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Cotton Research and Development Corporation

FINAL REPORT 2015

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Part 1 - Summary Details

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

CRDC Project Number: DAN1502

Project Title: Optimising water and nitrogen fertiliser management in cotton

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CRDC Research Program: 1 Farmers

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Part 3 – Final Report

Background

1. Outline the background to the project.

Cotton industry nitrogen management trends indicate an increase in nitrogen fertiliser application and a decline in nitrogen use efficiency. Research conducted by Dr Ian Rochester has shown that high yields can be achieved with total available nitrogen rates of 200-220kg/ha. Industry surveys reveal that significant proportions (44%) of cotton growers are applying in excessive of 250gN/ha. Based on the science excess nitrogen is being lost from the farming system via a number of different pathways. Namely applied nitrogen is either lost through denitrification, volatilisation, run-off or leaching processes.

The majority of Australia's cotton producing soil is grey or black vertisols which have high clay content and are naturally prone to waterlogging following heavy rain or surface irrigation. Periodic waterlogging can lead to nitrogen losses of 50-100 kg N/ha through denitrification processes[1]. These losses not only have an environmental impact but also a large impact on farming profitability.

This project will investigate the impact of various irrigation and nitrogen application strategies on N uptake and nitrogen use efficiency. By exploring the interaction, the data collated from the trial will increase the industry's knowledge of the impacts various management techniques on resource efficiency.

Objectives

2. List the project objectives and the extent to which these have been achieved, with reference to the Milestones and Performance indicators.

Objective 1: Investigate the impact of different irrigation and nitrogen management strategies on nitrogen uptake and nitrogen use efficiency

Milestone 1.1 Completion of literature review

A literature review of current and past research was completed by Mr Baird during August and September 2014. This exercise entailed a review of existing research data and publications, a review of current nitrogen related research projects and meetings with key researchers. The purpose of the literature review was to identify/confirm the research gaps and refine (if necessary) the research questions.

Key research publications authored by Dr Ian Rochester, Peter Grace, Graeme Schwenke, Roth & Roth, Chris Dowling, and D. Chen were reviewed. International research was also reviewed as there appeared to be a lack of trial work performed in Australia investigating the interaction of irrigation management and nitrogen efficiency. International researchers included K. Bronson, T. Fischer and M. Madhi.

A copy of the literature review is attached as Appendix 1.

[1] Rochester, 2003

Milestone 1.2 Trial design and data collection protocols developed in collaboration with leading researchers, cotton RDO's and CRDC DAFF Project Manager

During September 2014 Mr Baird consulted with Dr Ian Rochester, Mr Rod Jackson, Dr Ben McDonald, Mr Stephen Kimber, Mr Stephen Harden (NSW DPI Biometrician), Ms Sarah Clift (Cotton Info – Upper Namoi) and Mr Rodney Smith (trial site farm manager) to finalise the experimental treatments, design and the required methods and measurements for data collection.

Based on these discussions it was agreed that the proposed nitrogen and irrigation management trial would include three irrigation scheduling regimes and three nitrogen fertiliser rates.

Nitrogen fertiliser treatments consisted of 200, 250 and 300 kg N/ha (plant available amounts), while irrigation scheduling regimes consisted of 50, 70 and 100mm deficits from soil drained upper limit (DUL).

Experimental and the data collection protocols were developed for the following activities:

- Soil sampling to determine starting and ending soil nutrition status and soil moisture
- Soil characterisation (to establish bulk density, Plant Available Water Content (PAWC), Dried Upper Limit (DUL) and Critical Lower Limit (CLL))
- Soil water balance measurements using neutron moisture meter (NMM)
- Plant establishment counts
- Plant mapping
- Plant Maturity cuts
- Plant leaf samples
- Manual sampling for nitrous oxide emissions using portable gas chambers
- Yield Measurement

The trial design and experimental protocols were specifically developed to enable an assessment of both crop water use efficiency (WUE) and nitrogen use efficiency (NUE). a financial gross margin evaluation of the individual treatments will provide the basis of an economic assessment in identifying the most profitable nitrogen and water management option for growers.

Milestone 1.3 Water management by nitrogen experiment established

A water and nitrogen management experiment was successfully established at "Ruvigne", Gunnedah in September 2014. The research trial was co-located with the CRDC and the DAFF- Action on the Ground (AOG) "Determining optimum N strategies for abatement of emissions for different irrigated cotton systems" project (led by Mr Stephen Kimber) and the CottonInfo nitrogen management demonstration site (Ms Sarah Clift).

Figure 1 Nitrogen & water experiment - four leaf stage (left) and 30 days after first flower (right)

Milestone 1.4 In-crop measurements and sampling completed in accordance with agreed trial protocols

In-crop measurements and sampling was completed in accordance with agreed protocols. Specific activities included:

- Soil sampling to determine starting and ending soil nutrition status and gravimetric soil moisture
- Plant establishment counts
- Soil water balance measurement using neutron moisture meter
- Plant growth measurement/ characteristics
- GHG emissions through collection of the portable gas chambers
- Nitrogen uptake through leaf samples
- Plant maturity cuts- fruit mapping and nitrogen uptake
- Yield – hand picking and commercial pick.

Milestone 1.5 Optimise water application efficiency and distribution uniformity across all treatments

Neutron probes were placed at strategic positions (head ditch area and tail drain), enabling the measurement of irrigation application efficiency and uniformity. Siphon flow rate was varied by using different size siphons. Larger siphons (63 mm) were used for the first two waters to increase water advance times and application speed. Conversely smaller siphons (50 mm) were used to slow water advance during the peak plant water use period (January to March) to ensure adequate infiltration to depth and replenishment of the soil water deficit. Neutron probe readings were performed twice weekly through the season and immediately before and after each irrigation.

Milestone 1.6 Calculate seasonal water use and nitrogen uptake per treatment

Crop water use was monitored and measured by both neutron and capacitance probe technologies. Pre-season and post-season soil cores were performed to measure starting and final soil moistures. The cores were also used to aid in calibrating the Neutron Moisture Meter (NMM). The NMM readings were used to calculate soil water uptake of the crop during the growing season. NMM readings were taken regularly throughout the season including immediately before and following an irrigation event. Intensive monitoring ensured that a full water use comparison between treatments could be performed.

Leaf tissue testing was performed at 1st flower and 30 days after first flower and biomass cuts were taken at maturity to determine total crop nitrogen uptake. NUE for each treatment was subsequently calculated using the two equations below:

Internal Nitrogen Use Efficiency (iNUE)-

$$iNUE = \frac{Yield}{N\ uptake}$$

Applied Nitrogen Use Efficiency (aWUE)-

$$aNUE = \frac{Yield}{Applied\ N}$$

Milestone 1.7 Collate trial results with information and data collected by cotton RDO's

Experimental results have been analysed with the assistance from a number of collaborative researchers including Dr Ian Rochester, Graeme Schwenke, and Rod Jackson. Dr Ian Rochester supervised and provided scientific guidance in relation to NUE analysis. Relevant data from Dr Rochester's 2014-15 ACRI trial was also utilised in analysing the yield impacts of variable rates of nitrogen.

Collated gas emission results were evaluated by Graeme Schwenke (officially took over as the lead researcher for the AOG project in June 2015), while the water monitoring results were discussed with the support of Rod Jackson and Dr Janelle Montgomery (NSW DPI).
Due to limited water (ground water allocation only) the Ruvigne field area assigned for research activity was rationalised by utilising similar treatments within the neighbouring AOTG nitrogen trial. This enabled the desired number of repetitions to be achieved within a reduced footprint.

The Cotton Info demonstration sites within the Lower Namoi and the Gwydir Valley unfortunately used differing nitrogen rates and there was no irrigation monitoring so a direct comparison between that data and the experiment data from Ruvigne was not applicable.

Objective 2: Communicate results/findings to industry
Milestone 2.1 Present results and findings at key industry forums

Ruvigne Field Day
Cotton plant growth data s from the Ruvigne trial was disseminated to growers, agronomists, and industry advisors via an on-site field day on the 10th March 2015. Approximately 35 people attended the day to gather knowledge and information relating to the trial objectives, treatments and measurements to date. Speakers of the day included Rod Jackson – Leader Northern Irrigated Cropping (NSW DPI) & Rod Smith (Ruvigne farm manager) who gave an introduction to the research program and background information, Jon Baird (NSW DPI – *"Optimising water and nitrogen fertiliser management in cotton"*), Graeme Schwenke (NSW DPI- *"Determining optimum N strategies for abatement of emissions for different irrigated cotton systems"* project & Yvonne Chang (CSIRO- *"Monitoring greenhouse gas emissions from irrigated cropping systems"* project).

Following a courtesy barbeque lunch and presentations from the researchers, attendees were encouraged to walk through the trial and visually inspect the experimental treatments and the crop differences resulting from each management strategy. The day was seen as a success as attendees participated in a comprehensive discussion of possible nitrogen and water management options to improve yields and importantly boost farm profitability. Upper Namoi valley growers in particular were keen for further nitrogen management research post the 2014-15 season. . Information disseminated at the field day is attached as Appendix 2.

Figure 2 NSW DPI researcher Jon Baird addressing growers, consultants and advisors at the Ruvigne Field Day held in the 10th March 2015.

Figure 3 Field day attendees inspect the impact of water and nitrogen management treatment on crop growth

2015 Australian Cotton Research Conference

Mr Baird delivered a summary of the experiment results at the Australian Cotton Research Conference, Toowoomba (8-10th September, 2015).

