantly improved LAI (total) and, to a lesser extent, yield. It improved, but failed to correct Site and Boll numbers predictions.

Yield is generally under-predicted, primarily driven by too few bolls.
Few sites, but LAI not too bad: Is LAI / site too high?
Too few bolls may lead to high LAI /site? (via excess resources).

Question: How do wet conditions lead to too few sites?

Test performed re Nitrogen X water logging vs site numbers:

Question: Reduced N → less sites? / Excess N → more sites? How is this interacting with or without the additional effect of water logging.

Results: Reduced N with water logging simulated poorly – too few sites, low yield.
High N with no water logging gave better results.

Analysis: Water logging slightly increased shedding and therefore reduced yield.
However, the biggest effect of water logging is to reduce site production.
Increased N compensates by boosting site numbers.

c) LAI/site

In very dry conditions, site production is not too bad, but LAI is substantially over-predicted.

LAI/site too high by far – VPD (vapour pressure deficit) or other limiting factor on LAIGEN routine not accounted for?

d) Yield over predicted under dry conditions

High yield might be accounted for by LAI/site.
High yield predictions may also be contributed to by:

Boll shedding is low in dry treatments – this could be a result of excess LAI(?) and results in an excessive yield prediction. (?)

Nitrogen dynamics: Low (dry) SMI should limit N usage, but simulations still indicate that N is limiting yields, even though yield is already over predicted.

Early over prediction of LAI in wetter treatments of some years may reflect the unaccounted-for thrips damage in the crops. (2006-07 especially).

High yield of the 33 to 39 mm deficit was better simulated with adjusted higher N values with some (but limited) water logging effect. (Simulations run for 400+ Kg N, with, without and with reduced water logging). Excess N with no water logging produced 18.1 b/ha!
Conclusion: Some water logging effect is still required?

e) WatLogN

Also of note is that the routine WatLogN – the level at which water logging affects Nitrogen use – is NOT compared against SMI (soil moisture index), but rather against SW/UL (soil water/upper limit), which can be considerably different from SMI. The default value of WatLogN is 0.87, just as it is for WatLogC.

SW/UL can vary quite significantly from SMI (eg. SW/UL = 0.943 vs SMI = 0.827) so 'water logging' affecting N usage may not match reported SMI patterns.

Note: WatLogC is compared against SMI, so the default value of 0.87 for WatLogC does mean that water logging affects Carrying Capacity for SMI values above 0.87.

iii) **Simulation analysis of new production scenarios in Central Queensland and the Burdekin.**

a) Central Queensland (in collaboration with Richard Sequeria's project)
Bollgard II cotton created an opportunity for later sowing (November or December) in Central Queensland. Simulation of later sowing combined with historic rainfall records can assist in providing a risk profile for this change of management. Later sowing exposed cotton to different climatic conditions during squaring and early flowering in some seasons. High temperatures combined with fluctuating cloudy and humid conditions produced square shedding prior to any boll load; the result being excessive vegetative growth and reduced yield where these climatic conditions occurred.

Figure 7 shows the error in simulation of yield where physiological shedding or early fruit occurred at a November sowing in Emerald.

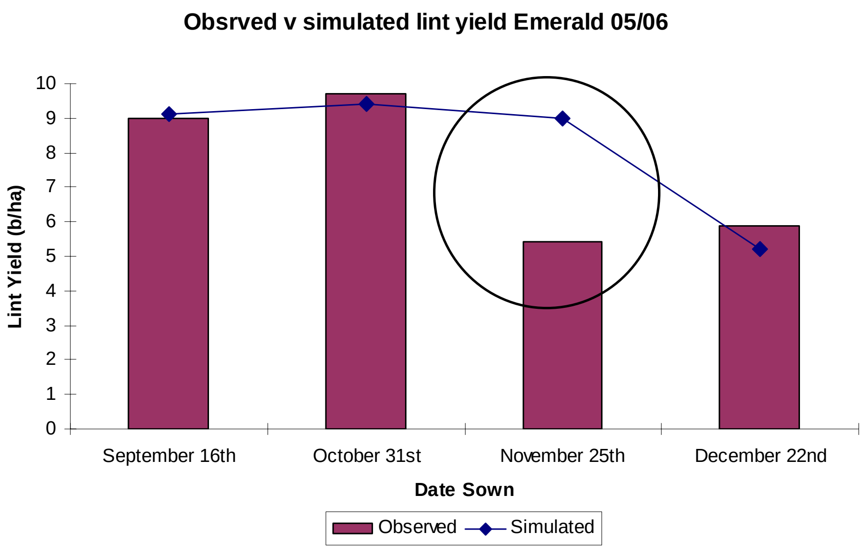


Fig. 7: Simulated vs. observed yields for different sowing dates at Emerald. Circled is the November 25th sowing where climate induced shedding of early squares occurred and OZCOT could not simulate this effect.

a) Wet season cotton at the Burdekin (in collaboration with Paul Grundy's project)

Cloudy humid weather is expected during squaring and early flowering at the Burdekin and the aim was to validate OZCOT in these conditions. This work is still in progress. Yields and crop growth parameters are being simulated from a climate interaction experiment that aims to quantify the effect of cloudy / humid conditions at different cotton growth stages. Sowing dates were varied to increase the chance of exposure to these conditions.

Preliminary simulation analysis is shown in Table 6. Maturity date was poorly predicted and yield was about ± 2 b/ha from observed for the 1st December and 8th January sowings. Early fruit shedding was severe when sown in December and would have contributed to the deviations from observed.

Table 6: Preliminary OZCOT validation of Burdekin sowing date experiment.

Sowing Date	Lint Yield (b/ha)		Maturity Date	
	observed	simulated	observed	simulated
1-Dec-08	8.02	10.5	21-May	20-Jun
20-Dec-08	8.55	8.96	21-May	16-Jun
8-Jan-09	12.11	10.26	30-Jun	13-Aug

References:

Constable GA, Hearn AB (1981). Irrigation for Crops in a Sub-Humid Environment. VI. Effect of Irrigation and Nitrogen Fertiliser on Growth, Yield and Quality of Cotton. Irrig Sci 3: 17 – 28.

Cull PO, Smith RCG, McCaffery K. (1981). Irrigation scheduling of cotton in a climate of uncertain rainfall. II. Development and application of a model for irrigation scheduling. Irrig Sci 2: 141 – 154.

Hearn AB, (1994). OZCOT: A simulation model for cotton crop management. Agric Sys 44: 257-299.

Muchow RC, Wood IM (1981). Pattern of infiltration with furrow irrigation and evaportranspiration of kenaf (*Hibiscus cannabinus*) grown on a Cununurra clay in the Ord Irrigation Area. Aust J Exp Agric Anim Husb 21: 101-108.

Sadras VO, Milroy S.P. (1996). Soil-water thresholds for the responses of leaf expansion and gas exchange: A review. Field Crops Research 47: 253-266.

