Part 1 - Summary Details

CRDC Project Number: **CRC79**

Project Title: Water relations of the Cotton Plant

Project Commencement Date: 01/01/2002 **Project Completion Date:** 30/06/2006

CRDC Program: On Farm

Part 2 – Contact Details

Administrator: Jo Cain, Administration Manager
Organisation: CSIRO Plant Industry
Postal Address: CSIRO Cotton Research Unit Locked Bag 59, Narrabri 2390
Ph: 02 6799 1500 **Fax:** 02 6793 1186 **E-mail:** Jo.Cain@csiro.au

Principal Researcher: James Neilsen, Post Doctoral Fellow
Organisation: CSIRO Plant Industry
Postal Address: CSIRO Cotton Research Unit Locked Bag 59, Narrabri 2390
Ph: **Fax:** 02 6793 1186 **E-mail:** james.neilsen@csiro.au

Supervisor: Lewis Wilson, Senior Principal Research Scientist
Organisation: CSIRO Plant Industry
Postal Address: CSIRO Cotton Research Unit Locked Bag 59, Narrabri 2390
Ph: 02 6799 1500 **Fax:** 02 6793 1186 **E-mail:** lewis.wilson@csiro.au

Signature of Research Provider Representative: ______________________

Part 3 – Final Report Guide (due 31 October 2008)

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

Background

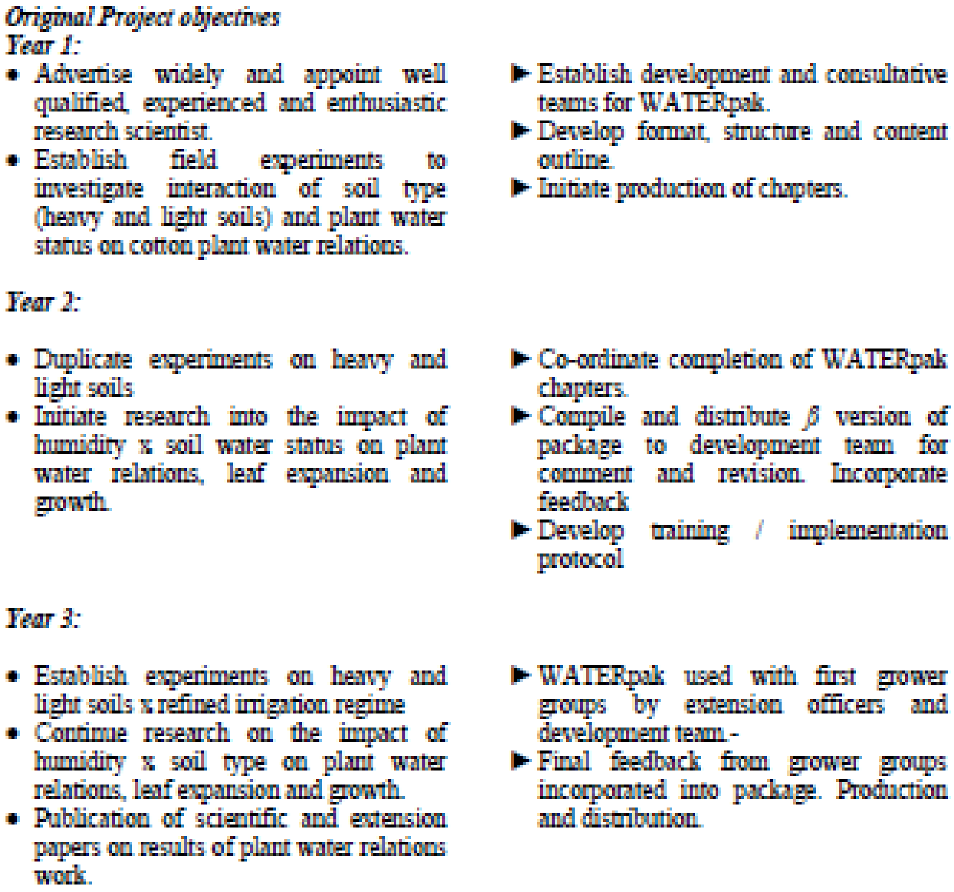
Personnel development: The project was developed as there had been an increasing research effort into water related issues. However, the majority of this research had focussed on engineering or soil issues, or approached the question of water management from a soil water perspective. The central component, the cotton plant, had received less attention. There was no researcher specialising or even working in this area in cotton in Australia. It was recognised by a number of groups within the industry that to make a significant and sustained impact in this area a researcher focused on water relations issues was required. T he position was proposed to be in the area of plant water relations. This is a key area that was poorly covered. Such research is fundamental to the development of optimum water management strategies and to understanding the response of the crop under different water supply, soil type and evaporative environments.

Science: The response of a plant to the available soil water status is modified by the rate at which the water stress is imposed. This can operate via a number of pathways and at a number of scales. Research by Cutler and Rains (1977) has documented the capacity of cotton to acclimate to drought stress due to previous exposure. Similarl it is well known that stress can induce deeper rooting than a high water supply (Cull, 1979). These two mechanisms involve a longer term adaptation of the plant. It is also recognised however that without these mechanisms acting, there is still an effect of the rate of soil drying on the plant response. Denmead and Shaw (1962) and Shaw and Laing (1974) showed that the impact of a given water deficit on plant function is greater when the evaporative demand is high. In reviewing the literature on plant response to soil water status, Sadras and Milroy (1996) showed that plants grown on heavy soils were less effected than those on lighter soils, even when the water status was indexed relative to the capacity of the soil to hold water. Therefore, to optimise the irrigation strategy for a given location it is necessary to know the response of the plant to the prevailing humidity and soil type. Currently, little information of this type has been developed for cotton grown in the various production areas of Australia.
Previous experiments both in Australia and the USA have demonstrated genetic variation in the response of cotton plants to moisture stress, including stomatal behaviour and osmoregulation. There is significant scope to explore this variation with an aim to identify beneficial traits for a given environment or to derive selection criteria to incorporate into a breeding program.
In this project we aimed to quantify the response of cotton to water status under contrasting conditions of soil type and atmospheric humidity in the growing regions. This information provides a basis for developing irrigation scheduling techniques as well as contributing to our understanding of adaptation and hence breeding.

Decision support: The importance of water management and the efficient use of water to the cotton industry are indisputable. The significance of WUE stems both from the need to maximise returns from a limited resource and from the political imperative of demonstrating to the community good stewardship of the resource. Corresponding to these two needs, good management and appropriate documentation become critical.
At the moment, there is little industry specific information relating to water measurement and management that is readily accessible to producers or advisors and certainly no material that attempts to deal with the issues in an integrated or structured way. The development of a WATERpak manual, following a similar structure and approach to that used in SOILpak could meet these needs. A development team will be established with representatives from the Australian Cotton CRC (especially NSW Agriculture and DPIQ). To have a significant impact on industry practice, the production of the manual should be coordinated with a specific education

program for its use. This will be coordinated through the CRC in collaboration with state department extension officers. This could be profitably linked with an education program on the use of HydroLOGIC.

