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

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1.0 Glossary

Border check systems are defined as surface irrigated areas that have slope in the longitudinal direction and free draining conditions at the lower end. Basin systems have no longitudinal slope and complete perimeter dykes to pond water and prevent run-off (Walker and Skogerboe, 1987). The National Engineering Handbook (U.S. Natural Resources Conservation Service, 1997) differentiates between three principal surface irrigation systems: contour, level and graded. Adapting the definitions, surface irrigation systems in the southern Murray Darling Basin can be differentiated into:

1. **Graded systems** – water flows in the direction of the land slope and the system has free draining conditions at the lower end. These systems can be classified as:
 - a. *Border check* systems if crops and pastures are grown “on the flat”.
 - b. *Graded Furrow* systems if row crops are grown on beds or hills.
2. **Basin systems** – have complete perimeter dykes and are only recommended for soils with low final infiltration rates and low slope. They can be classified as either:
 - a. **Contour systems** – with slope in the lateral direction (i.e. across the width of the bay) but not in the longitudinal direction (i.e. down the length of the bay).
 - i. *Natural contour* systems have check banks that follow the natural contour. Laser grading may have been done to remove reverse grades within bays.
 - ii. *Parallel contour* systems have been land-formed so that the check banks along the contour are parallel to each other.
 - b. **Level systems** – are level within irrigation bays (i.e. no slope in either longitudinal or lateral directions) and there is a terrace between each bay..
 - i. *Level basin* systems are used for growing rice “on the flat” and in rotation with pastures and winter cereals in a mixed farming enterprise.
 - ii. *Level furrow* systems are used for growing row crops such as cotton on hills or raised beds: i.e. side-ditch, beds in bays.

The terms *side ditch* and *bankless channel* are synonymous. They are defined as a supply channel, running with the slope down one side of an irrigation block, which does not have a bank on the inside of the bay (Swinton, 1994). Checks are placed across the channel at each contour bank to control water flow. The bed of the channel is below bay level and it acts as both supply and drain. The term *side-ditch* is used throughout this report to refer to this system of supply and drainage in basin systems.

2.0 Background

In the southern MDB, 83% of all irrigated land is irrigated using surface systems. The most significant opportunities to improve irrigation water productivity lie with the industries that use the most water through these systems: i.e. pasture production for dairy and grazing, and annual cropping for rice, cotton and grains (Meyer, 2005).

The two main types of surface systems found in the southern MDB are border check, which is predominant in the dairy and grazing industries of northern Victoria, and basin systems, which occupy 100% and roughly 30% (K. O’Keeffe, Cotton Info, *pers. comm.*) of rice and cotton growing areas respectively in southern NSW. Considerable work has been done over many years to improve border check systems (e.g. Campbell, 1989, Austin and Prendergast, 1997, Lavis *et al.*, 2006). However, the same cannot be said for basin systems, with published design recommendations by Swinton (1994) now 24 years old.

A review by North (2008) found that the profitability of basin systems might be increased by improving application efficiency and flexibility, enabling crops with a higher return per megalitre to be grown. The review also found that published design recommendations (Swinton, 1994) were outdated, not evidence based, and did not provide adequate guidance to support the adoption of developments such as high flow rates, side-ditch delivery and drain, terracing and level furrow systems.

Follow-up studies to these reviews (North *et al.*, 2010, Grabham, 2012) found the following:

- Opportunity times in commonly used side-ditch, parallel contour rice systems are in the order of 30-40 hours. These long opportunity times are primarily due to slow drainage.
- System application uniformity is poor in side-ditch, level furrow cotton systems, with measured differences between bays being as much as 255% for a single irrigation.
- There is a hydraulic connection between bays that occurs through the side-ditch in flat terrain when water backs up in the outlet structure and impedes outflow from the draining bay. This is the principal cause of both the observed long opportunity times and the lack of application uniformity between bays.

Design criteria are needed to overcome these deficiencies so that the advantages of basin systems used for rice and cotton (i.e. low labour, capital and energy requirements) are retained. This would ensure the capacity for a wider range of crops to be grown with minimal risk of waterlogging and with reduced deep drainage losses. Furthermore, design criteria are needed to standardise operating conditions and make basin irrigation performance more predictable, and to facilitate the development of autonomous irrigation systems. This will be of major importance to the rice industry if their goal to move to a more aerobic rice system (Clarke, 2016) is to be realised, as the labour required to flush irrigate will be a major impediment to its adoption.

Newer surface water management techniques using automated side-ditch systems and terraced layouts can provide significant labour savings and some energy savings. There is some information available on their operation (Grabham, 2013) and growers and research projects are

currently conducting systematic evaluation from a biophysical and economic perspective. However, it is apparent that although more accurate use of water and nitrogen, sensitively matched to soil physical, chemical and biological characteristics, field variability and crop physiology and development, may increase the efficiency of fertilisers (and potentially profit), none have yet been shown to have a large impact on N losses (Chen *et al.*, 2008). A large part of the problem is that unfavourable growing conditions through weather or changes in land and crop management can greatly influence the fate of applied fertiliser N. For example, annual differences in weather patterns can significantly affect crop N uptake resulting in N available for loss by denitrification or leaching below the root zone (Freney, 1997). Therefore, to make a dramatic reduction to agricultural N losses, high end technologies such as: controlled release products; urease and nitrification inhibitors (Chen *et al.*, 2008); foliar fertilizers (Smith *et al.*, 1991); polymer technological applications (Simunek *et al.*, 2016); and real time soil, water and remote sensing technologies (Zhang *et al.*, 2002; Ojha *et al.*, 2015), may be required, and will need to be more thoroughly evaluated.

The risk of nitrogen loss from denitrification increases with high inputs of N and decreasing oxygen content in the soil matrix, therefore irrigated cropping systems have the potential to promote high losses of N (Mosier *et al.*, 2002). A review showed that >100 kg N/ ha may be lost by denitrification in irrigated soils (Barton *et al.*, 1999). Management strategies to minimise N losses from high water and N input systems involve irrigation management (Rolston *et al.*, 1978; Rolston *et al.*, 1982; Jamali *et al.*, 2015); sub-surface drip, bed and furrow systems or flat layouts; high flow water supply systems (Gillies *et al.*, 2010; Smith *et al.*, 2009) that minimise surface waterlogging (Williams and Smith, CRCIF, 2010).

This project aspired to increase production and profitability of surface irrigated basin systems used by broadacre irrigated cropping industries in the southern MDB over the medium term (5+ years) by improving irrigation design and crop management practices in conjunction with new irrigation designs. In the shorter term, the project aims to quantify and therefore enable a significant reduction in N losses and an increase in the efficiency of fertilizer N in surface irrigated cropping systems.

The project will also provide information to irrigation designers and farmers that will allow them to build better performing, more flexible and precise basin irrigation systems. It is expected this improvement will occur through optimised designs which allow greater control over irrigation opportunity time while minimising capital and labour costs leading to reductions in deep percolation losses, an ability to move to lower cost production systems (e.g. flushing of rice), and/or increases in yields with less waterlogging.

3.0 Objectives

The objective of the project was to develop profitable, sustainable broadacre irrigation systems that increase the profitability and flexibility of farming systems in the southern connected regions of the Murray Darling Basin (MDB).

To realise this objective, the project was divided into four focus areas:

- 1) Working with growers in Participatory Action Research to prioritise research direction, inform project activities, and provide a pathway for extension.
- 2) Assessing the ability to apply defined irrigation depths with scheduled application, and determining the potential of precision irrigation to reduce deep drainage and waterlogging risks, while increasing nutrient and water productivity in broadacre surface irrigation systems.
- 3) Developing irrigation design criteria to enable the use of precision irrigation in basin surface irrigation systems.
- 4) Investigating the economic impact of irrigation system and infrastructure redevelopment on whole farm profitability and return on investment.

The project was a collaboration between two key research organisations, NSW Department of Primary Industries and Deakin University Centre for Rural and Regional Futures, and three grower groups, IREC, ICC and SG, located within the southern connected systems of the Murray Darling Basin. A participatory action research approach was used by the project proponents, with a steering committee comprised of representatives from the three grower groups, extension organisations (Murray and Riverina Local Land Services), industries within the region (rice, cotton and grains), and the research team. The steering committee determined the research priorities, ensured the relevance of the research, and assisted in the communication of research findings.

3.1 Key performance indicators

The key performance indicators of the project achievements are outlined in Table 1.

Table 1: Key performance indicators for the Maximising on-farm irrigation profitability project, including progress toward each indicator during the project, and outputs from each indicator.

KPI no.	KPI description	Status against KPIs	Date	Progress achieved against KPI	Outputs
2.1	Conduct a literature review of current data, knowledge and gaps to be addressed.	Achieved	30/11/2015	The literature review identified that basin systems were well suited to the soils on which they were developed. However there were limitations in basin systems related to drainage, potential for waterlogging and lack of flexibility in enterprise choice. The project will address each of these limitations when developing irrigation design criteria.	Literature review submitted to CRDC
2.2	Collect benchmark data on the interaction between inflow rate, paddock slope, surface roughness, infrastructure and soil types	Achieved Achieved	30/04/2016 30/04/2017	Data was collected at one field site in a contour basin layout in the Murray Valley (Deniliquin) during autumn and spring of two irrigation seasons.	Data available for validation of the model used in the development of basin surface irrigation design
2.3	Source and collect data including inflow, advance, recession, and soil infiltration rate	Achieved Achieved	30/11/2016 30/11/2017	Data was collected from three field sites in the Murray and Murrumbidgee valleys during spring and summer irrigation seasons. These field sites are representative of 1) contour basins, 2) conventional side-ditch layouts, and 3) side-ditch layouts with laterals.	Hydrographs developed providing data for model validation
2.4	Validate surface irrigation simulation model and use the model to determine best irrigation design parameters	Achieved	30/04/2018	Model has been able to simulate soil infiltration characteristics for the determination of maximum bay size for given flow rate and soil type.	Design curves developed
3.1	Undertake a literature review of key soil and water influences on denitrification processes.	Achieved	30/11/2015	The literature review identified research gaps in four broad areas: 1. N ₂ and soil gas dynamics; 2. field scale testing of the irrigation/nitrogen interaction; 3. fertiliser technology for slow release in flooded systems; 4. the need for a better understanding of remineralization of soil N and biological N inhibition. The agronomic field experiment activities in this project will address identified gaps 2	Literature review submitted to CRDC

				and 3 above.	
3.2	Identify methods and establish field sites	Achieved	31/1/2016	The key learning sites were established and aligned with the research priorities of each grower group. Each of the sites had plant and soil samples taken to allow the determination of treatment effects. Monitoring of soil water has occurred at each site.	Field experiment sites established and data collected
3.3	Collect data on the interaction between opportunity time, soil types, N losses and yield	Achieved Achieved	30/4/2016 30/4/2017	Field experiments continued at the IREC and ICC sites providing data across multiple seasons.	Data will be compiled once harvest is completed.
4.1	Collect & collate data on crop yield, water productivity and economic performance	Achieved Achieved	30/11/2016 30/11/2017	NSW DPI economists developed economic data to be validated by growers. Grower validation of the economic model is underway.	Economic data available for growers
5.1	Formation and operation of Management Committee and Steering Committee	Achieved	23/10/2015 5/10/2016 1/2/2017	Committee meetings are happening as per the project schedule. At their last meeting in October 2016 the Management Committee resolved to hold only one meeting per year. The Steering Committee will continue with two meetings per year with one being an inspection of field sites.	Minutes endorsed Minutes circulated Meetings minuted where appropriate
5.2	Establish grower led key learning sites including research activities and data collection protocols	Achieved	30/11/2015	Key learning sites were established. A project specification document was prepared which details the R&D activities at each site, and was approved by the project Steering and Management Committees.	Project specifications, suitable field experiment sites, data for analysis to determine the influence of irrigation and nitrogen treatments
5.3	Annual key learning site activity report	Achieved Achieved	1/04/2016 1/04/2017	A project workshop was held with Steering Committee and grower group representatives. This provided an overview of results and planning for the coming season. A project meeting with Steering Committee members and grower group representatives will be held once field experiments have been harvested and results compiled. This	Presentations by the project members at the workshop Project specifications were updated and have been provided to the Steering Committee for endorsement Meeting was held with project team and steering committee members 23- 24 August 2017.

				was held in July 2017.	
5.4	Article informing growers of the project and its focus	Achieved	9/2/2016	An article was written and published in the IREC Farmers' Newsletter Autumn 2016 edition.	IREC article available at http://irec.org.au/irec-farmers-newsletter-no-194/
5.5	Exchange of information between growers with project common interests	Achieved	15/12/15	Growers from Northern NSW visited the key learning sites during a farm automation tour in conjunction with the CRDC funded project "Benchmarking water use efficiency and crop productivity". Growers from southern NSW visited several sites in Northern NSW and also attended the Gwydir Valley Irrigators annual field day. A group of growers from southern NSW attended the Gwydir Valley Irrigators Association annual field day in February 2018.	Grower evaluation reports of farm tours conducted and results compiled.
		Achieved	7/02/2017		
		Achieved	15/12/2017		
5.6	Farmers informed of project focus and results to date	Achieved	1/4/2016	Presentations have been made informing growers of project results and progress to date in each of the areas in which project activities have been conducted	Various presentations by the project R&D team the full list of which is provided at Section 8.2 of this report.
		Achieved	1/4/2017		
5.7	Project objectives and progress clearly described to growers	Achieved	1/3/2016	Project objectives and progress have been described to 1464 irrigators and industry personnel through extension activities such as field days, newsletters, pre-season and industry meetings.	The full list of project presentations, newsletter articles, social media posts and scientific journal papers is listed in Section 8.2 of this report.
		Achieved	1/03/2017	Project results and plans have been described to 1190 irrigators and industry personnel through extension activities such as field days, newsletters, pre-season and industry meetings.	
6.1	Scientific findings of the project published in peer reviewed journal	Achieved	1/3/2018	Field experiments conducted at key learning sites enabling the development of relationships between remote sensing indices and crop N status in cotton.	<i>Ballester, Carlos, Hornbuckle, John, Brinkhoff, James, Smith, John and Quayle, Wendy 2017, Assessment of in-season cotton nitrogen status and lint</i>

					<i>yield prediction from unmanned aerial system imagery, Remote sensing, vol. 9, no. 11, pp. 1-18, doi: 10.3390/rs9111149.</i>
6.2	Prepare project final report	Achieved	30/4/2018	Final report completed and submitted to CRDC.	
6.3	Contribute to the Smarter Irrigation for profit extension plan	Achieved Achieved	1/4/2016 1/4/2017	Development of one-page project summary for the Smarter Irrigation for Profit project extension plan. Project personnel attended and contributed to the Smarter Irrigation for Profit project meeting, 21-22 March 2017.	Document available at http://www.cottoninfo.com.au/sites/default/files/documents/
6.4	Contribute data to the Smarter Irrigation M&E plan	Achieved	30/4/2018	Project has contributed as required to the Knowledge Harvest and Evaluation of the Smarter Irrigation for Profit project.	

4.0 Methods

4.1 Focus Area 1

Fostering collaboration and partnerships to facilitate the adoption of research findings

Objective: To facilitate the adoption of project results through effective collaboration, partnerships and extension.

General methodology

A Participatory Action Research (PAR) approach was used by the project team. The project team included researchers from NSW Department of Primary Industries (NSW DPI) and Deakin University; advisory services from Murray and Riverina Local Land Services, Rice Extension and CottonInfo; and three grower groups, (Irrigation Research and Extension Committee (IREC), Southern Growers (SG) and Irrigated Cropping Council (ICC)). Together the project team established the project objectives, directed project activity, and facilitated extension and adoption of project findings.

Key Learning Sites were established in collaboration with IREC, SG and ICC, and were used by the research team for large-scale field experiments. The experiments examined the interaction between nitrogen management and irrigation management in cotton and maize at two sites, with research into options to improve water productivity in rice farming systems undertaken at the third site (detailed in Section 4.2). The sites were important in the extension of research findings throughout the project.

The Participatory Action Research approach and the formation of a Steering Committee ensured the grower groups, extension organisations and industry representatives were informed throughout the project. The Steering Committee met formally twice each year. One meeting each year consisted of a tour to each of the key learning sites, while the second meeting focused on an annual results review and planning. Project results were regularly presented to growers through group activities such as field days and meetings. Over 900 grower and industry personnel received information about the project each time newsletter articles and factsheets were published through the grower group networks (refer to Section 8.2).

4.2 Focus Area 2

Investigate irrigation and nitrogen management strategies to improve water productivity in cotton, maize and rice farming systems

Objective: To improve crop yield, water productivity, nitrogen input efficiency and farm profitability across the three cropping systems of rice, cotton and maize.

Research questions:

- What is the effect of reduced deficit irrigation on nitrogen use efficiency (NUE) and water use efficiency (WUE) in irrigated cotton and maize?
- Can nitrogen use efficiency be improved through strategic irrigation and nitrogen scheduling?

- Is continuous double cropping a possible alternative to increase water productivity in the rice farming system?
- What crop and management regime will best allow continuous double cropping in the rice farming system?

General methodology

Three Key Learning Sites were established with a host grower group. Research questions and activities were determined in conjunction with each group to align with the overall project objective.

4.2.1 Key Learning Site 1

Grower group: Irrigation Research and Extension Committee, Whitton NSW. (34°32'41.14"S, 146°11'06.05"E)

Focus crop: Cotton.

Soil type: Red Chromosol (Isbell, 2016)

4.2.1.1 Experiment 1

A field experiment was established to investigate the hypothesis that a small irrigation deficit would increase plant N uptake, plant N use efficiency and lint yield in cotton. Main plots comprised irrigation treatment (applied through sub-surface drip irrigation) and sub-plots were the different fertiliser nitrogen application rates (Figure 1). The trial was planted to cotton (var. Sicot 74BRF) on 14th October 2015 at a rate of 130,000 seeds/ha and fertiliser N was applied as Anhydrous Ammonia.

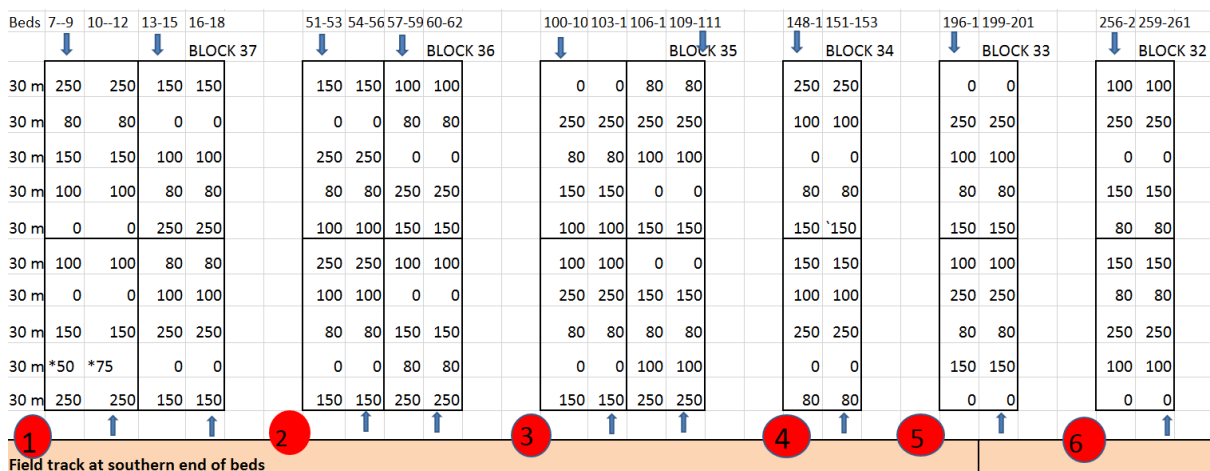


Figure 1: Design of the field cotton experiment to investigate the interaction between irrigation and nitrogen management on lint yield, water use efficiency and nitrogen use efficiency at Whitton in 2015. Numbers inside blocks denote the rate of fertiliser N (Anhydrous Ammonia) applied in kg ha⁻¹. The fertiliser was applied 2 weeks before planting the cotton seed. Red circles with numbers denote the irrigation control valve controlling the delivery of irrigation water via sub-surface drip for each block.

Fertilisation

Five nitrogen rates (0, 80, 100, 150 and 250 kg N/ha⁻¹) were applied in one pre-plant application of anhydrous ammonia in September 2015 with a commercial rig, two weeks prior to planting of the crop. The original plan was to provide three irrigation treatments,

comprising three irrigation deficits (35 mm, 70 mm and 105 mm) with three replicates and nitrogen rate had either two or four replicates within each main plot. The variation in replication for the nitrogen treatments occurred because of uncertainty around the ability to apply the different irrigation treatments. Two irrigation deficits, watering every day and watering every second day, were possible using the sub-surface drip system. The irrigation treatments were imposed during the period from first flower to first cracked boll which corresponds to the period of greatest water requirement and nitrogen uptake in the crop.

Irrigation monitoring

Water flow meters and sensors were installed to measure water application, matric potential and irrigation deficit throughout the crop growth period.

Drone multispectral data acquisition for determining biomass indices

Multispectral images of the site were acquired at five different periods of the season with a 5-band multispectral camera mounted to a drone. For each day of measurements, the camera was set up for a 75% overlap of the images in order to ensure that the experimental site was properly covered. This set of images was then uploaded to the cloud-based application Micasense Atlas Imagery & Analytics for Precision Agriculture service (<http://www.micasense.com/atlas/>), where all of the images were stitched together to provide a single high-resolution image of the whole site. Spectral data obtained from the red, red-edge and near-infrared bands was used to calculate structure and chlorophyll sensitive vegetation indices (the normalised difference vegetation index, NDVI, and the normalised red edge index, NDRE) to track crop nitrogen use across the season (Figure 2).

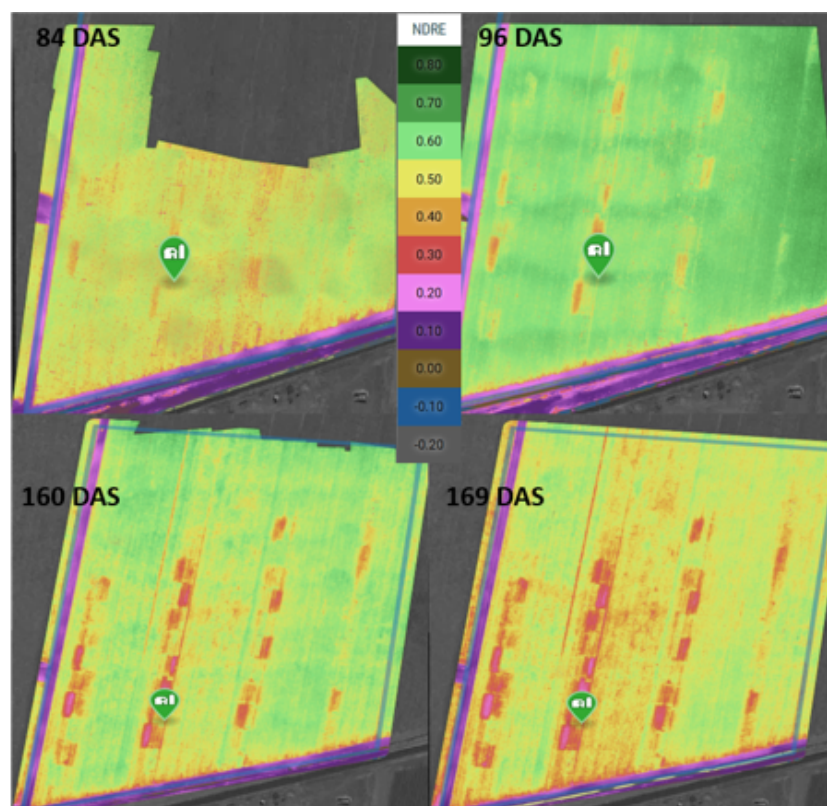


Figure 2: Normalised Difference Red Edge (NDRE) maps of the site at <10 cm pixel resolution showing the differences in crop nitrogen status between treatments across the season. DAS = Days after sowing. The red areas represent areas of lower N uptake.