Outcomes

5. Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

As stated previously the projects objectives were changed after commencement. The new outcomes are related to the 4 new objectives.

Objective 1:

The outputs were:

1. Measurement of the water use and yield difference between Bollgard II and conventional when unstressed.
2. Comparison of the relative response to moisture stress at different growth stages.
3. Explanation and prediction of water use differences in terms of insect damage induced changes to plant morphology; row spacing had no impact on this response.

The outcomes were:

1. Improved scheduling of Bollgard II in water short situations has been achieved and widely extended and adopted, due to the quantification of the relative yield losses when stressed at different growth stages. E.g. the message don't stress Bollgard II late in flowering.
2. A logical and science based explanation for the often contradictory water requirement results when Bollgard II is compared with conventional cotton varieties. This will enabled greater capacity to predict water requirements and make whole farm judgements irrigation scheduling when both technologies are on the same farm.
3. A recommendation that on-farm water balance comparisons be replicated.

Objective 2:

The outputs were:

1. A rigorous comparison of the response of high fruit retention Bollgard II varieties to a range of irrigation triggers based on soil water deficits.
2. Data showing to the high boll load during flowering Bollgard II responded to smaller deficits than previously reported for conventional cotton with lower fruit retention.
3. Data that demonstrated that varying the soil water deficit trigger in response to plant / climate measures of water stress should improve the efficiency of irrigation water use and permit more effective use of in-crop rainfall.
4. Evidence that irrigation application efficiency was inversely proportional to soil water deficit.

5. The yield benefits of reducing early season water stress in Bollgard II varieties was identified and demonstrated.

The outcomes were:

1. Different scheduling to conventional? can increase yield and WUE of BollgardII varieties.

2. Further research that can base irrigation scheduling on a combination of plant based water stress measurements and soil water deficit.

3. Extension messages: i) that yield and WUE can be increased in Bollgard II by irrigating at smaller deficits during flowering when temperature and evaporative demand is high; ii) high irrigation application efficiencies are harder to achieve when refilling smaller deficits and irrigation application efficiencies are farm and field specific.

4. Development / extension trials of early irrigation strategies to increase pre-flowering biomass of BollgardII varieties and measure WUE tradeoffs in different growing regions.

Objective 3:

The outputs were:

1. The growth, partitioning and yield response of cotton different water volumes applied frequently though pressurised tape was different to the same variety when furrow irrigated.

The outcomes were:

1. If cotton is irrigated with frequent small water volumes, in this climate, the crop factor should be varied in response to plant growth and climate to optimise yield and WUE.

2. Further research may be required.

Objective 4:

The outputs were:

Model validation studies of deficit irrigation experiments, sowing date experiments in CQ and climate interaction studies in the Burdekin

Progress toward modernising the programming language and incorporating new soil water and N modules from APSIM.

The outcomes were:
The need for OZCOT model enhancement if it is to be effectively used in the development of climate and management risk profiles in new production regions or changed cropping practices or the simulation of water balances for catchment wide studies or climate change scenario analysis.

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

   None

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

      1. A simple method for disinfecting leaves from Fusarium wilt while permitting transport to a Fusarium free site to conduct leaf area measurement.

      2. A method to calculate a local (lower Namoi) Kc from light interception.

   See methods section for more detail on the above.

   c) required changes to the Intellectual Property register.

   None

Conclusion

7. 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?

- Improved scheduling of Bollgard II in water short situations has been largely achieved with the contribution of the research conducted in this project. The need to avoid water stress late in flowering in Bollgard II as a first priority when allocating limited water and this message has been widely extended over the past 3 years.
- It was demonstrated that varying irrigation deficits, if linked to measures of plant stress, will improve crop performance and WUE. These benefits if adopted will impact on the 75% of Australia's irrigated cotton that is grown in a sub-humid climate with significant but variable in-crop rainfall and evaporative demand. For example, 1 in 3 seasons are wetter and milder than average so it could be possible to use a larger deficit threshold and capture more in-crop rainfall and save irrigation water for use on future cotton or rotation crops.
- This project has clearly showed the yield benefits of using a smaller threshold deficit for Bollgard II varieties when conditions are hot and dry during flowering. The 2006/7 season is a good example, based on lower Namoi consultant Steve Madden's grower group, where most scheduled using 70 to 80 mm deficit and produced similar yields to the 80mm deficit in used in these experiments. The 40mm deficit, applied during flowering in the same experiment, increased yield by 17% under these conditions.
- Key tradeoffs when irrigating with smaller soil water thresholds on clay soils were also measured by this project. The messages are 1) high application efficiencies are harder to achieve when replacing small deficits and 2) application efficiencies are

farm and field specific and highlight the need for continued integration of knowledge outputs from this project with irrigation optimisation projects.

- The question of which has the higher WUE, conventional or Bollgard II varieties, has been answered by showing that it depends on the impact that *Helicoverpa* damage has crop morphology. This understanding can be applied to predict water use and yield based on the type, severity and timing of damage to a conventional compared with a Bollgard II variety.
- The yield benefits of reducing early season water stress in Bollgard II varieties was identified and demonstrated in this project and the collaborating PhD project of Marcelo Paytas. However crop monitoring methods for the scheduling of early irrigation need reviewing and any water use efficiency tradeoffs quantified.
- It was demonstrated that the irrigation water requirement of cotton in pressurised systems (e.g. tape) was sensitive to climatic conditions and could be halved provided the crop factor is varied in response to plant growth and climate. Cotton grew differently in this system to furrow irrigation as increased water availability can be converted to vegetative growth not yield when irrigated using pressurised tape.
- This project produced data to show that replication is essential for paddock sized water balance trials and experiments. With increased interest in measuring smaller differences in water use at a field scale the consequences of not replicating are high as results can reflect field variability instead of treatment differences.
- New research methodologies developed here will provide indirect benefits to the cotton industry. These were (i) a method for treating plants collected in Fusarium areas that with would permit physiological measurements (leaf area) and (ii) a simple method of calculating a crop factor from light interception has saved valuable time in soil water measurement.

Extension Opportunities

8. Detail a plan for the activities or other steps that may be taken:

(a) to further develop or to exploit the project technology.

Stephen Yeates has moved to the Burdekin project and will have no involvement in the follow up project. However there is a commitment that publication of findings in the Cottongrower, Spotlight, scientific journals and update of WATERpak will be completed.

(b) for the future presentation and dissemination of the project outcomes.

Extension activities: An outcome of the presentation to CRDC on September 9 2009 was regional on-farm trials / demonstrations of early irrigation strategies and plant monitoring for early irrigation management.

Update of scheduling of Bollgard II cotton will be included in WATERpak late in 2009. Cottongrower and Spotlight articles are planned for late 2009 - early 2010.

(c) for future research.

The new 'Dynamic Deficits' project evolved out of the research conducted in this project. Further research may follow from Warren Conaty's PhD to continue the application of BIOTIC sensors in measuring plant water stress.