Objectives



Original Project objectives

Year 1:

- Advertise widely and appoint well qualified, experienced and enthusiastic research scientist.
- Establish field experiments to investigate interaction of soil type (heavy and light soils) and plant water status on cotton plant water relations.

▶ Establish development and consultative teams for WATERpak.
▶ Develop format, structure and content outline.
▶ Initiate production of chapters.

Year 2:

- Duplicate experiments on heavy and light soils
- Initiate research into the impact of humidity x soil water status on plant water relations, leaf expansion and growth.

▶ Co-ordinate completion of WATERpak chapters.
▶ Compile and distribute β version of package to development team for comment and revision. Incorporate feedback
▶ Develop training / implementation protocol

Year 3:

- Establish experiments on heavy and light soils x refined irrigation regime
- Continue research on the impact of humidity x soil type on plant water relations, leaf expansion and growth.
- Publication of scientific and extension papers on results of plant water relations work.

▶ WATERpak used with first grower groups by extension officers and development team.-
▶ Final feedback from grower groups incorporated into package. Production and distribution.

Due to the timing (original start date July 2001, actual start date January 2003) of the appointment of the researcher (James Neilsen) to the position, some of the original objectives have been modified during the course of the project, these changes have been advised during the annual reporting process. These changes are included below, however, all of the objectives stated in the original proposal have been achieved during the course of the project.

Experimental objectives - Year 1

James Neilsen was appointed and started in the position in January 2003.

The field experiments on differing soil types were not established in the first year. This was because James arrived halfway through the season and there was not a chance to establish experiments, these experiments were deferred to the second field season, however field experimental measurement as outlined below was conducted.

Experimental work was conducted into cotton plant water relations in the field. This work was not carried out over different soil types but was undertaken in an existing experiment were irrigation treatments were being imposed. Steve Milroy and Mike Bange were conducting an experiment investigating the effect of cultivars, and differences in determinacy, on the ability of crops to tolerate intermittent stresses. A drought treatment was imposed on the half the plants by skipping an irrigation in late January. Measurements of plant water stress through the period of imposed stress and recovery following the subsequent irrigation. Measurements that were undertaken included, pressure bomb readings of plant

water potential and IRGA measurements of photosynthetic activity. This experimental work allowed James to become familiar with techniques for measurement of water relations in and growth of the cotton plant.

Experimental objectives -Year 2

To achieve the original year one experimental objectives a field experiment was conducted on three different soil types, with monitoring of plant water relations, growth, and soil moisture throughout the growing season. The three experimental sites were established (2 at ACRI and 1 at Willawah) with a range of different soil types in close proximity to each other to ensure that climate was constant across the experiment and soil factors were the major difference between the sites. Stress treatments were imposed on the plants in the experiment, ranging from normal irrigation to severe stress. Measurements were taken during the imposed stress and through recovery following the subsequent irrigation. In addition to the main experimental program stated in the objectives, measurements were also taken from the field experiments of Dirk Richards (Limited water - systems experiment) and Ian Rochester (crop rotation). This data was being used to expand on the results and analysis from their experiments and add to the overall experimental program.

Experimental objectives - Year 3

The previous year's experiments were replicated in the field investigating the effect of soil type on the plant water relations of cotton. This was to verify and expand on the results of the soil type effect on plant water relations experimentation. The same three sites as in the previous seasons experiment were used. To undertake the original objective two of the second year, relating to the effect of the interaction between humidity and soil water status on cotton plant water relations it was decided to use replication through years to provided different climatic conditions. This use of time as a treatment enabled more intensive measurements to be undertaken in the experiments rather than spreading resources over an increased number of sites. An additional experiment to the stated objectives was established at ACRI to examine whether a crop with high retention early in the season (eg Bollgard II) required watering earlier and more frequently than a crop that was not holding as many early fruiting sites. The experiment investigated the effect of three levels of fruit retention on soil water extraction patterns, which we used as a measure of root development. The rationale for this approach was that crops with high fruit retention put more resources into fruit and less into vegetative growth, hence they may have a smaller root system less able to explore the soil for water. This experiment was conducted in conjunction with Grant Roberts (Farming system Scientist). In addition to the stated objectives James undertook a Cotton CRC funded scientific exchange to the USA (Florida, Texas and Arizona) from August 13 to September 2 2005. During this exchange James visited a number of different researchers and had a number of discussions that will be beneficial to his current and future research. James expanded his knowledge of the physiology and measurement of plant water relations.

Experimental objectives - Year 4

This project received a 6 month extension to bring it into line with the funding cycle due to the timing of commencement of the appointed scientist (James Neilsen). This field season completed the objectives of year three of the original proposal. The previous years' experiment was refined and the effect of soil type and climate on cotton plant water relations were investigated at the same three experimental sites. A refined irrigation regime was not used on the different soil types as more data was required to better understand the interaction between evaporative demand, soil type, soil moisture and plant water status. In addition to the stated objectives the research investigating the effect of fruit retention on root system development was repeated. The same levels of fruit retention and irrigation were used as for the previous season. During the season a third field experiment was conducted into the applicability of partial root zone drying (PRD) to increasing the water use efficiency of cotton. This was done using surface drip irrigation tape laid in every furrow (1m spacings) on a grey vertosol. Four treatments were established, with cotton being sown in two configurations; either solid, every bed planted, or alternate, one out of every two beds planted. Two irrigation treatments were imposed over the sowing configurations; fully irrigated, water from both tapes next to the plant, and PRD, water from only one side at any irrigation. Two papers from this research were presented at the 13th Australian agronomy conference in Perth in September 2006 and scientific journal papers are currently being prepared (see publication plan).

WATERpak objectives: Years 1, 2 and 3.