Plant and Soil Sampling and Measurements

Plant establishment counts were conducted 4 weeks after planting (18/11/2015). Whole plant sampling was conducted at first flower (4/1/2016), first cracked boll (8/3/2016) and immediately prior to defoliation (31/3/2016) to assess the impact of irrigation treatment and nitrogen fertiliser rate on crop nitrogen uptake. A hand pick was conducted (12th – 20th April, 2016) across three rows, 2 m in length (a total of six metres of plant row) to assess the impact of the treatments on lint yield.

Soil samples were collected in the field prior to the experiment and analysed for mineral N. Soil samples were not collected post-harvest. The ongoing plant analysis and soil moisture monitoring highlighted that the sub-surface drip irrigation had not been able to impose differences in soil water deficits that would have caused differences in soil N balance.

4.2.1.2 Experiment 2

An experiment investigating the influence of irrigation deficit on water use, N uptake, nitrogen use efficiency and lint yield in irrigated cotton (2 years; 2016-2018) was located at Point Farms, Darlington Point, NSW (34°39'02"S, 145°54'01"E) with syphon irrigation. The soil is classified as a Chromosol (Isbell, 2016). It is a clay loam, locally known as a red brown earth and typical of one of the main irrigated soil types in the Murrumbidgee Valley. Some chemical and physical characteristics are provided in Table 2 obtained from samples taken from the experiment area.

Cotton (*Gossypium hirsutum L.*, cv SICOT 746 BRF Bolgard 2) was planted at 130,000 seeds/ha on 1.8 m wide beds with 90 cm row spacing, following previous cotton with minimum tillage. The crop was managed for pests, disease and growth regulation as commercial practise. Crop diaries for the 2016/17 and 2017/18 season to the time of writing this report are provided in Table 3 and Table 4, respectively.

Table 2: Soil characteristics for the field trial at Darlington Point, NSW.

Soil Depth	pHw	EC	Total C	Total N	Colwell-P	Available K	Ca/Mg	Gravel	Sand >	Silt	Clay
(cm)		(dS m ⁻¹)	(%)	(%)	(mg/kg)	(mg/kg)		>2 mm	20µM	2-20 µM	< 2 µM
0-30	7.9	0.1	0.97	0.09	50	545	1.5	0.2	29.4	18.8	51.8
30-60			0.58	0.05				0.3	28.6	14.8	56.7
60-90			0.38	0.03				0.2	28.7	11.8	59.5

The experiment design was completely randomised with three replications (Figure 3). The main plots were irrigation deficit, based on the number days between irrigation events. Watermark™ sensors (Ψ ; kPa) at 23 cm soil depth were used to measure the difference in soil matric potential that resulted from the different irrigation deficits. The irrigation deficit treatments were imposed from one week prior to first flower (3/1/2017) to the final irrigations which occurred for the short and standard deficit on 16/3/2017 and for the long deficit on

27/2/2017. The details of the irrigation deficit treatments were as follows: a) Short deficit; irrigation every 7 days; Ψ ; -30–40 kPa b) Standard deficit; irrigation every 14 days; Ψ ; -70–80 kPa c) Long deficit; irrigation every 19 days; Ψ ; - 90–110 kPa.

The experimental plots were in exactly the same locations in both years.

Table 3: Field diary for the cotton N and irrigation deficit field experiment at Point Farms, Darlington Point in the 2016/17 cotton season.

Date	Field Activity
27/8/2016	Baseline soil profile sampling (0-90 cm)
17/10/2016	Crop planted. Var. SICOT 746 BRF Plant density 18 plants/ linear metre
4/11/2016	Establishment counts
21/11/2016	Urea broadcast – 90 kg N/ha
28/11/2016	Soil moisture monitoring and redox sensors installed. Soils sampled 0- 90 cm.
21/12/2016- 21/1/2017	Petiole analysis - 5 samplings
28/12/2016	Urea side dressed. Standard rate – 180 kg N/ha; Reduced rate - 90 kg N/ha
3/1/2017	Irrigation treatments begun. Full profile on all treatments. Thereafter – short deficit ~ 7 days, standard deficit ~ 14 days, long deficit ~ 19 days.
12/1/2017	Soil profile sampling 0-30 cm. First flower plant sampling.
4/2/2017	Pix applied (600 ml)
15/2/2017	Pix applied (2L)
21/2/2017	First cracked boll plant sampling
4/4/2017	Defoliation plant sampling.
7/4/2017	Defoliation 1 applied to long irrigation deficit treatments.
18/4/2017	Defoliation 2 on long irrigation deficit. Defoliation 1 on short and standard irrigation deficit treatments.
4/5/2017	Harvested long deficit irrigation treatments
11/5/2017	Harvested standard deficit irrigation treatments
30/5/2017	Harvested short deficit irrigation treatments
2/6/2017	Post harvest soil profile sampling 0-90 cm

Table 4: Field diary for the cotton N and irrigation deficit field experiment at Point Farms, Darlington Point in the 2017/18 cotton season to date.

Date	Field Activity
12/7/2017	Basal fertiliser applied - anhydrous ammonia @ 180 kg N/ha
5/9/2017	Pre-irrigation
28/9/2017	Pre-season soil profile sampling 0-90cm
3/10/2017	Crop planted SICOT 746 BRF and rolled @ 18 plants/linear metre
17/10/2017	Soil sensor and camera installation.
25/10/2017	Establishment counts
21/11/2017	Flumes installed for water application measurement
4/1/2018	Urea side dressed. Standard rate – 129 kg N/ha; Reduced rate -64 kg N/ha. First flower plant sampling.
8/1/2018	Irrigation treatments imposed. Full profile on all treatments. Thereafter – short deficit ~ -40 kPa, standard deficit ~ -80 kPa, long deficit ~ -110 kPa days.
15/01/2018	Soil profile sampling 0-30 cm. First flower plant sampling.
2/2/2018	Plant assessment - cutout
5/2/2018	Mepiquat Chloride (Pix) applied (2 L/ha)

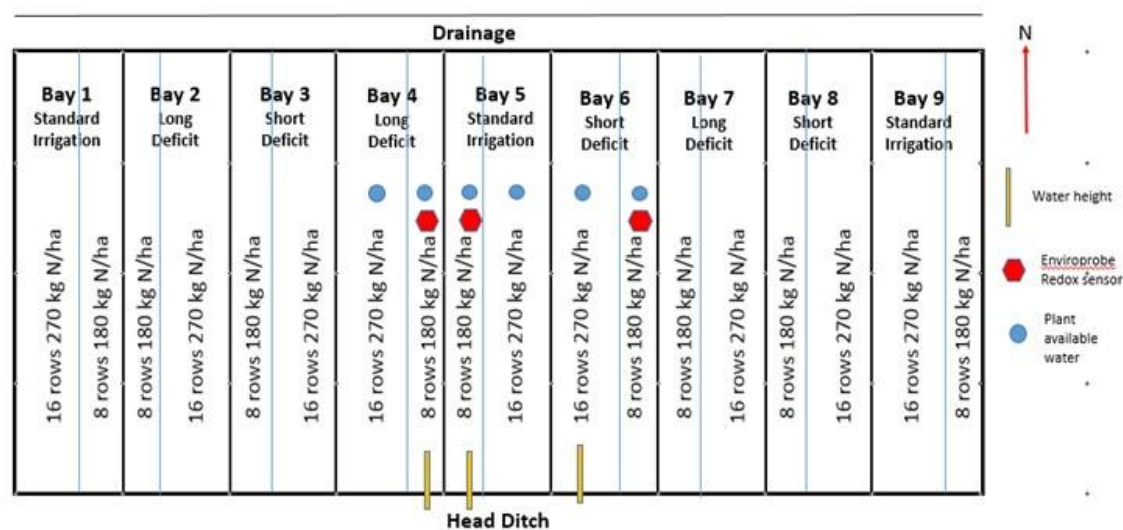


Figure 3: Schematic of the cotton irrigation x nitrogen interaction trial at Point Farms, Darlington Point, NSW, 2016-17 which was repeated in the 2017/18 season.

In the first season (2016/17), each main plot was split for two rates of urea–N fertiliser, a higher rate, which was standard farm practise, and a lower rate (270 and 180 kg N ha⁻¹, respectively). In the second year (2017/18) the standard and low rates were 309 and 244 kg N ha⁻¹, respectively. Plots within each irrigation deficit treatment were 640 m long and 16 rows wide for the standard N rate and 640m and 8 rows wide for the reduced fertiliser N rate. Due to the wet spring in the region in 2016, the fertiliser was applied later than usual in two

applications (Table 3). In 2016 a small plot (30 m x 5.4m) nitrogen rate trial was also established (J Smith, NSW DPI; CRDC project UQ1502) adjacent to the larger scale irrigation treatments comprising a control (zero nitrogen) and five nitrogen rates (50, 100, 150, 200, 400 kg N/ha), all applied by side dressing on the 28th December, 2017 which was irrigated as standard practise. The zero plots of this trial were used in the N use efficiency calculations derived for the larger scale trial.

In 2017, weather conditions for soil preparation were very good throughout the winter. Top dressing fertilisation of the trial area was somewhat late (at first flower) due to the side dressing method being used to replicate the previous year as closely as possible, which did not coincide with the grower practise of broadcasting urea across the rest of the field about two weeks earlier.

Water Measurements

In both experimental seasons, two soil moisture probes (EnviroPro™), one metre long with sensors at 10 cm intervals were installed in one plot of each irrigation deficit treatment, one in the standard fertilisation treatment and the other in the reduced fertiliser treatment (six probes in total). As well as continuous soil moisture measurements, these probes also measured soil temperature and salinity at each depth. Each of the fertiliser subplots had Watermark sensors installed at 5 and 23 cm depth to monitor soil matric potential. Redox potential sensors (Paleoterra™) were installed at 5, 23 and 45 cm soil depth to monitor the soil redox potential and assess waterlogging during irrigations. One reference electrode (Ionode™ IJ64 ORP sensors) was placed at 23 cm depth. All the probes and sensors were wired to loggers which enabled the measurements to be monitored remotely online in real time. The loggers use modules from Electric Imp™, which include WiFi connectivity, an antenna and a microcontroller with a variety of digital and analog interfaces for connecting to sensors and controlling power management.

A water height sensor was installed in the supply channel to record channel water height and before the irrigation treatments were imposed, flumes with water height sensors were installed in one furrow of each plot of each irrigation treatment to estimate the amount of water applied. In the second experimental season (2017/18) flumes were also installed 50-100 m from the drainage end of the same furrow where flumes had been installed to measure water supply, to attempt to estimate water run-off. Estimates of water application were also made by recording the time of syphon start and end times, syphon diameter and channel head height. A weather station located on the western edge of the paddock was used to collect the meteorological conditions during the season.

Plant and soil measurements

Plants from one metre of row were collected at first flower, cut out and defoliation from each N subplot (Table 3 and Table 4). The plants were mapped for plant height, number of squares, number of nodes, first boll retention and nodes above white flower. Biomass, total N and crop N uptake were determined by high temperature combustion according to standard methods after drying and grinding. In both seasons, periodical measurements of stomatal conductance were performed with a leaf porometer in the plots where all the sensors were installed to assess the effect of the irrigation treatments on leaf gas exchange. Measurements were performed at solar midday on cloud-free days from the fifth leaf below the terminal of 6–8 plants per plot.

Weekly measurements of vegetation indices such as the normalised difference vegetation index (NDVI), the normalised difference red edge index (NDRE) and the simplified canopy chlorophyll content index (CCCI = NDRE/NDVI) were taken with a multi-spectral camera mounted in a drone flown at 100m altitude. The indices were used to track crop biomass development and N concentration across the season. Petiole samples (petiole from the fifth leaf below the terminal in 30 plants) were taken on January 3rd, 9th, 16th and 21st in all the plots from this experiment as well as 18 plots (three replicates of each fertiliser N rate) from the fertiliser N rate experiment conducted beside this experiment for crop N assessment in the 2016/17 season. Petioles were dried at 70°C and finely milled; 0.1 g of the sample was extracted by shaking in 100 ml of distilled water for 1 hour, filtered and analysed for nitrate using a nitrate ion selective electrode (Rochester *et al.*, 2001).

Relationships between the results obtained from the petiole sampling and the vegetation indices obtained from the multi-spectral images were also explored.

Maturity was assessed in every treatment by counting and weighing lint from open bolls from 6 m of row (2 m of plant row across 3 rows), located at the northern, mid and southern points in each treatment on 7 occasions (2017) and sampling is still ongoing at the time of this report in (2018). Weekly boll collection from the same plants provides an indication of when 60% of mature bolls is achieved for each treatment.

The field experiment was commercially harvested. Lint yield was determined using the Cotton Growers Association bale trailer as well as from the bolls collected from the maturity picks (Plate 1). The round modules harvested from the experiment were ginned by RivCot with the lint collectors emptied after every round and lint that did not necessarily make up a full bale, weighed and added to the full bale weights to ensure an accurate lint yield calculation from the large scale plots. Lint was classed and quality parameters determined from every plot by Proclass, Griffith.



Plate 1: Round modules of harvested seed-cotton from the field experiment being weighed on weigh-trailer prior to being ginned at RivCot gin, Carrathool, NSW and classed by Proclass in Griffith, NSW.

The site was soil sampled pre-planting to 90 cm, divided into 30 cm increments and analysed for nutrients, and basic soil properties using a tractor mounted soil sampling rig. Further soil sampling to 90 cm was conducted post the first fertiliser application when soil moisture instrumentation was installed and to 30 cm (hand auger) in January at first flower for further nitrogen and texture analysis. A final soil sample was conducted immediately after harvest. Soils were dried at 70°C, ground to 2mm and analysed for mineral N and total N using standard methods.

Measurements of nitrate using an ion specific electrode in irrigation water run off immediately after broadcasting urea were made in the 2018 season (data not able to be included at the time of writing the report).

4.2.2 Key Learning Site 2

Grower group: Southern Growers, Jerilderie NSW. (35°31'86"S, 145°53'14"E)

Focus crop: Rice

Soil type: Red, sub-natric Sodosol (Isbell, 2016), known locally as a Willbriggie clay loam (Churchward and Flint, 1956)

An experiment to determine whether continuous double cropping was a possible alternative to increase water productivity in the rice farming system was established at Key Learning Site 2 at Jerilderie. A new short-season rice variety, cv. Viand, was direct seeded in three 3 ha bays in November 2015. Each bay was a combination of flat surface (traditional layout) and 1.83 m beds. The beds were always located on the low side of the bay to ensure an adequate depth of water could be applied across the top of the beds during the low temperature sensitive microspore period of the crop. This ensured that grain yield of the two surface layout treatments were not impacted by environmental conditions.

Soil redox potential probes (Paleoterra™) were installed with three sensors at 5, 10 and 20 cm soil depth within each probe to monitor the soil redox potential in the two surface layouts during the drainage period of the rice crop. One reference electrode (Ionode™ IJ64 ORP sensors) was placed at 10 cm depth. The sensors were wired to loggers which enabled the measurements to be monitored remotely online in real time.

The rice within each surface layout treatment in each bay was harvested with a commercial header, with the grain weight of each area measured using a weigh bin and the area calculated by walking the perimeter of each layout with a handheld GPS.

Following harvest of the rice the stubble was mulched and burnt and a short-season wheat variety, cv. Condo, was planted into the three experiment bays. The surface layout treatments, beds and flat, were maintained in the wheat crop.

It was planned to expand the field experiment from three bays to six bays in the 2016/17 rice season to enable two water management treatments to be imposed (conventional drill sown vs delayed permanent water) as well as the surface layout treatments. However, it became obvious in September 2016 that the required earthworks planned for October would not be possible because of the exceptionally wet September.

In consultation with the grower group preference was given to doing the land-forming and earthworks to ensure the paddock was at a standard that would enable water management

treatment differences to be determined accurately. It was necessary to allow time for the soil to dry out sufficiently to allow machinery onto the paddock and the decision was made to cancel the planned rice crop in the experimental block for the 2016/17 rice season.

In lieu of growing a rice crop in the experiment block at Jerilderie, measurements (redox, matric potential, water depth) were taken in a rice field experiment at Yanco Agricultural Institute that was part of the Agrifutures Australia funded project “Moving forward with NIR and remote sensing: PRJ-009772”. Two bays were monitored: a ponded water control and a crop that received delayed permanent water until panicle initiation and which was flush irrigated post-flowering and through grain filling (Plate 2). Measurements were made to compare the effect of the two treatments on soil redox and matric potential in order to assess the potential for flush irrigation of rice to modify soil conditions to better suit the following winter crop without affecting rice yields or quality.



Plate 2: Field layout at Yanco Agricultural Institute measuring soil redox and matric potential on standard drill sown crop (top left) and one with delayed permanent water and flush finishing (post flowering, bottom right) to increase soil oxygen levels and improve establishment conditions for subsequent winter crop production.

Land-forming and earthworks commenced in January 2017 at the SG key learning site at Jerilderie and was completed to the detail supplied in Figure 4. Flow measuring equipment was installed in the up-upgraded layout to measure flows onto all plots (bays). All bays were supplied individually, with volumes delivered measured by the flow meter (Figure 5). Drainage water was pumped off and volumes measured using flow meters on the pumps. The block was pre-irrigated and beds formed enabling planting of wheat, cv. Corack, in May 2017. Plots were instrumented to measure redox and matric potential following sowing of the wheat.

The wheat was cut for hay in October 2017, following a visual assessment of the progress and maturity of the wheat crop by members of the project team, the grower group and an independent agronomist. The assessment estimated that grain harvest of the wheat would not be possible before the need to plant the rice, cv. Viand, potentially jeopardising the yield potential of the rice crop.

Rice variety Viand was planted across the six experiment bays in November 2017. Three replicates of the water management treatments, conventional drill sown and delayed permanent water, were applied. The surface layouts of flat and beds were applied in each bay with the treatments able to be randomised within the bay following the redevelopment of the key learning site.



Earthworks Summary Proposal

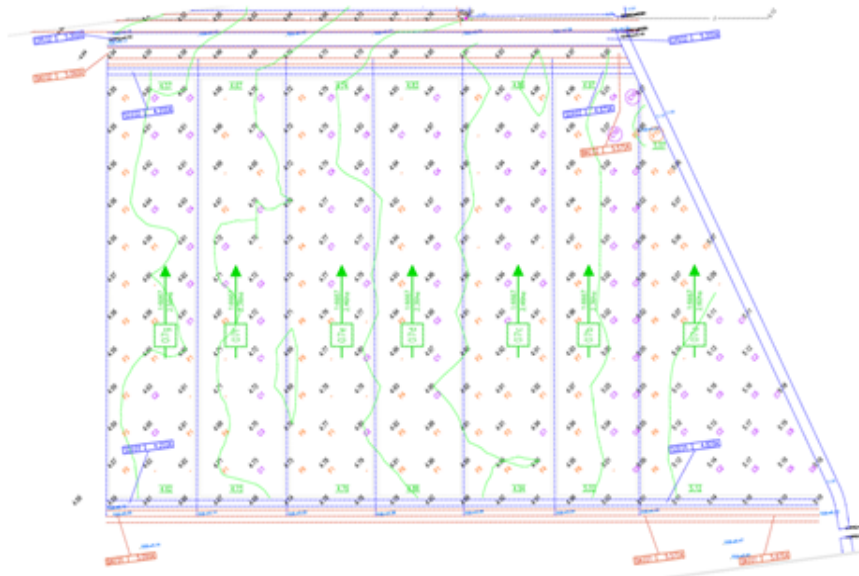


Figure 4: Field plan for the redevelopment of the Southern Growers Key Learning Site at Jerilderie.



Earthworks Summary Proposal

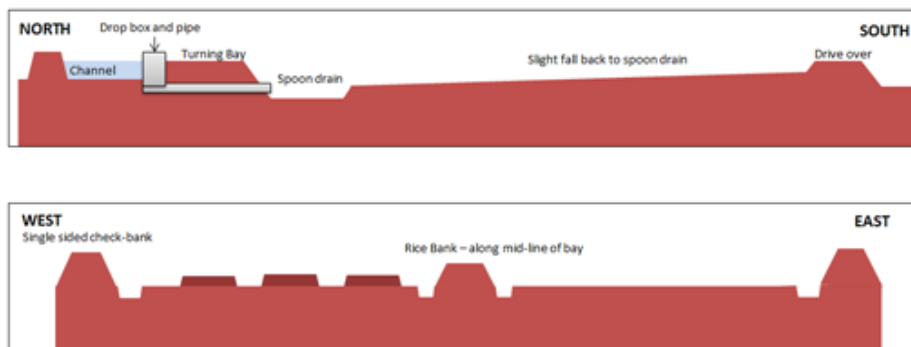


Figure 5: Layout of the individual bays that can now be supplied with and drained of water independently enabling accurate measurement of water with the different irrigation treatments.

Soil redox potential probes (Paleoterra™) were installed, following planting of the crop, with three sensors at 5, 10 and 20 cm soil depth within each probe to monitor the soil redox potential in each of the water management and surface layouts treatments. One reference electrode (Ionode™ IJ64 ORP sensors) was placed at 10 cm depth. The probes were connected via Wi-Fi to loggers which enabled the measurements to be monitored remotely online in real time.

Grain yield will be measured from each of the surface layout treatments (not yet complete at the timing of writing the report).

4.2.3 Key Learning Site 3

Grower group: Irrigated Cropping Council, Numurkah, Vic. (35°99'01"S, 145°34'64"E)

Focus crop: Maize

Soil type: Red Sodosol (Isbell, 2016), known locally as a Moira loam (Skene and Poutsma, 1962)

A field experiment to investigate the benefits of applying most fertiliser up-front compared to applying most of the fertiliser in-crop and shorter vs standard practise irrigation deficits on grain yield, N uptake and water use in maize was established at Numurkah. Maize (P0021 pioneer hybrid, CRM 100) was established with 90,000 seeds ha⁻¹ (2015-2018). Treatments were divided across 8 fully automated (Rubicon Water) border check bays (380 m long and 45 m wide) and repeated on the same area for the 3 years of the project (Plate 3).



Plate 3: Head ditch with automated stops along its length supplying the irrigation water to the Irrigated Cropping Council key learning site. Plate shows members of the Maximising on-farm irrigation profitability R&D team and steering committee members during field site visit in February 2016.

Soil type

The soil type within the trial paddock was a loam to clay loam A horizon (0-10 cm), with a stiff sodic blocky brown clay B horizon that cracks when dry. Generally, it drains well. Chemical characteristics from baseline samples are shown in Table 5 and were collected using a manual corer throughout the area and to a soil depth of 90 cm. Locations of the sampling sites are shown in Figure 6.

Table 5: Baseline soil chemical characteristics taken at the establishment of the field experiment at the Irrigated Cropping Council Key Learning Site at Numurkah in October 2015.

Soil Depth	pHw	EC	Total Organic C	Mineral -N	Colwell-P	Available K	Ca/Mg	CEC	Exch. Na
(cm)		(dS m ⁻¹)	(%)	(mg/kg)	(mg/kg)	(mg/kg)		Meq /100g	%
0-30	6.8	0.08	0.61	5.1	63	410	1.47	14	4.4
30-60				2.1					
60-90				1.8					



Figure 6: Satellite image of the location of the baseline soil sampling sites taken from across the Irrigated Cropping Council Key Learning Site in October 2015.

Nitrogen and Irrigation

The maize field experiment had two irrigation management and two N management strategies with two replicates per treatment (eight bays in total; Figure 7). Baseline soil sampling was conducted pre-trial from 0–90 cm soil depth in October 2015 (Table 5) and thereafter, soil was tested by the ICC for mineral N, at the same profile depths in October of 2016 and 2017 to guide fertiliser N application for the maize crop.