Approximately 100 cotton industry researchers, agronomic advisors and government agency representatives attended Session 4: Crop Nutrition. Much interest and discussion was generated with respect to the profitability assessment of various nitrogen and water management combinations. There were a number of enquiries regarding future research and possible research collaboration, emphasizing the importance of nitrogen and water management in cotton.

The slideshow presented at the conference can be viewed on the website http://www.cottonresearch.org.

A copy of the conference abstract is attached in Appendix 3.

Milestone 2.2 Publish trial results

A summary of the trial results has been delivered to the Upper Namoi Cotton Grower Association (UNCGA) & Lower Namoi Cotton Grower Association (LNCGA) during September 2015. The summary was distributed to the industry via the industry contact list and the localised CottonInfo team.
A copy of the experiment summary is attached in Appendix 4.

A Spotlight article outlining the results of the trial will be published in the December 2015. (Based on discussions with CRDC Communications Manager Ms Ruth Redfern & Ms Melanie Jensen)

An Australian Cottongrower article that was written in consultation with Dr Ian Rochester (CSIRO) is planned for a future magazine edition.

Objective 3: Provide technical support to regional cotton development officers (Cotton Info Team) in the implementation of on-farm trials in the NSW Border Rivers, Gwydir and Namoi valleys.

Milestone 3.1 Assist with soil coring activities

Upper Namoi
Pre-season soil coring at Ruvigne was completed on the 8th September 2014. Mr Baird supplied technical support in the analysis of the soil cores and calculation of soil mineral nitrogen. This technical support was used to determine nitrogen applied rates for the AOG and Cotton Info trials based at the Gunnedah site. Mr Baird became caretaker of the Cotton Info trial at Gunnedah while the RDO position was vacant. Future collaboration has been identified and planned for the coming cotton season at “Ruvigne” with the new RDO Ms Katie Slade.

Lower Namoi
Mr Baird has been in regular contact with Mr Geoff Hunter (Lower Namoi Cotton Info) and has visited the Cotton Info nitrogen demonstration site at Narrabri. Mr Baird has supported Mr Hunter with technical help when required and with agronomic issues within the Namoi Valley.

NSW Border Rivers
Due to the lack of water in the NSW Border Rivers a Cotton Info Team nitrogen demonstration site has not been established for the 2014-15 season. Hence no support has been necessary.

Gwydir
During November 2014 Mr Baird visited “Redmill”, the site of Gwydir Valley Cotton Info nitrogen demonstration site coordinated by Ms Alice Devlin. No technical support for Ms Devlin was required however a commitment for further collaboration has been agreed in future nitrogen related trials.

Milestone 3.2 Assist with the installation of soil water and water flow measurement equipment

The irrigation management at the CottonInfo demonstration trial site at Ruvigne was undertaken by Mr Baird and all relevant data relating to the CottonInfo trial treatments was provided to Ms Clift and later to Ms Katie Slade for analysis.

The Cotton Info trial situated at Moree ("Redmill") has no irrigation treatments and is not measuring soil moisture so no irrigation support was required.

Geoff Hunter (CottonInfo: Lower Namoi) conducted water monitoring utilising hardware supplied and operated by Mr Baird. Irrigation technical support was also provided by Dr Janelle Montgomery (NSW DPI – Moree).

Methods

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

Trial Design

The design of the experiment was developed with the assistance of Dr Ian Rochester and Mr Rod Smith (Ruvigne farm manager). Full field length plots (570m long and 48x1m rows wide) were established. Irrigation treatments of 50, 70 & 100 mm soil water deficits were imposed while smaller sub plots (8m wide) within the irrigation treatments utilized to impose the three nitrogen rates of 200, 250 & 300 kg N/ha). The total area of the experiment was 19.6ha.

The field length sub plots were eight metres wide to ensure the trial aligned with the machinery used on the farm. The eight metre wide plot had a buffer area on each side as the commercial picker was six metres wide (ie. there was a four metre buffer between the harvested plots).

Pre-Plant Soil Samples

Soil cores were taken randomly from each plot, from the top, middle and bottom transects of the paddock. Soil cores were segmented at 0-10 cm, 10-20 cm, 20-30 cm, 30-60cm, and 60-100cm then bulked together and sent to NSW DPI Wollongbar to analysis- soil nitrate.
Bulk density was also calculated and nitrogen analysis values (mg/kg) converted to paddock volumes (kg/ha).

Applied Nitrogen Rates

The recommended N rate was calculated using soil test results and the NutriLOGIC program. The aim of the trial was to impose three available N rates treatments of 200, 250 & 300 kg N/ha on the crop.
In order to reduce the complexity and achieve the desired amount of available nitrogen for each treatment pre-plant nitrogen rates of anhydrous ammonia were adjusted according to the soil test results. Two in-crop applications of Nitrogen were applied to the experiment at the 2^{nd} and 3^{rd} irrigation event, totalling 80 kg N/ha. The nitrogen was applied in the form of Urea, using an “N Buggy” to distribute the granules into the field’s water supply channel.

Establishment Count

The seedling establishment of the trial was measured from the 10th day after the first cotton plant emerged. The establishment rate was calculated by counting the number of viable seedlings per 10 metres, and dividing it by 10, giving a plant rate per metre. The recommended establishment rate is 12 plants per metre, while a plant stand less than 6 plants/m usually has a negative impact on potential yield.

Early Vigour (Growth)

Early seedling vigour was measured from emergence to first squares. Early plant vigour was assessed by measuring the plant height and also the number of nodes per plant. Two measurements were taken from each plot, (Site No.1 - 50m from the head ditch and site No. 2 - 50m from the tail drain).

Vegetative Growth Rate (V.G.R.)

VGR was monitored weekly from first square (where 50% of plants have squares) until cut out or four nodes above white flower (NAWF). Two measurements were recorded from each plot (approx. 50 m from head ditch and 50 m from the tail drain). Height measurements from the ground to the top terminal on 10 plants (within 2 m) were taken. The number of nodes after the cotyledons to the top of the terminal were counted.

These measurements are specifically designed to provide information to assist with growth regulator use during rapid vegetative growth. It is common practice to alternately, or also, apply growth regulators at cut out (when flowering and fruit set has stopped). This application timing is designed to suppress unnecessary vegetative growth during boll ripening and can ensure more even crop maturity.

Nodes Above White Flower

NAWF is a measure of plant growth. A high number indicates high plant growth, while a lower number will indicate the plant's vigour is slowing down. NAWF data was added into the online crop growth tool (Cottassist.com.au) where it was plotted on a predefined line of optimum plant growth.

Plant Fruit Load

Plant fruit load was measured by counting the total amount of fruit (squares, flowers and bolls). This exercise provides potential yield information and the plant's conversion of inputs to fruit production. Fruit loads were counted in 1 metre lengths and then divided by the plant population (i.e. total fruit per m / plants per m = fruit load per plant). Two metre rows were counted, one from the head ditch and one from the tail drain areas of each plot and then averaged down to one metre. This measurement was undertaken weekly from the first flower to plant cut-out.

Plant Boll Load

Boll numbers were counted from late flower to cut-out with the aim of identifying potential yield (ie. provide a clear picture of the conversion of fruit to lint producing bolls). The method used for counting bolls was the same as the fruit counting, but only taking in account the bolls on the plant. When counting boll numbers later in the season prior to plant cut-out, only "pick-able" bolls were counted (i.e. bolls larger than 3 cm in diameter).

Leaf Samples

Leaf samples were taken at 1st flower, +30 days after first flower. Leaf samples provide analytic data of the plants nutritional activity. They are used primarily by the industry for investigating if there are any nutritional deficiencies within the plant. Fifty leaves (from the 4th node from the terminal) were randomly collected from each plot. All leaf tissue analysis was undertaken by the NSW DPI Wollongbar laboratory.

Plant Maturity Fruit Mapping

Once experimental plots had reached plant maturity or at least 20 % open bolls, complete plant samples were taken from each trial plot. 1 metre samples were taken from the head ditch, middle of the row and tail drain. A complete plant mapping exercise was undertaken of the samples. Measurements included: plant height, plant nodes, squaring nodes, number of bolls (broken into categories of bolls on lateral branches, first position bolls and rest of plant bolls).

Nutrient Uptake Samples (Biomass Cuts)

From the plants that were sampled for the plant maturity plant mapping, 3 representative plants were selected from each sub-sampled metre. The plants were prepared for drying by removing the lint from the seeds and dicing the plant matter up finely. The dried plant matter was finely grinded and analysed for plant nitrogen % at the NSW DPI Wollongbar laboratory. The nitrogen % of the samples was then multiplied by the difference in weights of the dry and wet plant matter; this gave the total amount of nitrogen uptake for the experiment treatments.

Soil Moisture Monitoring

A number of technologies were used to measure soil water balance within the trial plots. A theta probe was utilised to monitor moisture in the top 0-15cm while a neutron probe provided soil moisture data to 1.2m. Soil depth ranges monitored by NMM were 15-30, 30-45, 45-60, 60-75, 75-90, 90-120cm. Capacitance probes were installed in selected treatments to enable real-time monitoring of soil water and assist in irrigation scheduling decisions.

Rainfall

In-crop rainfall was measured by an automatic weather station and recorded. Rainfall was categorised into effective and non-effective amounts (75 % of total rainfall was considered effective[2]). Effective rain was utilised to measure GPWUI.