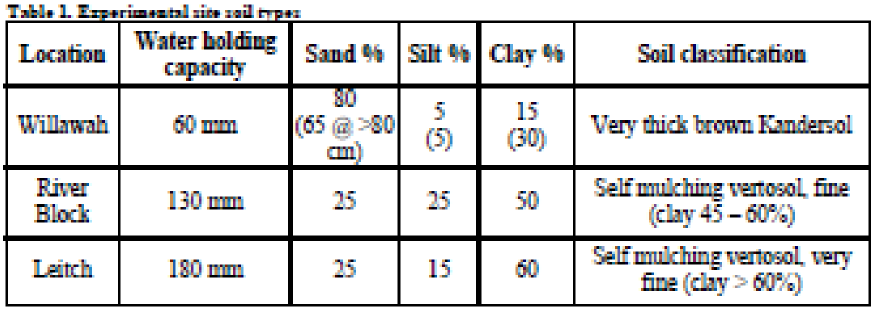
Due to the time taken to appoint a scientist to this position Steve Milroy had already initiated WATERpak, and a WATERpak committee (Steve Milroy, Graham Harris, David Williams Guy Roth and Helen Dugdale) had been established before James Neilsen arrived in Narrabri. Authors had been contacted and individual chapters had been received by the WATERpak committee from these authors for review. Dirk Richards and James Neilsen were appointed to the committee to replace Steve Milroy when he left CSIRO in Narrabri in July 2003. The WATERpak committee completed reviewing, editing and compilation of WATERpak and it was released to the cotton industry in August 2004. This project had input into WATERpak through James's involvement in the committee from July 2003 and also in chapter writing, although not to the extent of the original project proposal. All of the WATERpak objectives have been achieved.

Methods

- Effect of soil type and climate on plant water status

That main experimental program of plant water relations as affected by soil type and climate was undertaken over 3 seasons with a similar experimental method being used in each season. In each season 3 experimental sites were established (2 at ACRI and 1 at Willawah) with a range of different soil types (Table 1) to conduct experimental work into cotton plant water relations in the field.

Table 1. Experimental site soil types



Location	Water holding capacity	Sand %	Silt %	Clay %	Soil classification
Willawah	60 mm	80 (65 @ >80 cm)	5 (5)	15 (30)	Very thick brown Kandersol
River Block	130 mm	25	25	50	Self mulching vertosol, fine (clay 45 – 60%)
Leitch	180 mm	25	15	60	Self mulching vertosol, very fine (clay > 60%)

The experimental locations were chosen as they represented a wide range in soil types while maintaining similar climatic conditions. This was set in the first season's experimental work when climatic factors were not intended to be studied. The subsequent use of these experimental sites for measuring the effect of climate as opposed to trying to locate sites in different regions with similar soil types resulted from the intensive measurement required by the experiments. It became obvious that replication through seasons would be the most effective method of studying different climatic conditions for the purpose of this project and that having a different set of sites to study the climatic effect would not be possible.

The response of plants was measured under a range of irrigation treatments, with moisture stress applied during the period immediately prior to and during flowering. Two different stress treatments were imposed on the plants in the experiment; normal irrigation and severe stress. Normal irrigation was in line with farmer (or research station) practice for the paddock, with irrigations applied as required. The stress treatment involved skipping two irrigations starting at early flowering (usually these were the first two irrigations received by the crop). This time was selected for the imposition of stress as it is during this stage that the cotton plant is under ever increasing demand for moisture for both vegetative and reproductive growth. The potential effect of moisture stress at this stage on yield also increases from early to peak flowering and it is also possible to further investigate the plant response through manipulation of fruit numbers. Measurements were taken during the imposed stress and through the recovery period following the subsequent irrigation in both the fully irrigated and stressed treatments.

To prevent rainfall from interfering with the application of soil moisture stress in the limited water treatments plastic was used in rows in the second an third seasons after some effect of rainfall on stress development during the first seasons research. This plastic was laid in the furrows and pegged along the plant line to exclude the majority of rainfall from entering the soil profile. Only rain which preferentially flowed down the stem of the plant would be able to reach the root zone of the plant. The only down side to the use of this plastic could be the heating up of the soil under the plastic and any effect this may have on soil microbial or plant root functioning, to limit this effect the duration of plastic cover in the furrows was kept to a minimum.

The variety Sicot 289 BR was used for the experiments, this variety was still a prevalent variety at the time of commencement of the experimental program and it was decided to reduce outside influence on the interpretation of results to continue to use this variety through all years of the experiment rather than switch to Sicot 71BR during the course of the experiments. Measurements on the experiments in the 3 seasons included, soil moisture monitoring, leaf water potential, measurement of leaf expansion rates, biomass development and final yield and quality. Measurement of plant water status was made using a PMS instruments pressure chamber, which measures plant leaf water potential. Leaf water potential measurements were taken on the first fully expanded leaf of randomly selected plants, with 2 leaves measured per replicate at each reading. Where possibly readings were taken both pre-dawn and in the afternoon (12.30 – 14.00). Pre-dawn is when the water potential in the plant is likely to be closest to equilibrium with the soil and this will provide the minimum reading of leaf water potential that the plant will experience during that day. Afternoon readings will indicate the maximum leave of stress imposed on the plant and will be most useful in scheduling irrigations. The number of measurements that may be undertaken using the pressure chamber is limited by the length of time taken for each measurement as increasing the pressure in the chamber has to be done slowly to allow a true

reading of plant water status to be obtained, and by daylight in the pre-dawn readings as you can only work until just after dawn before the readings are affected and don't provided a true minimum for the plant.
Leaf water potential measurements were conducted prior to the imposition of water stress in all treatments to get a base line comparison between treatments and then at regular intervals after the irrigation/stress imposition events. Measurements on all three sites at the same time post irrigations were attempted, however, timing of measurement had to be modified to account for cloudy days, rainfall and spray applications to the paddock. Leaf area measurement was used as a non-destructive measurement of water stress, to indirectly estimate levels of plant water stress in the field. Ten plants in each rep had the upper 4 leaves tagged and measured prior to the imposition of moisture stress. The leaves were then measured at regular intervals during the course of the experiment. Leaf measurement was by measuring the length of the midrib of the leaf which was then corrected to an area using the formula developed by Constable (1981).

Plant vegetative and reproductive development was recorded multiple times during each of the growing seasons. Destructive harvests of 1 meter of row from all plots were taken before the imposition of treatments and then sequentially at the subsequent irrigations during the treatment period. Plant height, numbers or fruit leaf area and dry weight were recorded. All plots were harvested for yield and quality at the end of the season using the CSIRO single row picker and cotton was ginned in the CSIRO small gins before being put through the HVI machine to assess fibre quality. In addition to this bulk quality measurement, stratified samples were taken from the plant in 3 sections (bottom, middle and top) to be enable the impact of timing of stress to be related to differences in cotton quality.