BAY 9	BAY 8	BAY 7	BAY 6	BAY 5	BAY 4	BAY 3	BAY 2
Up-front (F2)	Split (F1)	Up front (F2)	Split (F1)	Up front (F2)	Split (F1)	Up front (F2)	Split (F1)
Watermark (5,10,20,30,60)	Watermark (5,10,20,30,60)	Watermark (5,10,20,30,60)	Watermark (5,10,20,30,60)	Watermark (5,10,20,30,60)	Watermark (5,10,20,30,60)	Watermark (5,10,20,30,60)	Watermark (5,10,20,30,60)
IRRIGATION I1 off ~ 50-70 kPa @ 20 cm or Ray's rec.	IRRIGATION I2 Off- 20-40 kPa or 50% I1	IRRIGATION I1 off 50-70 kPa @ 20 cm or Ray's rec I1	IRRIGATION I2 Off- 20-40 kPa or 50% I1	IRRIGATION I2 Off- 20-40 kPa or 50% I1	IRRIGATION I1 off 50-70 kPa @ 20 cm or Ray's rec	IRRIGATION I2 Off- 20-40 kPa or 50% I1	IRRIGATION I1 off 50-70 kPa @ 20 cm or Ray's rec
Sentek	Sentek			Sentek	Sentek		

Figure 7: Field experiment plan for the Irrigated Cropping Council key learning site at Numurkah in the 2015/16 irrigation season.

The fertiliser N rate and timing of application strategy was led by the grower and aimed to apply the same amount of total fertiliser N to the crop through the two different application timing strategies. The up-front strategy applied between 64 – 75% of the total fertiliser N requirement for the crop prior to planting with the remainder applied in-crop. The in-crop strategy applied only a small amount upfront with 58 – 78% of the required fertiliser N applied during the crop growing season (Table 6).

Table 6: Fertiliser treatments imposed in the maize irrigation-N experiment at Numurkah 2015-18.

Year	Starter Fertilizer <u>Soygran</u> (kg/ha)	Total Urea-N (kg/ha)	Up front Fertilizer Treatment	In-Crop Fertilizer Treatment
2015/16	350	218	75:25	40:20:20:20
2016/17	350	250	72:22:6	42:20:15:15:8
2017/18	340	276	64:12:12:12	36:14:14:14:12:12:12

The irrigation deficit treatments were randomised across the eight bays whilst the fertiliser treatments were alternated in each bay.

The irrigation deficit treatments were imposed after the fourth irrigation and remained until the end of the irrigation season. In the first two years (2015–2017) the two irrigation deficit strategies were: i) standard grower irrigation practice (average 45 kPa matric potential) and; ii) short irrigation deficit (average 30 kPa matric potential). The standard grower irrigation was extended -50kPa -70kPa in 2017/18 to accentuate differences in the soil moisture regime. Matric potential was monitored throughout the season in each bay by installing two Watermark sensors at 5, 15, 30 and 45 cm depth. An example of the data from 2017/18 is shown in Figure 8.

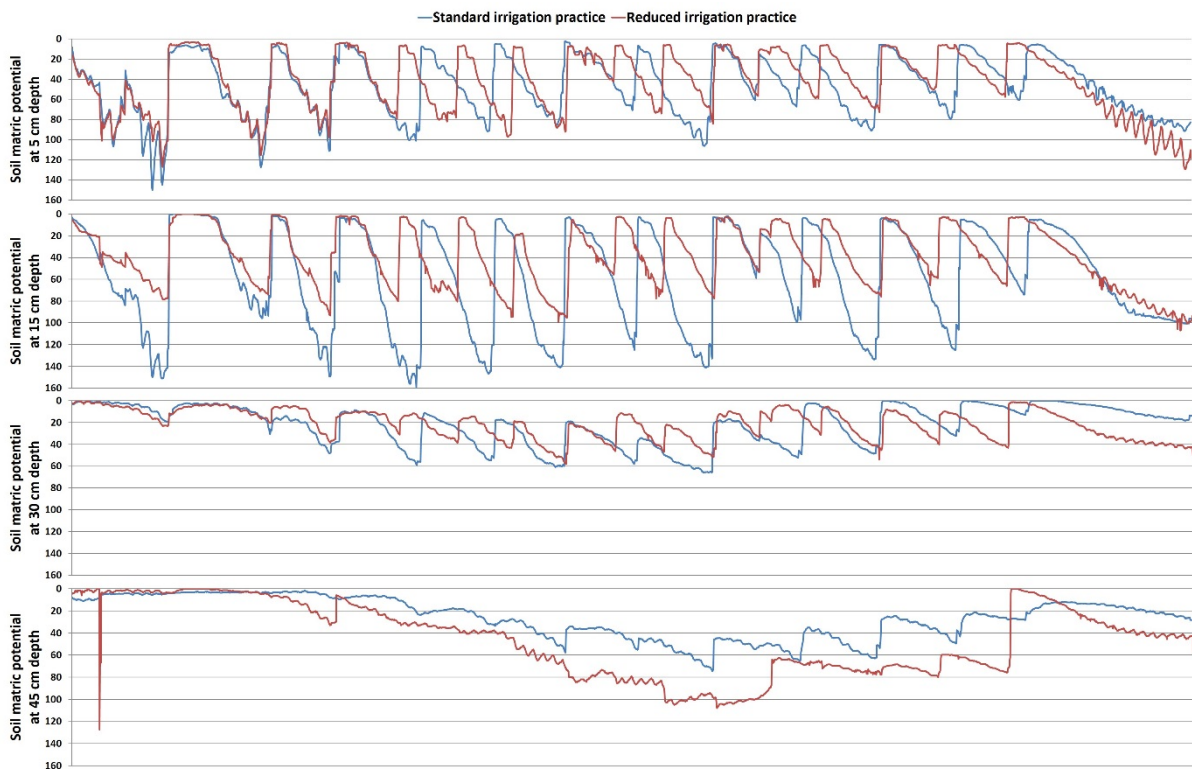


Figure 8: Example of soil matric potential for the two different irrigation strategies (red line -20 – -40 kPa as reduced irrigation practice; blue line -50 – -70 kPa as standard irrigation practice (2017/18 season), monitored in each bay with two Watermark sensors at 5, 15, 30 and 45 cm soil depths.

Plant sample collection and analysis

Establishment counts were conducted approximately two weeks after sowing counting 1 m in 2 rows at eight random locations in each bay. Whole plant samples were collected for biomass and total N at approximately the seven leaf stage, typically in the first week of December of each year and at physiological maturity. In the 2015/16 season, plant biomass was collected by selecting three random sites (2 rows x 1 m) at the top and bottom of each bay that had a similar plant density to those determined for plant population. This amounted to six replicate samples/bay, or 48 individual samples in total.

In the second and third year data was used from the Sentinel-2 satellite constellation to determine crop spatial variability and target sampling locations. This provided images every five days, at a 10 meter resolution, which is at a fine enough scale that allows multiple pixels across the width of each treatment area in the Numurkah trial. The images were processed in Google Earth Engine to obtain the normalised difference vegetation index (NDVI), which is known to be strongly correlated with plant biomass. The areas of mean NDVI (between 40-60%) in each treatment were then found, and a sample was taken at those locations (Figure 9). This gave representative samples of the average crop performance in each treatment and allowed the irrigation and N treatments across each bay to be compared.

The left figure shows the variability within each treatment area separately, with the target sample locations in the mean (white) areas of each treatment. The right figure shows the overall field variability. Two additional markers (with blue dots) capture a 20-40% and 40-

60% area, while existing sampling points from the map cover the other (0–20%, 60–80%, >80%) regions.

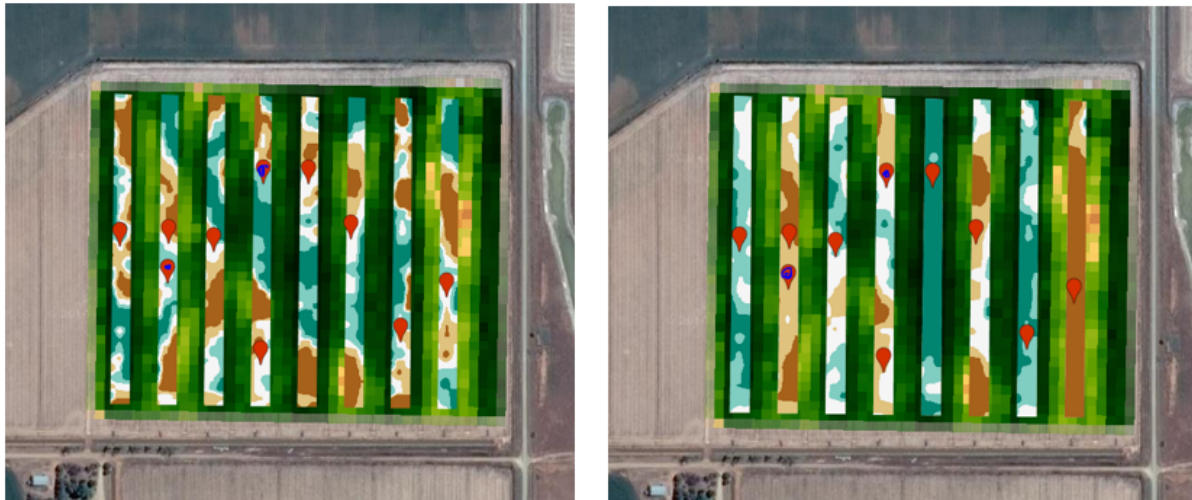


Figure 9: NDVI map of the maize field experiment at Numurkah 2018 derived from Sentinel 2 satellite images at physiological maturity. This map was used to guide the plant biomass sampling strategy in the 2017/18 season. A plant sample, using GPS co-ordinates, was taken in each of the following NDVI regions (with the respective colour used in the maps): <20% area (dark brown); 20–40% area (light brown), 40–60% area (white), 60–80% area (light green) and, >80% area (dark green).

The histogram of NDVI across all the treatment areas is shown below, along with the boundary NDVI values between the various percentiles.

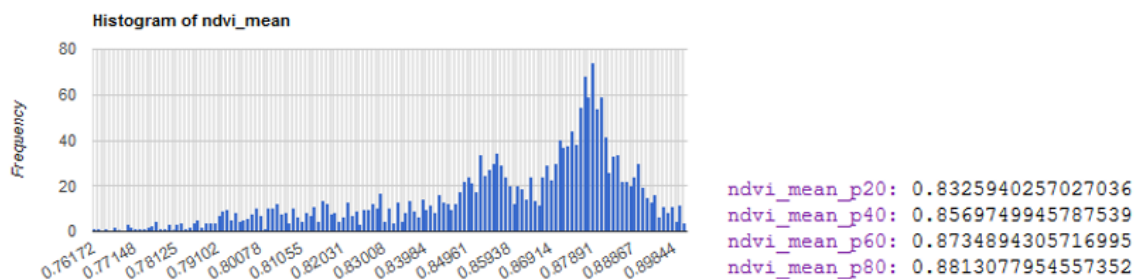


Figure 10: Histogram of NDVI values, used to interpret the plant growth variability in the treatments for sampling optimisation in end-of-season biomass sampling in maize in the 2017/18 season.

Using the NDVI enabled a strategic approach to sampling that allowed the number of biomass samples required to measure crop N uptake in maize to be reduced from 48 to 10. Rationalisation of the plant sampling was particularly useful for sampling maize because it has very high biomass per sample at physiological maturity. The results of this NDVI map will be compared with the final yield map obtained from the header yield monitor at harvest (not yet complete at the time of writing the report).

The plant samples were dried at 70°C in a dehydrator and mulched and, in the case of replicated samples from each bay, were homogenised during fine grinding prior to total N analysis using a high temperature combustion standard method (Leco analyser). Nitrogen uptake was then determined by multiplying the dry matter by the N concentration.

The maize was harvested in each year and grain weights obtained from each bay using the co-operator farmers harvester and a portable weigh bin and GPS measurement of the harvested area (not yet complete at the time of writing the report).

4.3 Focus Area 3

Develop best practice design guidelines for basin surface irrigation systems

Objective: To determine best practice designs for basin irrigation layouts so that water productivity can be reliably increased through a reduction in crop losses to water logging and water loss through deep drainage.

Research question: What are the optimal values for the design parameters of basin surface irrigation systems that will allow bays to be operated to maximise water and nitrogen efficiency in line with the findings of Focus Area 2?

General methodology

To maximise profitability, surface irrigation systems should be designed to minimise crop losses to waterlogging and water losses to deep drainage. This is achieved by applying the target depth of water in the shortest possible time. In basin systems, this means bays need to be designed so they have quick advance and recession phases. Control over the infiltrated depth is then provided through the time water is held on the surface of the bay. If this can be done, then the target depth will be applied with greater control, precision and uniformity.

Earlier work has recommended a maximum opportunity time (water and off bays) of 10 hours in order to minimise the risk of crop loss to waterlogging in basin systems (North *et al.*, 2010). This project sought to extend this work and determine the following two key design parameters:

- The appropriate bay size for a given inflow rate and soil type that will allow bays to be watered and drained in a given opportunity time (i.e. 10 hours).
- The minimum step (terrace) between bays for a given paddock slope, bay size, surface geometry and roughness so that drainage is unimpeded in level basin systems that are supplied/drained using a side-ditch.

Both optimum bay size and minimum step depend on the interaction of several variables: flow rate and infiltration for bay size; and roughness, water depth, bay length and surface storage volume. To evaluate these interactions by field experiment would be difficult, expensive and time-consuming. However, mathematical models are particularly suited to the task as they are able to simulate the effect of all major interactions over a range of operating conditions and determine an optimal solution relatively quickly and economically for given design conditions.

Mathematical models can only provide a simplified representation of real world conditions so the accuracy of this representation needs to be checked against actual field data to give confidence in the model predictions. Additionally, the infiltration characteristic of the soil and the surface roughness are key input parameters required by any model to simulate an irrigation event and they are generally unknown. Field data was collected during irrigations in

a range of common basin layout designs, on typical soil types and using typical flow rates in order to determine typical infiltration and roughness values by inverse modelling and, to validate the model outputs using a separate set of data.

Because this is a design question, it was possible to simplify two aspects of the modelling:

1. The number of basin layout types modelled – it is not necessary to model all design permutations and their interactions across soil type, flow rate, etc. Rather, a design irrigation event was modelled in a limited number of basin layout types considered representative of current practice in the rice and cotton industries of southern NSW.
2. Model outputs – results from the many simulation runs were summarised in simple design charts for use by irrigation designers.

Focus Area 3 involved five tasks:

1. Review currently available irrigation models to assess their suitability for answering the two key basin design questions.
2. Collate existing data sets and, where missing, collect new data on irrigation performance in the range of basin designs of interest to determine design surface roughness and infiltration functions for soils typically found under basin systems in southern NSW.
3. Use modelling to determine optimum values for the two key design parameters:
 - a. bay size for given inflow rate and soil type (including maximum bay length);
 - b. conditions under which side-ditch supply/drain of bays works without impeding drainage (including minimum terrace)
4. Validate the model outputs using a second set of data.
5. Produce design charts for use by irrigation designers.

4.3.1 Models for designing basin systems

The modelling work involved three aspects:

1. Modelling to determine Kostiakov infiltration parameters and surface roughness.
2. Modelling irrigations in a single basin to determine the bay size for a given flow rate and soil type.
3. Modelling irrigations in inter-connected (side-ditch) basin systems to determine the minimum terrace given paddock slope, bay size, surface geometry and roughness so that drainage is unimpeded.

Following a review of the literature, the following models were selected for use in each component of the work:

1. IPARM (Gillies, 2008) and SISCO (Gillies and Smith, 2005) are the two most commonly used models for determining bay scale infiltration parameters from irrigation event data. These two models were compared in a model calibration exercise using the field data collected for the project.
2. The surface irrigation model WinSRFR (Strelkoff *et al.*, 1998; Bautista *et al.*, 2009) was the best model for determining optimal basin sizes for a range of inflow rates, bay surface configurations and different soil types in single bay systems. WinSRFR is a one-dimensional model for the analysis of single basin systems with four functions:
 - a. Event analysis - irrigation event analysis and parameter estimation functions;

- b. Physical design – design functions for optimising the physical layout of a field;
 - c. Operations analysis – operations functions for optimizing irrigations;
 - d. Simulation.
3. The B2B model (Grabham, 2012) was the only available tool for modelling flows in basin systems where a hydraulic connection between bays can influence supply and drainage flow rates. It was developed to account for a restricted recession phase, a variable discharge in the downstream bay and hydraulic interactions between bays. The model estimates the flow rate in the interconnecting structure, accounting for field supply and drainage from the upstream bay and bay-to-bay head differential.

4.3.2 Systems modelled

Representative layouts and design events

The two most common farming systems in southern NSW where basin systems predominate are rice and cotton.

- **Rice based farming systems** – contour systems with rice grown in rotation with winter crops and pastures.
 - Two configurations of **parallel contour systems** were examined.
 - **Contours** with side-fall on bays and no slope in the longitudinal direction.
 - **V-bay** contours with fall from the sides into the centre and no slope in the longitudinal direction.
 - The design “event” in these systems is a spring irrigation of a drill sown winter crop timed to occur when the soil reaches the refill point.
 - High antecedent moisture content.
 - Roughness equivalent to a tall, drill-sown crop & non-submerged flow.
 - Parallel contour bays – Manning’s $n = 0.285$ assuming sowing occurs within banks so drill rows run along and across bays.
 - V-Bays – Manning’s $n = 0.15$ assuming a 3m wide by 50 mm deep path of easier flow down the centre of the V.
- **Cotton farming systems** – level furrow systems with cotton grown in rotation with other summer and winter crops.
 - Two configurations of **level basin furrow systems** (no slope in either direction within bays) were examined.
 - Level furrow systems **without laterals** - furrows run perpendicular to a drive-through side-ditch.
 - Level furrow systems **with laterals** – furrows run parallel to the side-ditch and are fed from both ends by drive-through lateral ditches.
 - The design “event” in these systems is a summer irrigation of cotton (the most waterlogging sensitive crop in the rotation).
 - High antecedent moisture content.
 - Roughness equivalent to bare earth (as found in cotton furrows) and submerged flow (Manning’s $n = 0.10$).

Soil types

Basin systems are (or should be) sited on slowly permeable soils. This can safely be assumed for rice soils, which have generally been assessed and classified as “non-leaky” (Murray Irrigation Limited, 2013). Consequently, it is not necessary to model all soil types found on the Riverine Plain of southern NSW. This allowed a simplified categorisation of the soils typically found under basin systems in southern NSW based on profile characteristics of the major soil types (Hughes, 1999):

1. **Red-brown earth (RBE)** – these are Chromosols (Isbell, 2016): texture contrast (duplex) soils with 10-40 cm of light clay loam topsoil overlying a clay sub-soil.
2. **Transitional red-brown earth / non-self mulching clay (TRBE)** – these are Sodosols (Isbell, 2016): texture contrast soils with weakly structured, high clay, sodic B horizons.
3. **Self-mulching clay (SMC)** – these are Vertosols (Isbell, 2016): strongly structured, uniform, heavy clay soils.

Flow rates

Three flow rates were modelled:

1. Low– 1 L/s/m of bay width, equivalent to a flow of 8.6 ML/day in a 100 m wide bay.
2. Medium – 2 L/s/m of bay width, equivalent to a flow rate of 17.3 ML/day in a 100 m wide bay.
3. High – 3 L/s/m of bay width, equivalent to a flow rate of 26.0 ML/day in a 100 m wide bay.

4.3.3 Collection of field data

Description of sites

Contour system

Location:	Deniliquin , 35° 29' 36" S, 144° 58' 23" E
Soil type:	Transitional red brown earth - a grey, sub-natric sodosol (Isbell, 2016), classified locally as a Morago clay loam (Smith, 1945).
Description:	Evaluations were conducted in bays 3 and 4 of a 12 bay, parallel contour system (Figure 11 left).
Bays:	410 m long, 90 m wide, 3.6 ha bay surface area.
Slope:	Overall field grade – 1:2000 (NOTE – the measured slope across bays 2, 3 and 4 bays was 1:1700). Final grade in bays – 1:4000. Step at contour banks = 23 mm.
Supply:	Bays can be supplied through either: <ul style="list-style-type: none">• a side-ditch<ul style="list-style-type: none">○ 400 mm deep on a 1:2000 grade (same as field slope).

- 750 mm pipe inlet set below supply level to flow full and deliver 10 and 25 ML/day at a head-loss across the structure of 20 and 100 mm respectively.
- a channel
 - operating depth of 1 m, a full supply level 300 mm above the top of Bay 1 and zero bed slope.
 - 450 mm diameter pipe inlet to each bay, designed to deliver 15 ML/day flows.

Drainage: All bays are drained at the supply end of the bay through the side-ditch.

V-Bay system

Location: **Jerilderie**, 35° 19' 47" S, 145° 31' 33" E

Soil type: Transitional red brown earth: a brown, sub-natric Sodosol (Isbell, 2016) classified locally as a Wilbriggie clay (Churchward and Flint, 1956).

Description: Evaluations were conducted in bays 1 to 5 (mainly bay 4 & 5) of an 8 bay, parallel contour V-bay system (Figure 11 right).

Bays: 220 m long, 100 m wide, 2.0 ha bay surface area.

Slope: Overall field grade – 1:1000.

Grade in bays – 1:1000 from the contour bank to the centre drain, with the centre drain cut down 50 mm.

Step at contour banks = 50 mm.

Supply: Bays are supplied through a side-ditch

- 400 mm deep on a 1:1000 grade (same as field slope).
- 900 mm wide stop with floor set level with bed of side-ditch.

Drainage: All bays are drained at both ends through side-ditches.

Level basin with laterals

Location: **Whitton - Field 19**, 34° 35' 6" S, 146° 15' 14" E

Soil type: Red brown earth: a brown, Chromosol (Isbell, 2016), classified locally as a Birganbigil sandy loam (van Dijk, 1961).

Description: Evaluations were conducted in bays 1, 2 and 3 of a 7 bay, level furrow system with laterals: i.e. furrows run parallel to the side-ditch and are fed from both ends by shallow, drive through ditches (laterals) running perpendicular to the side-ditch (Figure 12).

Bays: Bay 1 – 465 m long, 240 m wide at supply, 120 m wide at other end, 8.4 ha bay surface area.

Bay 2 – 465 m long, 300 m wide, 14 ha bay surface area.

Bay 3 – 465 m long, 190 m wide, 8.8 ha.

Slope: Overall field grade – 1:1700.

Final grade in bays – 0.

Step at contour banks: Bay 1 to 2 = 160 mm; Bay 2 to 3 = 140 mm.

Supply: Bays are supplied from the northern end through a side-ditch.

- 400 mm deep, 4.1 m bed width, a 1:1 batter on side-wall and zero grade within bays.
- 760 mm pipe inlet set below grade to flow full and with a 300 mm sill on the head-wall at inlet.

Laterals are 300 mm deep, 3.0 m bed width, a 1:7.5 batter on the side-walls and zero grade within bays.

Furrows are 240 mm deep, 130, 510 and 740 mm bed, middle and top width, with a 2.0 m centre-to-centre spacing and zero grade.

Drainage: All bays drain back to the side-ditch through the laterals.

Level basin without laterals

Location: **Whitton – Field 7**, 34° 32' 45" S, 146° 12' 36" E

Soil type: Transitional red brown earth: a brown sodosol (Isbell, 2016), classified as a Mundiwa clay loam (van Dijk, 1961).

Description: Evaluations were conducted in bays 2, 3 and 4 of a 7 bay, level furrow system without laterals: i.e. furrows run perpendicular to the drive-through side-ditch and are watered from it and drain back into it (Figure 13).

Bays: 450 m long, 143 m wide, 6.1 ha bay surface area.

Slope: Overall field grade – 1:940.

Final grade in bays – 1:8000 rising from side-ditch to top of bay; zero side-fall.