Publications

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)

Project publications to date:

Yeates S., Roberts J., Nielsen J. and Richards D., 2009. Toward better water management of Bollgard II cotton. The Australian Cottongrower, Jun-July 2009: 22-27.

Yeates S. 'Toward better water management of Bollgard II cotton' published for the QDPI's 'More Crop Per Drop' in March 2009

Yeates S, Roberts J, and Richards D, 2008. Toward better water management of Bollgard II cotton. Proceedings 14th Australian Cotton Conference, Gold Coast, Qld, 12-14 August 2008.

Paytas M., Yeates S.J., Fukai S., Huang L., 2008. Effect of early moisture deficit on growth, development and yield in high retention BT cotton. Proc. 14th Australian Agronomy Conf. September 2008, Adelaide, SA.

Paytas M. Yeates S.J, Fukai S., Huang L. 2007. Early production of biomass in high retention cotton. Proc. World cotton Conference-4, September 2007, Lubbock, Texas, USA.

Publication plan next 6 months:

- At least one scientific Journal publication reporting the deficit experiments.
- Update of WATERpak.
- Cottongrower and Spotlight articles.

Publications from Collaborating and past CRC Projects:

Yeates S.J. 2009. Issues for New Crop Research and Development in Northern Australia: Using BT Cotton as a case study. Farm Policy Journal **6** (2): 25-34. Australian farm Institute ISSN 1449-2210.

Grundy P and **Yeates S.** 2008. Burdekin crops prosper despite big wet. The Australian Cottongrower October-November 2008: 18-22.

Grundy P and Yeates S. 2007 The Australian Cottongrower, October – November 2007. Is a sustainable cotton industry possible in the Burdekin? P16-20.

Yeates S. Strickland G, Moulden J, Davies A, 2007. NORpak-Ord River Irrigation Area. Cotton Production and Management for the Ord River Irrigation Area (ORIA) 2007. Cotton Catchment Communities CRC. www.cottoncrc.org.au/publications/northern.

Yeates S.J, Constable GA, and McCumstie T. (2009). Irrigated cotton in the tropical dry season.I: Yield, its components and crop development. (accepted for publication in Field Crops Research)

Yeates S.J, Constable GA, and McCumstie T. (2009). Irrigated cotton in the tropical dry season II: Biomass accumulation, partitioning and RUE. (accepted for publication in Field Crops Research)

Yeates S.J, Constable GA, and McCumstie T. (2009). Irrigated cotton in the tropical dry season III: Predicting the impact of temperature and cultivar on fibre quality. (accepted for publication in Field Crops Research)

Duggan, B.L., Yeates, S.J., Gaff, N. and Constable, G.A. (2008)
Phosphorus fertilizer requirements and nutrient uptake of irrigated dry-season cotton grown on virgin soil in tropical Australia
Communications in Soil Science and Plant Analysis 39: 282-301

Duggan, Brian L, Yeates, Stephen J. and Constable, Greg A. (2008). Bed preparation techniques and herbicide tolerance technology for tropical dry season cotton production. Trop. Agric. (Trinidad). 82(3), 233-240.

Field days / workshops other presentations

- Cottongrower article July 2009
- More crop per drop March 2009
- Cotton Collective 2009.
- CRC Science Forum 2008, 2009.
- Big Day Out 2009
- Cotton Conference 2008
- Most valley field days at least once in last three years.
- Cotton Consultants Association conference 2007, 2008
- Spotlight
- Several 'Cotton tails'
- Web on Wednesday – several
- Many farmers, consultants, researchers and international visitors (Brazil, Israel, South Africa, USA) inspected the research.

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

The inclusion of ET data in the ACRI weather section in the Cotton Catchment Communities web site via the query data base (http://tools.cotton.crc.org.au/tools/acriweather/wx.aspx).

Part 4 – Final Report Executive Summary

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.

It was demonstrated that varying irrigation deficits, if linked to measures of plant stress, will improve cotton yield and WUE. These benefits if adopted will impact on the 75% of Australia's irrigated cotton that is grown in a sub-humid climate with significant but variable in-crop rainfall and evaporative demand. When conditions were hot and dry during flowering, as in the 2006/7 season, frequent irrigation of Bollgard II cotton (40mm deficit) increased yield by 17% and WUE by 8% compared to the commonly used deficit (70-80mm) in the lower Namoi that season. In contrast, in 2007/8, where during flowering in-crop rainfall was greater and evaporative demand lower, stretching irrigation during flowering (54 to 78mm deficits) maximised yield, WUE and captured more in-crop rainfall than irrigating at a 40mm deficit. However, irrigation application efficiency tradeoffs are farm specific and need to be measured before adopting small deficits.

Improved scheduling of Bollgard II in water limited situations has been largely achieved with the contribution of the research conducted in this project. The need to avoid water stress late in flowering in Bollgard II was confirmed as yield losses per day of stress were double the conventional variety at the same growth stage. This message has been widely extended over the past three years.

The question of which has the higher WUE, conventional or Bollgard II varieties, has been answered by showing that it depends on the impact that *Helicoverpa* damage has on crop morphology. In a situations where insect damage was moderate Bollgard II used less water than the conventional variety because the conventional variety grew for longer to compensate for the damage. Where insect damage is minimal there is no difference because the plants are morphologically identical. However the situation where early tipping of the main-stem was the only insect damage to the conventional variety, it had the highest yield and WUE due to the improved canopy structure

The irrigation water requirement of cotton in pressurised systems (e.g. tape) was sensitive to climatic conditions and could be reduced provided the crop factor is varied in response to plant growth and climate. Cotton grew differently in this system compared to furrow irrigation.

OZCOT model enhancement is need if it is to effectively simulate climatic risk in new production regions or changed cropping practices or the simulation of water balances or climate change scenarios.

This project produced data to show: 1) replication is essential for paddock size water balance trials and experiments; 2) a review of plant monitoring methods for early irrigation scheduling is required; 3) new research methodologies developed here will provide indirect benefits to the cotton industry.

Appendix 1:

A Comparison of Conventional and Bollgard II® cotton on (30”) 0.75m row spacing

Janelle Montgomery, NSW DPI, Steve Yeates, CSIRO, Andrew Parkes, ‘Keytah’ and Peter Gall, Keytah.

Aims:

1) Measure the actual water consumed on a field basis by 2 cotton farming systems, namely Bollgard II® and conventional cotton both planted with 30” (0.75m) row spacing.
2) Calculate the water use efficiency of each farming system in terms of bales per ML (Gross Production Water Use Index and Irrigation Water Use Index)
3) Measure variety differences between each farming system.

Methods:

Trial Layout:

One replicated trail was established to compare Conventional and Bollgard II® cotton on 0.75 m (30”) row spacing at Keytah during the 07/08 season. The trial layout is presented in Figure 1.