GHG Emission Chambers

In order to measure nitrogen loss in the form of gaseous exchange a manual gas sampling system was installed. PVC chambers supplied by NSW DPI Soils Department were installed both on top of the cotton beds and in the bottom of the furrows. Chambers were installed within the three irrigation treatments (50, 70 & 100 mm deficits) at the same nitrogen rate of 250 kg N/ha. There were four chambers per plot; two on top of the beds and two in the furrows (one in a fertiliser row and the other in a non-fertiliser row). Gas samples were collected from the chambers at the hour mark (i.e. 0 min and 60 min) between 10:00am and 12:00pm as this was recommended as the optimum sampling period.

Yield Measurement

After the defoliation process, samples within each plot were handpicked pre the commercial picking, using the procedure listed below and hand ginned at ACRI.

- Two metre samples were collected from each treatment plot at the head ditch, middle of the field and tail drain; total 6 metres.
- The number of plants within the meter was recorded
- The lint from the pick-able bolls was removed by hand.
- The lint was ginned at the ACRI hand gin where the lint turnout was recorded for final yields

During the commercial picking operation the individual round modules serial numbers from each plot were recorded to enable traceability during the ginning process. The trial was picked by a John Deere 7760 round module picker, so preliminary yield assessments were undertaken using a portable scale. Weight data was then converted to kg/ha once lint turnout and moisture was forwarded by the gin.

Fibre Quality Assessment

The hand-picked cotton was processed at ACRI utilising CSIRO ginning equipment. The gin results from the commercially picked cotton were collected from the grower. Fibre quality was then incorporated into the results to evaluate if treatment strategies had an effect on final quality.

Seed Nitrogen

The separated cotton seed from the ginned handpicked samples (approximately 500gm/sample) was carefully bagged and sent to Dr Ian Rochester for processing (NIR machine). Seed protein content was then used to calculate plant nitrogen uptake during the growing season. Utilising the methodology developed by Dr Rochester protein values were then multiplied by 4.6 to give seed the nitrogen uptake percentage.

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[2] WaterPak, 2010

Post-harvest soil samples
Soil samples were collected after the experiment was harvested. Sampling occurred before the field was treated with fertiliser and followed a similar field sampling pattern as the pre-fertiliser soil sampling. Samples were analysed for soil water moisture and residual nitrogen.

Nitrogen Use Efficiency (NUE)
Two NUE equations were used for evaluating the NUE of the experiment treatments-

Internal Nitrogen Use Efficiency- Indicates the efficiency of a cotton field in producing lint in regards to the Nitrogen accumulated by the crop. The N uptake of the treatments were calculated from the results of the plant maturity biomass cuts.

$$iNUE = \frac{Yield}{N\ uptake}$$

Recent research has found the optimum value for iNUE to be 12.4±0.3 kg lint/kg crop[3]. Higher values being under fertilised, and lower values equalling over fertilisation.

Applied Nitrogen Use Efficiency- indicates the crops conversion of applied Nitrogen to yield.

$$aNUE = \frac{Yield}{Applied\ N}$$

Nitrogen research has found the optimum value for aNUE to be 15, with an optimum range of 13 – 18 kg lint/ kg N applied.

The economic optimum nitrogen rate was determined for the treatments in the experiment by examining the logarithmic nitrogen response curve. The function of the cost of applied nitrogen ($1.10/kg) and the return for cotton lint ($2.20/kg) was plotted onto the response curve to evaluate the optimum application nitrogen rate.

Water Use Efficiency (WUE)
WUE for the trial was evaluated using two water use indices -
Irrigation Water Use Efficiency Index (IWUI) – relates production only to the irrigation water used.

$$IWUI = \frac{Yield}{Applied\ Irrigation\ water}$$

Gross Production Water Use Efficiency Index (GPWUI) - the amount of lint produced per unit volume of total water input.

$$GPWUI = \frac{Yield}{Applied\ irrigation\ water + effective\ rainfall + used\ soil\ moisture}$$

Gross Margins
To evaluate the potential financial returns of each water and nitrogen treatment combination a gross margin analysis was undertaken utilising the NSW DPI template developed by Ms Janine Powell (NSW DPI Economist). Nitrogen efficiency is measured by the cost difference

[3] Rochester, 2014

in the extra application of nitrogen (i.e. with the 200 to 250 kg N/ha treatments the difference in the cost is 50 kg N/ha). Irrigation economic efficiency is calculated the same manner with the cost of the extra water applied. Costs of fertiliser inputs were based on retail prices, while labour costs assigned to irrigation strategies were calculated with the assistance of Mr Rod Smith.

Statistical Analysis

The statistical analysis of the experiment results was conducted by the NSW DPI biometricians based at the Tamworth Agricultural institute.
The analysis is attached in Appendix 5.

Results

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

Objective 1: Investigate the impact of different irrigation and nitrogen management strategies on nitrogen uptake and nitrogen use efficiency

The Ruvigne experiment results have been separated into the following chapters:

- Site Characteristics
- Plant Growth Measurements
- Water Use Efficiency
- Nitrogen Use Efficiency
- Green House Gas Emissions
- Yield
- Gross Margins

4.1 Site Characteristics

Field 11, "Ruvigne" Gunnedah, Upper Namoi Valley, North West NSW
The experiment was located at Field 11 on the farm "Ruvigne". Soil characterisation showed that the soil is a brown vertosol with high amounts of clay content[4]. Predominately Australia's cotton grown soils are grey to black clay soils, but for the Upper Namoi area this soil is considered to be representative of the irrigated cotton soils. Results of the pre-plant soil test (Appendix 6: **Error! Reference source not found.**) showed that there was 40 kg N/ha of residual nitrogen in the soil profile. As outlined above the available nitrogen treatments selected were 200, 250 & 300 kg N/ha. Based on the pre-crop soil tests, the actual applied nitrogen rates for each treatment within the experiment were 160, 210 & 260 kg N/ha respectively. Plant available water capacity (PAWC) for cotton at the site was calculated at 145 mm to the depth of 1.2 metres.

The soil characterisation is attached in Appendix 6.

4.2 Plant Growth Measurements

Weekly Plant mapping measurements
Weekly plant mapping occurred from 1st flower through to plant maturity during the experiment to measure the treatments impact on cotton plant growth. The results suggest irrigation treatment had the greatest impact on growth. Figure 4 illustrates the late season growth and productivity of the 50 mm deficit treatments compared to the other irrigation treatments (70 & 100 mm deficits).

The varied Nitrogen rates did not have a significant impact on the growth and development of the cotton plants. Although it was noted that the 200 kg N/ha with 70 mm deficit did have less growth late in the season and earlier plant senescence compared to the 300 kg N/ha at 70 mm deficit.