- Water use of high retention cotton

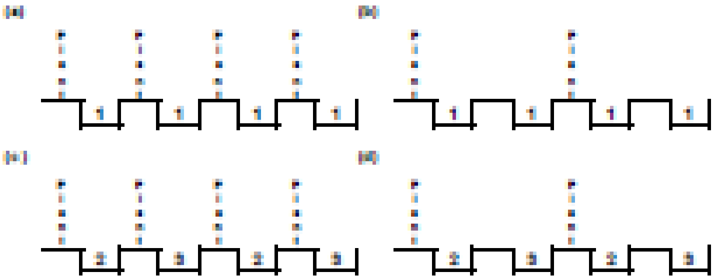
To measure differences in water extraction, as a measure of root development, between the high and low retention crops an experiment was established with three levels of fruit retention in the Bt transgenic variety Sicot 71BR: high (no manual fruit removal), medium (fruit removal from the bottom 5 fruiting branches) and low (all fruit removed from the plant continued until the medium treatment reached cut-out)). Manual fruit removal was undertaken between every irrigation in the medium and low retention treatments. This manual fruit removal involved removing fruit as squares from the plant but maintain the leaf area on the plant (not removing the whole fruiting branch). Keeping up with the level of fruit removal was somewhat difficult during the peak period of the season with large amounts of labour required to remove fruit between irrigations, and when this time was reduced by spraying and rainfall events sometimes it was difficult to complete the whole experiment between irrigations events especially in 2005 -06 season with more frequent irrigation due to the climatic conditions. In some cases the number of rows damaged per plot was reduced in order to reduce the labour requirement and keep the experiment on track. In addition to fruit removal a water stress treatment was also included. This involved missing the first two irrigations for comparison with fully irrigated cotton. This was included to encourage the early development of the root system and to investigate if early-season water stress had any effect on the development of the root systems of the different fruit retention treatments.

The depth of water extraction was monitored by assessing soil moisture content using paired neutron probes in both the plant row and the associated furrow. Soil moisture content was assessed at weekly intervals as well as prior to each irrigation. The use of paired tubes enabled measurement of the extraction in the hill and the furrow to be measured. Two neutron probe tubes were installed per plot, in the middle row 2m from the end of the fruiting plot. The use of neutron probe measurements to record water extraction in place of destructive harvesting of the root sample allowed for more intensive measurement, in addition to alleviating all of the practical problems associated with root extraction from the field.

Measurements were taken of fruit retention in all experiments at the end of the season as well as machine picks to assess yield and provide samples for fibre quality testing. In the first season maturity picks were also taken to assess effects on crop maturity.

- Partial root zone drying

A preliminary experiment researching partial root zone drying (PRD) was conducted in the field with input from Greg Constable. The experiment was conducted under a urface laid drip tape irrigation system. The results may be valuable for planning future research and in directing the potential for application of this technology to improve WUE in cotton. The Bollgard II® cotton variety Sicot 71BR was used. The experiment was grown in two row configurations on 1-metre beds: solid had one metre row spacing, while the alternate had one row of cotton planted then one row blank (Figure 1). Irrigation was applied by surface drip tape with the tape laid in every furrow. Two irrigation treatments were imposed over the sowing configurations. The fully irrigated crop was watered using the tapes in both furrows at each irrigation (Figure 1 a and b), while the PRD only received irrigation from one furrow per irrigation (Figure 1 c and d). Drip irrigation was applied daily or every two days to maintain the fully irrigated crop near the field capacity. The drip irrigation system was capable of delivering 2 mm per hour. The fully irrigated and PRD treatments both had the same amount of water applied at each irrigation, to achieve this the PRD was irrigated for twice as long as the full irrigation.



Water application and movement across rows was monitored using neutron probe tubes placed in the hill were plant measurement was occurring and the 2 adjacent furrows.

Leaf water potential was monitored using a pressure chamber at times throughout the experiment. Stomatal response was assessed using a rapid screening porometer on two occasions. The rapid screening porometer passes a know volume of air thorough the leaf to which it is attached and the time taken for this air to pass through the leaf is a representation of the stomatal opening of the leaf. In addition, vegetative and reproductive growth was measured using destructive dry matter harvests as described in the soil and climate effect of plant water status methods section and machine pick yield and quality harvests were also conducted.

Results

- Soil and climate effects on plant water relations

The cotton plant responds differently to water stress on different soils types when the level of moisture stress is expressed as a volumetric capacity eg mm. This is because soil types contain different amounts of water and a certain volume extracted from one soil will be a different percentage of the total when compared to another soil type. However, there was no significant difference in the response of cotton the soil moisture deficit across the three soil types (Figure 2), when soil moisture content is expressed at the fraction of transpirable soil water (FTSW). FTSW represents the total amount of plant available water in a soil profile as a percentage. Expressing soil moisture in this form allows soils with different water holding capacities to be directly compared for their plant response. So a clay soil with available moisture of 180 mm can be plotted against a sandy soil with a water holding capacity of 60mm. Even when expressed as FTSW the response of cotton on the lightest soil type was flatter than on the heavier soil types, however, it was not significantly different. This means that cotton plants respond to soil moisture deficits in much the same manner across all soil types tested.

This research has found that soil type does not influence the appearance of plant stress when differences in soil moisture holding capacity are taken in to account. FTSW may be a valuable index to improve irrigation strategies across different soil types, it is a useful measure of soil moisture that can be applied across soil types to understand the interaction between soil moisture, evaporative demand and plant growth. The use of FTSW as a measurement of soil water availability, and therefore of plant function, may provide a benchmark for irrigation scheduling allowing development of accurate recommendations for different deficits for each soil type and evaporative demand scenario.

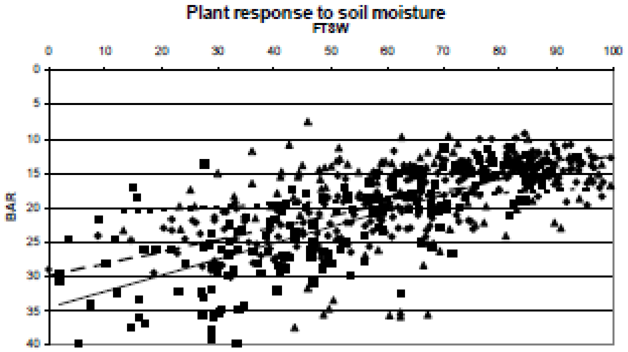


Figure 2. Afternoon leaf water potential (BAR) in response to normalised soil water (FTSW) on three soil types Leitch (7 solid line), River block (8 dashed line) and Willawah (9 dotted line) over three seasons.

The effect of humidity on cotton plant response to soil moisture status is shown in Figure 3. The effect of humidity is represented by levels of vapour pressure, high (30) medium (20 – which was the average vapour pressure reading of the experimental measurements) and low (10). The level of vapour pressure has a large effect on the ability of the plant to cope with a given level of soil moisture stress. High levels of vapour pressure increase the level of stress the cotton plant experiences for a given soil moisture status. This increased stress level means that the effect of a soil moisture deficit can be different depending on the environmental conditions and just monitoring crop status through soil moisture measurement will not give a complete understanding of plant status.

Situations occur where plants are under stress even where there is readily available moisture for the plant (figure 2). In these situations that application of additional irrigation to crops will not stop any yield losses from occurring as the ability of the plant to take up water from the soil is being exceeded by the evaporative demand placed on the crop. It is hoped that further work in conjunction with these results will produce a guide as to when additional irrigation will be of no benefit to reduce plant stress.