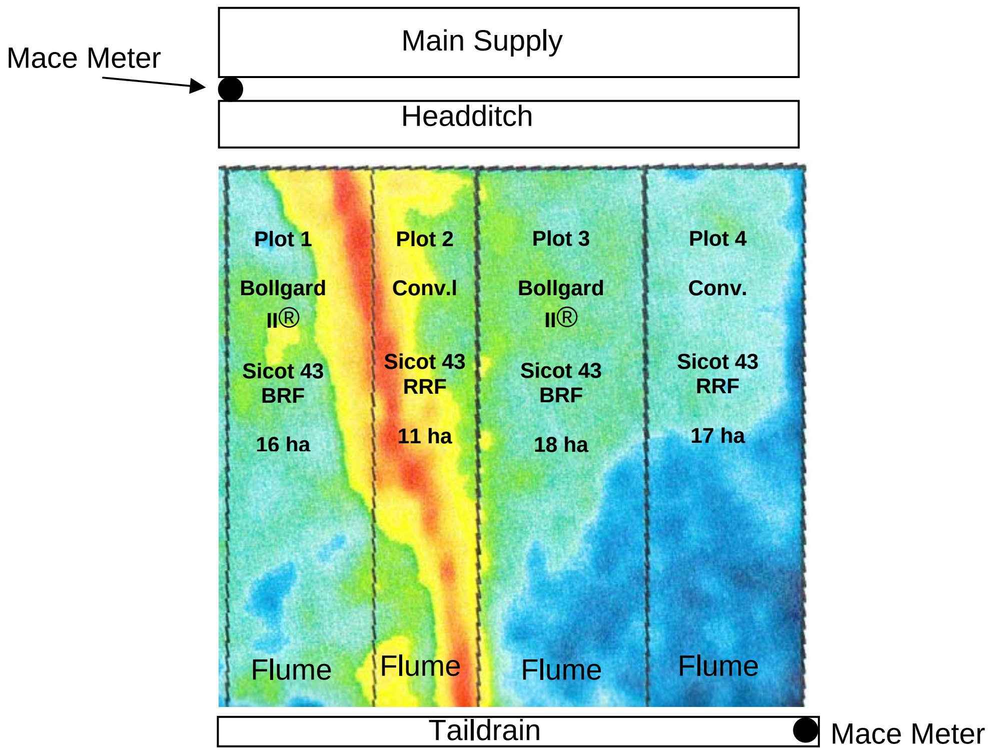


Figure 1: Experimental layout of trial site

Soil Variation:

Water availability was low during the 07/08 season. Keytah only had one field available for this particular trial; however the field had a great deal of variation with a prior stream running through the field as shown in the EM survey (Figure 1). Replication is essential under these conditions.

Measurements:

Water applied to each plot was measured using a mace meter located in the pipe connecting the main supply to the head ditch (See Figure 1). Runoff was measured using an Irrimate^{TM} flume and a mace meter was located in the pipe where tail waters flowed from the field. Starting and ending soil moisture was measured within each plot. Rainfall was measured at the Keytah weather station, approx 300m from the trial site. Soil moisture monitoring and scheduling was conducted by Keytah Management based on normal farm practice.

Results & Discussion:

Yield

The yield for each plot is shown in Table 1. Plot 4 had a significantly lower yield. The head ditch was emptied into this plot which may have resulted in some waterlogging reducing yields. The difference in yields between plots clearly shows the importance of replication in on-farm trials. Had there been no replication and the conventional treatment only been located in plot 4 the trial would have given completely erroneous results.

Table 1: Yield of each plot and the average for the conventional and Bollgard II varieties

Plot	**1**	**2**	**3**	**4**	**Average**	
Variety	Bollgard II 43 BRF	Conventional 43 RRF	Bollgard II 43 BRF	Conventional 43 RRF	Bollgard II 43 BRF	Conventional 43 RRF
Yield Bales/Ha	12.11	12.28	12.08	10.90	12.1	11.6

Water Use

All plots received 4 irrigations. The Bollgard II crop received on average 6.1 ML/ha of irrigation water and the conventional 7.3 ML/ha as shown in Table 2. There was little difference between the two varieties in the amount of water that infiltrated the soil (net applied) and available for plant use (assuming no deep drainage).

Table 2: A comparison of irrigation water use during each irrigation event for Bollgard II and Conventional Cotton

		Irrigation Event					Total
		Waterup	1	2	3*	4	
Bollgard II 43BRF	**Inflow (ML/ha)**	1.9	1.2	0.9	1.0	1.2	6.1
	Runoff (ML/ha)	0.2	0.2	0.2	0.1	0.4	1.1
	Net Applied (ML/ha)	**1.7**	**1.0**	**0.6**	**0.8**	**0.8**	**5.0**
Conventional 43RRF	**Inflow (ML/ha)**	2.0	1.5	0.9	1.3	1.5	7.3
	Runoff (ML/ha)	0.3	0.4	0.3	0.2	0.9	2.1
	Net Applied (ML/ha)	**1.7**	**1.1**	**0.6**	**1.1**	**0.6**	**5.2**

One capacitance probe (C-Probe) was installed in the majority soil type within each plot. The probes were not calibrated, so cannot provide volumetric water content changes, however their readings can be used to give an indication of differences in water use between the two varieties. Table 3 shows the summed C-probe reading taken directly before and after an irrigation event for each probe.

Table 3: The difference in C-probe readings before and after an irrigation event for each plot.

Plot		1	2	3	4	AVERAGE	
Variety		**BRF**	**RRF**	**BRF**	**RRF**	**BRF**	**RRF**
IRRIGATION 1 4/01/2008	Before irrigation event	191	193	201	236		
	After irrigation event	254	259	264	292		
	Difference in soil moisture	63	66	63	56	63	61
IRRIGATION 2 1/02/2008	Before irrigation event	200	209	207	231		
	After irrigation event	254	248	262	295		
	Difference in soil moisture	54	39	55	64	54	52
IRRIGATION 3 24/02/2008	Before irrigation event	191	197	200	220		
	After irrigation event	251	251	261	289		
	Difference in soil moisture	60	54	62	69	61	62
IRRIGATION 4 11/03/2008	Before irrigation event	184	md	195	223		
	After irrigation event	251	md	258	288		
	Difference in soil moisture	68	md	63	65	65	65

This data suggests no difference in profile water between the Bollgard II and conventional cotton. This is expected given the two varieties were similar looking plants. That is, the morphological differences between the plants were minor and therefore you would expect water use to be similar.

Table 4 provides a summary of the water use indices for each plot. Water use indices relate production to the quantity of water used. The lower yield in plot 4 resulted in lower water use indices for this plot.

The average Irrigation Water Use Index (IWUI) was 2.0 and 1.6 b/ML for the Bollgard and the Conventional respectively. The average Gross Production Water Use Index, which accounts for all water sources (irrigation water, soil water and rainfall) was 1.3 b/ML for Bollgard II and 1.1 b/ML for Conventional.