[4] Office of Environment & Heritage, NSW, 2015

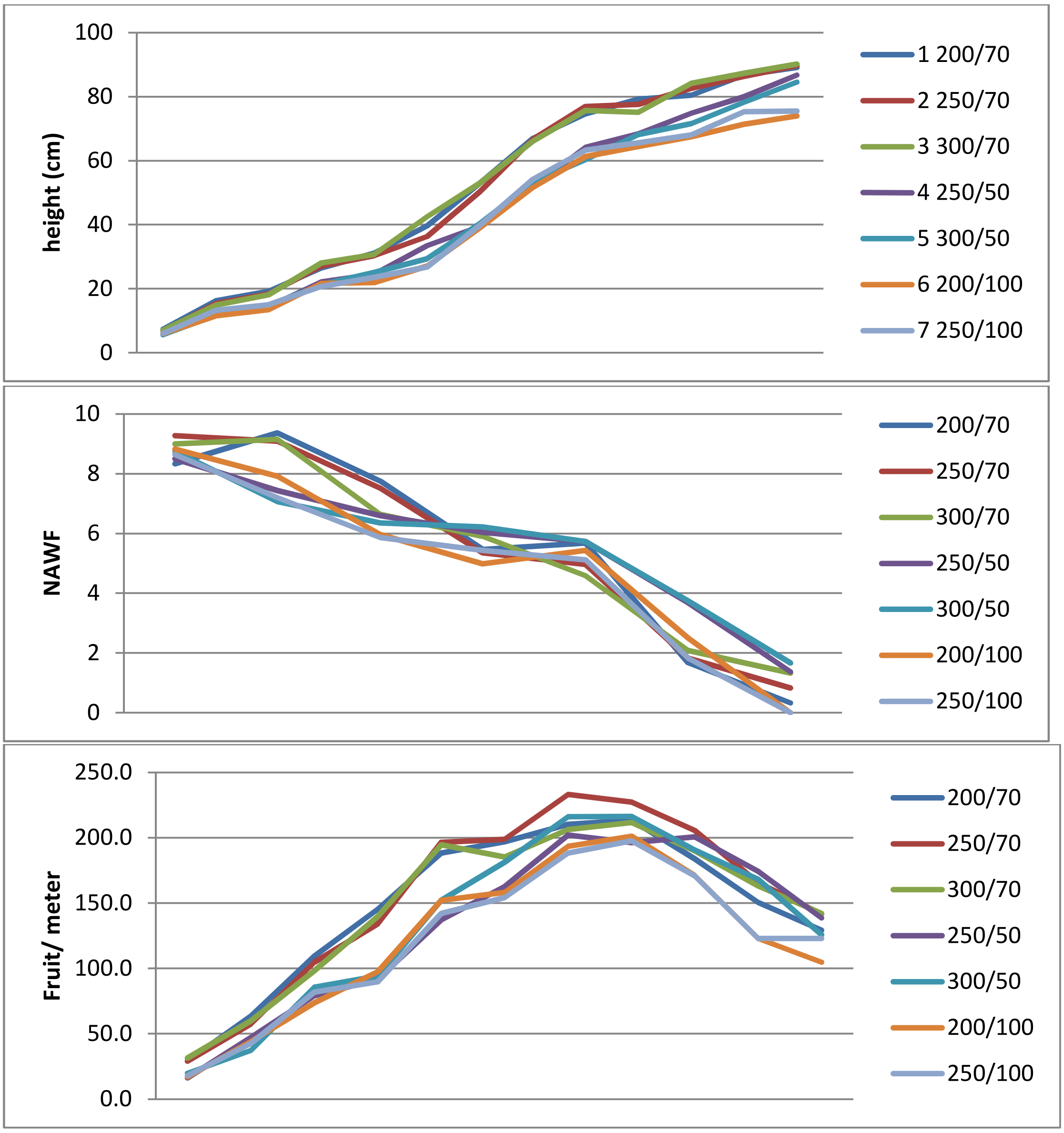


Figure 4 Plant Growth recordings

Plant Mapping at crop maturity

The plant mapping performed at plant maturity, showed the relative influence of water and nitrogen treatments on the plant productivity. From the results it is evident the high water input strategy had an impact on plant productivity with the higher nitrogen rate (300kgN/ha) and lower 50 mm irrigation deficit increasing fruit production. Figure 5 Treatment influence on boll numbers. N rate (left) and Irrigation rate (right) highlights the impact the varied irrigation and nitrogen rates on cotton boll production. The irrigation treatments had a greater impact on fruit numbers as the 50 mm rate averaged 21.5 bolls/plant while the 70 & 100 mm deficit averaged 18.3 & 17.5 bolls/plant respectively. Nitrogen application had a similar trend line but the 300 kg N/ha rate resulted in a lower number of 20.4 bolls/plant.

Table 1 Maturity plant mapping results reiterates this trend as the 50 mm deficit treatments resulted in a higher node and squaring node count, along with higher number of bolls per plant. Fruit retention was not affected by either irrigation deficit or nitrogen rate, but the lower irrigation deficit treatments (i.e. 50mm and 70mm) appeared to increase the lateral boll numbers on the plant.

Plant stand appears to have had an impact on these results when fruit per plant values were converted to fruit per meter as shown by Table 1 Maturity plant mapping results. This is evident where the 50 mm treatments resulted in the greatest number of fruit per plant but were lower than the 70 mm treatments in regards to fruit per meter.

	Treatment	1	2	3	4	5	6	7
	Rates	70 mm/ 200 kg N	70 mm/ 250 kg N	70 mm/ 300 kg N	50 mm/ 250 kg N	50 mm/ 300 kg N	100 mm/ 200 kg N	100 mm/ 250 kg N
	Nodes	22.84	23.56	23.71	24.23	25.45	23.73	23.33
	Squaring nodes	14.73	15.47	15.50	15.85	17.59	15.89	15.72
	Fruit retention %	64.65	66.56	65.54	67.73	65.77	63.72	62.35
Bolls/pl	1st position	9.52	10.30	10.16	10.74	11.57	10.12	9.80
	lateral branches	3.30	3.34	3.61	4.34	4.96	2.84	2.48
	total	17.43	19.10	18.64	20.83	22.13	18.19	16.80
Bolls/m	1st position	79.88	81.25	83.88	72.63	83.13	75.75	77.25
	lateral branches	27.50	24.63	30.63	28.13	32.13	18.75	18.00
	total	144.88	147.63	154.75	138.63	153.75	131.50	128.50

Table 1 Maturity plant mapping results

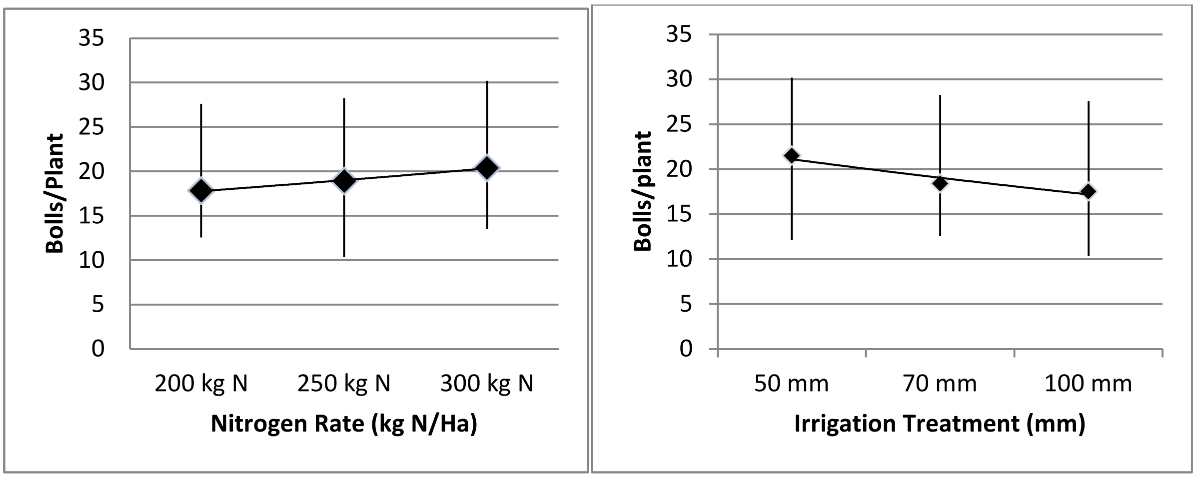


Figure 5 Treatment influence on boll numbers. N rate (left) and Irrigation rate (right)

4.3 Water Use Efficiency

The irrigation schedule was based on soil water deficits from PAWC (145.5 mm). Figure 6 Irrigation timing and applied water describes the applied and accumulative amounts of water received by each treatment. The 50mm treatment resulted in 10 irrigation events with an average of 0.63 ML/ha applied per event. The 70mm and 100mm deficits resulted in 8 & 6 irrigations respectively and 0.78 ML/ha and 0.81 ML/ha applied per irrigation respectively. Interestingly the difference in the total amount of water applied between the 50 & 70 mm deficits was only 0.1 ML/ha.

Less water applied more often can lead to better continued crop but can result in a lower reproductive to vegetative growth ratio.

Figure 7 Soil water deficits for the 70 mm treatment highlights the water use of the three nitrogen rates (200, 250 & 300 kg N/ha) at the 70 mm deficit during the experiment. The nitrogen effect on plant water use was minimal until the later part of the season where the prolonged plant growth of the high nitrogen rate of 300 kg N/ha resulted in greater water use

during that period compared to the lower nitrogen rates (i.e. the greater plant biomass led to greater water use).
Bars represent means ± SE

Figure 8 Experiment highlight the two WUE indicators that were used for comparison: IWUI (yield/applied irrigation water) and GPWUI (yield/total water used by crop). It must be noted that all treatments favoured highly against the industry average GPWUI of 1.17 bales/ML (Montgomery 2012). The 250 kg N/ha applied nitrogen rate at both 70 & 100 mm deficits resulted in the highest GPWUI values of 1.49 & 1.52 b/ML respectively. The "low" input management strategy of 200 kg N/ha at the 100 mm deficit resulted in a GPWUI of 1.42 b/ML, lower than 1.45 b/ML achieved by the "high" input management strategy of 300 kg N/ha at the 50mm deficit.

The 100 mm deficit treatments resulted in a high IWUI (200 kg N/ha: 2.3 b/ML & 250 kg N/ha: 2.46 b/ML), compared to the 50 & 70 mm irrigation deficits. The 70 mm with 200 kg N/ha treatment resulted in the lowest IWUI (1.99 b/ML) due to the lower yield when compared to the treatments with similar water deficits (50 & 70 mm deficits).

Note Figure 8 Experiment GPWUI & IWUI contains data from a "dryland" adjacent to the irrigated trial site. Volumetric soil moisture from the "dryland" site was calculated for a comparable baseline WUE dataset. The "dryland" treatment was not considered a part of the experiment outcomes, but the WUE comparison was useful for the project.