Step at contour banks: Bay 1 to 2 = 135 mm; Bay 2 to 3 = 290 mm; Bay 3 to 4 = 320 mm; Bay 4 to 5 = 200 mm; Bay 5 to 6 = 135.

Supply: Bays are supplied from the eastern side through a side-ditch:

- 400 mm deep, 4.0 m bed width, a 1:7.5 batter on the side-walls, and zero grade within bays.
- One 1800 mm Padman MaxiFlow™ culvert set below supply level to flow full, and with drop box and rubber flap inlet.

Drainage: All furrows drain back to the side-ditch.

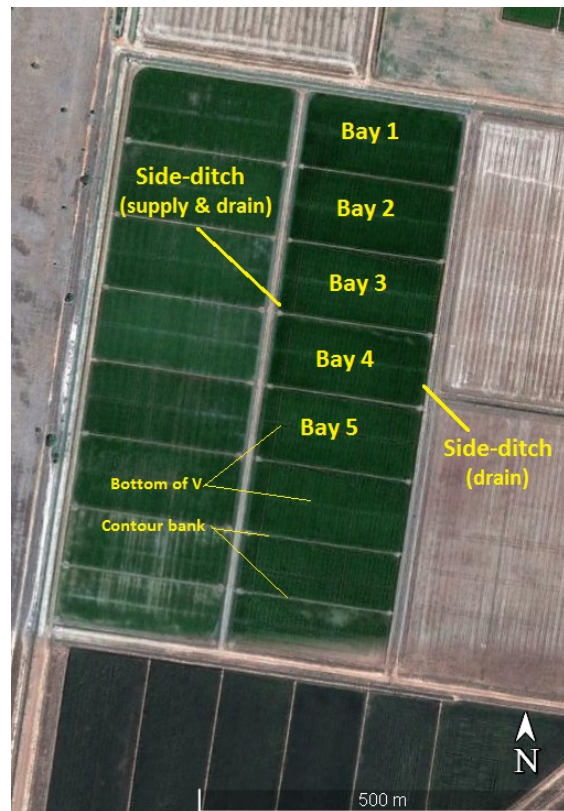


Figure 11: Aerial image of the parallel contour system at Deniliquin (left) and the V-bay contour system at Jerilderie (right) used for collecting irrigation field data. The labelled bays are the bays from which irrigation data was collected. The locations of key features (channels, banks, etc) are indicated. Scale and direction are shown at bottom right.



Figure 12: Aerial image of the level furrow system with laterals at Whitton (Field 19) used for collecting irrigation field data. Irrigation data was collected from bays 1, 2 and 3. The locations of key features (channels, furrow orientation) are also indicated. Scale and direction are shown bottom right.



Figure 13: Aerial image of the level furrow system without laterals at Whitton (Field 7) used for collecting irrigation field data. The labels indicate the bays from which irrigation data was collected. The locations of key features (side-ditch; furrows) are also indicated. Scale and direction are shown.

Data collected

The following data was collected during each irrigation event:

1. Water flows

- In the contour system at Deniliquin.
 - Three Rubicon Water Slipmeters™ were installed in the side-ditch to measure flows between bays 2 and 3, 3 and 4, and 4 and 5. The quality of the data obtained from these meters was very high.
 - Mace AgriFlow™ loggers were installed 1 m up from the outlet in the 450 mm pipes from the supply channel to each of bays 3 and 4. These meters were not as accurate as the Slipmeters™ because of turbulence created by the drop-box inlet and the short section of pipe between this inlet and meters. Flows were calibrated against the accurate Rubicon Flume Gate™ meter at the farm inlet 850 m away.
- In the V-Bay contour system at Jerilderie, Omnidata Star Flow™ meters were used in a control section of square sided fluming on the upstream of the 900 mm wide Padman stops.
- In the level furrow system with laterals at Whitton-Field 19, the Mace AgriFlow™ meters were installed 1 m up from the outlet and on the side-wall of the 760 mm diameter pipes between bays. These pipes flowed full and the flow was laminar and non-turbulent, so these readings are considered accurate. No data was available from the irrigation company to verify these flow rates.
- In the level furrow system without laterals at Whitton-Field 7, the Mace AgriFlow™ meters were installed in the middle of the floor of the Padman MaxiFlow™ culverts and 1 m up from the outlet. The drop box inlet created turbulent flow conditions and the (very) short section of culvert upstream of the meter resulted in this affecting velocity readings. No data was available from other sources to verify the flow rates measured at this site, so flow measurements here are considered to be of lower quality.

2. Depth of water at the delivery end of the bay

The head of water above the soil surface at the supply end of all bays was measured using capacitance water depth loggers.

- At the parallel contour site at Deniliquin, five depth sensors were spaced evenly (17.5 m apart) across the width down the bay and 5 m in from the edge of the side-ditch. Readings from the 5 loggers were used to estimate an average depth of water on the bay.
- At the V-Bay site at Jerilderie, six depth sensors were spaced across the width of the bay 5 m in from the edge of the side-ditch. Two sensors were placed 1 m in from the contour bank, another two sensors were placed 25 m in from the contour banks, and the last sensor was placed at the lowest point in the middle of the bay.
- At both level furrow sites, four depth sensors were placed in furrows: two in both corners at the side-ditch end of the bay; and the other two in the corners at the far end of the bay.

3. Wetted area

- In the contour systems, the wetted area was mapped at 0.5 to 1 hour intervals by walking the wetting front and recording its position using a Trimble DGPS.
- It was not possible to map the wetting front in the level furrow systems using DGPS. Neither was it possible to map using aerial drone imagery as the canopy was too thick. Instead, water advance was measured in 5% of the furrows in the bay using Wi-Fi connected advance sensors and capacitance depth loggers.

4. GPS survey and levels of key features and monitoring points

- All layouts were mapped using the Trimble DGPS and the location of all structures and monitoring points recorded.
- A level survey was conducted to measure heights of each monitoring point as well as the levels of key features, such as sill heights of water control structures; bay and raised bed surfaces; and channel, drain and furrow bed heights.

Table 7, Table 8, Table 9 and Table 10 show meta-data describing the information collected from the 13 irrigation evaluations conducted. The data from the three irrigation events in the V-Bay system at Jerilderie was collected during an earlier project.

Table 7: The irrigations measured and the data collected in the parallel contour system at Deniliquin.

Date	Delivery/Drain	Antecedent Soil moisture	Flow rate	Bay	Roughness	Wetting front advance	Flows on and off	Water depth at delivery end
18 April 2016	Side-ditch delivery and drain	50 mm deficit 2 nd autumn	15 ML/day to block	3 4	Bare cultivated soil	Bay 3 only	On and off with Slipmeters	Yes
10 Dec 2016	Side-ditch delivery and drain	80 to 125 mm 1 st "spring"	15 ML/day	3 4	Cut pasture Standing pasture	Bay 3 Bay 4	On and off with Slipmeters	Yes
20 Dec 2016	Individual supply and drain	60 mm 2 nd "spring"	15 ML/day	3 4	Cut pasture Standing pasture	Bay 3 Bay 4	On with Mace meter Off with Slipmeter	Yes
10 Mar 2017	Individual supply and drain	1 st autumn	15 ML/day	3 4	Bare, graded soil	Bay 3 Bay 4	On with Mace meter Off with Slipmeter	Yes
21 Mar 2017	Side-ditch delivery and drain Whole block	2 nd autumn	15 ML/day	3 4	Bare, graded soil, sealed by previous irrigation	Bay 3 Bay 4	On and off with Slipmeter	Yes
10 Apr 2017	Individual supply and drain	3 rd autumn	15 ML/day 7 ML/day	3 4	Bare soil, with emerging pasture	Bay 3 Bay 4	On with Mace meter Off with Slipmeter	Yes
8 Sep 2017	Individual supply and drain	1 st spring	7 ML/day	3	Standing pasture	Bay 3	On with Mace meter Off with Slipmeter	Yes

Table 8. The irrigations measured and the data collected in the V-bay contour system at Jerilderie.

Date	Delivery/Drain	Antecedent Soil moisture	Flow rate	Bay	Roughness	Wetting front advance	Flows on and off	Water depth at delivery end				
17 Oct 2008	Side-ditch delivery and drain	1 st summer Dry	20 ML/day into block, but varying into bays	1	Bare soil, with drill lines for rice	Bay 4 & 5	Flows on off with Starflow loggers	Yes				
28 Oct 2008		2 nd summer 50 mm deficit		2					Bare soil, with drill lines for rice	Bay 4 & 5	Flows on off with Starflow loggers	Yes
13 Nov 2008		3 rd summer 50 mm deficit		3								
			4									
				5								

Table 9. The irrigations measured and the data collected in the level furrow system with laterals at Whitton-Field 19.

Date	Delivery/Drain	Antecedent Soil Moisture ¹	Flow rate	Bay	Roughness	Wetting front advance	Flows on and off	Water depth at delivery end
28 Jan 2017	Side-ditch delivery and drain	n/a	25 ML/day into block and varying flows into bays	2 3	Bare soil in furrows	Bay 2	Flows on & off with Mace meters in pipes	Yes
6 Feb 2017		50 mm			Bare soil in furrows	No	Flows on & off with Mace meters in pipes	Yes
13 Feb 2017		47 mm			Bare soil in furrows	no	Flows on & off with Mace meters in pipes	Yes
22 Feb 2017		71 mm			Bare soil in furrows	no	Flows on & off with Mace meters in pipes	Yes

1 – Antecedent soil moisture obtained from Irrisat (<https://irrisat-cloud.appspot.com/>) for this paddock at these times

Table 10. The irrigations measured and the data collected in the level furrow system without laterals at Whitton-Field 7.

Date	Delivery/Drain	Antecedent Soil Moisture ¹	Flow rate	Bay	Roughness	Wetting front advance	Flows on and off	Water depth at delivery end
6 Mar 2017	Side-ditch delivery and drain	n/a	Decreasing from 50 to 25 ML/day	2	Bare soil in furrows	No	Flows on & off with Mace meters in culvert	Yes
16 Mar 2017		78 mm		3	Bare soil in furrows	Bay 3	Flows on & off with Mace meters in culvert	Yes

1 – Antecedent soil moisture obtained from Irrisat (<https://irrisat-cloud.appspot.com/>) for this paddock at these times

4.4 Focus Area 4

Investigate the economic impact of investment in irrigation development on whole-farm profitability

Objective: To assess the economic performance of irrigation systems currently in use by growers and new irrigation systems. The analysis evaluated capital requirements, operating costs and financial returns, over a sequence of years and crops.

Methodology:

1. Identify analysis required

The Economics and Industry Opportunities team of NSW DPI were engaged by the project management team in late 2016. As part of the engagement process the economics team scoped the type of results the project management team were looking to achieve and what types of analysis best suited the requirements.

2. Determine data required to carry out analysis

3. Build data collection survey framework

4. Identify case study scenarios to align to activity objective

5. Collect data through survey design

A survey form was developed to gather data from growers within each of the three grower groups involved with the project. The data obtained for each case study included the area upgraded, crop rotations and gross margin budgets before and after the investment/development, capital expenditure on layout change and/or infrastructure investment, and any changes to overhead costs.

6. Analyse data using a variety of methods

The analysis used in the economics activity ranged from gross margin budgets calculations through to whole farm budgets in order to determine the marginal rate of return on capital investment and discounted net cashflow analysis over 20 years.

A gross margin is the gross income from an enterprise less the variable costs incurred in achieving it. Variable costs are those costs directly attributable to an enterprise and which vary in proportion to the size of an enterprise. For example, if the area of wheat sown doubles, then the variable costs associated with growing it, such as seed, chemicals and fertilisers will approximately double. A gross margin is not profit because it does not include fixed or overhead costs such as depreciation, interest payments, rates and permanent labour, which have to be met regardless of enterprise size. Gross margins are generally quoted per unit of the most limiting resource, for example, land, labour, capital or irrigation water (NSW DPI 2018). Table 11 shows the average commodity prices used in the analysis. These prices are based on an inflation-adjusted time series from the last ten years.

Table 11: Commodity prices used in the gross margin analysis that formed part of the economic assessment of the benefit of irrigation development on whole farm returns and marginal rate of return on the capital invested.

Commodity	\$/t or bale
Cotton lint	\$461
Cotton seed	\$399
Rice	\$340
Wheat	\$232
Barley	\$232
Maize	\$278
Soybeans	\$475
Canola	\$513
Faba beans	\$315

Overhead costs were estimated after discussion with the case study growers. Overhead costs varied considerably between farms because labour requirements, insurance, repairs and maintenance, extra fuel, and administration costs varied with business structure and extra machinery and assets on hand.

Average land values were used for each region, along with an assumption of an allocation of 3 ML/ha for each hectare under irrigation. In both cases this was to avoid confounding the results with other variables. In practice, land value and owned water allocation varies widely and many growers operate using a combination of allocation and purchased temporary allocation each year. Water trading is a separate issue to irrigation layout development. Water pricing can vary from farm to farm and between regions, due to regional pricing structures, on-farm pumping costs, fees and accounting method used.

A simple budget comparison showing the marginal rate of return is used for each case study. This method shows the extra returns, extra costs and net gain from a development in summary form. The budget shows the extra profit from a development expressed as a percentage return on the extra capital invested. Generally if the marginal rate of return is well above the market interest rate (i.e. an alternative investment) then the development is worth analysing further.

Discounted cashflow analysis over a 20-year period was used since it is the most accurate method of estimating what a development will deliver as a rate of return on capital over a reasonable period of time (or lifespan). Estimates of marginal return using a marginal tax rate of 20% were used. Income tax varies considerably with business structure and off-farm investments, so the actual marginal tax rate may vary widely. This is more to serve as a reminder that tax implications for the individual businesses should be considered also.

5.0 Results

5.1 Focus Area 1

Fostering collaboration and partnerships to facilitate the adoption of research findings

One of the major benefits of the project was the opportunity for irrigators across the basin to be exposed to projects and irrigators in other areas. There were two inter-valley visits (February 2017 and 2018) with approximately 45 farmers and industry personnel from southern NSW and northern Victoria travelling to northern NSW and southern Queensland.

Feedback from the two tours showed the immense value in such activities (Figure 14).

All tour attendees in both years said they gained knowledge or skills as a result of the tour. Other feedback showed:

- 100% of attendees said it was beneficial to visit farms in other irrigation regions (Figure 14).
- 77% of attendees said they would do things differently as a result of what they learned on the tour. This included: one farmer installing large pipe through the bank irrigation systems; one installing small pipe through the bank (Waverley) system; and one installing automation and beds in a side-ditch.

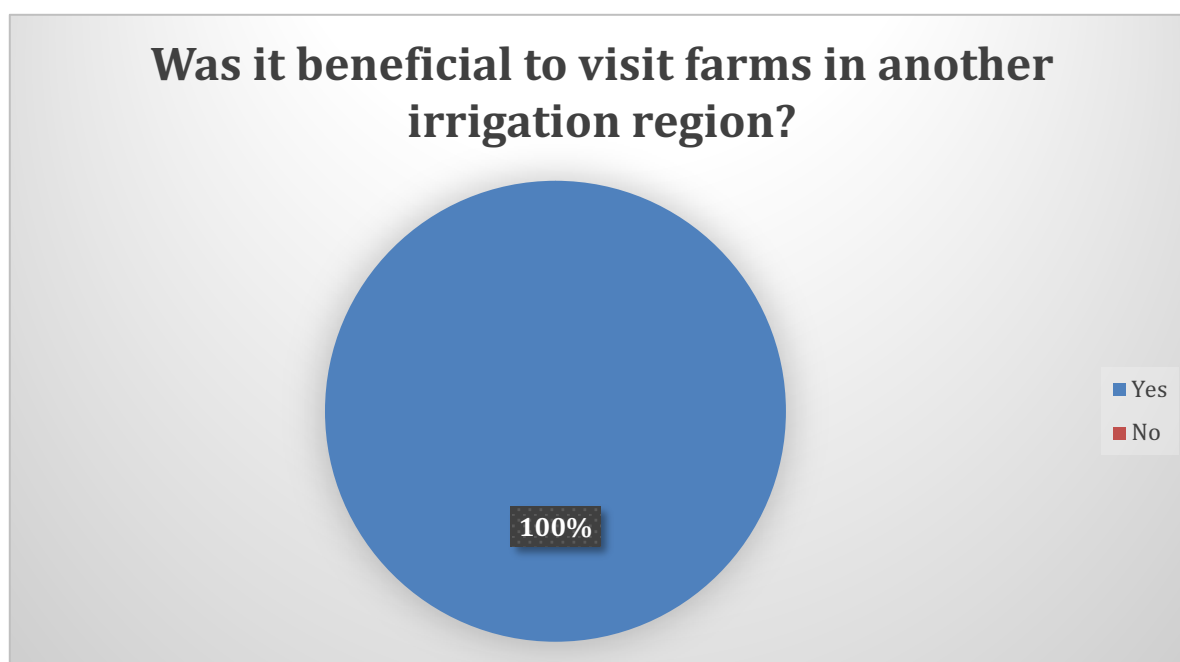


Figure 14: All respondents from both 2017 and 2018 Northern Tours said it was beneficial to visit farms in other regions.

The transfer of knowledge and skills was not one way. There were also two southern automation tours which saw over 70 growers from northern NSW and Queensland tour southern NSW and northern Victoria, including the ICC key learning site, learning all about automation and experiencing first-hand the different types of automation in use on farm.

Layouts seen on these tours galvanised conversion of syphon layouts to beds in a side-ditch. Northern irrigators also attended an IREC irrigation automation bus trip in June 2017 (Plate 4). Some of the northern irrigators have automated bankless layouts as a result of the interaction with southern irrigators. One farmer also plans to convert their entire syphon-irrigated layouts to automated beds in side-ditch system.

During the life of the *Maximising On-Farm Irrigation Profitability* project a total of 14 field days with 893 attendees were held across the three Key Learning Sites:

Irrigated Research and Extension Committee held nine field days with 345 attendees. Field days included local and interstate groups visiting the key learning site, being exposed to the project and associated irrigation automation technology as well as the impacts of varying irrigation deficit on cotton growth and lint yield.

Irrigated Cropping Council held two field days at the key learning site with 107 attendees. The benefits of a shorter irrigation deficit and alternate timing of N application in maize was demonstrated.

Southern Growers held three field days at varying sites that included the key learning site with 441 attendees. The lessons learnt from installing raised beds and potential for double cropping in rice were highlighted.

The complete list of workshop and field days are provided in Section 8.2.



Plate 4: Northern farmers were part of the IREC Automation bus trip in June 2017 which looked at automated layouts in the Murrumbidgee (photo Iva Quarisa).

These field days and tours have resulted in practice change on farm, with growers from the Riverina, northern NSW and northern Victoria changing irrigation layouts and installing automated surface irrigation systems. In northern Victoria two growers have changed their irrigation management and nitrogen application in maize production, adopting the shorter irrigation deficit.

Several southern NSW irrigators have installed raised beds and are exploring what crops are suitable for double cropping in rice farming systems. The raised beds are essential in the double cropping program as they assist with winter drainage. Whole farm profitability can be increased by growing three crops in two years.

5.2 Focus Area 2

Investigate irrigation and nitrogen management strategies to improve water productivity in cotton, maize and rice farming systems

5.2.1 Key Learning Site 1

Grower group: Irrigation Research and Extension Committee, Whitton and Darlington Point, NSW

Focus crop: Cotton

5.2.1.1 Experiment 1

Lint yield

There was a statistically significant ($P < 0.001$) yield impact as a result of the different irrigation practices with watering every day (standard grower practice) producing 0.17 t ha^{-1} more than when the crop was watered every second day, with lint yields of 2.17 and 2.00 t ha^{-1} , respectively. Significant ($P < 0.001$) increases in lint yield as a result of N fertiliser rate were also evident (Figure 15). There was no significant interaction between the irrigation and N practices. However, the experimental conditions necessary to be able to test this properly, whilst still being able to adequately maintain the crop health, were not possible. Maximum lint yield, 2.3 t ha^{-1} , was achieved at fertiliser N rate of 190 kg N ha^{-1} . At the economic optimum fertiliser N rate of 171 kg N ha^{-1} the lint yield was 2.29 t ha^{-1} .

The N fertiliser-use efficiency (NFUE, defined as $\text{kg lint} / \text{kg N applied}$) ranged from 25.8 at 80 kg N ha^{-1} to 8.9 at 250 kg N ha^{-1} . NFUE at the optimum N rate of 171 kg N ha^{-1} was 13.4 which is within the current industry N best practice guidelines.

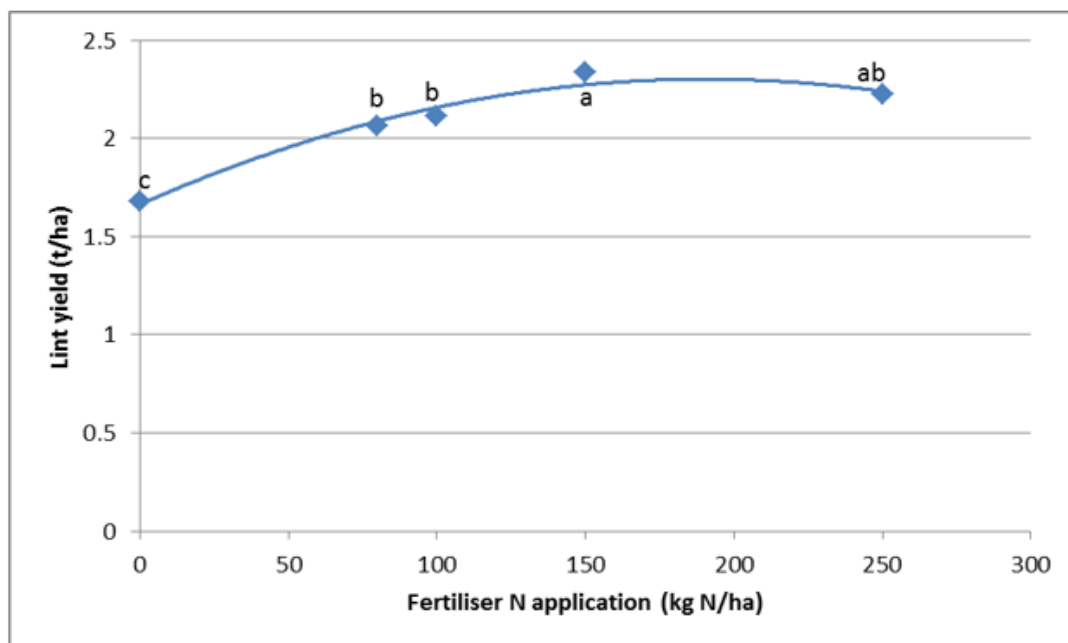


Figure 15: The response of cotton lint yield to applied nitrogen fertiliser at Whitton, NSW, in the 2015/16 cotton season. Lint yield increased with increasing fertiliser N application up to the application rate of 150 kg N ha⁻¹. Different letters column signify a significant difference resulting from the N fertiliser rates that were applied

Crop Nitrogen Uptake

Crop N uptake was measured in the 0, 100, 150 and 250 kg N ha⁻¹ fertiliser N treatments at first flower and at defoliation. Crop N uptake increased with N fertiliser application (Figure 16) however, there was no significant effect of irrigation management on crop N uptake at either stage (data not shown).