Plot	**1**	**2**	**3**	**4**	**Average**	
Variety	**43 BRF**	**43 RRF**	**43 BRF**	**43 RRF**	**Bollgard II**	**Conventional**
Production details						
Area grown (ha)	15.52	10.82	17.51	16.59	**16.52**	**13.71**
Total production (bales)	187.90	132.90	211.60	180.90	**199.75**	**156.90**
Average Yield (bales/ha, t/ha)	12.11	12.28	12.08	10.90	**12.10**	**11.59**
Water supply						
Total irrigation applied on cotton (ML/ha)	6.31	7.08	5.93	7.49	**6.1**	**7.3**
Irrigation Water Use Index (Bales/ML)	**1.92**	**1.73**	**2.04**	**1.46**	**2.0**	**1.6**
Soil Water						
Used Soil reserve (ML/ha)	-1.92	-1.88	-1.40	-1.14	**-1.7**	**-1.5**
Rainfall						
Total in season rain (ML/ha)	4.59	4.59	4.59	4.59	**5**	**5**
Seasonal water usage (total) (ML/ha)	8.98	9.79	9.12	10.94	**9**	**10**
Gross Production Water Use Index (Total) (Bales/ML)	**1.35**	**1.25**	**1.32**	**1.00**	**1.34**	**1.13**

Plant Monitoring

The morphological differences between the varieties were much less this season, which was reflected in similar yields. The tipping percentage in the conventional variety was much lower than the 80 to 90% observed in previous seasons and there was only a small difference in fruit retention as shown in Table 4.

Similar to previous trials the conventional variety was about 5 days later maturing due to the combined effects of tipping and slightly lower retention. The importance of late season leaf health shown by 67 and 78% of final boll growth occurring after cut-out was again measured this season. Disease, insufficient N uptake, water stress and insect pests all reduce leaf photosynthesis at this time.

Table 4: Plant monitoring results

	Bollgard – 43-BRF	**Conventional – 43 RRF**
Tipping %	5	37
Retention - all sites % on 8/1/08	87	79
Final Boll Number /m^2	144	160
% final boll weight grown after cut out on 5/2/08	67	78
Open Bolls % - April 4th	58	35

Conclusions:

An important driver of plant water use is the plant structure. Obviously a larger plant, larger leaves etc will use more water. During this season, the conventional and Bollgard II plants has a similar structure – morphological differences between the two were much less, they looked very similar. It was a mild season with few stresses. Although insect damage can differ between the two varieties, it too wasn't as great this season. Therefore what resulted was a similar looking plant in the conventional and Bollgard stands which accounts for the similar yield and water use.

A significant outcome from this trial is that it clearly shows the importance of replication. If any variation is expected in a trial, whether it is soil variation or variation in management, replication is vital.

Appendix 2: **Report on the performance of the OZCOT model for simulating Variable Deficit trials conducted at Myall Vale research station for the three seasons 2006-07, 2007-08 and 2008-09.**

Report by: David Johnston (October 2009)

Description of trials:

Variable deficit trials were conducted by Stephen Yeates on the Myall Vale research station in Chico block for the three seasons 2006-07, 2007-08 and 2008-09. The trials were conducted and data gathered as part of the project "Optimal Production and Water Use of High Retention Cotton and other New Technologies".

The trials consisted of varying irrigation schedules, both in number of irrigation applications and timing if irrigations during crop development.
Each season included:

- a very frequent irrigation trial (Blue – wettest)
- a frequent irrigation trial (Green – wet)
- a 'typical', slightly reserved irrigation trial (Red – typical)
- a limited irrigation trial (Grey – dry).

Some years included extra trial irrigation patterns that have not been analysed due to limited ability to compare between years and also limited data collected to assess model performance.
Observations were taken of initial soil nitrogen and fertilizer applications, soil water readings by neutron probe measurements, and crop observations at various points throughout the season for leaf area, site production, boll retention, boll counts, lint production and biomass production.

Simulations were then run in OZCOT (stand–alone version) to assess its performance in modelling crop growth and water use. Crop growth alignment was assessed on LAI development and maximum leaf area, fruiting site production, boll counts over time, open boll counts, seed cotton per boll and final lint yields.

Description of seasons:

The three growing seasons over which the trials were conducted represent a very fortuitous variety in climatic conditions which is useful in testing the model performance by allowing model behaviour at growing condition extremes to be observed.

The 2006-07 growing season was a hot, dry year with unusually high VPD values throughout the season. Early season thrips damage was also more notable than normal.

The 2007-08 growing season was a mild and relatively wet year. Early season insect damage was well controlled. Radiation was probably sub-optimal for the early part of the season, but limited disease was reported.

The 2008-09 growing season represented a fairly 'average' year and possibly represented the closest approximation of the seasons of the early to mid 1980's during which much of the OZCOT model functionality was developed and 'tuned' (Yeates). This season did not have the extreme heat of the 2006-07 season, nor the cool, wet conditions that dominated the 2007-08 season. It did have a significant rainfall event in early February, a few days after an irrigation, so a short period of potential water-logging did occur. Some verticillium damage was reported in some of the trials. Pest pressures were generally well controlled and had little or no effect on trial performance.

OZCOT Simulations:

OZCOT model simulations were run using 'default' settings with the following parameterisations:

Weather — Myall Vale met data (ACRI met station + A3 rainfall where available)
Soil — Chico block soil parameters (by Dirk Richards and Steve Yeates)
Variety — Sicot 71BR variety file
Agronomy — As recorded for initial soil nitrogen, fertilizer applications and irrigation applications

Additional model runs were also conducted with various setting adjustments. The most useful of these were:

- varying WatLogC : 0.87(default), 0.90, 0.95 and 1.0
- Increasing initial N : uptake N = 92 – 100(actuals), 150, 240
- Increasing applied N : kg applied 200(actual), 240

(these adjustments were applied in various combinations).

Summary — Model Simulation Performance:

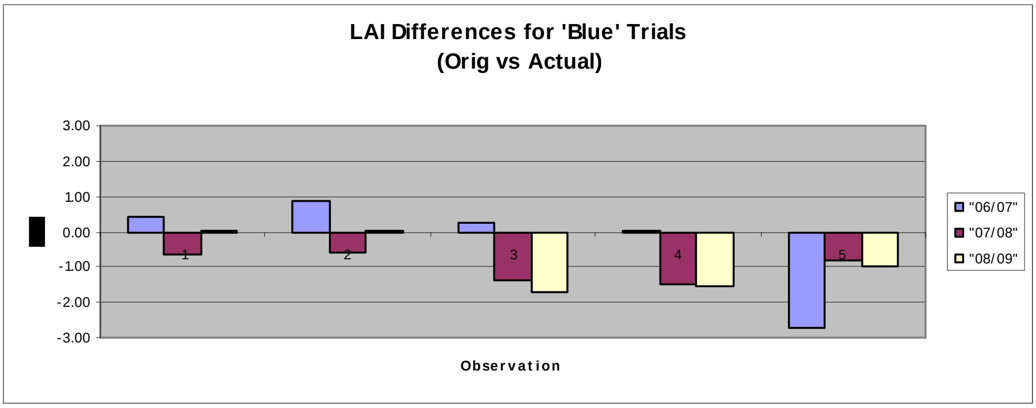
[Actual trial data and simulated model outputs, with graphs, are contained in the spreadsheet "Deficit Trials – Output Summary.xls". This spreadsheet holds outputs from most of the variations of model parameter settings tested. The following comments are a summary of observations made of the performance of the model using these various settings for the model.]