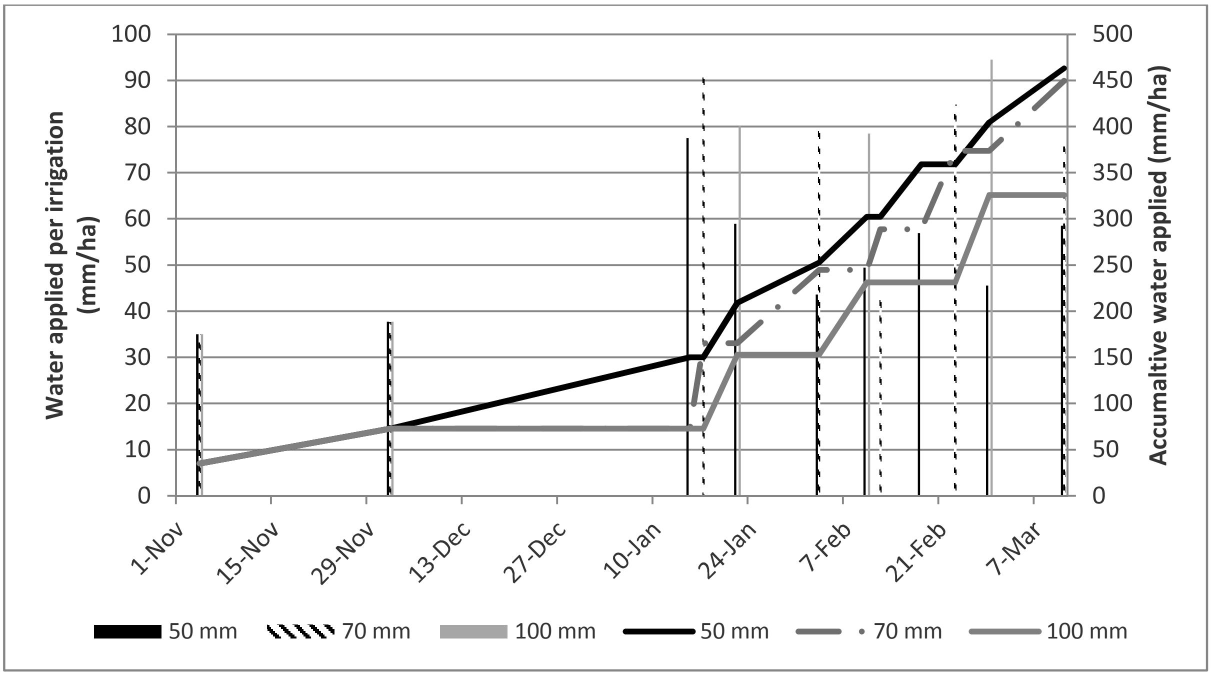


Figure 6 Irrigation timing and applied water

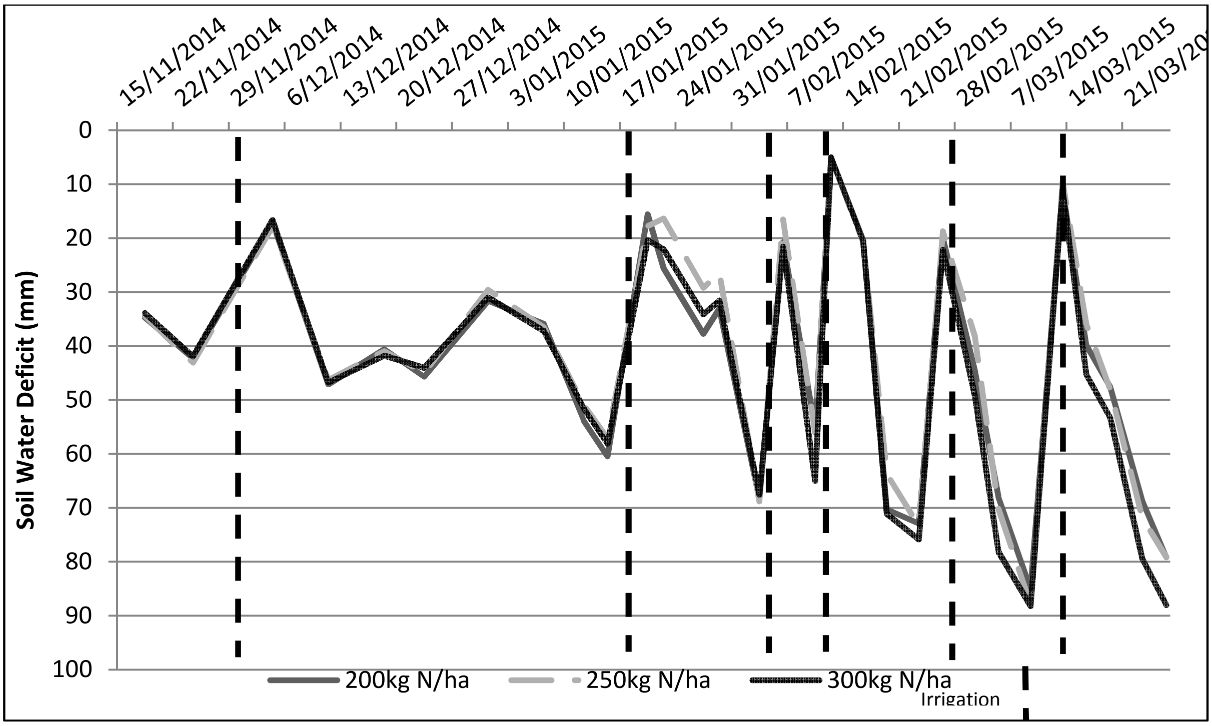
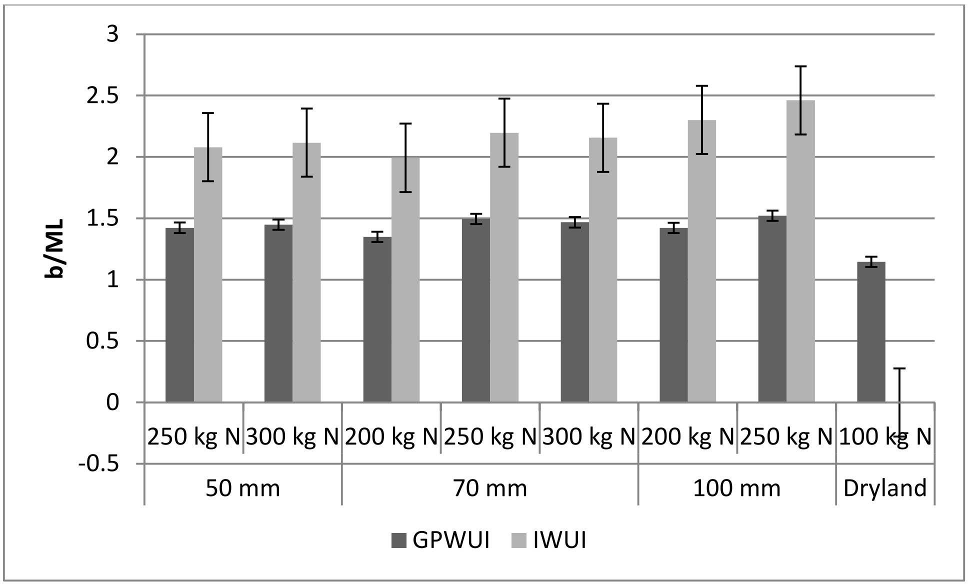


Figure 7 Soil water deficits for the 70 mm treatment



Bars represent means ± SE

Figure 8 Experiment GPWUI & IWUI

Irrigation Deficit	Available Nitrogen	Yield b/Ha	Starting Soil Moisture ML/Ha	Irrigation Water Applied	Effective Rainfall ML/Ha	Ending Soil Moisture	Total Available Water	IWUI b/ML	GPWUI b/ML	WUE kg/mm/Ha
50 mm	250 kg N	13.16	0.62	6.33	2.79	0.49	9.25	2.08	1.42	3.23
50 mm	300 kg N	13.39	0.62	6.33	2.79	0.49	9.25	2.12	1.45	3.29
70 mm	200 kg N	12.18	0.62	6.11	2.79	0.49	9.03	1.99	1.35	3.06
70 mm	250 kg N	13.66	0.62	6.22	2.79	0.49	9.14	2.20	1.49	3.39
70 mm	300 kg N	13.41	0.62	6.22	2.79	0.49	9.14	2.16	1.47	3.33
100 mm	200 kg N	11.23	0.62	4.88	2.79	0.49	7.90	2.30	1.42	3.23
100 mm	250 kg N	12.01	0.62	4.88	2.79	0.39	7.90	2.46	1.52	3.45
Dryland	100 kg N	3.46	0.62	0.00	2.79	0.39	3.02	N/A	1.15	2.60

Table 2 Treatment water use and WUE

4.3 Nitrogen Use Efficiency

Table 3 Treatment nitrogen use efficiency shows that the nitrogen uptake for the treatments within the experiment was similar, and there was no significant difference between the experimental treatments for seed nitrogen %, total nitrogen uptake and internal crop NUE (iNUE). An explanation for this could be that the 50 kg N/ha differences in the applied nitrogen treatments were not large enough to create a large enough effect. In designing the trial the applied rates were considered within the optimum range but a lower or higher set of nitrogen rates may have produced significant differences.
Although there was no significant difference past research has shown that Internal NUE has an optimum range of between 12.2 and 13 kg lint/kgN (Rochester 2011). Values above 13 suggested that deficiencies of N (not enough applied fertiliser) while values below 12.2 suggested the crop was over fertilised.

From the experiment the optimum iNUE was calculated to be 13 ± 0.4 kg lint/kgN. A reason for the higher value could be due to cotton cultivar. Sicot 74BRF has greater yield potential then Sicot 71BRF (as tested by Rochester 2003). The greater yield potential means that the plant has a greater ability to convert nitrogen uptake to lint production. This is supported by Rochester's work where an earlier cultivar resulted in an optimum iNUE of 10. The changes in iNUE with cultivars means that new and continued research into the ability of modern cultivars to uptake nitrogen is required to ensure research findings are relevant with modern farming practices.

The 50 mm irrigation treatment had low variability and along with the 70 mm deficit was within the optimum iNUE range. While the 100 mm treatments expressed great variability in nitrogen efficiency and averaged under fertilisation.

Unlike the irrigation rates, all the nitrogen treatments produced iNUE values with high variability. The 200 & 250 kg N/ha rates were considered over fertilised while the 300 kg N/ha was just within the optimum NUE range.

The iNUE data of the treatments show that irrigation scheduling had a greater impact on nitrogen uptake efficiency compared with the applied nitrogen rates observed in this experiment. Adding to the theory that irrigation can influence NUE and that smaller amounts of water more frequently will improve crop nitrogen uptake.