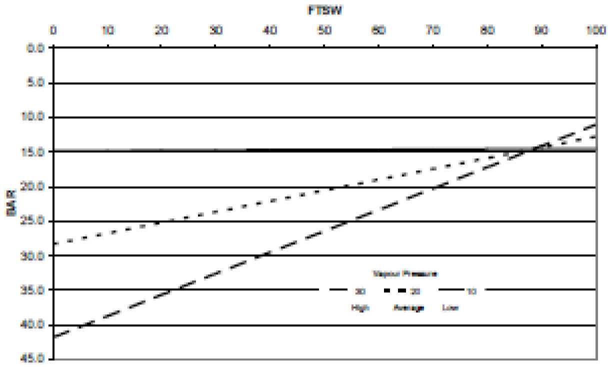


Figure 3. The effect of vapour pressure on plant response to soil moisture deficit.

There was a wide variation in yield response to the treatments imposed on the three sites across the three seasons (table 2). The yield response at Willawah in first two seasons stress treatments was low due to the nature of irrigation on this soil type. On the light Willawah soil, irrigations are more frequent than the other soil types, this frequent irrigation means that although the same level of moisture stress is imposed on the plants this stress is not imposed for the same period of time and the crop has longer to compensate at the end of the season. In the 2005/6 season there were severe climatic effects (very hot, dry days) on the plant during the imposition of moisture stress. The climatic conditions caused a yield reduction as the stressed plants ceased vegetative development and finished the bolls on the plant before growing a top crop.

In the river block the low difference between yields relate to low yields of the control treatment in the first and third seasons (Table 2). This is because outside factors dictated that the irrigation schedule of the 'control' treatment was not optimal for the experiment, however, this was not a major constraint to the experimental objectives as it will have had minimal effect of the plant water status measurements, despite a major cumulative effect on final yield.

The stress treatment on the heaviest soil at Leitch had the largest effect on yield (Table 2). In the first season rainfall during the imposition of stress reduced the effect of the stress treatments. In the second and third seasons the stress treatment reduced yield as Leitch had the longest irrigation interval and the longer period of imposed stress. Like river block in the third season the cotton plant ceased vegetative growth and finished the bolls on the plant before attempting to grow a top crop.

The response of yield to the irrigation treatments is complicated by the irrigation of the full treatment and conditions the crop is exposed to outside of the treatment period. Understanding the effect of soil type and climate on yield response of the crop will require more detailed measurement over a range of soil moisture deficits throughout the season and measurement of well grown crops with known periods of climatic stress.

Table 2. Cotton yield (bales/Hectare)

Site	Season	03/04	04/05	05/06
Willawah (kandersol)	Full irrigation	8.9	9.6	9.4
	Stressed	9.2	8.6	5.4
R6 (fine vertosol)	Full irrigation	5.8	8.8	5.2
	Stressed	4.9	8.2	5.3
Leitch (very fine vertosol)	Full irrigation	8.2	10.1	10.2
	Stressed	7.2	5.0	3.3

A relationship was established between pre-dawn and afternoon leaf water potential measurements. On most occasions leaf water potential has been measured twice per day, a regression between these measurements indicated that the afternoon measure of leaf water potential is correlated with the minimum level of stress that is received by the plant (predawn measurement)(n = 477) (Figure 4).

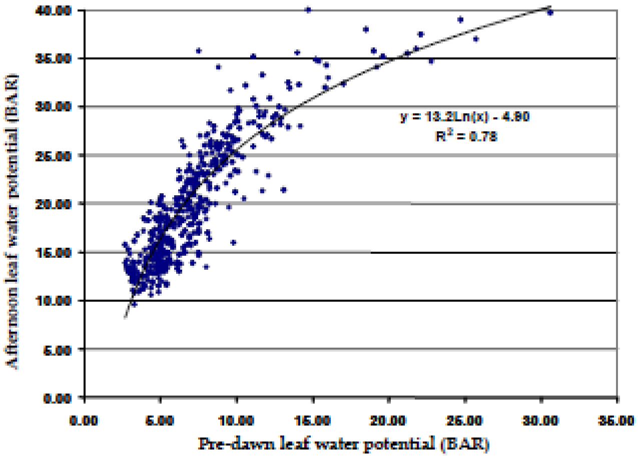


Figure 4. Relationship between pre-dawn vs. afternoon leaf water potential (n = 477)

Removing seven points were the predawn leaf water potential exceeded 20 BAR from the river block site from the third year of the experiment (n = 470) produces a linear relationship between the two sets of leaf water potentials (Figure 5). This data is in line with the normal levels of moisture stress that is experienced by irrigated cotton plants,
Pre-dawn leaf water potential (BAR), Afternoon leaf water potential (BAR) pre-dawn readings in excess of 20 BAR are not representative of an irrigated crop and are unlikely to be replicated under normal conditions. The equation from the second data set is likely to be more useful in possible irrigation scheduling from pre-dawn leaf water potential measurements. Y = 1.80X + 7.2 (R2 = 0.76).

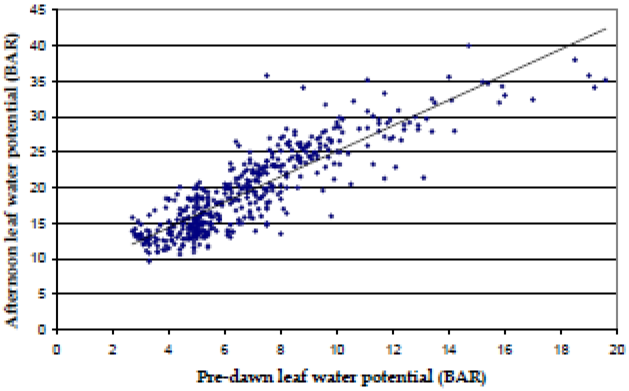


Figure 5. Relationship between irrigated conditions pre-dawn and afternoon leaf water potential (n =470)

- High retention water use

There were no differences between fruit removal treatments in terms of soil water extraction under either irrigation regime in either season (figure 6). There were differences between the water stress treatments with the stressed treatment extracting more moisture from the soil profile than the irrigated (figure 6).

Figure 6 shows the soil water from the hill probe tubes at 3 times for each season, prior to the imposition of treatments, at mid flowering and the last probe reading taken. In the 2005/06 season the final probe reading was later in the season than in the previous season to further examine the effect of fruit retention post last effective flower on soil water extraction which had been identified by Steve Yeates and Dirk Richards in their complementary research. There is a trend for the high retention crop to extract less moisture from depth late in the season but there is no significant difference (figure 6f). The effect of the stress treatments was reduced in the second season as twice as much rainfall fell during January/February in the 2005/06 seasons as the 2004/05 season. This rainfall would have masked the effect of water stress in the stressed treatments and increased their yield (table 3). In addition, in both seasons the crops that had a medium level of fruit retention out yielded the high retention crops under the water stressed conditions. The loss of early fruit may have enabled the development of a larger plant able to take greater advantage of the later irrigation applications (table 3).