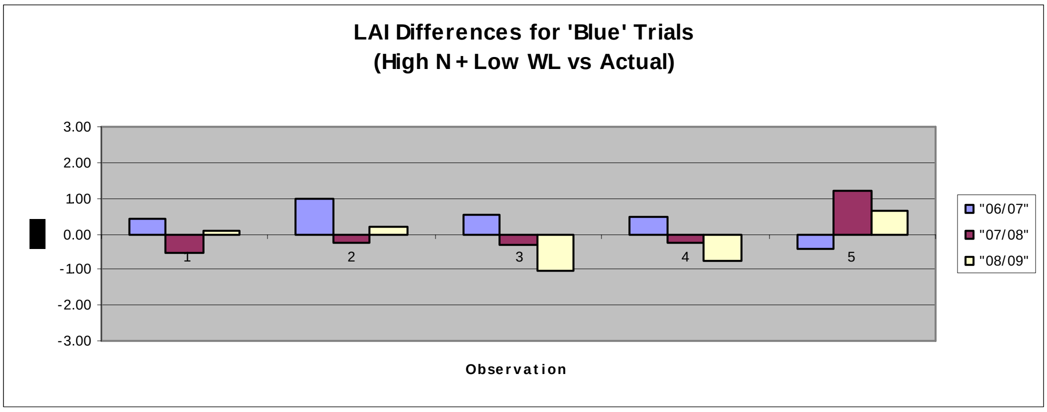
<u>Prediction of LAI development</u>

For drier trials, OZCOT over predicted the LAI.
The worst prediction observed was for the 'Grey (dry)' trial in 2006-07, the hot dry year.
LAI was over predicted for all trials for the early part of the 2006-07 season, but most significantly for the 'dry' trials.

LAI was generally reasonable, both in development timing and maximum LAI predicted for the moderate trials in both 2007-08 and 2008-09.

Some unusual fluctuations were predicted in the wettest trials with LAI ending up being a little on the low side. Reducing the water logging effect (WatLogC = 0.87 → 0.95) and adding some extra Nitrogen (92kg → 150kg N applied) significantly helped to limit the fluctuations and allowed the model to simulate a recovery to close to observed LAI values. This effect was consistent for the wettest trials for both 2007-08 and 2008-09.

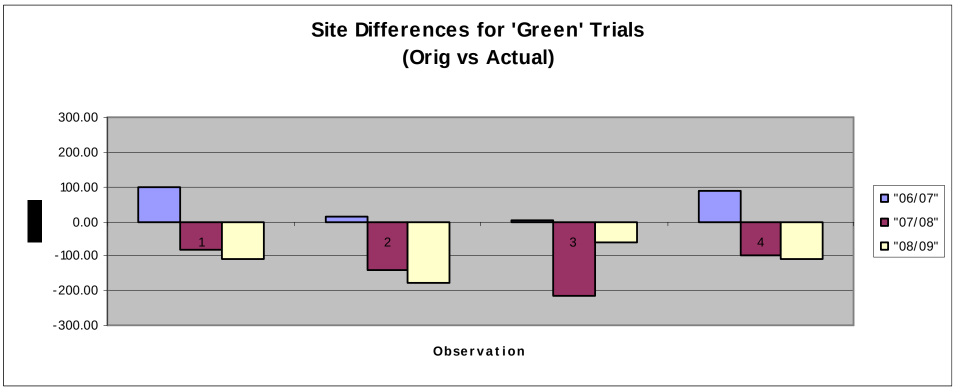


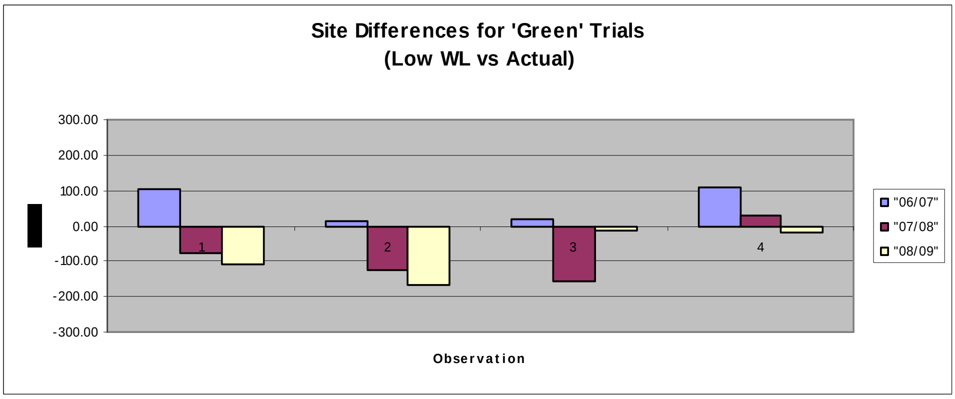


[Wettest trials' LAI prediction improved by reducing water logging and boosting nitrogen]

Prediction of Site numbers

Site development was predicted most accurately for the drier trials, with wetter trials having delayed development (approx 20 days by mid 2008-09 season), and/or too few sites (150 – 200 per metre too few in 2007-08 'Blue- wet' trial). Reduced water logging improved the prediction of the total number, especially in the wettest trials, but the delay was still evident. Adding extra Nitrogen and reducing the water logging can result in an 'over shoot' of the total site number.