The applied NUE (aNUE) of the nitrogen treatments (160, 210 & 260 kg N/ha applied fertiliser) did have significant difference ($p \leq 0.001$). This is illustrated by Figure 10 aNUE of experimental treatments where the three dominant data sets are aligned with the applied nitrogen rates. Irrigation rate had no impact on aNUE. The shadowed box is the optimum range for aNUE for Australian cotton systems developed by Rochester (13 to 18 kg lint/kg N). The 160 & 210 kg N/ha applied nitrogen rates at both 70 and 100 mm deficits were found to be within aNUE optimum range.

Irrigation deficit (mm)	*Applied N (kg N/ha)*	*Seed N (%)*	*N uptake (kg N /ha)*	*internal NUE (lint kg/ kg N)*	*applied NUE (lint kg/ kg N)*
70	**160**	3.70	203.51	13.98	17.38
70	**210**	3.68	234.16	13.25	14.55
70	**260**	3.76	236.48	13.07	11.63
100	**160**	3.75	203.65	13.69	16.65
100	**210**	3.67	190.62	15.15	13.35
50	**210**	3.65	210.03	13.12	13.04
50	**260**	3.69	236.84	12.04	10.98
	F statistic	0.790	0.070	0.310	0.290
	F prob.	0.469	0.933	0.739	0.748
	sed	0.044	29.892	1.913	0.829

Table 3 Treatment nitrogen use efficiency

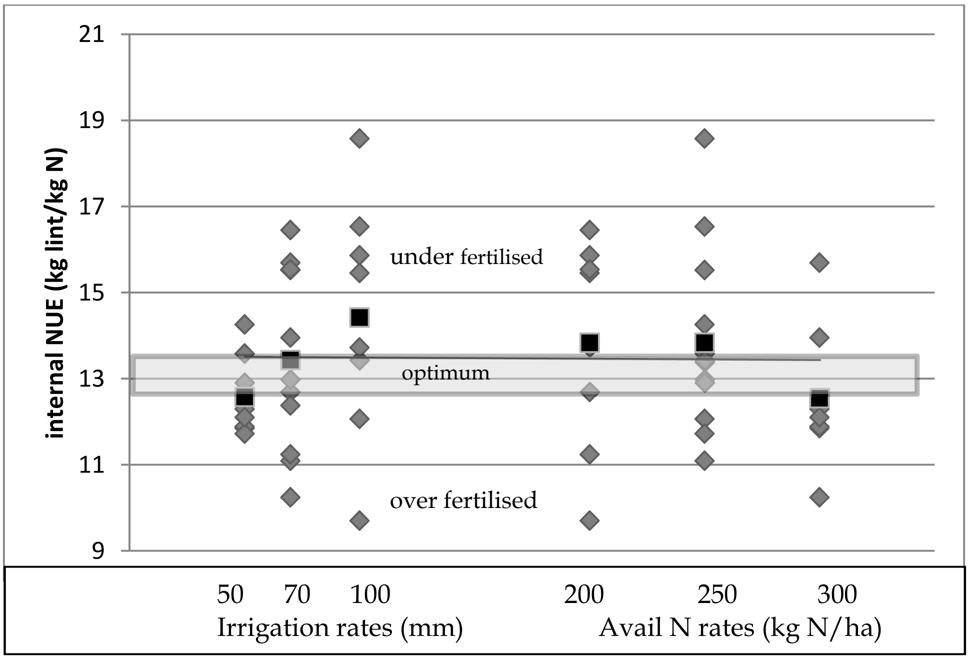


Figure 9 Experiment iNUE

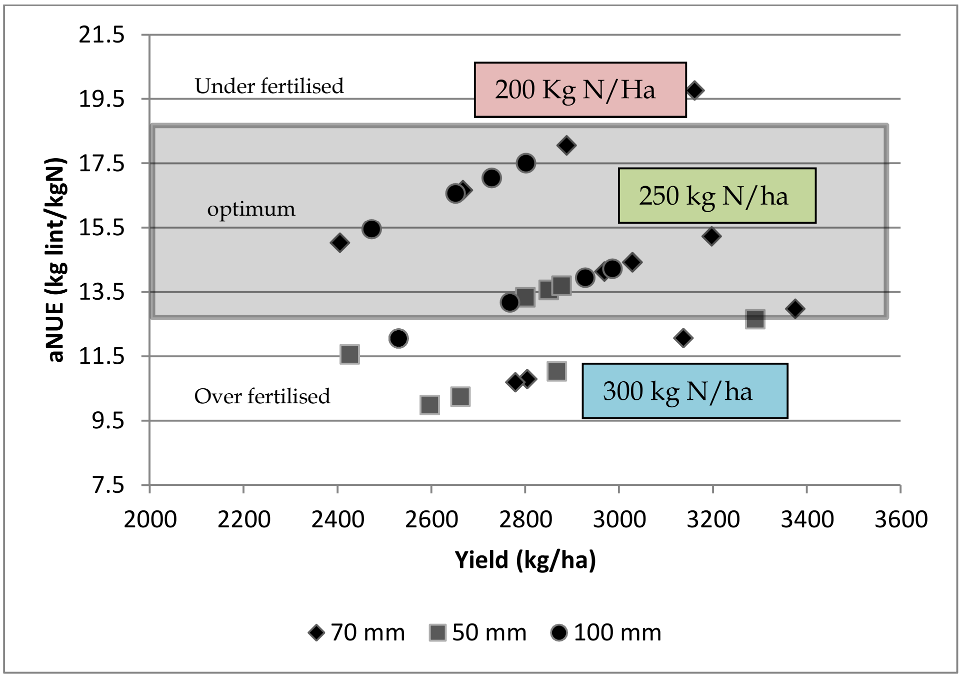


Figure 10 aNUE of experimental treatments

4.4 Green House Gas Emissions (GHG)

Figure 11 N_2O emissions from the manual gas chambers show a large spike early in the growing season. This can be explained by the application of nitrogen to the crop prior to the sampling date. Later spikes in the season can be attributed to GHG spiking after an irrigation event or rainfall. An analysis of the data suggested that the irrigation deficit treatments did not significantly influence total N_2O emissions, supporting Schwenke's AOTG results delivered at The Australian Cotton Research Conference (2015) that the N_2O emissions from the non-irrigated furrows (N-furrow) did increase later in the season. These results aid in explaining the nitrogen loss pathway from a cotton crop through gaseous forms.

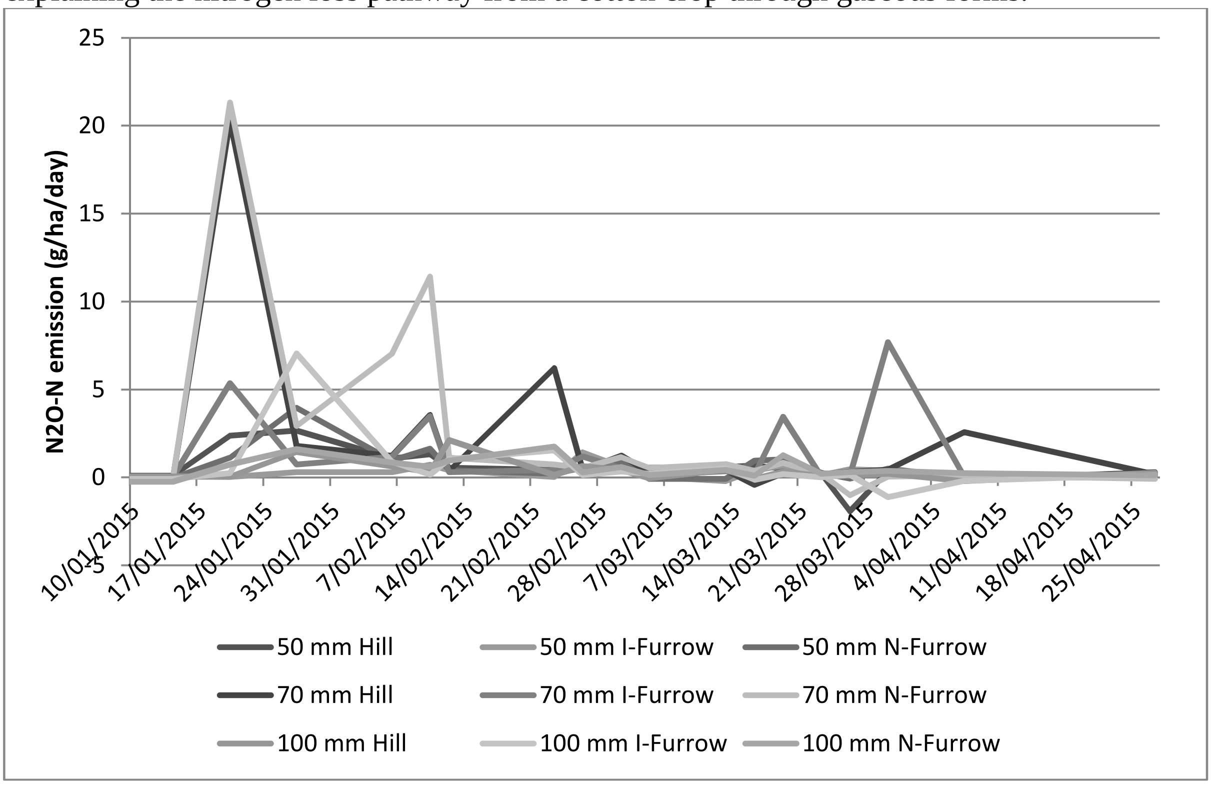
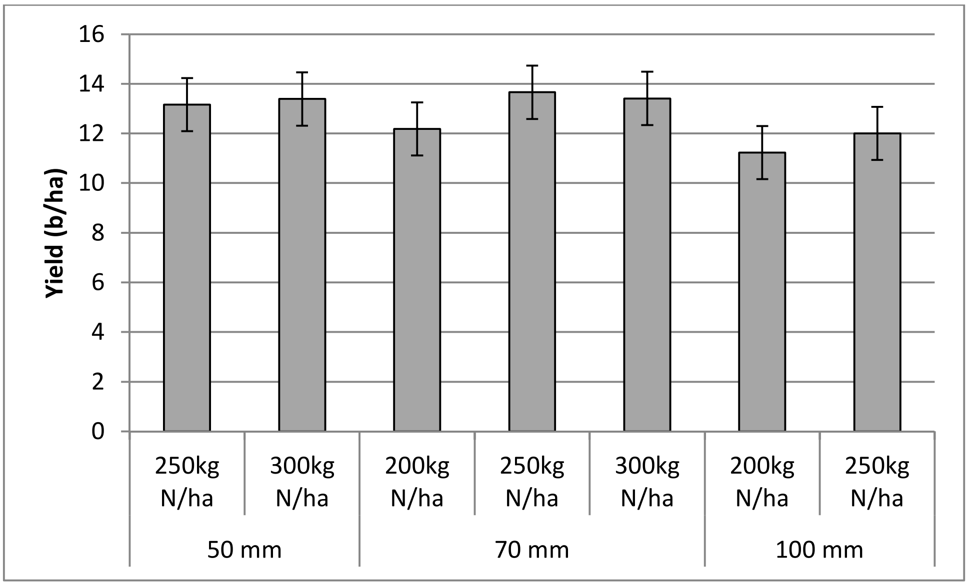