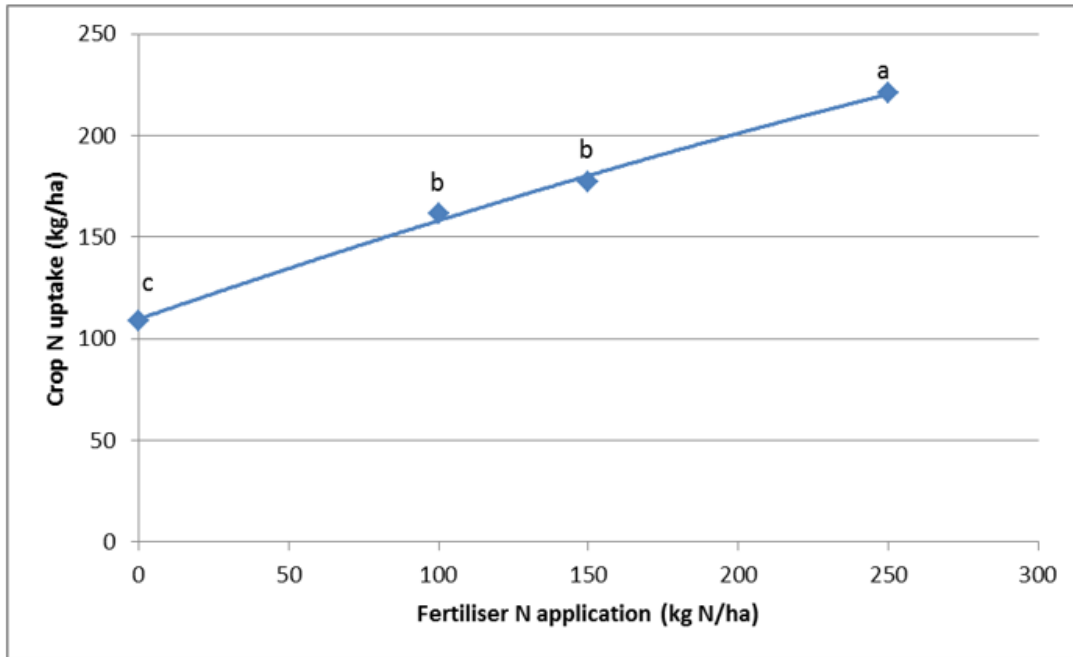


Figure 16: The relationship between crop N uptake and fertiliser N application at Whitton, NSW, in the 2015/16 cotton season. . Different letters signify a significant difference resulting from the N fertiliser rates that were applied

Crop N uptake was 188 kg N ha⁻¹ where the economic optimum N fertiliser rate of 171 kg N ha⁻¹ was applied (Figure 16). The difference between the optimised uptake (188 kg N ha⁻¹) and the crop N uptake from the unfertilised plots (109 kg N ha⁻¹) indicates that theoretically, the deficit in soil supply of N was met by a fertiliser application of only 79 kg N ha⁻¹. However, the yield response curve (Figure 15) indicates that 80 kg fertiliser N ha⁻¹ did not provide the yield maxima. Therefore, crop N uptake and lint yield was likely limited by factors other than N, which at this particular site is likely to have been waterlogging and compaction.

Fertiliser use efficiency

There was no statistically significant effect of irrigation on Internal Nitrogen Use Efficiency (iNUE, defined as kg lint/kg crop N uptake). The iNUE declined ($P < 0.001$) with higher N fertiliser rates ranging from 18.5 kg kg⁻¹ with 0 N applied to 10.7 kg kg⁻¹ when 250 kg N ha⁻¹ was applied. When the fertiliser N rate was optimised iNUE was 12.2 kg kg⁻¹ which is approaching the industry N best management practice target of 12.4 kg kg⁻¹.

There were also no statistical differences of apparent nitrogen fertiliser recovery (ANFR defined as: N uptake in fertilised crops - N uptake in zero crops/N fertiliser applied (kg ha⁻¹)) from the effects of irrigation treatment and N fertiliser rate. Across the range of N fertiliser rates from 100 to 250 kg N ha⁻¹ there was a declining trend from 60% to 48% ANFR, respectively. Only at the highest N rate of 250kg N ha⁻¹ was there any separation in ANFR between the irrigation treatments with 38% and 57% ANFR in the treatment watered every day compared to that watered every second day, respectively.

The ANFR was 46% where the optimum fertiliser N rate had been applied.

Seed N and export of N off-farm in seed

No statistical difference occurred in seed N concentration or N removal in seed as result of the irrigation treatments. There was a significant effect ($P=0.001$) of N removal as a result of

the rate of fertiliser being applied (Table 12) although the highest rate of fertiliser N did not provide the greatest amount of N removal from the field in seed.

Table 12: The effect of N fertiliser rate applied on seed N concentration in cotton and the amount of N removed from the system in the seed. Different letters within each column signify a significant difference resulting from the N fertiliser rates that were applied.

N fertiliser rate (kg N/ha)	Seed N concentration (%)	N removal (kg N/ha)
0	3.8 ^b	68.8 ^b
100	4.5 ^{ab}	105.7 ^a
150	4.9 ^a	121.5 ^a
250	4.6 ^{ab}	114.2 ^a
LSD (P=0.06)	0.8	26.6

Using ultra-violet (UV) light wavelength indexes as tools for cotton management

The project has advanced understanding of the ability to assess crops in-season N status more rapidly using multispectral drone deployed cameras which are now more cheaply available than ever before and have readily available and rapid image processing packages. The utility of these methods for reliable N management remains ambiguous for many end users, particularly individual farmers and consultants, compared to more established, but expensive and time consuming petiole sampling and analysis. Other applications of vegetation indices, for example, NDVI and NDRE, obtained from crop imagery such as early to mid-season yield prediction and variable application rates for growth regulation and defoliation all require further evaluation.

At the Whitton field station drone-deployed multispectral data collection was used to assess the possibility of using NDVI and NDRE for in-season N management.

Statistically significant relationships were found between plant N% at first flower (83 DAS) and the chlorophyll sensitive indices SCCI, TCARI/OSAVI and TGI in an adjacent cotton trial established on side-ditch, separate from the IREC key learning site. For practical purposes in-crop N applications, if necessary, need to be applied at least 1 week or longer prior to first flower. Nevertheless, in some seasonal situations, growers are top dressing N close to or even after first flower suggesting the vegetation indices may be useful for confirming the need for these applications and giving extra information on crop performance.

The data showed that N fertilisation had a significant effect on N uptake at first cracked boll, when measurements were taken in the 0, 100, 150 and 250 kg N ha⁻¹ treatments. At this stage, both vegetation indices (NDRE and NDVI) were significantly correlated (P<0.01) with N uptake with NDRE yielding the strongest correlation (Figure 17).

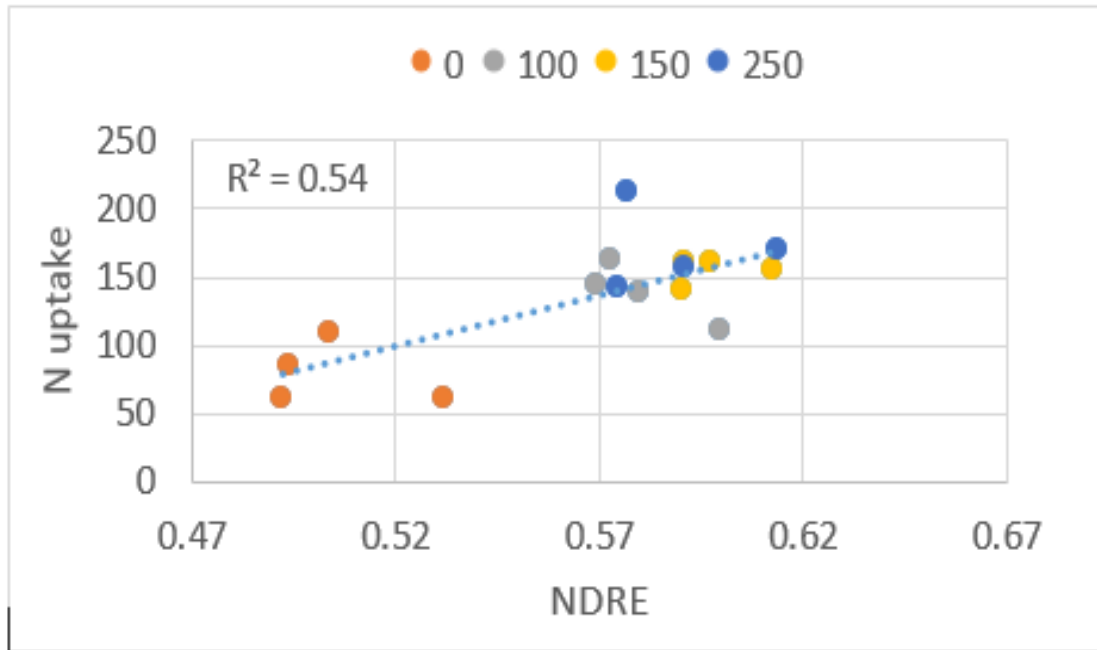


Figure 17: The relationship between crop N uptake and the Normalised Difference Red Edge (NDRE) vegetation index at first cracked boll for four different fertiliser N application rates 0 (orange), 100 (grey), 150 (yellow) and 250 (blue) kg N ha⁻¹.

NDVI and NDRE indexes were significantly correlated with yield ($P < 0.01$) from 96 days after seeding. The NDRE index (sensitive to chlorophyll content) was better correlated with yield than NDVI early in the season suggesting this index may be useful for yield prediction (Table 13). However, NDVI provided the strongest correlations with yield for the late stages of the crop.

Table 13: Coefficient of correlation obtained from the relationships between the NDVI and NDRE indexes with yield (on average for all the blocks and treatments) for each measurement day.

Days after seeding	NDVI	NDRE
84	0.23	0.07
96	0.45	0.72
119	0.87	0.77
160	0.94	0.82

5.2.1.2 Experiment 2

The data presented and discussed is from the 2016/17 season as the 2018 season is current at the time of writing this report and data collection is still ongoing for the season, unless specified.

Soil redox potential sharply decreased at the three measured depths after an irrigation event. However, there was no reason to consider that waterlogging was a problem in any of the irrigation strategies in the experiment as soil redox values were usually above the

threshold of 350 mV, considered as the value at which oxygen is limiting to plant growth. Only in the final irrigation, applied to the short deficit treatment, did redox potential at 23 cm and 41 cm depth drop significantly below the 350mV threshold (Figure 18). The decrease was not observed in the 5 cm sensor suggesting either rapid drainage or preferential flow from the soil surface to deeper in the profile. There were heavy localised thunderstorms during the period with 10 mm of rainfall falling at the field on the 13th March, 2017. This was followed by the final irrigation on the 16th March, 2017 which may have contributed to the greater reduction in soil redox in the short deficit.

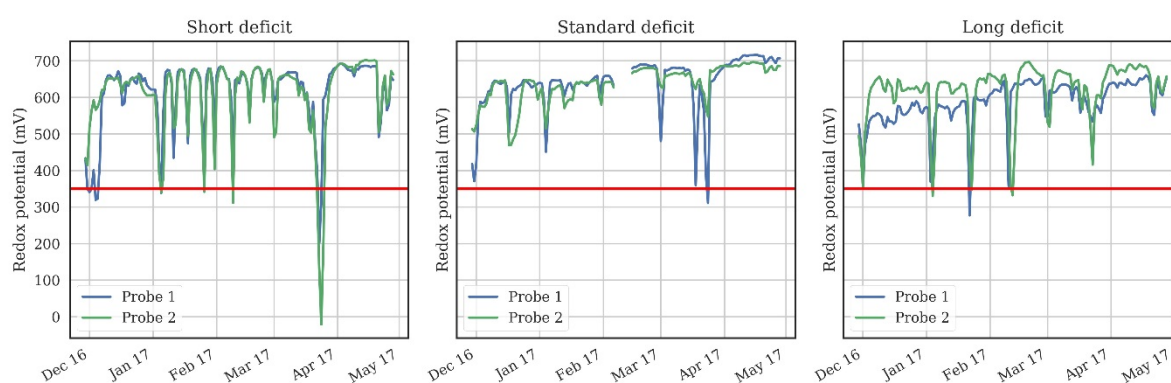


Figure 18: Seasonal evolution of the soil redox potential for each irrigation and fertilisation treatment at 23 cm depth. The green and blue lines represent two probes placed in each irrigation treatment for the short irrigation deficit (left), standard irrigation deficit (middle) and long irrigation deficit (right). The red area represent the area below the threshold of 350 mV at which soil oxygen is limited.

Soil moisture and water use efficiency

The different irrigation treatments were imposed from just prior to first flower (January 3rd, 2017) resulting in, nine, five and four irrigation events in the short, standard and long deficit treatments, respectively (Figure 19). This period corresponds to a period of rapid fruiting and maximum water and N uptake by the plants.

Crop evapotranspiration (ET_o) was similar in all treatments; the short interval was 2% higher than the standard treatment and 4% higher than the long deficit. The absolute amounts of crop ET_o were determined as 968 mm, 949 mm, and 926 mm respectively.

Comparison of irrigation treatment water use efficiency expressed as lint yield/unit of seasonal crop ET_o (kg m⁻³) was 0.23 kg m⁻³ in the short deficit, 0.22 kg m⁻³ in the standard and 0.21 kg m⁻³ in the long deficit. The different irrigation treatments were sufficient to impose moisture stress conditions that reduced cotton yield and crop water use efficiency although the crop water use was similar.

There were no significant differences in crop water use observed according to nitrogen application rate within irrigation treatments.

The soil moisture probes showed that plants from the long deficit treatment extracted water from deeper soil layers (85 cm depth) than plants from the standard and short deficit irrigation treatments (50 cm depth) (Figure 19). The differences observed in crop ET_o between the different irrigation strategies indicate that exploitation of a greater soil profile depth when irrigated less frequently, provided similar crop water use compared with a shallower soil water profile irrigated on short deficits.

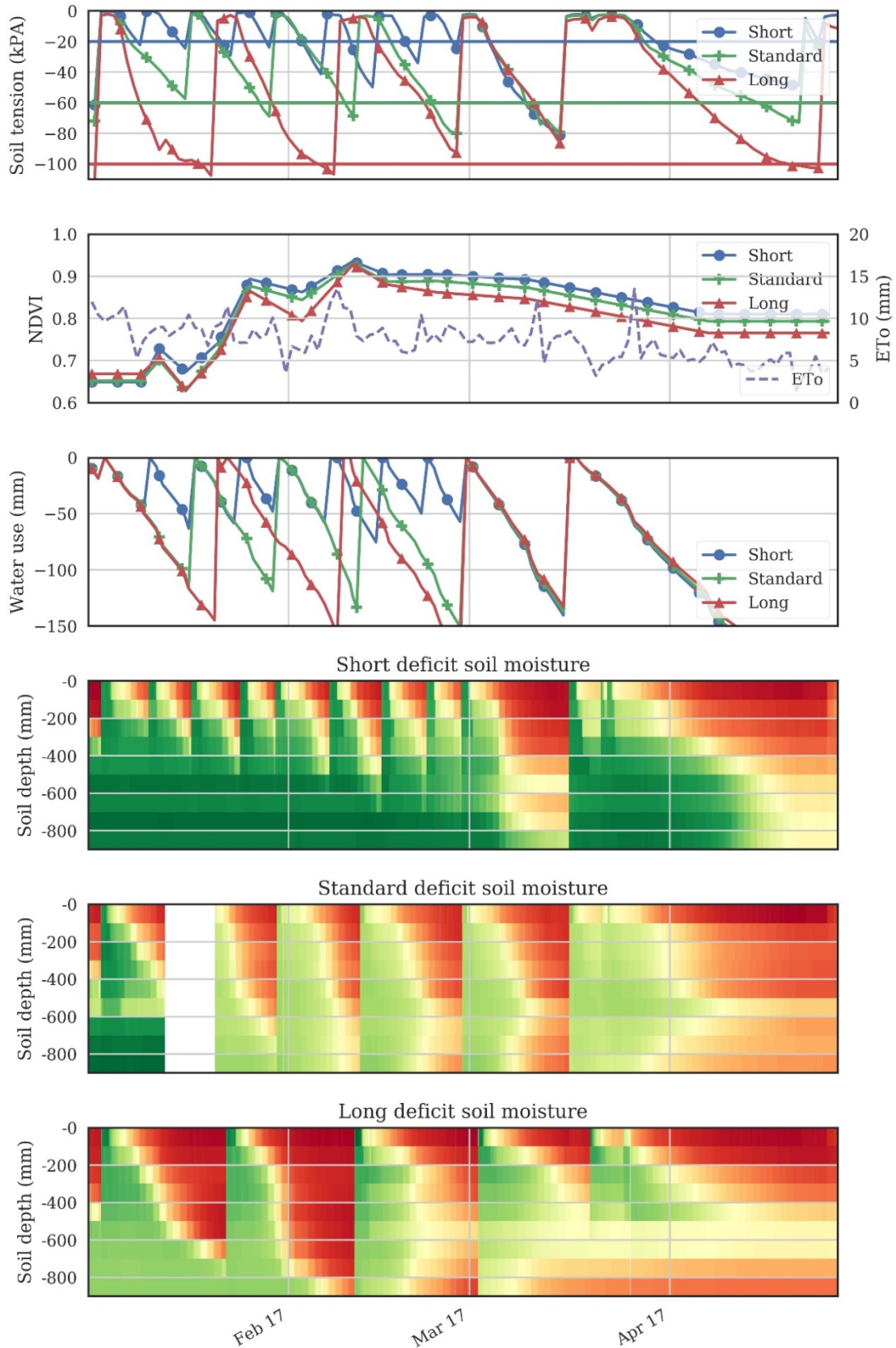


Figure 19: Irrigation schedule and soil moisture characteristics achieved for short irrigation deficit (7 day irrigation interval), standard irrigation deficit (14 day irrigation interval) and long irrigation deficit (19 day irrigation interval) in cotton at Darlington Point, 2017. The lower three graphs qualitatively show soil moisture vs soil profile depth (y-axis), with green indicating saturated and red indicating dry.

Leaf Porometer Measurements

Plant stress indicated by water use efficiency, plant growth and yield (discussed later) were reflected in leaf porometer measurements in both 2016/17 and 2017/18 cotton seasons. The standard and long irrigation deficits led to a temporal reduction in stomatal conductance compared to the short deficit (Figure 20, A). The greatest reduction in stomatal conductance was 32 and 37% in the standard and long irrigation deficits respectively, compared with the short deficit treatments. This reduction occurred when the long and standard deficits had not been irrigated for 13 days. Following irrigation, stomatal conductance returned to similar values compared to those of the short treatment (Figure 20, A).

The relationship obtained between the normalised stomatal conductance and soil matric potential indicates -70 kPa as the threshold value at which stomatal conductance starts decreasing under conditions of high evaporative demand (Figure 20, B) and would be the trigger point for irrigation to occur.

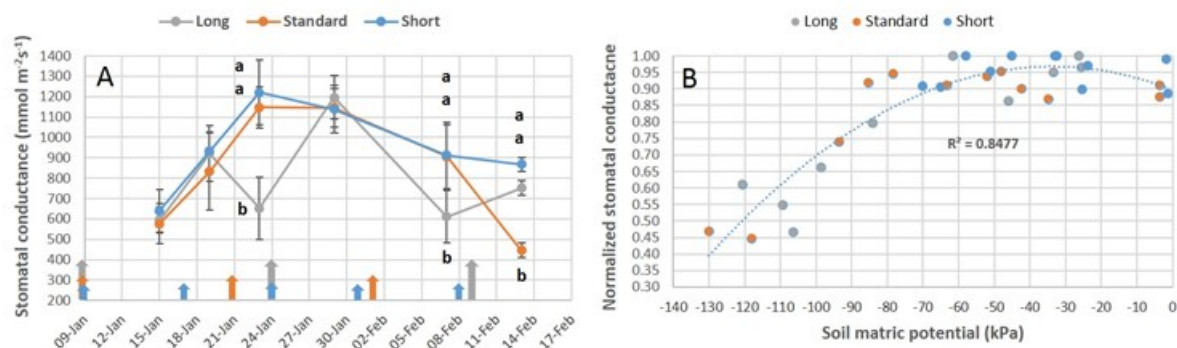


Figure 20: A) Stomatal conductance measurements for each treatment from 15 January 2018 to 13 February 2018. Vertical bars indicate the standard deviation. Different letters within each measurement date indicate statistically significant differences ($p < 0.05$) between treatments. Vertical arrows at the bottom of the figure indicate when an irrigation event took place for each treatment (blue = short deficit, orange = standard practice and grey = long deficit); B) The relationship obtained between the normalised stomatal conductance and soil matric potential showing a reduction in stomatal conductance as the soil matric potential decreased (longer irrigation deficits).

Crop plant growth and yield.

Plant height, number of nodes and number of squares (first stage of boll development) was the same across all plots at first flower (7 days after the start of the irrigation treatments) (Figure 21). However, at cut-out, plants were significantly taller in the short and standard irrigation deficit treatments which may influence defoliation decisions. In this trial, defoliant was applied by aircraft and it was considered most practical to defoliate all treatments equally. However, the long deficit treatment height and biomass could have been managed with a single defoliation rather than the 3 necessary for the other more vigorous treatments (Figure 21). In the 2016/17 season, in which there was ongoing rainfall between cut out and harvest, some growers in the region were applying defoliant up to 5 times. Although it was difficult to predict these rainfall conditions earlier in the season, moderating irrigation intensity can potentially be used to manage plant growth to produce a smaller, less leafy canopy and reduce volume and mass of plant residues post-harvest that could require more efficient mulching.

There was a decline in first position retention by cut-out as irrigation deficit was extended from the short to long irrigation deficit treatments. There was also significant decline in the

number of squares by cut-out in the long irrigation deficit treatment compared with the other two treatments indicating a shorter maturity in the long treatment rather than loss of the squares.

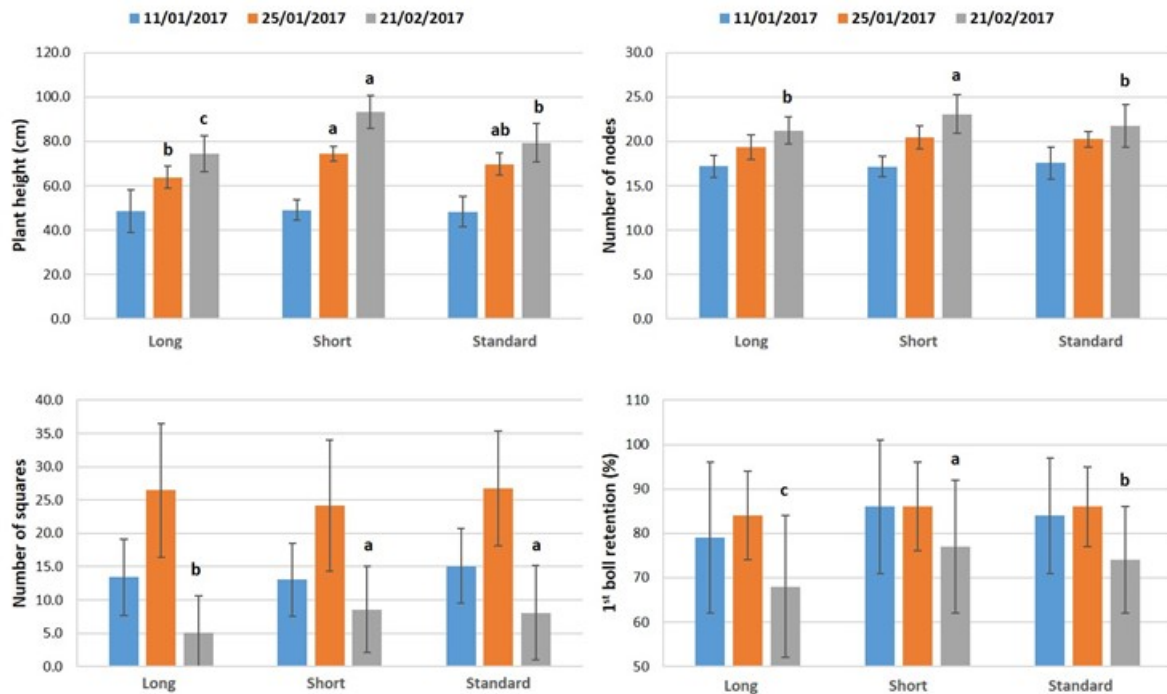


Figure 21: Plant height, number of nodes, number of squares and first boll retention determined in the irrigation treatments at January 11th (first flower), January 25th (mid-flowering) and February 21st (cut out). Different letters between columns of the same measurement date (same colour) denote statistically significant differences (P<0.05). Vertical bars indicate the standard error.