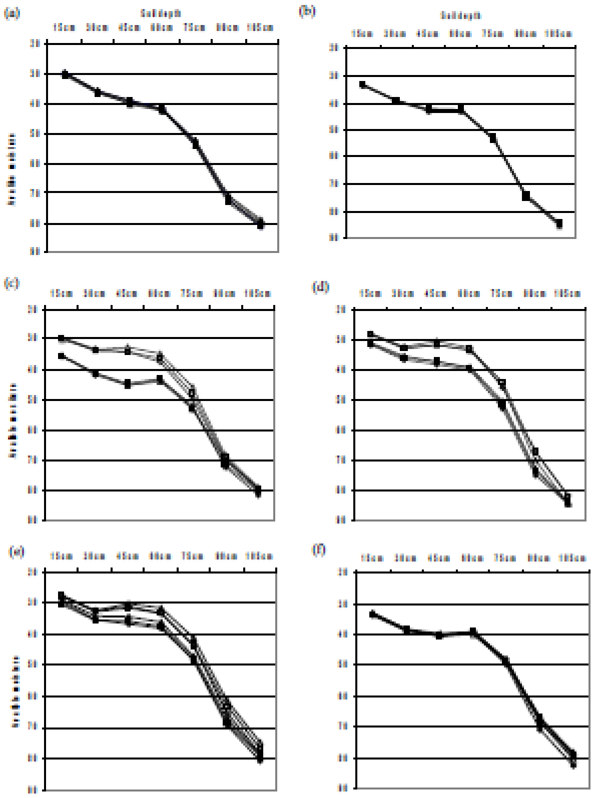


Figure 6. Water extraction at of all treatments: high retention (7), medium retention (8) and low fruit retention (9) for full irrigation (closed symbols) and water stressed (open symbols), prior to irrigation (a and b), at mid flowering (c and d) and at final reading (e and f) in the 2004/05 (a, c and e) and 2005/06 (b, d and f) seasons.

Under full irrigation in the 2005/06 season total dry matter biomass was greatest in the high retention crop with 883 g m-2 compared to 863 g m-2 for the medium and 745 g m-2 in the low retention. The difference in dry matter production shows that although the no fruit plants were taller (data not shown), total dry matter production was highest in the high retention treatments.

Table 3. Yield Bales/hectare from the high retention and medium fruit removal treatments

		Irrigation	
		Full	Stressed
High retention	2004/05	13.0	5.5
	2005/06	13.7	10.2
Medium Retention	2004/05	12.4	7.5
	2005/06	14.2	12.0

The level of fruit retention had no effect on the depth of water extraction of the cotton crops. The addition of water stress before and during flowering caused the plants to extract more water from the profile but there was no interaction with the fruit removal treatments. This indicates that water use of the plants and the level of early root development was not dictated by the level of crop fruit retention.

- Partial root zone drying

The full irrigation treatments in both the solid and alternate planted configurations had higher fruit numbers than the corresponding PRD treatments. There was no difference in average boll size between the full and PRD irrigation treatments. The PRD plants had a smaller total biomass than the full irrigation treatments (Table 4).

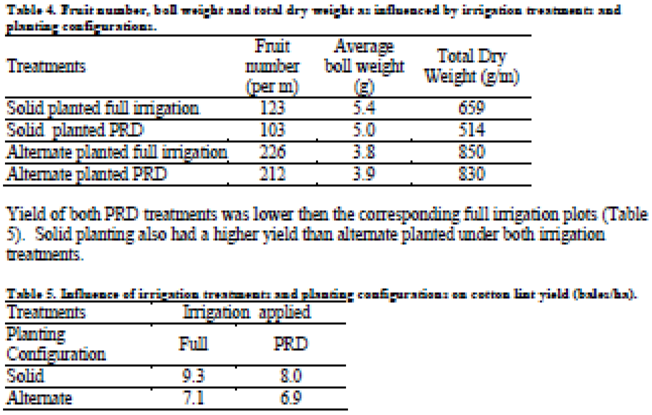


Table 4. Fruit number, boll weight and total dry weight as influenced by irrigation treatments and planting configurations.

Treatments	Fruit number (per m)	Average boll weight (g)	Total Dry Weight (g/m)
Solid planted full irrigation	123	5.4	659
Solid planted PRD	103	5.0	514
Alternate planted full irrigation	226	3.8	850
Alternate planted PRD	212	3.9	830

Yield of both PRD treatments was lower then the corresponding full irrigation plots (Table 5). Solid planting also had a higher yield than alternate planted under both irrigation treatments.

Table 5. Influence of irrigation treatments and planting configurations on cotton lint yield (bales/ha).

Treatments	Irrigation applied	
Planting Configuration	Full	PRD
Solid	9.3	8.0
Alternate	7.1	6.9

PRD reduced the number of fruit (retained) on the plant in both planting configurations, and there was no increase in boll size to compensate for the loss of fruit numbers. The PRD plants were shorter than the full irrigation treatments in both planting onfigurations. Shorter plants with fewer fruit and reduced yield indicates that although the same amount of water was applied to both irrigation treatments, the PRD crops were less water use efficient than the full irrigation treatments. In addition there was no difference in the timing of stomatal closure between the irrigation treatments in either of the planting configurations (figure 7) on any of the measurement dates. This suggests that PRD was not having an effect on plant response to climate and therefore not allowing for increased stomatal opening greater photosynthesis.

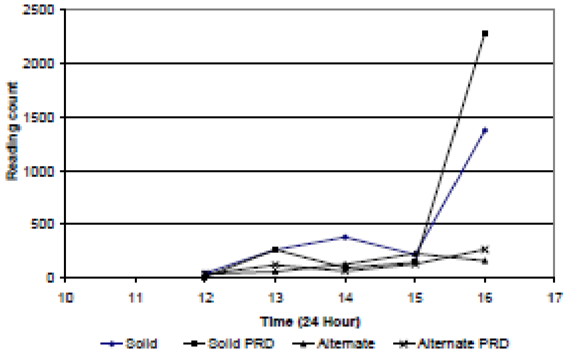


Figure 7. Late season stomatal resistance as measured by the rapid screening porometer for all 4 treatments on the 14/02/2006. Higher Y axis readings indicate less stomatal conductance.

It is anticipated that it would be difficult to achieve PRD on the cracking clay soils that are most common in the Australian cotton industry. This experiment used a drip irrigation system and alternate planted cotton to achieve PRD that would not be a commercially acceptable and/or viable practice. However, under the deficit furrow irrigation system commonly used in the cotton industry the establishment of PRD on common vertosol soils is generally not practical. In season rainfall would further reduce the likelihood of effective application of

PRD in cotton. This preliminary experiment showed no beneficial effect of PRD on cotton development or yield.