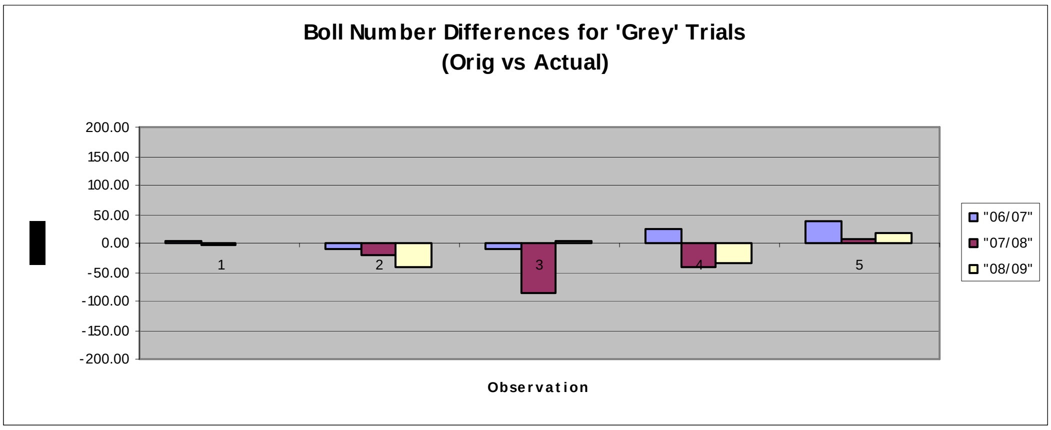


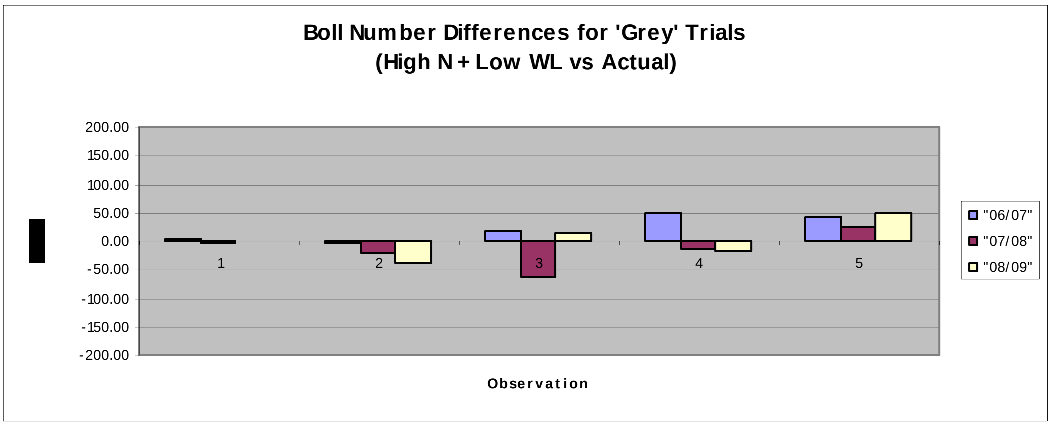


[Reduced water logging improved prediction of site numbers in wet trials]

Prediction of Boll numbers

Largely followed the patterns observed for site numbers.
Very dry trials varied from this pattern in that site numbers were reasonable, while boll numbers were over predicted as was yield. This may indicate that insufficient shedding occurs in very dry conditions.





[Boll numbers were over predicted for very dry trials]

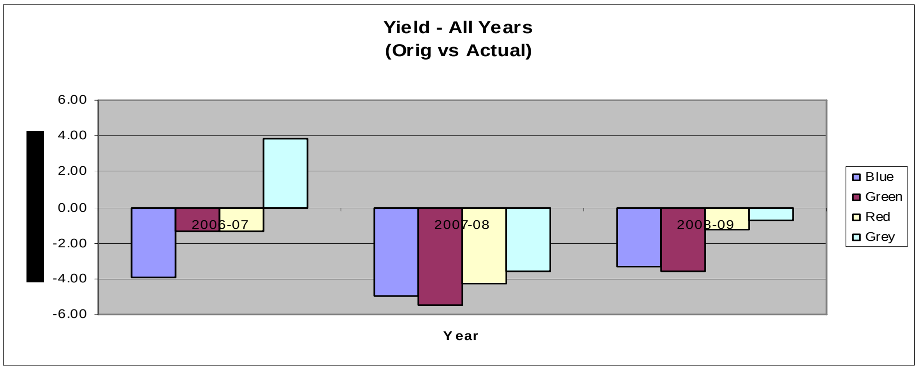
Prediction of Yield

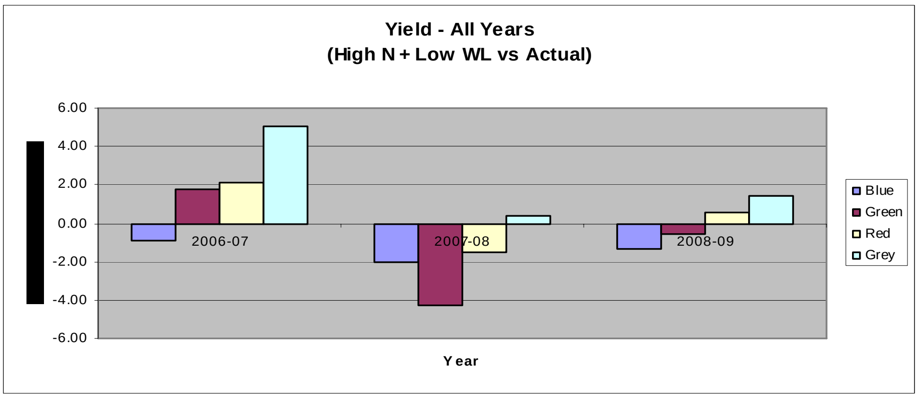
Broad generalisation: Under predicted in high yielding crops and over predicted in low yielding crops.

Crops in good conditions (mild- warm climate and well irrigated) had yield under predicted which was proportional to the under prediction of bolls and, similarly, the under prediction of sites. Under prediction of site → under prediction of yield. Reducing water logging effect and boosting nitrogen improved the situation.

Crops in hot dry conditions had yield over predicted, some by > 50%. This was proportional to the over prediction in boll numbers, while site numbers were predicted fairly accurately.
Sites OK, but too many bolls → too high yield: shedding too low.
Changes to water logging trigger had an effect, but water logging should not have happened at all.
Model responsiveness to nitrogen in very dry trials also raises some questions on nitrogen dynamics in the model.

Boll size, as represented by the varietal parameter 'Seed Cotton/Boll' was varied from the default of 5.0 to 5.5 and 5.8. While some differences were noted, the error in total yield generally was such that fine adjustments in this parameter were effectively meaningless. Simulations that did produce yields closer to the mark indicate that a review of the default boll size from the current 5.0 to 5.5 may be warranted.





[Yield in wetter trials was improved by limiting water logging, yields in driest trials (06/07 – Grey) adversely affected by reducing water logging and boosting nitrogen].

Disscussion Points:

Based on the observations and analysis of the model performance as outlined above, the following points should be discussed and remedial actions considered and appraised:

1. Nitrogen Uptake in OZCOT

Nitrogen uptake needs to be boosted beyond the 240 kg mark to achieve the yields observed. This is consistent with new varieties performing beyond the point where 240kg of N is sufficient.
Currently OZCOT paper refers to UPTAKN_MAX – this is not in the OZCOT model – and this is stated to be set at 240 kg ha^{-1} based on work by Basinski *et al.* (1975) .
OZCOT does not limit the initial Uptake N pool, but does use the 240 kg ha-1 limit to apportion out the effective addition that fertilizer applications make to the pool.
Rocky has new figures that could be used, the equations re-worked and documentation amended. The size of this pool does affect the calculation of the VNSTRS (Veg N Stress factor) which in turn can affect the Fruiting Site Production and LAIGEN (note p262 of OZCOT paper).

(This issue needs to be re-evaluated in light of the fact that the new Cotton component will be using APSIM SoilN. How the core OZCOT model integrates with SoilN needs to be reviewed to assess whether any part of the current problem will remain when simulations are run in AussieCot or in ASPIM with the new Cotton component).