Nodes above white flower (NAWF) and total number of bolls separated into small, medium and large sizes were observed at cut-out (Table 14) to investigate how the irrigation deficit treatments had affected boll size and maturity of the crop. Irrigation had a significant effect on NAWF, small and large sized bolls. The short irrigation deficit treatment had the highest number of NAWF and the highest number of small bolls indicating slower maturation compared with the other treatments. The greatest number of large bolls was observed in the standard deficit treatment. However, there was no statistical difference ($p < 0.05$) in large boll numbers between the standard and the long deficit and both were significantly greater than those counted in the short deficit. No significant differences were found between treatments in the number of medium sized and total bolls.

Table 14: Statistical analysis of the number of nodes above white flower (NAWF), number of small, medium and large bolls, and total number of bolls determined at cut-out (February 21st, 2017). Different letters within each column signify a significant difference resulting from the irrigation deficit treatments that were applied.

Treatment	NAWF	Small bolls	Medium bolls	Large bolls	Total bolls
Short deficit	3.92a	10.17a	4.68	3.78a	17.94
Standard deficit	2.89b	9.75a	4.75	5.50b	19.06
Long deficit	2.63b	6.19b	4.33	4.73ab	14.95
180 Kg N/ha	2.64	7.96	4.76	4.41	16.57
270 Kg N/ha	3.66	9.45	4.41	4.94	18.06
ANOVA	Sig.	Sig.	Sig.	Sig.	
Irrigation	0.000	0.000	0.761	0.017	0.056
Fertilization	0.000	0.065	0.481	0.273	0.299
Irrigation x Fertilization	0.403	0.258	0.390	0.808	0.405

The short irrigation strategy yielded 10.1 bales ha⁻¹, significantly greater than 9.2 and 8.5 bales ha⁻¹ for the standard and long irrigation deficit respectively when the standard fertiliser rate (270 kg N ha⁻¹) was used. The yields were significantly lower for the reduced rate of fertiliser and followed a similar trend between the irrigation treatments (Table 15).

Table 15: Lint yield, plant biomass at defoliation (end-of-season) and crop N uptake for the different irrigation and nitrogen rate treatments at the key learning site at Darlington Point in the 2017/18 cotton season.

Irrigation Deficit/kg N ha ⁻¹	Yield (kg ha ⁻¹)	Yield (b ha ⁻¹)	Plant biomass (t ha ⁻¹)	N uptake (kg N kg ⁻¹)
Short/270	2299.9	10.1	16.5	237.8
Short/180	2083.3	9.2	16.5	214.1
Standard/270	2079.7	9.2	15.0	224.4
Standard/180	1967.9	8.7	15.7	201.5
Long/270	1940.7	8.5	13.3	217.6
Long/180	1800.5	7.9	12.0	198.6
Irrigation	54.5	0.24	0.97	n.s.
Fertilizer	43.1	0.19	n.s.	6.9
Irr x Fert	n.s.	n.s.	n.s.	n.s.
p<0.05 s.e.				

The higher fertiliser N rate produced a significant increase in crop N uptake compared with the lower fertiliser N rate. The irrigation deficits had no significant impact on total N uptake and there was no significant interaction on total N uptake between the fertiliser N rate and irrigation deficit due to high variability in the measurements across the replicates of the irrigation treatments (Table 15).

The irrigation interval affected N use efficiency through its effect on yield. Although the short deficit treatment generally tended to provide improved N use efficiencies for all the different NUE calculations, compared with the other treatments, the data was variable and statistical significance was only achieved for agronomic, physiological and applied N use efficiency (Table 16). The economic optimum for internal N use efficiency has been defined by Rochester (2011) to be 12.4 +/- 0.4 with lower values indicating over fertilisation and higher values under fertilised. In this scenario, the standard practise with a reduced rate of fertiliser would be considered the most efficient treatment. The relatively low efficiencies in all the

treatments are likely caused by the difficult seasonal conditions in the 2016/17 season. Environmental conditions leading into the season lowered yield potential and, without a corresponding reduction in fertiliser N application, led to reduced efficiency.

The general trend in both fertiliser rates was that as irrigation interval decreased, N uptake increased, although this was not found to be statistically significant. It is likely that some water stress in the long and standard treatment caused lower N uptake during the reproductive and peak growth stage. The result confirmed the hypothesis that for best management practise, shortening the irrigation interval enhances N uptake, increases N use efficiency and therefore is likely to reduce the potential for N losses to the environment.

Table 16: Nitrogen use efficiency calculations for the different irrigation and nitrogen rate treatments at the key learning site at Darlington Point in the 2017/18 cotton season.

Irrigation Deficit/ kg N ha ⁻¹	Recovery N use efficiency %	Agronomic N use efficiency kg/lint/kg N	Crop internal N use efficiency kg/lint/kg N	Physiological N use efficiency kg lint/kg N	Applied N use efficiency kg lint/kg N
Short/270	40.4	2.7	9.7	6.9	8.5
Short/180	47.4	3.0	9.8	6.4	11.6
Standard/270	35.4	2.0	9.3	5.7	7.8
Standard/180	40.4	2.6	10.1	6.7	11.1
Long/270	32.9	1.5	9.0	4.5	7.2
Long/180	38.8	1.6	9.2	4.0	10.2
Irrigation	ns	0.22	ns	0.57	0.22
Fertilizer	ns	ns	ns	ns	0.18
Irr x Fert	ns	ns	ns	ns	ns

Although yield increases and some water and N efficiencies were observed with the short deficits compared to the longer ones, other management considerations, particularly maturity and being able to harvest the crop successfully are important in the relatively short-duration growing season in the southern region. Defoliation and picking operations can become more complex and difficult with more effective rainfall in mid-April to June. As the crop period progresses into Autumn and early Winter, shorter daylight hours and lower daytime air temperatures provide added challenges, usually only allowing picking to occur for 5-6 hours/day with suitable moisture conditions. Harvesting the crop as early as possible also assists with cash flow and enables more timely ground preparation for the following season.

The different irrigation deficits had a clear effect on the amount of growth regulation required and the number of defoliant applications (Table 17). The long deficit only required a single application of Mepiquat Chloride as plant height was just over 70 cm at cut-out compared with 80 cm in the standard deficit and 90 cm in the short deficit (Figure 21) although in this experiment all irrigation deficit treatments had the same number of Mepiquat chloride applications. Biomass was approximately 1t ha⁻¹ greater in the short deficit compared with the standard and 4 t ha⁻¹ greater than the long deficit (Table 15) which meant a third application of Mepiquat Chloride was necessary for this irrigation deficit treatment. Maturity, indicated by 60% of the total number of bolls open, was delayed by 3 days in the short irrigation deficit and came 3-4 days earlier in the long irrigation deficit compared to the standard irrigation deficit. However, due to rain events in May 2017, the time between the final harvest dates for the three treatments was quite large; the season was shortened by a

week for the long deficit and extended by 19 days for the short deficit compared with the standard watering interval (Table 17).

Table 17: Growth regulation, defoliation management and maturity assessment for the irrigation and nitrogen treatments at the key learning site at Darlington Point in the 2017/18 cotton season. Three applications of Mepiquat Chloride (Pix) were used on all treatments due to aerial application. However, 1 application (in parentheses) would have been suitable for the long deficit treatment due to its reduced plant height.

Irrigation x fertiliser strategy	No. of pix	No. of defoliations	60% open boll date	Harvest date
Short (7 days) 180 N	3	3	25/04/2017	30/5/17
Short (7 days) 270 N	3	3	27/04/2017	30/5/17
Usual (14 days) 180 N	3	2	21/04/2017	11/5/17
Usual (14 days) 270 N	3	2	24/04/2017	11/5/17
Long (19 days) 180 N	3(1)	2	18/04/2017	4/5/17
Long (19 days) 270 N	3(1)	2	17/04/2017	4/5/17

Lint quality from all treatments was of acceptable grade with no price penalty in this study. However, lint quality was affected by irrigation interval but not by fertiliser rate or the interaction between the two factors as determined by a High Volume Instrument (HVI) for cotton classing (Table 18). High and low micronaire (fibre fineness and maturity) can incur significant price penalties with 3.4–4.9 being acceptable. Micronaire increased according to irrigation deficit since typically, as maturity increases micronaire increases. Higher micronaire can also be associated with water stress and the quality results are consistent with the other data indicating the long deficit endured some stress such that lint yield, water use and stomatal conductance were all affected.

Table 18: Lint quality parameters obtained from the treatments in the irrigation-N trial at Darlington Point, 2017. Spinning consistency index (SCI) gives a coefficient of quality from a calculation involving a number of different HVI measurements including micronaire, fibre length, length uniformity, fibre reflectance and yellowness. Moisture (Mst(%)) is lint moisture content related to maturity. Micronaire (Mic) relates to fibre maturity and thickness. Maturity (Mat) the maturity of the fibre. UHML (in) is mean fibre length of 50% of the longest fibres. Uniformity index (UI) is the ratio between UHML and the mean length of the whole sample, SF is % of short fibres (<13 mm), Str is a measure of fibre strength, Elg; fibre elongation; Rd is reflectance, related to colour, +b is a measure of yellowness (colour).

Two way ANOVA												
	SCI	Mst (%)	Mic	Mat	UHML (in)	UI (%)	SF (%)	Str (g/tex)	Elg (%)	Rd	+b	
Irrigation	** F(2,12)=4.1	**** F(2,12)=2.1	**** F(2,12)=5.1	**** F=15.75, 1	** F=7.062, p ns	ns	ns	ns	ns	ns	**** F=34.846, 1	
Long	149.667	8.25	4.735	0.873	1.196	84.55	5.9	33.983	6.333	74.133	6.4	
Standard	151.833	7.983	4.558	0.868	1.216	85.033	5.8	32.7	6.633	75.733	5.883	
Short	160	8.75	4.045	0.858	1.235	84.917	5.8	33.817	6.367	75.483	5.317	
Fertiliser	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	
180	152.333	8.356	4.474	0.867	1.217	84.511	6.033	33.544	6.489	75.144	5.844	
270	155.333	8.3	4.418	0.867	1.215	85.156	5.633	33.456	6.4	75.089	5.889	
Irrig X Fert	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	
Long X 180	149	8.333	4.787	0.873	1.195	84.367	6.1	34.3	6.3	73.567	6.433	
Long X 270	150.333	8.167	4.683	0.873	1.197	84.733	5.7	33.667	6.367	74.7	6.367	
Std X 180	151.333	8	4.563	0.867	1.224	84.833	5.933	32.733	6.733	75.8	5.767	
Std X 270	152.333	7.967	4.553	0.87	1.208	85.233	5.667	32.667	6.533	75.667	6	
Short X 180	156.667	8.733	4.073	0.86	1.231	84.333	6.067	33.6	6.433	76.067	5.333	
Short X 270	163.333	8.767	4.017	0.857	1.239	85.5	5.533	34.033	6.3	74.9	5.3	

* significant at ps0.05; ** significant at ps0.01 and; *** significant at ps0.001

Petioles

Concentrations of nitrate in petioles measured in both the N rate trial and the irrigation trial were at a maximum at 597 degree days at approximately 18- 21 g N kg⁻¹ which is relatively low compared with the 30 g N kg⁻¹ measured in Narrabri (Constable *et al.*, 1991), but similar to the common critical range for petiole nitrate at flowering (Hearn, 1981), (Figure 22).

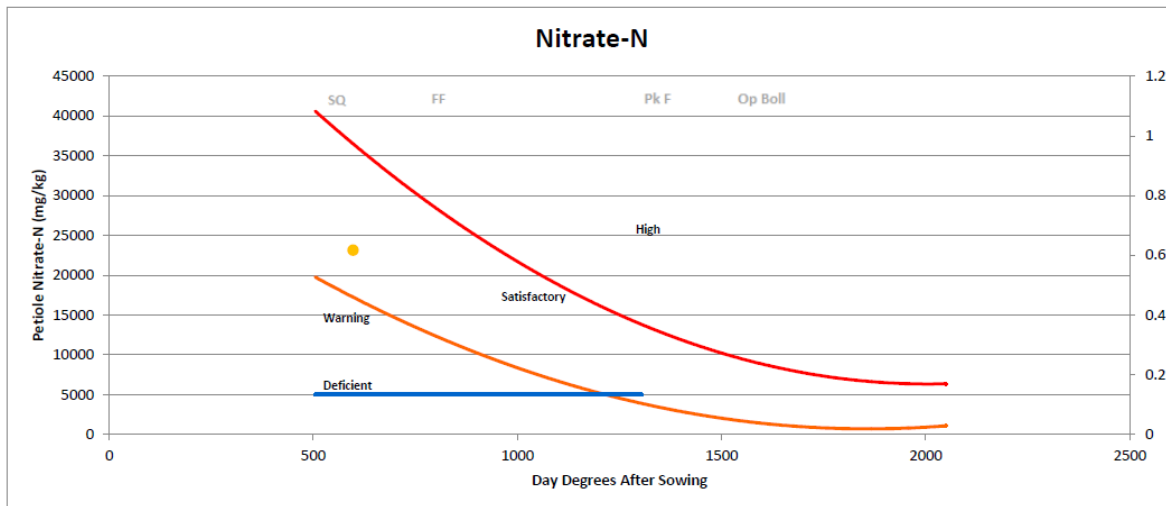


Figure 22: Chart showing the range of nitrate-N status of cotton crops as the season progresses. The yellow point represents the point for the average of the field experiment showing it within the satisfactory range at that growth stage.

The differences in the datasets reflects the recommendations of those authors, that the use of petiole testing to indicate N status, needs evaluation and calibration in each production region, due to soil type variation and different cultivars. The application of fertiliser N significantly increased concentration of petiole NO₃⁻N at all sampling dates with the exception of the 150 kg N ha⁻¹ treatment. The nitrate concentrations declined with time in all fertiliser levels with the greatest declines in the lowest N levels. The linear decline with time observed by Constable *et al* (1991) was not observed here. Instead, there was a significant decrease between 756 degree days (3/1/17) and 831 degree days (9/1/17), the period just prior to the onset of flowering, after which the values flattened or declined more slowly (Figure 23). When plotted on the chart commonly used by agronomists (Figure 22) the values determined here would indicate the plants require further fertiliser. Although, this is in contrast to what the iNUE data (maximum of 10.1) was indicating and suggest that the crop was limited by factors other than N and in this particular season these included, difficult ground preparation and air temperatures above 40°C during flowering and boll development.

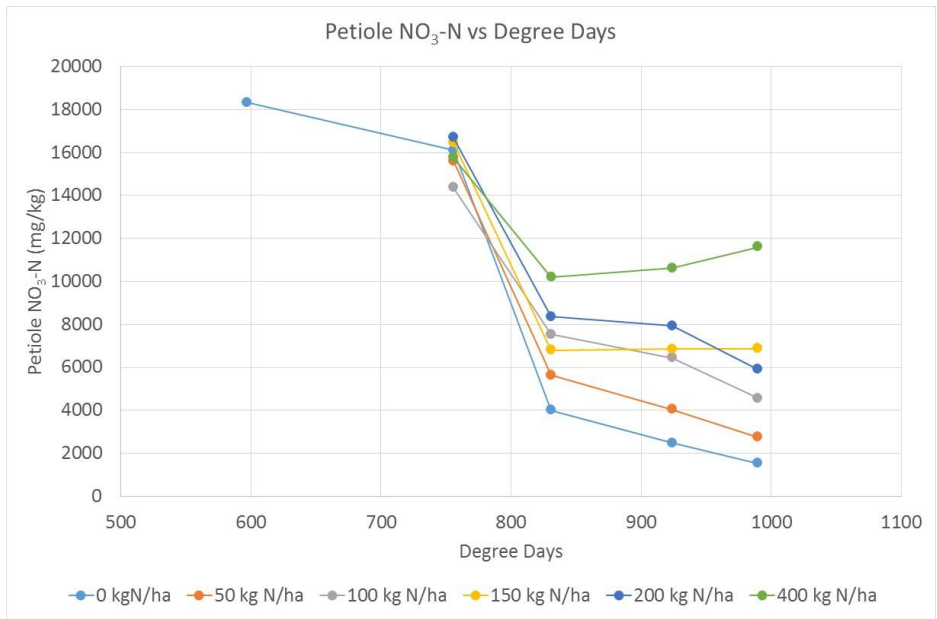


Figure 23: The relationship between plant development (day degrees) and petiole nitrate-N concentrations across 5 fertiliser rates in the CRDC funded UQ1502 N fertiliser rate trial that bordered the key learning site at Darlington point in the 2016/17 cotton season.

Detection of cotton nitrogen using near infra-red spectral resolution remote sensing

Drone deployed observations of the spectra of the cotton plants were also made at the same time as plant and petiole samples were taken throughout the cotton growing season. The spectra were interpolated and then used to develop calibrations and comparisons with the nitrogen data collected.

Nitrogen uptake at first flower in the irrigation experiment provided an exponential relationship with NDRE (Figure 24).

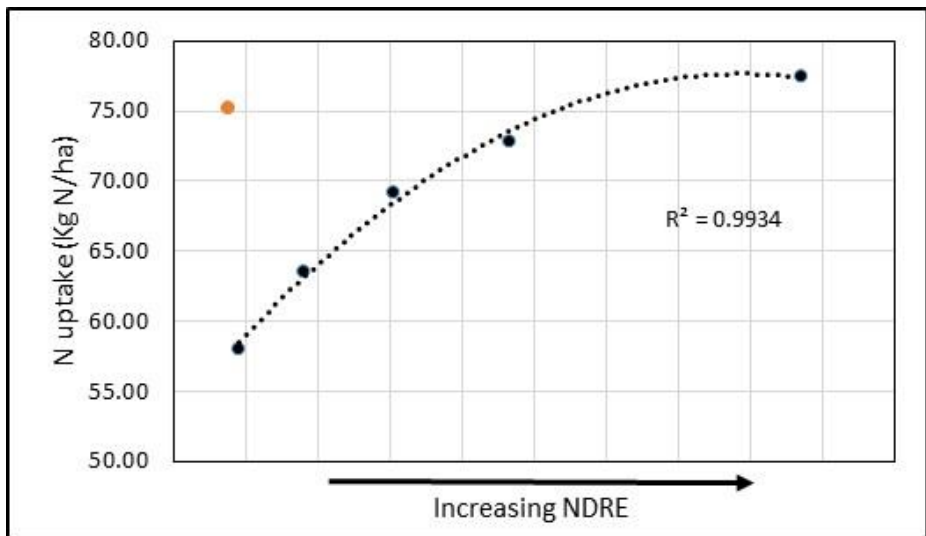


Figure 24: The relationship between NDRE collected by drone and N uptake at first flower in the irrigation and nitrogen trial at the key learning site at Darlington Point in the 2016/17 cotton season. The orange dot indicates an outlier corresponding to the long deficit treatment with N rate of 180 kg N ha⁻¹.

The spectral images taken with the drone enabled monitoring of the seasonal evolution of the vegetation indices most commonly used to track biomass development, NDVI, and crop N status, NDRE and CCCI (Figure 25). A total of 10 images of the experiment were taken throughout the season. Irrigation had an effect on the seasonal evolution of the vegetation indices. Irrigation deficit impacted on NDVI shortly after the imposition of the different deficits with NDVI higher in the short deficit treatment than in the standard and long treatments. Differences in NDVI between the short deficit and the other treatments for each date, particularly with the long deficit treatment (irrigated every 19 days), fluctuated depending on the number of days from the last irrigation was applied (i.e. the plant water status) at the time of the measurements. For example, all the treatments had similar values of NDVI on the first measurement day when all had been irrigated 7 days previously (Figure 25). The next images were taken two days later when the short treatment had been irrigated the day before. At that moment the short treatment had higher NDVI than the other two treatments. The same was observed following the third NDVI measurement when the long and standard deficits were 13 days since irrigation and the short deficit had been irrigated one week previously. However, differences between the standard and long deficits compared with the short treatment were more notable than in the previous NDVI measurement. Four days after the standard deficit was irrigated for the first time since the beginning of the treatments (at the same time as the short deficit received the second irrigation on January 21st), differences in NDVI between the standard and the short deficits were significantly reduced while differences between the short and the long deficits (19 days with no irrigation) increased. As observed for the standard deficit, irrigation in the long deficit treatment had an increasing effect in NDVI as observed on January 24th, when differences observed between this and the short treatment were lower than in the previous measurements.

The opposite was observed for the CCCI with the long deficit showing generally higher values and the short deficit the lowest. Irrigation in this case had a temporary effect of reducing CCCI, which was more notable in the standard and long deficit than in the short deficit treatment.

NDRE was similar between treatments across the season. The NDVI and CCCI both increased throughout the season until February 11th when they peaked and then slightly decreased until maturity.

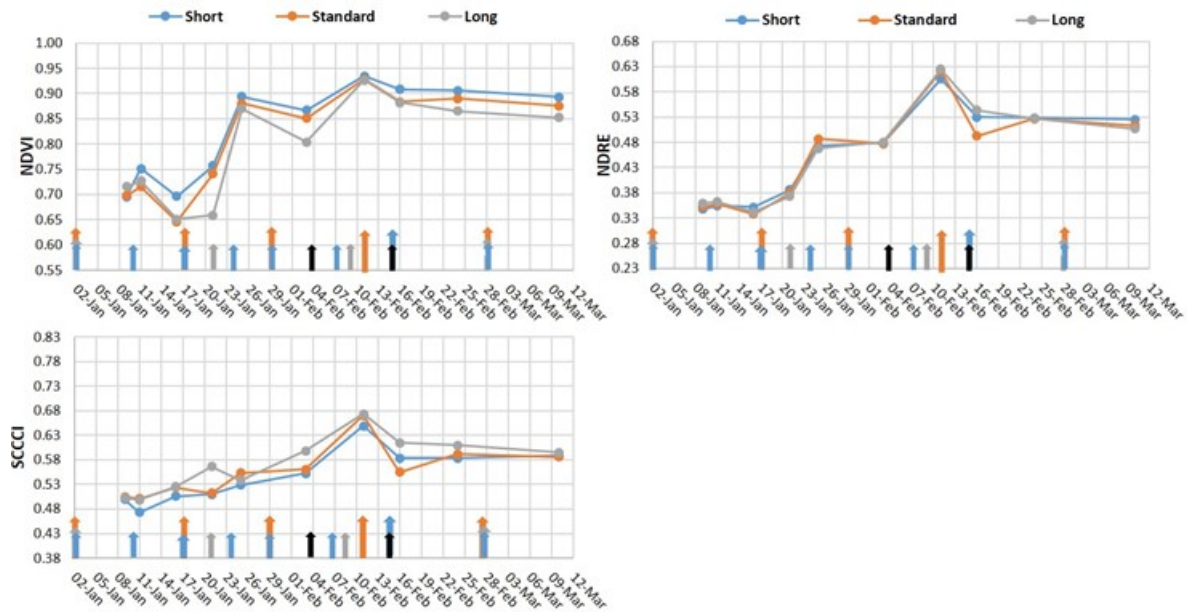


Figure 25: Seasonal evolution of the NDVI, NDRE and SCCI for each of the irrigation treatments during 2017. Blue, orange and grey arrows indicate irrigation events in the short, standard and long deficit treatments, respectively. Black arrows indicate two dates when Mepiquat Chloride was applied to the site.