Outcomes

The outcomes achieved to date are detailed below:

a) The variation in cotton response has been studied under a range of different soil and climatic conditions. From this research we have developed an understanding of how the cotton plant responds to moisture stress on different soil types and how the effect of climate can affect this response at different levels of available soil moisture. The results of the project are being incorporated into the OZCOT model and will ultimately flow through to HydroLOGIC which uses OZCOT as its engine. In conjunction with further work being developed the data will also be used to provide better irrigation decision points for high levels of evaporative demand and different soil types. These outcomes will help to provide tailored irrigations strategies for different cotton production regions.

b) James contributed significantly to the co-ordination and development of a manual on irrigation management: WATERpak. WATERpak has been released to and up taken by the cotton industry as a practical guide to irrigation managements in cotton.

c) The potential effect of high retention in Bollgard II on root growth and water requirements was explored. James showed that there was no detectable difference in water use by the high retention Bollgard crops, so the principles for deciding on the need for irrigation are the same as for conventional cotton.

d) The potential to use PRD to enhance water use efficiency was explored. James found PRD did not provide improved water use efficiency or yield.

5. Please describe any:-

a) Technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);

The developments from this project are in terms of improved understanding for development of decision support systems and also leading to improved management of irrigation use matched to plant demands. There have been no commercially significant developments from this research at this stage.

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

As a result of this research an equation has been developed to describe the relationship between pre-dawn and afternoon leaf water potential (see results section). This relationship is strong through the range of measurements conducted and is practically useful in the normal operation range of plant stress from an irrigated cotton farms. This allows the pressure chamber to be used as an irrigation scheduling tool with afternoon readings while still providing an indication of the minimum level of stress that is experienced by the plants. In addition the use of this equation will improve research techniques by eliminating the requirement for the pre–dawn measurement of leaf water potential in most experimental situations.

The use of a rapid screening porometer was evaluated in the research on partial rootzone drying. These porometers has been developed primarily for screening of wheat varieties when large numbers of genotypes need to be screened quickly. The use of this instrument in cotton to determine stomatal closure was found to be problematic as there is a very large variation in the timing of the closure and the nature of the instrument makes subtle changes in stomatal aperture difficult to differentiate. It is possible that to accurately perform these measurements a full automatic porometer or a LiCor 6400 photosynthesis machine may be required, although in some climatic conditions normalising the readings of the LiCor may be difficult.

c) Changes to the Intellectual Property register.

No changes should be required to the intellectual property register.

Conclusion

The likely impact of the research will be improved irrigation scheduling through a better understanding of how the cotton plant responds to moisture stress under different soil and climatic conditions and an improved understanding of how different levels of fruit retention affect plant root development.

- Improved irrigation of cotton through understanding responses to soil type and climate

Differences in climate, especially evaporative demand, and soil type can significantly influence the plants response to soil moisture content. This creates problems in using fixed deficits for irrigation as thethese may not reliably match the plant's requirements if the weather is unusually hot and dry or the soil is more sandy. A way around this problem is to obtain data on the plants response to stress under a range of soil and climatic conditions and 'standardise' them, and this is the aim of using the 'fraction of transpirable soil water' (FTSW) as an alternative assessment of soil moisture status. The cotton plant behaves the same way to stress on all soil types when the soil water holding capacity of the soil is taken in to account and expressed FTSW. This allows for cotton plant response to be normalised so different soil types with known water holding capacities can be compared in terms of the level of stress imposed on the plant. This will be useful in decision support systems and possibly on cotton farms for irrigation scheduling between different known soil types.

The prevailing climatic conditions have a very large effect on the ability of the plant to cope with a given level of soil moisture deficit, even under low levels of soil moisture deficit on high evaporative demand days the plant can still experience stress which will have an impact on yield. There are some climatic conditions under which cotton plant is unable to take up enough moisture even from a nearly full soil moisture profile that the plant will become stress no matter if more water is applied. This will have implications in terms of irrigations strategies during hot weather when water can be applied in an attempt to reduce stress levels within the plant. With some further work a decision point at which the application of water to a crop under certain climatic conditions will be of no benefit will be produced.

- Streamlined evaluation of plant leaf water potential

There is a strong relationship between pre-dawn and afternoon leaf water potential, this relationship can be used to limit the amount of measurements that are required to determine both minimum levels of plant stress and the for irrigation scheduling. This will mainly be of use in continued research activity as the industry has moved away from the use of the pressure chamber as an irrigation scheduling device.

- High retention crops extract soil moisture similarly to lower retention crops.

There is no difference in soil moisture extraction and therefore extent of root development between crops that have high and low levels of fruit retention before cutout (NAWF >4.5). This means that hight retention crops (such as BG II®) should be irrigated in a similar manner to lower retention cotton. The high level of early reproductive development does not appear to affect the below ground vegetative development of the crop. Anecdotal evidence suggests that cotton farmers were treating BGII ® crops as a softer plant in the early season, irrigating them earlier than conventional crops and not allowing them to experience the same levels of moisture deficit. This difference in irrigation is especially important when water is limiting as many crops do not have enough water available to them to finish the whole season. Treating the crops softer earlier in the season reduces the possibility of catching precipitation and may reduce the amount of water available to the crop in the most water sensitive times in terms of yield loss of peak flower and boll fill. This research could lead to improved early season water use efficiency in high retention crops.

- Partial Rootzone Drying offers not benefit for improved WUE.

There appears to be no benefit from partial rootzone drying in cotton production systems in terms of plant stomatal control, biomass production or yield. Even under a drip system where water placement could be targeted no benefits of the application system were found. Under a traditional furrow irrigation system, achieving PRD would be extremely difficult on the clay soils they are characteristic of much of the industry because of lateral water movement. PRD irrigation systems are unlikely to have any impact on the cotton industry, however, looking at irrigation system delivery, deficit irrigation and new methods of scheduling irrigations for the cotton plant still need to investigate from a plant response perspective as well as an engineering perspective.

Extension Opportunities

The results of the research are currently being investigated for incorporation into the OZCOT simulation model. With the current development of the OZCOT model it is being investigated if this should be done in the standalone version of OZCOT or in the APSIM – OZCOT model environment. The latter version of the model has improved soil –water modules which better capture differences between soil types. Once incorporated in the simulation model the information from this project will be available for use in DSS tools including HydroLOGIC. The results of this project should give a wider understanding of different soil and climatic effects for model simulations and improve the robustness of the simulations.

A number of presentations have been conducted during the undertaking of the project relaying the results as they occurred to industry. It is anticipated that the results of the research will be continued to be communicated at field and industry information days.