2. Water Logging

Water Logging appears to have too great an effect when left at the default level (WatLogC = 0.87). Simulated results indicate a better fit at about WatLogC = 0.95.

The wetter the trial the worse the under-prediction of site production and boll retention.
Limiting the effect of water logging in the one of the wettest trials in the wettest year significantly improves LAI (total) and, to a lesser extent, yield. It improves, but fails to correct Sites and Boll numbers.

Yield is generally under-predicted, primarily driven by too few bolls.
Few sites, but LAI not too bad: Is LAI / site too high?
Too few bolls may lead to high LAI /site? (via excess resources).

Question: How do wet conditions lead to too few sites?

[Test performed re Nitrogen X water logging vs site numbers:
Question: Reduced N → less sites? / Excess N → more sites? w/wo water logging.
Results: Reduced N with water logging simulated poorly – too few sites, low yield.

High N with no water logging gave best results.

Analysis: Water logging slightly increased shedding and therefore reduced yield. However, the biggest effect of water logging is to reduce site production. Increased N compensates by boosting site numbers.

]

3. LAI/site

In very dry conditions, site production is not too bad, but LAI is way over predicted.

LAI/site too high by far – VPD or other limiting factor on LAIGEN not accounted for?

4. Yield over predicted under dry conditions

High yield might be accounted for by #3 above (LAI/site).
High yield predictions may also be contributed to by:

Boll shedding is low in dry trials – this could be a result of excess LAI(?) and results in an excessive yield prediction. (?)

Nitrogen dynamics: Low (dry) SMI should limit N usage, but simulations still indicate that N is limiting yields, even though yield is already over predicted.

Early over prediction of LAI in wetter treatments of some years may reflect the unaccounted-for thrips damage in the crops. (2006-07 especially).

High yield of irrigated crop ('blue') better simulated with adjusted higher N values with some (but limited) water logging effect. (Sims run for 400+ N, with, without and reduced water logging). Excess N with no water logging produced 18.1 b/ha!
Conclusion: Some water logging effect is still required?

5. WatLogN

Also of note is that WatLogN – the level at which water logging affects Nitrogen use – is NOT compared against SMI, but rather against SW/UL, which can be considerably different from SMI. The default value of WatLogN is 0.87, just as it is for WatLogC.

OZCOT uses:

```
IF (SW/UL.GT.WATLOG_N) THEN              ! waterlogging 28/5/96
  IF (AVAILN.GT.30.) THEN
    AVAILN = AVAILN-0.983          ! Hearn & Constable
  ELSE
    AVAILN = AVAILN*0.99           ! Hearn Constable
```

ENDIF
ENDIF

SW/UL can vary quite significantly from SMI (eg. SW/UL = 0.943 vs SMI = 0.827) so 'water logging' affecting N usage may not match reported SMI patterns.

Note: WatLogC is compared against SMI, so the default value of 0.87 for WatLogC does mean that water logging affects Carrying Capacity for SMI values above 0.87.

– 2006-07 & 2007-08 Season Testing Report

Deficit Trial Analysis Summary
Of OZCOT Simulations
2006-07 & 2007-08

The two growing seasons of 2006-07 and 2007-08 represent very different seasonal patterns for the cotton crop grown at Myall Vale. This can be very useful for model validation, especially with the inclusion of the new dominant variety S71 BRF.

2006 - 07 was a hot, dry year which had early thrips damage. VPD was unusually high for much of the season.

Blue (wettest) '06 Trial: -

Sites : simulated OK
Bolls : simulated OK
LAI : Over predicted early. Max LAI within ~0.5
Yield : Slight UNDER prediction [11.4 vs 12.3] - Why? (FNSTRS still limiting at 150 kg N?)
SeedCot/Boll variation: Best at base of 5.0
Notes: WaterLogging not shown to be much of an issue, if at all.

Green (wet) & Red ('typical') '06 Trial: -

Sites : OK
Bolls : Slight over prediction. Longer season? More LAI? Less boll loss?
LAI : **Over prediction early**. Thrips damage? VPD effect on leaf expansion?
Yield : Over prediction. Higher LAI effect?
SeedCot/Boll variation: Negligible effect. Larger bolls slightly better.

Grey (dry) '06 Trial: -

Sites : Not too bad.
Bolls : Over predicted – significantly. Boll shedding too low?
LAI : Big error. Model Over predicted. Thrips damage early? More VPD stress not accounted for?

Yield : Over predicted [6.1 vs 11.1] Model responsive to input changes for WatLog and N, but water logging effect should have been minimal for this dry treatment so N effect is more likely. Likely N stress more sever here with low SMI depleting NUptake value. N is limiting, even with excess yield!

SeedCot/Boll variation: not valid effects. 5.0 as valid as any.

2007 – 08 was a mild, wetter year. Some water logging was evident in heavily irrigated trials. Thrips damage was generally well controlled in the early part of the season.

More typical of a year that the OZCOT model would have been developed under. Reducing Water Logging effect and boosting Nitrogen significantly improved performance, particularly on wetter treatments.

Blue (wettest) '07 Trial: -

Sites : simulated too few sites (150 – 200 per metre too few) Water Logging effect? Even when water logging was suppressed?

Bolls : simulated too few by about the same rate. Boll shedding due to water logging? Or too few sites produced?

LAI : Close. Significant improvement when Water Logging was suppressed and N boosted

Yield : UNDER prediction [11.0 vs 13.0] - Why? Too few sites? → too few bolls (Some N Stress mostly from Feb'08 on: water logging?)

SeedCot/Boll variation: Best at 5.5 – marginal gain

Notes: Water Logging having a significant effect?
Too few sites but LAI OK?

Green (wet) & Red ('typical') '07 Trial: -

Sites : Slight delay. Green slightly under predicted. Red close to OK.

Bolls : Under prediction. Model shows greater drop in boll numbers than observed. Model loses too many bolls? Water Logging effect wrong?

LAI : Close. Red with suppressed water logging even over predicted LAI (Standard settings better). Water logging effect on LAI more accurate than on boll load – error in effect on boll load?

Yield : Under prediction. Green significantly (9.5 vs 13.8) Boll shedding effect?

SeedCot/Boll variation: Small effect. Larger bolls (5.8) better, especially for Green treatment.

Notes: Water Logging and N boost had a limited effect – less for drier treatment.

Grey (dry) '07 Trial: -

Sites : Slight under prediction and slight delay, but not too bad.

Bolls : OK (sort-of). Boll shedding simulation not too bad in drier treatment?

LAI : OK. Slight over prediction in late season. Model well tuned for this scenario?

Yield : Close [12.4 vs 12.0]. Some N or water logging effect as default model Under predicted yield [8.5 vs 12.0] – Most probably N stress. Likely N stress more severe here with low SMI depleting NUptake value. N is still limiting with extra N added!

SeedCot/Boll variation: No effects. VERY flat response.

Notes: Water Logging and N boost had a limited effect – mostly more N available.