The analysis of the petiole samples taken at the fertiliser N rate experiment showed that differences in petiole N content (g NO³-N) between treatments were notable from the second sampling day on January 9th with the N content being higher in the treatments with the higher N fertilisation rate (Figure 26). There was a good correlation (r^2 ranging between 0.84–0.87) between the petiole N content and the CCCI obtained from the spectral images for each day of measurements (Figure 26). An r^2 of 0.34 resulted ($P < 0.01$) when the data for the three days was pooled together for analysis. However, comparing data from the different days, CCCI values obtained on January 16th were higher than those obtained on January 9th and 21st for similar values of petiole N content (Figure 26). The relationship between CCCI obtained from the spectral measurements and petiole NO³-N content shown in Figure 26 was most likely affected by the plant water status at the time of sampling. Petiole samples on January 9th and 21st were taken seven and four days after an irrigation event. On January 16th, however, samples were taken 13 days after the last irrigation (N rate experiment was irrigated as the standard practice in the irrigation x nitrogen experiment) when transpiration was significantly lower than the potential rate as shown by the stomatal conductance measurements taken on the same day in the irrigation experiment (Figure 26). Under drought stress, leaf blade moisture content has been reported to drop earlier than petiole moisture content, leading to increased nutrient concentrations in the former (Davis 2008). As remote sensing measurements rely mostly on the leaves reflectance, differences in nutrient concentration between leaves and petiole under drought stress could explain the higher CCCI values obtained on January 16th compared to the other two days of measurements for a similar NO³-N petiole content. In fact, when data from that day was removed from the assessment, r^2 for the relationship between CCCI and NO³-N petiole content increased from 0.34 to 0.79 ($p < 0.001$).

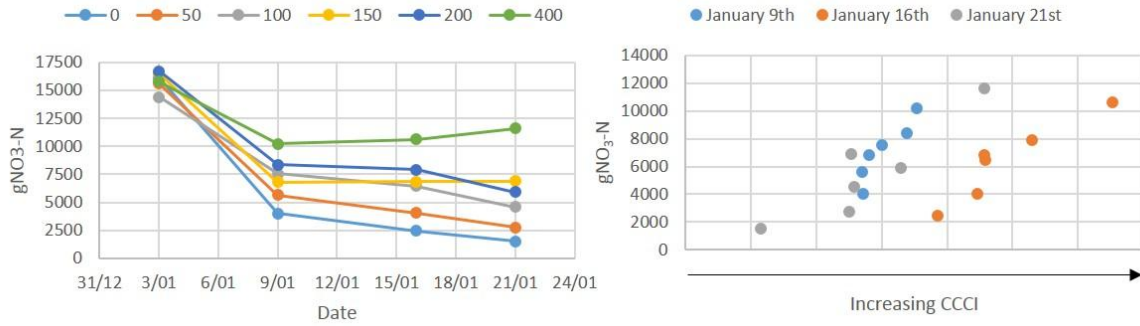


Figure 26: Petiole N content (g NO⁻³-N) in the different N rate treatments for the four measurement days in the CRDC UQ1502 fertiliser N rate experiment that bordered the key learning site at Darlington Point (left). The relationship between the petiole N content and the CCCI obtained the same day from spectral images (right).

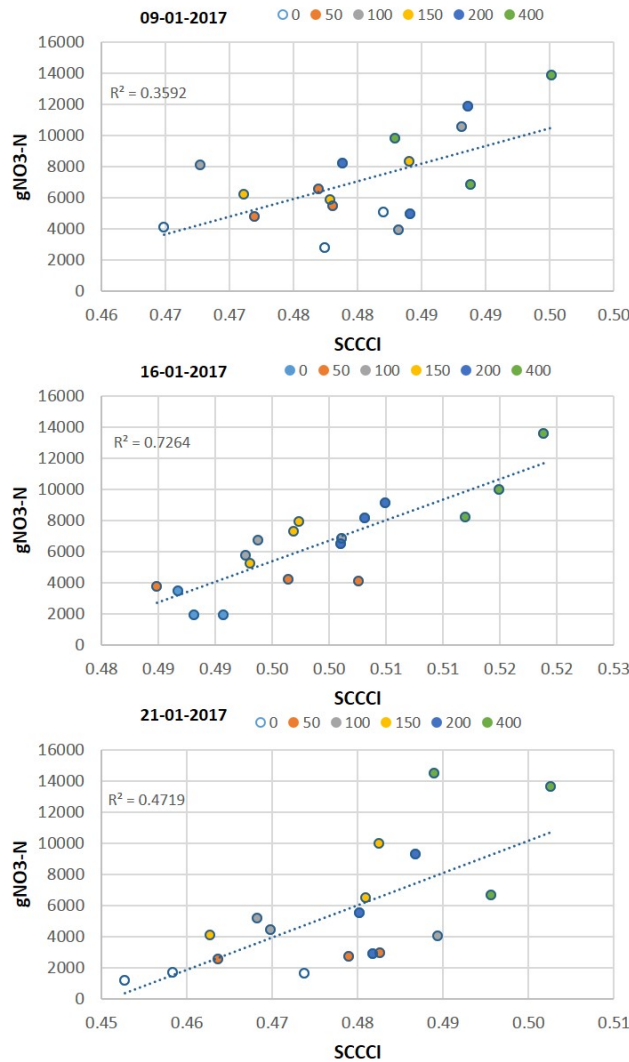


Figure 27: Petiole nitrate levels (g NO⁻³-N) in the CRDC funded UQ1502 fertiliser rate experiment, which bordered the key learning site, at Darlington Point vs CCCI over the cotton flowering period in the 2016/17 cotton season.

Soil Nitrogen

Preliminary observations of soil N data are presented as data analysis is ongoing at the time of writing this report. The soil mineral-N supplied to the cotton crops by fertilizer in the two seasons was quite different, partly caused by weather conditions which affected application timing and by consultant decisions on rates. In 2016/17 soil mineral N (0-30 cm) pre-trial baseline, sampled at the end of August, 2016 was approximately 39 kg N ha⁻¹ in unfertilised soil and after a wet winter and spring. In contrast in 2017/18, pre-plant soil mineral N (0-30 cm) was measured as 108 kg N ha⁻¹ with very large variation 59 – 152 kg N ha⁻¹ depending on sample location within the field. In 2016/17, following fertilisation of 270 kg N ha⁻¹ in which the fertiliser was applied relatively late on 21/11/2016 and 28/12/2016, by first flower (12/1/2017), mineral N (0 – 30 cm) had risen only marginally to a mean of 74 kg N ha⁻¹ (*n*=6) with a maximum value of 108 kg N ha⁻¹. This was in stark contrast to soils sampled at first flower in 2018 (15/1/2018), which contained on average 334 kg N ha⁻¹, fertilised with anhydrous ammonia in July of the previous winter followed by side dressed urea (total fertilizer N = 309 kg N ha⁻¹) at first flower. By post-harvest in June 2017, soil mineral N was measured at 82 kg N ha⁻¹ in the upper 30 cm of the soil profile with approximately 20 kg N ha⁻¹ more remaining in the higher rate of N compared with the reduced rate. In 2017 pre-season soil samples which were taken at the irrigation supply end of the furrows compared to the drainage end of the furrow (0-30 cm), there was a significant difference (*p*<0.05) in mineral N in the 0-30 cm interval (Figure 28). The drainage end of the field contained approximately 40 kg N ha⁻¹ more in the upper part of the profile than the head and illustrates how N is transported down the fall of the paddock with irrigation potentially causing variability.

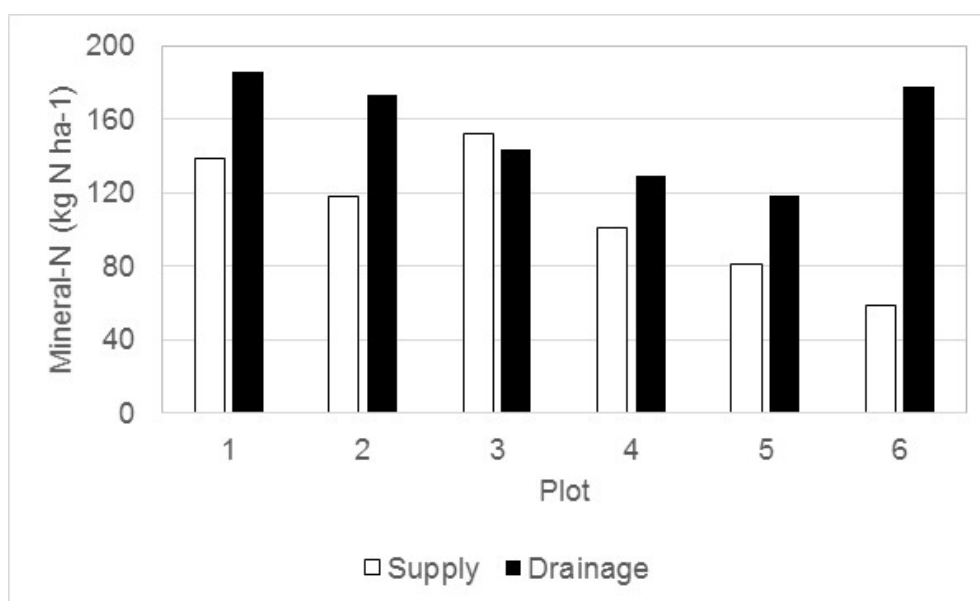


Figure 28: Comparison of soil mineral N (0-30 cm) measured at the supply and drainage ends of the irrigation furrows in 6 treatment plots of the key learning site at Darlington Point on September 28th 2017.

There was no difference between soil mineral N measured in the deeper soil profile (30 – 90 cm); 68 kg N ha⁻¹ compared with 59 kg N ha⁻¹; in August, 2016 and September, 2017 respectively at the key learning site at Darlington Point.

5.2.2 Key Learning Site 2

Grower group: Southern Growers, Jerilderie, NSW

Focus crop: Rice

There was no significant difference ($p=0.05$) in grain yield between the traditional flat surface layout compared to grain yield from rice grown on beds, with grain yields of 12.77 and 11.84 t ha⁻¹ respectively. Soil at 5 cm soil depth in the beds oxidised sooner than the soil at the same depth in the flat layout.

Flush finishing of the rice crop allowed soil matric potential and soil redox to increase (Figure 29 and Figure 30 respectively). Soil redox below 350 mV indicates limitation in the availability of soil oxygen (O₂) and alternate sources of O₂ are sought for microbial activity, such as NO₃⁻. The increases in both soil matric potential and redox provided very different soil moisture conditions compared to the standard permanent water and drain at an estimated time for grain harvest moisture and ground conditions suitable for traffic to coincide.

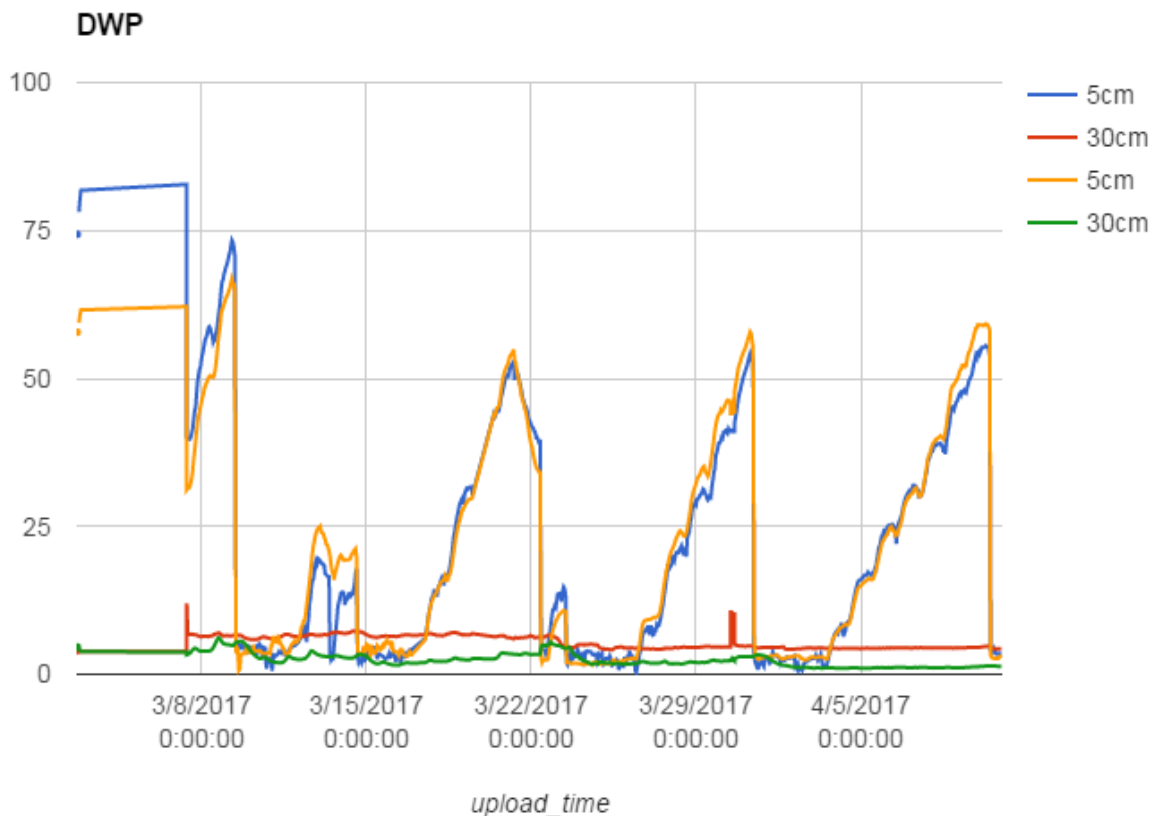


Figure 29: Matric potential (y axis) in the bay that was established using delayed permanent water (DPW) and flush finished post flowering at the key learning site at Jerilderie.

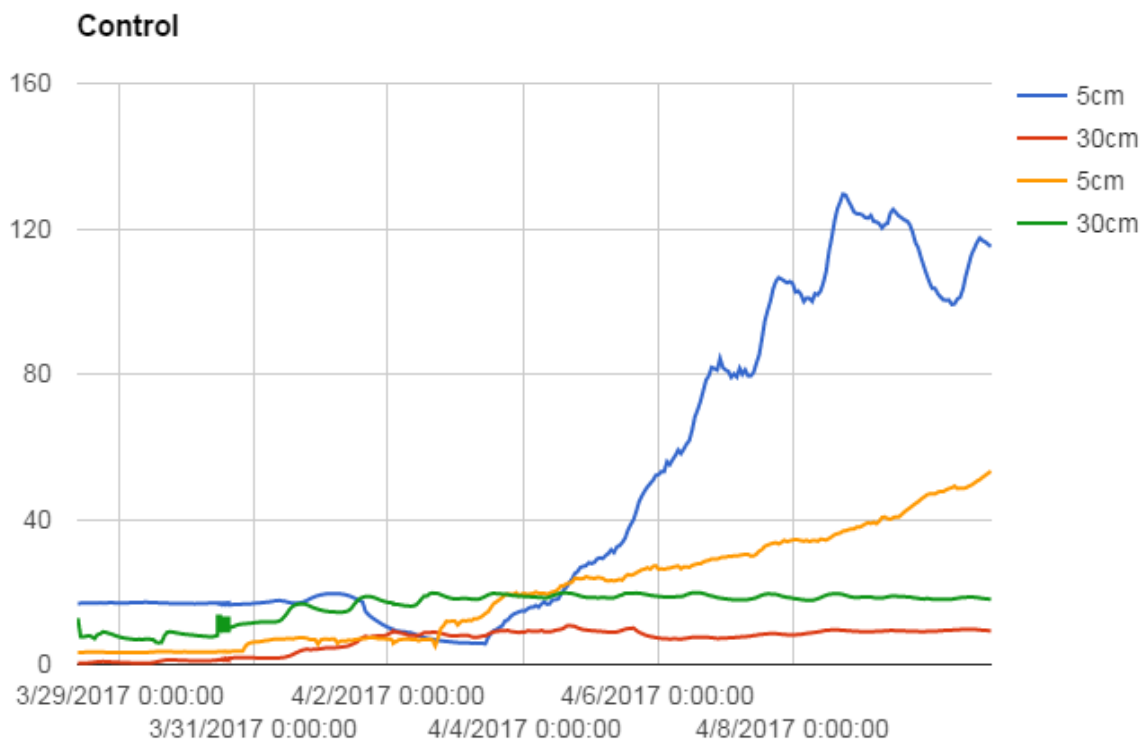


Figure 30: Matric potential (y axis) in the bay that had permanent water maintained until ideal draining time for rice at the key learning site at Jerilderie.

The flush finishing increased soil oxidation earlier in the rice season compared to when water was maintained and drained at the normal time (Figure 31). The flush finish also resulted in improved soil oxidation to a greater depth due to flushing occurring when plants were still using water compared to the normal draining time undertaken when plant water use is declining with the plant past physiological maturity.

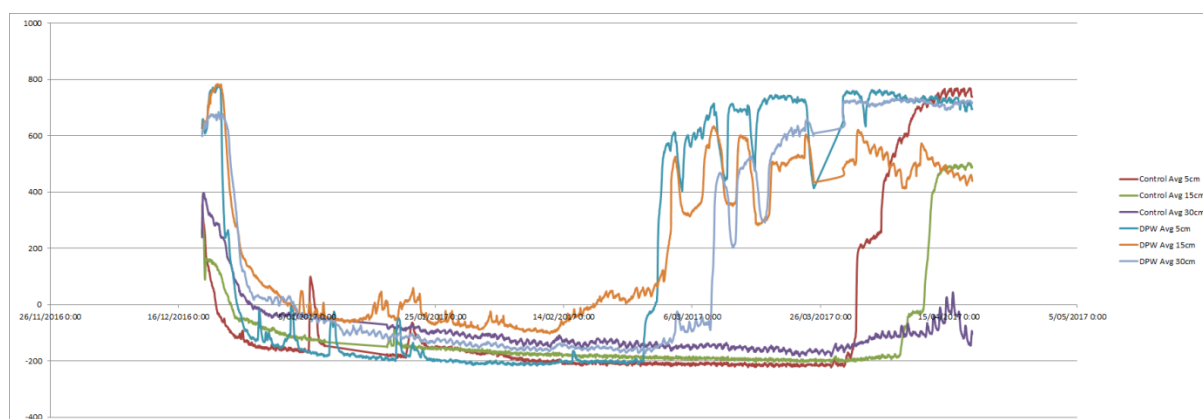


Figure 31: Soil redox (milliVolts; y axis) over time. Flush finishing the rice crop allowed re-oxygenation of the soil earlier and to a greater depth than conventional water management.

The higher redox readings provide an indication of improved soil condition for the following winter crop. Improved soil condition is a key aspect in trying to improve the productivity of the rice farming system and is worthy of further investigation on a larger scale to determine the practicalities of such a water management practice.

5.2.3 Key Learning Site 3

Grower group: Irrigated Cropping Council, Numurkah, Victoria

Focus crop: Maize

Plant establishment and biomass

In the 2015/16 season, plant establishment was relatively poor due to saturated seed bed conditions caused by pre-irrigation and a 40 mm rain event and sowing soon after. Mean plant establishment was 88,000 plants/ha but was so highly variable (analysis not shown) that three of the bays were not able to be included in the final harvest results.

In the 2016/17 season, plant establishment was good at 92000 plants/ha with no significant differences in establishment ($p < 0.05$) in and between the bays (data not shown).

The overall means of total harvest biomass are shown in Table 19. The results varied quite markedly from year to year and therefore are treated separately. The relatively low biomass in 2016/17 was not reflected in the harvest data and was caused by the plants being sampled earlier in the season, at the 5th leaf stage. The first two seasons of data provided contrasting results. The short deficit irrigation and up-front fertiliser produced marginally higher N uptake (Figure 32) and grain yield (Figure 35) in 2015/16. However, the reverse was true for 2016/17. There were markedly different environmental conditions in the two seasons. In 2015/16 there were very high ($> 40^{\circ}\text{C}$) air temperature spikes during the plant reproductive phase, in which the short deficit irrigations offered some protection against moisture stress. In the following season, intervals of very high air temperatures were also encountered but not at the same critical growth stages. In both seasons, using upfront fertiliser compared with in-crop split applications indicated improved, or made little difference to, grain yield.

In both the 2015/16 and 2016/17 season, the mean of crop N uptake at the 5-7 leaf stage was up to 34.4 kg N ha. At the 5-7 leaf stage there was no difference (duplicates only) in N uptake between the irrigation deficits, nitrogen application timing or interaction of the two. This indicates all treatments were relatively even with respect to N availability and uptake prior to the imposition of the irrigation treatments and were not subject to confounding soil or site variations.

In 2015/16, at maturity, mean N crop uptake was 166.6 kg N ha⁻¹ and 148.9 kg N ha⁻¹ for the short and standard irrigation deficits, respectively with no significant difference ($p < 0.05$) between the two treatments. The upfront application of fertiliser produced a significant difference ($p < 0.001$) in crop N uptake in this season with 175.6 kg N ha⁻¹ accumulated compared with 139.9 kg N ha⁻¹ where most fertiliser was applied in-crop (Figure 32, a). There was also a significant interaction ($p < 0.001$) between the two factors with short deficit and up front placement increasing seasonal N uptake by 50 – 60 kg N ha⁻¹ compared with the other combinations.

In the 2016/17 season total N uptake at maturity was higher than the first season and the uptake trend was reversed, in that a greater uptake was observed in the standard deficit treatment compared with the short deficit treatment; 224 and 184 kg N ha⁻¹ respectively (Figure 32, b). In the 2016/17 season, although there was no observed difference in average crop N uptake between split and up front applications (Figure 32), the standard irrigation frequency of 7 days with a split application gave the highest seasonal N uptake of 244 kg N ha⁻¹.

Table 19: Plant biomass in maize at the key learning site at Numurkah in the 2015-18 maize production seasons according to fertiliser placement and irrigation deficit at 5-7 leaf stage and end-of-season. Standard refers to a soil moisture deficit imposed from watering every 7 days; short refers to a soil moisture deficit imposed every 5 days. n/a: data not available at time of writing report.

Season	2015/16		2016/17		2017/18	
Biomass (t ha⁻¹)	5-7 leaf stage	End-of-season	5-7 leaf stage	End-of-season	5-7 leaf stage	End-of-season
Overall biomass	1.2	21.4	0.3	25.8	0.78	n/a
Irrigation						
Standard deficit	1.1	20.2	0.31	27.0	0.8	n/a
Short deficit	1.2	22.7	0.29	24.7	0.79	n/a
Fertiliser						
Up-front	1.2	22.8	0.3	25.7	0.85	n/a
Split	1.2	20.0	0.3	26.0	0.72	n/a

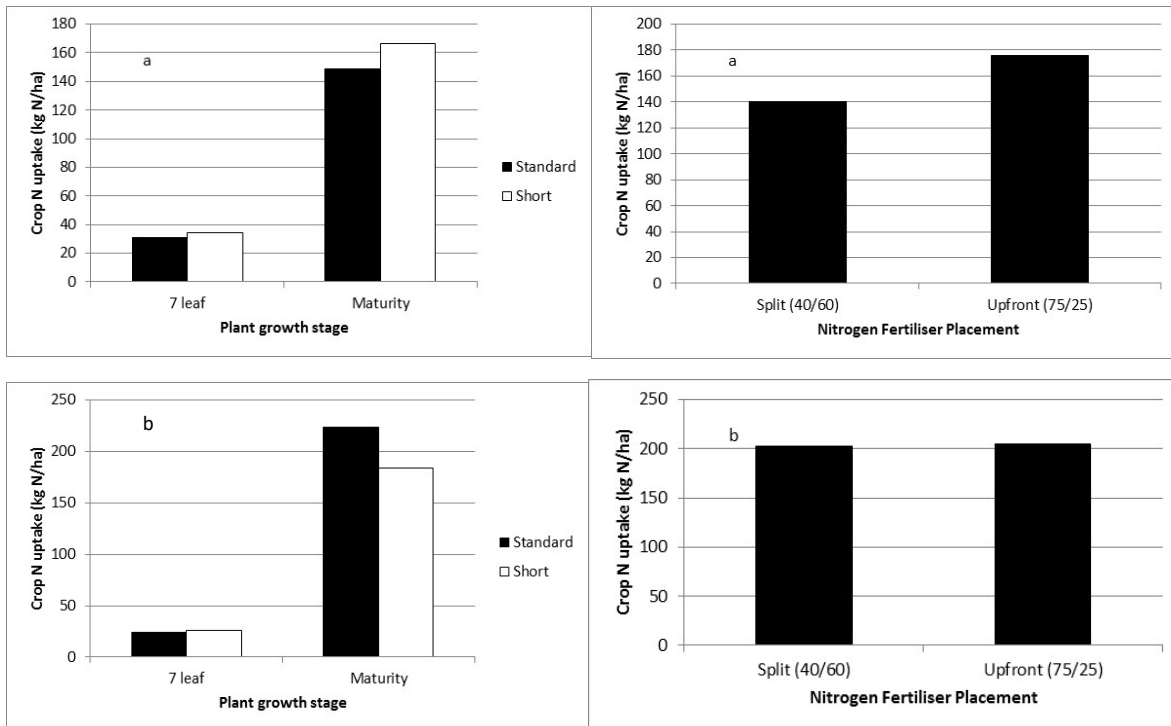


Figure 32: Nitrogen uptake in maize at physiological maturity at the key learning site at Numurkah, (a) 2015/16 season and (b) 2016/17 season according to fertiliser placement and irrigation deficit. Standard refers to a soil moisture deficit imposed from watering every 7 days; short refers to a soil moisture deficit imposed every 5 days.