Figure 11 N_2O emissions from the manual gas chambers

4.5 Yield

The treatment yields of the 250 & 300 kg N/ha treatments at both the 50 & 70 mm water deficit irrigation schedules were statistically similar ($P \leq 0.001$) with no advantages in applying the higher nitrogen rate (300kg N/ha) over the moderate rate of 250 kg N/ha. It is also evident that the lower deficit irrigation schedule (50 mm) where although it produced a plant with higher boll numbers, it did not result in higher yields. The 200 kg N/ha at 70 mm (13.41 bales/ha) and the 200 & 250 kg N/ha at 100 mm deficits (11.23 & 12.00 bales/ha respectively) had significantly ($p \leq 0.001$) lower yields compared to the trial's highest yield (250 kg N/ha at 70mm with 13.6 bales/ha).

The yields achieved within this experiment suggest that growers can expect no productivity gain from increasing input levels to excessive amounts. This is supported by long term nitrogen rate trials conducted by Dr Ian Rochester based at Australian Cotton Research Institute (Narrabri, NSW). In an experiment that had similar field history to the "Ruvigne" trial (back-to-back cotton), Rochester found the economic optimum applied nitrogen fertiliser rate to be 135 kg N/ha (2015). Rochester determined the economic optimum nitrogen rate by examining the logarithmic response curve of nitrogen response to yield and the cost of applied nitrogen ($1.50/kg) and the return for cotton lint ($2.20/kg). Using the same methodology (including the nil nitrogen yields), the economic optimum rate for the "Ruvigne" experiment was deemed to be 195 kg N/ha. The value is higher than Dr Rochester's but three factors must be noted, the higher yields produced at Ruvigne, the lower cost of nitrogen application ($1.10/ kg) and the lack of low applied nitrogen rates (0 – 100 kg N/ha) on the "Ruvigne" trial.



Lsd ≥ 1.07 b/ha at P ≤ 0.001
Figure 12 Treatment yield

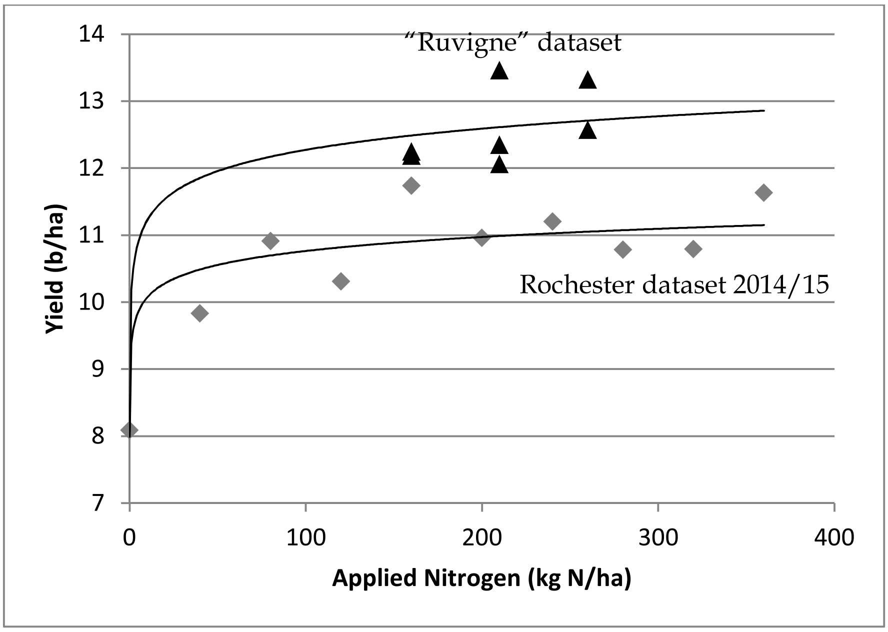


Figure 13 Yield response to applied Nitrogen

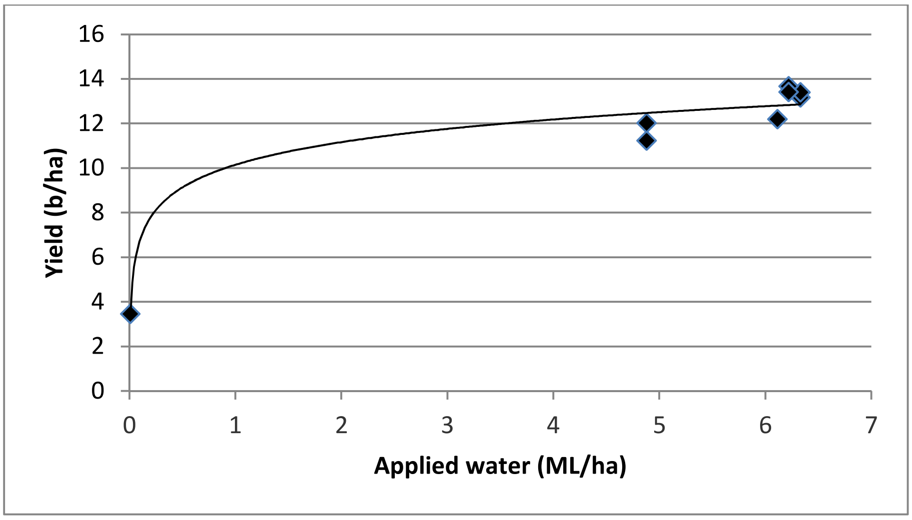


Figure 14 Yield response to applied water

4.6 Gross Margins

As yield has a major impact on crop gross margins, the 250 kg N/ha on a 70 mm deficit resulted in the highest profit margin of $4559 per hectare. The high nitrogen rate (300 kg N/ha) with the 50 mm deficit had the highest input cost, an extra $79/ha higher than the 250kg N/ha at 70 mm deficit and a difference of $210/ha in gross margin when the experimental yield is included.

While both the 100 mm treatments resulted in low gross margins on a $/ha basis the advantages of limited water application is obvious for $/ML returns. This equation is especially important for growers who have limited water availability and want to improve farm returns based on a megalitre basis. From the experiment the 100 mm with 250 kg N/ha resulted in the greatest irrigation gross margin of $792/ML, which is $60/ha greater than the next highest treatment (250 kg N/ha with 70 mm deficit). The two 50 mm treatments were over $100/ha less than the 250 kg N/ha at 100 mm, while the lower yield meant the 200 kg N/ha at 70 mm deficit had the lowest return with $628/ML.

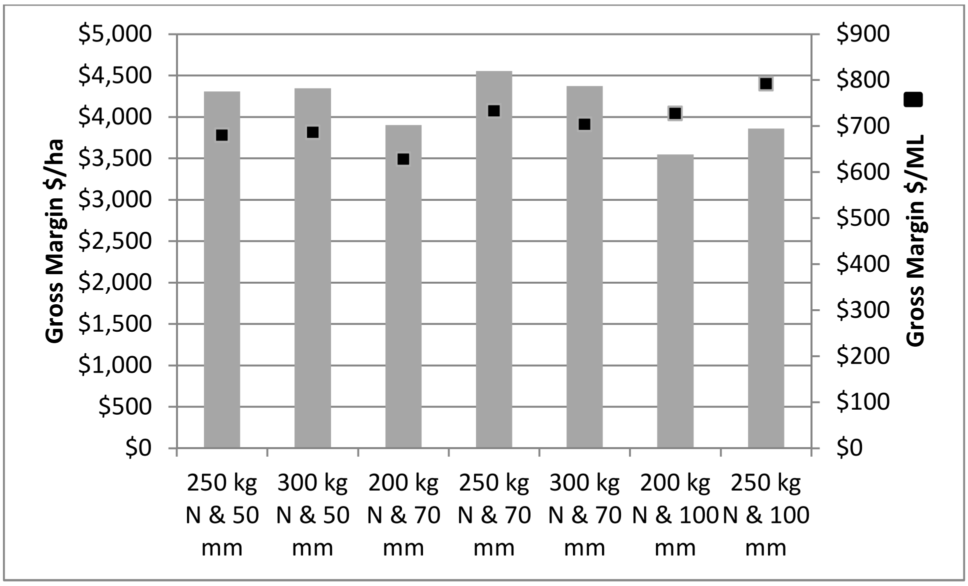


Figure 15 treatment gross margins

Statistical Analysis:
Statistical analysis of the experiment results is attached in Appendix 5.