In undertaking their new project the researcher will be collaborating with various industry groups in a number of valleys over the next seasons, during the establishment of the new project the researcher will be discussing the results of past project with industry to explain the direction of the new project and how it builds on the knowledge gained. This will disseminate the information to areas that the researcher has not previously visited and with a number of industry groups.

Research from this project will also be useful in any update to WATERpak, specifically section 3 “Irrigation management of cotton”. In addition a number of scientific papers are being undertaken to report on the results of the research (outlined in the publications section). The researcher is assessing working up of simple guide lines in terms of cotton plant response and the limits for the plant to cope with climatic conditions and when it is beneficial to apply water during periods of high evaporative demand. This would be extended through a publication such as the cotton grower, however, to achieve this may require some addition data from the new project (CRC 1.02.05).

Water remains a key issue for the cotton industry, this project ‘Water relations of the cotton plant” investigated the effect of soil type and physiology on the plant water relations of cotton. Interpretation of this research has found that soil type does not influence the appearance of plant stress when normalised for soil moisture holding capacity, expressed as the fraction of transpirable soil water (FTSW). FTSW may be a valuable index to improve irrigation strategies across different soil types. Future research could use the results and broaden the scope of the current project and would investigate plant responses to soil factors through assessment of root exploration, plant water uptake and the response of cotton to normalised soil moisture deficits (FTSW). A plants’ response to soil moisture depends on many factors, key of which are soil type and evaporative demand (related to the saturation deficit of the air). The FTSW is a useful measure of soil moisture that can be applied across soil types to understand the interaction between soil moisture, evaporative demand and plant growth.

Future projects will build on outcomes of the current research by investigating the interaction between FTSW and the way in which the cotton plants’ requirement for water is affected by evaporative demand (the interaction between temperature and humidity). This is critical in understanding how irrigation strategies should be modified to allow for the interaction of soil type, temperature and humidity – which is currently lacking. Experiments over the past 3 seasons have focused on the effect of soil type on plant stress when saturation pressure deficit is constant between the different soil types (e.g. measuring plant stress on different soil types within in close geographical proximity). By measuring over a range of irrigation events a data base for a range of soil types and a limited range of evaporative demands has been developed. Analysis of this data suggests we can account for the effects of soil type by expressing soil water content as the fraction of transpirable soil water (FTSW).

The use of FTSW as a measurement of soil water availability, and therefore of plant function, may provide a benchmark for irrigation scheduling allowing development of accurate recommendations for different deficits for each soil type and evaporative demand scenario. FTSW is well suited for inclusion in decision support systems and the project would explore linking this measurement with HydroLOGIC.

The increased range of climatic conditions under which experiments have been undertaken will further validate the results of this research and improve the effectiveness of understanding climatic data and FTSW effects cotton plant response to stress and how this affects yield

8. 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)

Neilsen J.E. and Roberts G. (2006). Water extraction of high retention cotton crops. “Ground Breaking Stuff” - Proceedings of the 13th Australian Agronomy Conference, Perth Western Australia.

Neilsen J.E. and Constable G. (2006). Investigation into partial root zone drying in cotton cropping systems. “Ground Breaking Stuff” - Proceedings of the 13th Australian Agronomy Conference, Perth Western Australia.

Neilsen J.E. (2006). Soil type effect on cotton plant water relations. Proceedings of the 13th Australian Cotton Conference August 8 – 10 2006, Gold Coast.

Neilsen J.E. Constable G.C. (2004). Soil and climate influence on water relations of the cotton plant. 12th Australian Cotton Conference August 10 – 12 2004, Gold Coast.

WATERpak – A guide for irrigation management in cotton. This project was involved in Coediting and chapter authoring (2.1 Assessing whole farm water use efficiency and 3.1 Cotton growth response to water stress).

Publication plan –
A number of fully referred scientific papers are planned to come from this research: The first will be on the effect of soil type and climate of cotton response to water stress – this paper will outline the main results of the research project in terms of cotton plant response. The second will be on the effect of fruit retention on cotton root development – this will present the results of the fruit removal experiment. In addition there is the possibility of a methods paper on the use of pre–dawn vs. afternoon leaf water potential measurements in cotton research and another paper based on modifications to computer simulation models relating from this project.

Part 4 – Final Report Executive Summary

Improved understanding of cotton plant response to water stress.
Experiments to establish the response of cotton plant to soil water stress under different soil types, climatic conditions and fruiting loads have shown that (i) the response of cotton to water stress is different on different soils (eg heavy clay vs. sandy-loam) (ii) these differences can be accounted for when soil moisture content is normalised for water holding capacity, expressed as the fraction of transpirable soil water (FTSW) (ii) that climate, especially evaporative demand, can cause plant stress even when the crop has adequate soil moisture and (ii) there is no difference in soil water extraction and therefore root development by crops with different levels of fruit retention. Field experiments were run over three cotton seasons at three sites with widely different soil types around Narrabri NSW. The response of the cotton plant to moisture stress, imposed by skipping irrigations around flowering, was measured as leaf water potential using a pressure chamber. Cotton plants were found to behave in the same way to moisture stress on all soil types when the soil water holding capacity of the soil was taken in to account and expressed as a percentage or fraction of transpirable soil water (FTSW). Over the three seasons prevailing climatic conditions have a

large effect on the ability of the plant to cope with a given level of soil moisture deficit. Even under low levels of soil moisture deficit, on high evaporative demand days plants often experienced stress which had an impact on yield. There are some climatic conditions under which the cotton plant is unable to take up enough moisture even from a soil profile with readily available water that the plant will become stressed no matter if more water is applied. Identifying these conditions and their management implications are the subject of ongoing research.

The results of this research will provide a basis for refined irrigation management through understanding the effect of climate and soil type to reduce water stress and providing decision points for future management. This information will also be included in decision support systems through inclusion in future versions of HydroLOGIC.
A separate experiment conducted over two seasons also in Narrabri showed no difference in soil moisture extraction and therefore extent of root development between crops that have high and low levels of fruit retention before cutout. High retention crops (such as BG II®) should be irrigated in a similar manner to lower retention cotton. The high level of early reproductive development does not appear to affect the below ground vegetative development of the crop.
A preliminary experiment was also conducted to investigate partial rootzone drying in cotton. This showed no benefit from partial rootzone drying in terms of cotton plant stomatal control, biomass production or yield. This project has significantly improved our understanding of basic responses of cotton to soil moisture stress and how this is influenced by climate and soil type. This knowledge is vital in developing improved irrigation strategies for cotton and achieving maximum yield from applied water.

Dr James Neilsen
CSIRO Plant Industry and Cotton Catchment Communities CRC,
Locked Bag 59, Narrabri NSW 2390.
(02) 6799 1526 james.neilsen@csiro.au