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.

Project outputs such as the trial results delivered to the CGA's and the trial site field day have increased grower awareness of alternative water and nitrogen management strategies. Grower adoption of improved water and nitrogen management will optimise input efficiency and improve farm profitability.

Presently growers believe that recent research isn't relevant to their farming business, whether it's a different climate or different physical constraints (soil sodicity etc.). Conducting trials on commercial farms, delivering the results through grower networks and by holding demonstration field days increases grower engagement and knowledge of input management in systems that are similar to their own farms.

Industry networking particularly in the Upper Namoi was seen as a priority during the project, as the area traditionally has had limited field research. Rod Smith ("Ruvigne" farm manager) explains that this was an encouraging aspect on the project "*Great to see a trial away from Narrabri, and out in this area, ground truthing industry researched recommendations… the treatments are relevant to our area and as a result of this trial I see water as more of a key to increasing my productivity… not excessive nitrogen rates*". This was an encouraging sign that growers can gain confidence from the project's results and modify their management strategy to improve farm efficiency.

One particular attendee to the field day was Mr Sam Simons, an agronomist with Agromax Consulting, who had this to say about the experiment, "*It's great to see a thorough experiment in this valley (Upper Namoi Valley) particularly with nitrogen and irrigation timing… The irrigation scheduling is highly important in this area as we have growers who have limited allocation and others who probably aren't irrigating to their best ability… with results like these I will be able to give growers clearer answers when developing a (management) strategy for the season*".

As this was a short term project (one year) the time frame between availability of experiment results and grower engagement was very limited. There is an expectation that increased grower awareness and input management knowledge can only increase with further publication and dissemination of the experiment results.

6. Please describe any:-

a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);
N/A

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

c) required changes to the Intellectual Property register.

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?

The interaction between nitrogen uptake and irrigation application is strong. The results of this project suggested that optimised irrigation application drives efficiencies in crop nitrogen uptake. The 50 mm irrigation deficit resulted in plant nitrogen uptake levels that were consistent and low variability. This supported the conclusion that frequent, and smaller amounts of water application meant the cotton plant absorbed nitrogen with greater consistency. This interaction would allow growers to be more confident in their crops ability to utilise the applied crop nitrogen and neglect the trend of applying higher than required levels of nitrogen as crop insurance rather than for crop requirements. Lowering applied nitrogen rates would lead to greater industry efficiency and less nitrogen loss from the farming system.

The experiment showed no significant increase in yield when plant available nitrogen was greater than 250 kg N/ha (210 kg N/ha applied fertiliser). Applying excessive nitrogen above what the crop requires means there is a greater chance of nitrogen being lost from the farming system via non-plant pathways (ie. de-nitrification, etc.).

Growers have been defending the recent industry trend of applying high crop inputs by claiming that "it's cheap insurance for greater crop productivity". By incorporating gross margins into the project a clear message can be delivered to the industry. Namely by aiming to meet the crop's demands (for nitrogen and water) growers will save significantly costs within their farming operations. By substituting a "high" input strategy (eg. 300KgN/ha and 50mm deficit) with an optimised "moderate" input strategy (250kgN/ha and 70mm deficit), a grower with 400 ha of cotton could save approximately $31,000 annually in grower costs.

The experiment found the "moderate strategy" of 250 kg N/ha with a 70 mm deficit to be the optimum input strategy for cotton growers in the Upper Namoi valley. The "high" input strategy failed to gain an increase in productivity to warrant the extra applied amounts of nitrogen and water, while the "low" input management strategy meant growers received a productivity and gross margin discount. The results highlight the importance of taking a holistic approach when optimising a management strategy for cotton production. Growers and consultants need to develop crop input budgets that consider optimal water and nitrogen application rates that match the actual crop requirements.

Below are some take home messages that were distributed to growers through the Cotton Info summary to aid them in better optimising their nitrogen and water management strategy.

<u>Points to consider when developing a nitrogen & water management strategy</u>

- Soil tests are crucial in calculating Nitrogen budgets for your crop.
- Consider the available water for your crops when applying nitrogen – don't apply large amounts of nitrogen in a limited water situation.
- Irrigations do have an impact on nitrogen uptake efficiency, so optimising your irrigating practices will improve your nitrogen use efficiency.
- It's crucial to have level fields with adequate irrigation infrastructure if you intend to adopt an intensive irrigation strategy. Poor water application efficiency will exacerbate plant stress.
- High input strategies do produce a plant with greater fruit potential, but plant stress events will have a greater effect on yield potential and therefore this strategy leads to more risk in a farming system

- The pre-water event accounted for 15-25% (depending on irrigation treatment) of total water applied in this trial. Improving the efficiency of water application in the first and second irrigations would greatly reduce water losses and improve seasonal water productivity.

Although the research trial has only generated data from one season, the results of the project show that the cotton growers could potentially lower nitrogen fertiliser application rates without compromising yield productivity. The added bonus for cotton producers is that gross margins could improve due to increased input efficiency and the lower input costs.

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.

To build on the project's findings, the establishment of similar demonstration trials within other cotton growing regions (different climatic and soil conditions) would engage a greater number of growers and increase awareness and potential adoption of optimal water and nitrogen input strategies.

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

Project results are to be published in industry relevant publications and also in broader agricultural publications that will promote trial results to a greater share of the Australian irrigation community.

An article is in scheduled to be published in the December 2015 edition of Spotlight.

Presentations of the project's final results will continuously be given through the 2015/16 growing season to promote optimisation of nitrogen and water management. Presentations are expected to occur at future field days within the Upper & Lower Namoi Valley's.

(c) for future research.

Future projects should continue to investigate the improvement of NUE by improving irrigation techniques. This could include different forms of irrigation, different application techniques (volume variability, placement) and application strategy (PAW deficits). To further demonstrate water and nitrogen efficiency it would be advised to have more sites at within various valleys (or climates) to greater optimise efficiency values to specific farm management strategies.

A number of additional research questions have emerged during the analysing of this project. These include:

- Are NUE & WUE researched values still relevant to modern cotton cultivars (74 BRF & future Bollgard 3 cultivars)?
- As plant nitrogen uptake is strongly related to water application, can growers utilise irrigation to optimise nitrogen uptake and improve NUE?

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)

- Literature Review - Appendix 1
- Experiment review summary; short article released to growers of the Namoi Valley, through CottonInfo and CGA networks - Appendix 4
- An article based on the experiment results is due to be published in the December 2015 issue of the Spotlight magazine

- An article written in consultation with Ian Rochester was due to be published in the next edition of Australian Cottongrower magazine. However due to the unfortunate passing of Dr Rochester on the 18th September 2015 steps will be undertaken to find a suitable alternate co-author and reviewer.

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

The NSW DPI website has electronic version of agronomic fact sheets attached, when replicated data is available a factsheet containing results from project DAN1502 will be uploaded with the approval of CRDC.

Part 4 – Final Report Executive Summary

During the 2014-15 Australian cotton season NSW Department of Primary Industries research and development agronomist Mr Jon Baird conducted a research project to investigate the interaction of nitrogen and water management. The project was situated on “Ruvigne”, a commercial farm within the Upper Namoi Valley. The aim of this research was to determine the impacts of various irrigation and nitrogen rate treatments on plant growth, cotton lint yield, nitrogen use efficiency (NUE) and water use efficiency (WUE). Results from the one year project have shown that growers can potentially optimise input efficiency and improve crop returns. Of the management strategies researched, Mr Baird found that the “moderate” input strategy (250 kg N/ha with a deficit of 70 mm) resulted in higher WUE, NUE, lint yield and importantly higher gross margins per hectare.

Typical grower management strategies were incorporated into the experiment to investigate three levels of water and nitrogen inputs - high, moderate and low. The treatment inputs contained three irrigation schedules set at soil water deficits of 50 mm, 70 mm & 100 mm, and three total plant available nitrogen application rates of 200 kg N/ha, 250 kg N/ha & 300 kg N/ha.

Results suggested that the “moderate” input management strategy (250 kg N/ha & 70 mm deficit) was the optimum nitrogen and water combination. This management strategy had the greatest lint productivity and gross margins. The experiment results would seem to confirm previous research work (ie. Dr Ian Rochester) that cotton growers can, in many circumstances, reduce nitrogen fertiliser inputs and continue to produce high profitable yields.

The gross margin for the “moderate” input management strategy of 250 kg N/ha with 70 mm deficit returned over $200 /ha more than the “high” input management strategy of 300 kg N/ha and a 50mm irrigation deficit schedule. Optimising management strategies to improve input use efficiencies can lead to better returns for the growers at the farm gate. Putting this saving into perspective means that growers with 400 ha of cotton could generate an additional $80,000 of returns in a cropping season by implementing the optimised management approach identified in this applied research trial.

It must be noted that the results and subsequent analysis is based on the 2014-15 season only and is specific to the typical environmental conditions of the Liverpool plains in the Upper Namoi valley. Further applied research is planned at Ruvigne during the upcoming 2015-16 season to verify the 2014-15 findings.