Irrigation

The two irrigation treatments provided two different soil tension environments for plant roots (Figure 33). Although the data indicates that the soil profile was not being re-filled in either treatment at 30 cm soil depth, the standard practise treatment had greater extraction of soil moisture from deeper depths in the soil profile. This data will be compared across treatments with final harvested yields to correlate average rootzone soil tension with yield and also to determine if nutrient availability under these different extraction patterns is impacting yields. This data will also be analysed against ETo data to understand the impact of deficits across the treatments and the best irrigation strategies under the various conditions experienced over the monitored irrigation seasons. The seasons have been quite different in maximum ETo conditions, allowing a wide range of possible factors to be incorporated into irrigation

strategy recommendations being developed in the project.

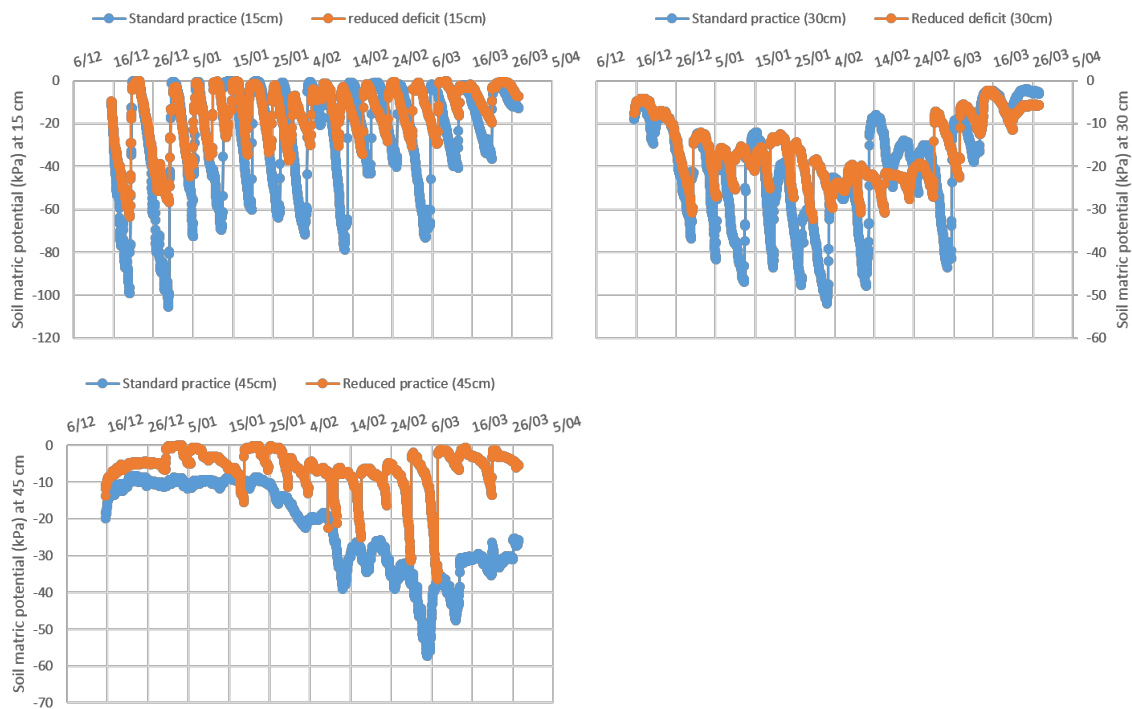


Figure 33: Soil matric potential recorded in short and standard deficit irrigations at 15 (top left), 30 (top right) and 45 cm (bottom left) soil depths in maize at the key learning site at Numurkah.

The short deficit treatment (Bays 3, 5, 6 and 8) received significantly more water than the standard practise; 6.5 compared with 5.1 ML (Figure 34; excludes the first 2 establishing irrigations) which will have impacted the variability in crop N uptake and grain yield.

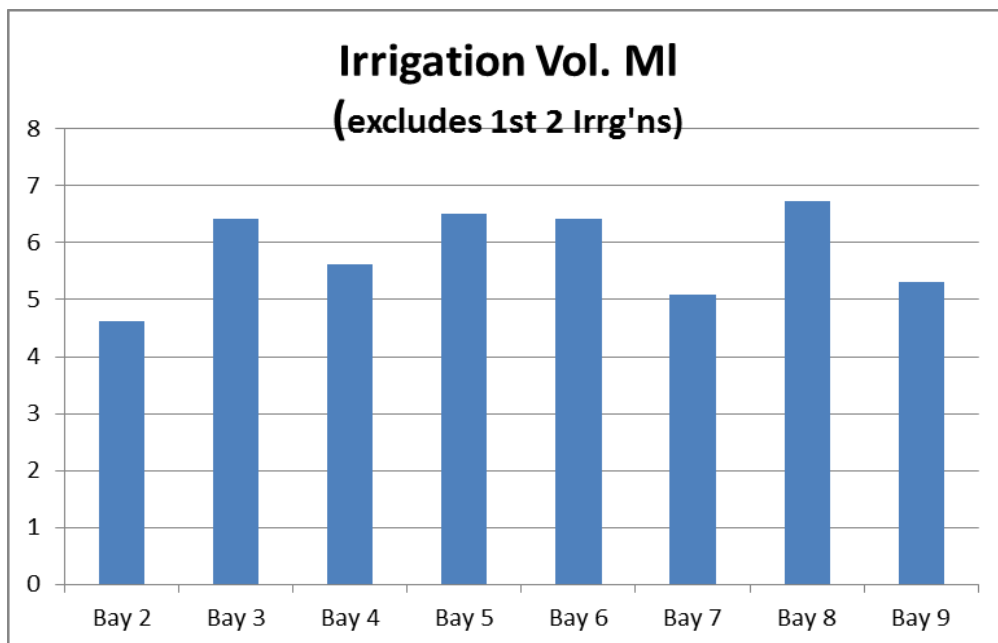


Figure 34: Measurement of irrigation water applied across the 8 bays used in the field experiment at the key learning site at Numurkah. Bays 3, 5, 6 and 8 had the short irrigation deficit applied and bays 2, 4, 7 and 9 had the standard irrigation deficit applied.

Grain Yield

Grain yield was low in 2015/16, resulting from poor establishment of the experiment due to irrigation and a rainfall event coinciding. No grain yield data was able to be collected in Bays 7, 8 and 9, for that season which did not allow all treatments to be replicated as planned. A summary of data for the two seasons (Figure 35) indicates that a short irrigation deficit of -20 – -40 kPa may be preferable on this soil type, particularly when there are hot conditions (> 40°C) during plant reproductive growth stages. The grower observed that more frequent watering tended to protect the crop from high daytime and night time temperatures, maintaining improved leaf turgor.

Daytime air temperatures during the growing season peaked at 44°C but this did not occur at times which were absolutely critical for yield impact in the 2016/17 season. There was no significant difference ($p < 0.05$) in grain yield due to irrigation deficit in the 2016/17 season.

Nitrogen fertiliser timing did not influence grain yield ($p < 0.05$) in the 2015/16 season. However, a 26% improvement in grain yield in the upfront compared with the split N application strategy was observed in the 2016/17 season.

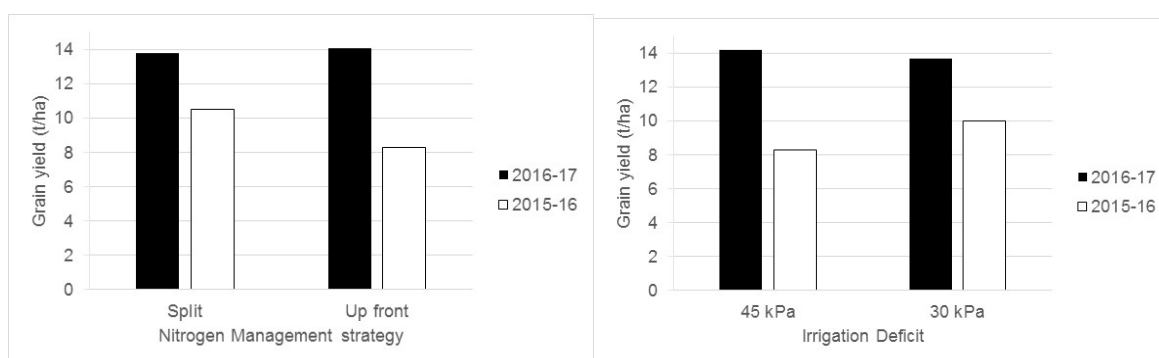


Figure 35: Grain yield vs irrigation and management strategy in maize in northern Victoria over two cropping seasons (2015/16 – 2016/17).

5.3 Focus Area 3

Develop best practice design guidelines for basin surface irrigation System

Irrigation data collected from the parallel contour system at Deniliquin is summarised in Table 20. Analysis of the data collected from the other three sites is yet to be finalised at the time of writing the final report.

While the major purpose of the field data was to inform the modelling (described in the next sections), there are a number of observations and findings that are noteworthy.

5.3.1 Side-ditch influence on drainage times

Building up a volume of water in a bay and delivering it to the downstream bay through the side-ditch generally resulted in irrigation advance times at the Deniliquin site of roughly 4–5 hours, compared to 7 – 10 hours when bays were irrigated at a constant 15 ML/day from the supply channel. However, the effect on drainage of the hydraulic connection between bays through the side-ditch far outweighed any advantage of faster advance times, with water lying on bays for around 40 hours when the whole paddock was irrigated through the side-ditch on 21st March 2017 (Table 20). The effect of this can be seen in the aerial photograph in Plate 5, which shows water backed up into the six bays upstream of the one being irrigated. This is the norm in paddocks with such a flat grade (i.e. with a paddock overall grade of 1:2000).



Plate 5: Aerial photograph of the irrigation of the parallel contour system at Deniliquin on the 21st March 2017 (second autumn irrigation). The whole paddock was irrigated through the side-ditch and the image shows how water has backed up in the six bays upstream of the one being watered (bottom right).

5.3.2 Surface roughness influence on water depth at the supply end of the bay

Surface roughness affected the head of water required at the supply end of the bay to drive advance. The greater the surface roughness, the greater the depth of water needed to push water to the other end of the bay as there is no slope in the direction of advance in these systems. The effect of this in the parallel contour system at Deniliquin is shown in Figure 36. The logarithmic curves fitted to this data show that, for a flow rate of 1.9 L/s/m bay width and a high roughness ($n = 0.43$), a step of 150 mm would be needed to prevent water backing up and impeding drainage in a 450 m long terraced bays. For a smooth surface (i.e. bare earth, $n = 0.1$), a step of only 70 mm would suffice.

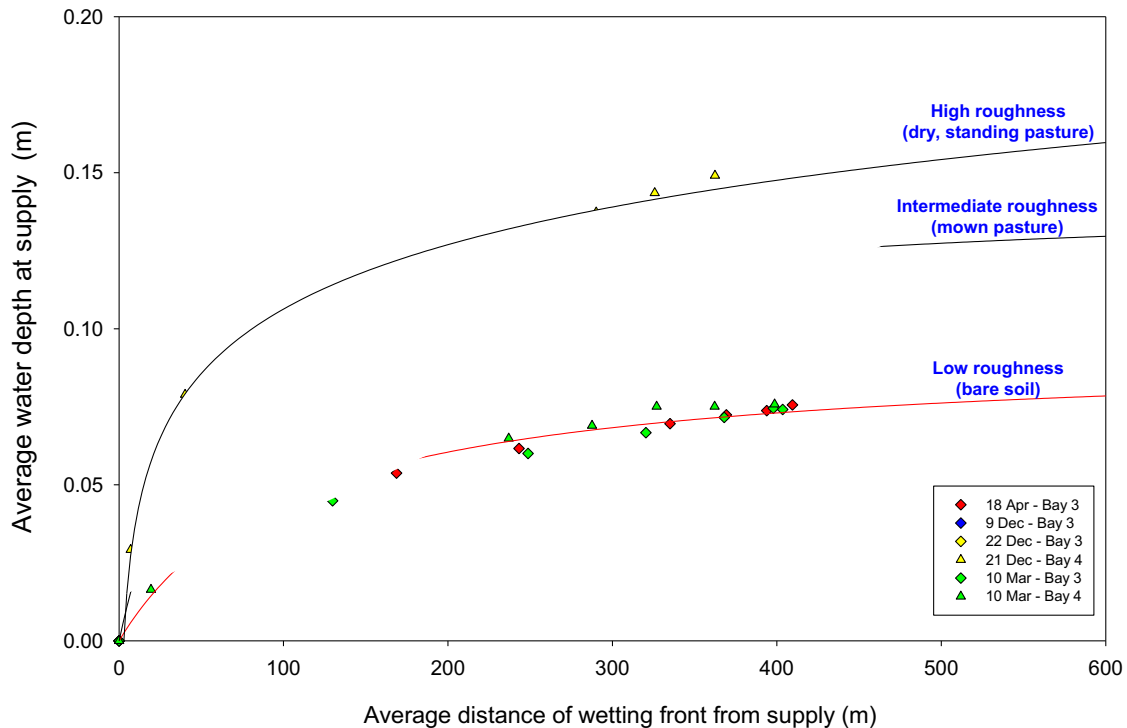


Figure 36. The relationship between surface roughness and the average depth of water at the supply end of bays from six irrigation events with varying antecedent moisture contents in the parallel contour system at Deniliquin. In flow rates either varied (falling) or were constant depending on whether supplied through the side-ditch or from the channel, but averaged 15 ML/day for the 90 m wide bays.

5.3.3 Influence of soil moisture content and surface roughness on drainage time

The irrigations on the 21st December 2016 and the 10th March 2017 illustrate the interaction between antecedent soil moisture content and surface roughness and their effect on opportunity time (Table 20). Similar volumes of water were applied during these irrigations, however:

- The soil was moist prior to irrigation on the 21st December and the bay surface was rough (dry pasture, $n = 0.30$ & 0.43). Less water infiltrated the soil and a large volume took longer to runoff (Figure 37).
- The soil was dry prior to irrigation on the 10th March and the bay surface was smooth (bare earth, $n = 0.10$). More water infiltrated the soil and a smaller volume ran off quickly (Figure 37).

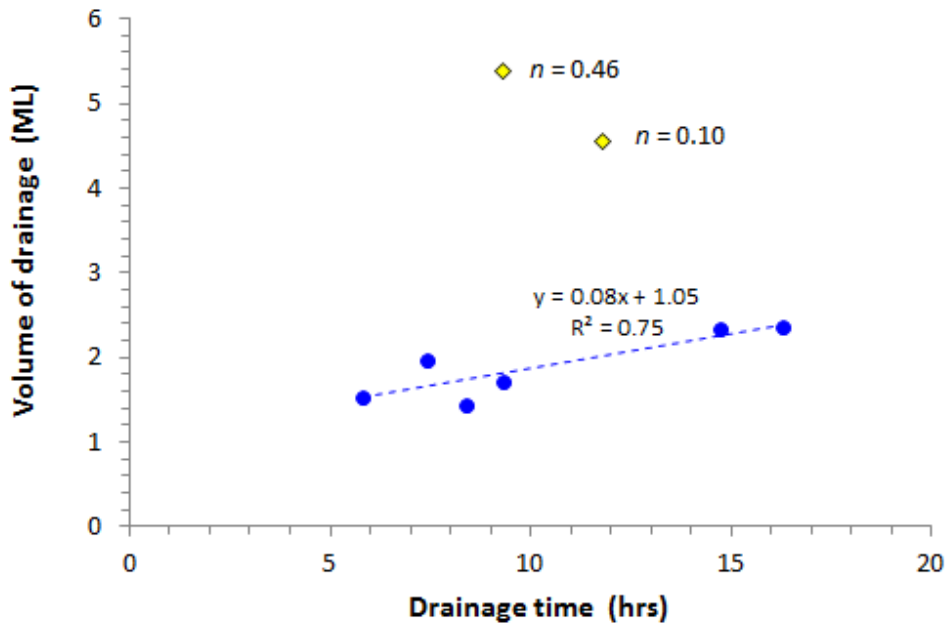


Figure 37. The relationship between time taken to drain parallel contour bays (Deniliquin) and the volume of drainage when bays are individually supplied and drained (blue circles). For comparison, the greater volume of water to be drained from bays when they are watered and drained through a side-ditch is shown by the yellow diamonds. The n values (estimated Manning's roughness coefficient) for the two side-ditch irrigated/drained events illustrate how drainage time is dependent on downstream conditions in these systems, rather than on roughness (and slope) in the draining bays.

Table 20. Summary of results from the data collected during the irrigation evaluations in the parallel contour system at Deniliquin.

Delivery infrastructure	Soil moisture	Flow rate	Roughness	Drainage	Bay	Date	Volume on (ML)	Volume off (ML)	Total Depth Applied (mm)	Depth Applied during advance (mm)	Estimated Manning's <i>n</i>	Advance time (hrs)	Drainage time (hrs)	Opportunity time (hrs)
Side-ditch delivery and drain	Dry Soil	15 ML/day from scheme supply but varying flow into Bays	Med - low	Obstructed	3	9-Dec-16	11.95	7.44	125	78	0.40	13.4	20.3	33.8
			Med - high	Unobstructed	4		7.44	4.54	80	80	0.46	8.5	11.8	20.3
	Wet soil		Low	Obstructed	3	18-Apr-16	8.93	7.14	49	39	0.09	4.6	13.3	18.2
				Unobstructed	4		7.14	5.37	49	n/a	n/a	4.8	9.3	14.3
	Low		Obstructed	3	21-Mar-17	24.41	22.25	60	50	0.06	4.9	38	43.1	
				4		22.25	20.34	53		4.5	34.5	39.2		
Individual supply - drain	Dry Soil	15	Low	Unobstructed	3	10-Mar-17	4.92	1.53	94	74	0.10	8.1	5.8	14.1
					4		4.8	1.45	93	70	0.10	7.6	8.4	16.0
	Wet soil	15	Med - Low		3	21-Dec-16	4.58	2.37	61	28	0.30	7.3	16.3	24.8
			Med - High		4		5.28	2.34	81	36	0.43	9.9	14.7	25.2
	Low	7	Very high		3	10-Apr-17	4.83	1.97	79			7.6	7.4	15.2
					4		3.64	1.72	53			12.3	9.3	21.6
	3	8-Sep-17												

5.3.4 Surface roughness and infiltration parameters

From the field data obtained from the contour system at Deniliquin, it was possible to identify the better infiltration model to use in calibrating the Kostiakov parameters: IPARM or SISCO.

Prior to calibration, a literature review was conducted to provide a database for comparison. The range of Kostiakov parameters reported for a range of major soil groups found on the Riverine Plain of south-eastern Australia are shown in Table 21. The effect of antecedent moisture conditions on the infiltration characteristic is clearly seen, with “first” irrigations of dry soil having markedly different Kostiakov parameters.

Table 21. Previously reported modified Kostiakov parameters for the three major soil groups on the Riverine Plain of south-eastern Australia that are found under basin systems in southern NSW. Data is from Hume (1993) – Deniliquin; Maheshwari and Jayawardane (1992) – Kerang, Shepparton and Griffith; and Hornbuckle (1999) – Kooba.

Site	Soil type	Irrigation Features		Modified Kostiakov Parameters			
		Season	No. of Irrig's	K (mm/min ^a)	a	f _o (mm/min)	C (mm)
Deniliquin	TRBE	Autumn (1 st irrig'n)	2	7.9 (4.9-10.9)	0.62 (0.6-0.64)	0	-
		Spring (after winter)	5	36.4 (23.9-48)	0.12 (0.06-0.2)	0	-
		Summer (not 1 st irrig'n)	3	32.1 (24.8-41)	0.12 (0.05-0.19)	0	-
Kerang/ Mitchell	SMC	-	4	34.8 (19-48.4)	0.04 (0.00-0.07)	0.09 (0.05-0.12)	-
Kerang/ KARF	SMC	-	18	54.6 (15.3-104.1)	0.02 (0.00-0.06)	0.01 (0.00-0.08)	-
Shepparton	RBE	-	4	10.6 (4.5-17.5)	0.17 (0.01-0.35)	0.05 (0.00-0.10)	-
Griffith	TRBE	-	18	55.8 (25.4-93.6)	0.01 (0.00-0.02)	0.01 (0.00-0.10)	-
Kooba	SMC, Deep Water Table	-	-	50 (10-310)	0.34 (0.06-0.47)	0	-
		1 st irrig'n	-	60	0.25	0.00	-
		Later irrig'n	-	20	0.33	0.00	-

The IPARM infiltration model is based on volume balance and is constructed by applying the principle of mass continuity to the flow of water within an irrigated furrow, border or basin [Gillies (2008), Chapter 4]. It states that the volume of water applied to the field, calculated by multiplying the constant inflow rate Q_0 (m³/min) by elapsed irrigation time t (min) must equal the sum of the volume temporally stored on the soil surface V_s (m³) and the volume infiltrated V_i . Over time, the leading edge of the water front x (m), described by the term “advance” moves down the furrow and eventually reaches the end of the field L (m), at which point the runoff term V_R (m³) is added to the equation (Equation 1):

$$Q_0 t = V_i + V_s + V_g \quad (1)$$

The Modified Kostiakov equation (Equation 2) is commonly used to describe the cumulative infiltrated depth at a given opportunity time (τ):

$$Z = k\tau^a + f_o\tau + C \quad (2)$$

where Z is the cumulative depth of infiltration, τ is the opportunity time, k and a are empirical infiltration parameters, f_o is a semi-empirical steady state infiltration parameter and C represents the crack infiltration term.

IPARM was applied to estimate the infiltration parameters using advance and inflow data. Different scenarios were investigated to obtain the modified Kostiakov parameters based on the field data obtained from the Deniliquin trial site (Table 22).

Table 22. Parameters of the modified Kostiakov equation obtained using IPARM for four separate irrigations in the parallel contour basin system at the Deniliquin trial site (red brown earth, sodic sub-soil; bay 410 m long; shape factor (k) = 0.77)

Scenario	Field & bay	Hydraulic Characteristics			Modified Kostiakov Parameters			
		Depth at inlet (mm)	Inflow (L/s/m)	Mannings n (s/m ^{1/3})	K (mm/min ^a)	a	f_o (mm/min)	C (mm)
#1	F2-B3	50	2.99	0.03	50.22	0.19	0.00	0.00
#2	F2-B3	70	3.14	0.04	41.55	0.21	0.00	0.00
#3	F2-B4	74	2.99	0.01	21.59	0.33	0.00	0.00
#4	F2-B4	84	2.66	0.01	18.88	0.24	0.07	0.00

IPARM was found to have a number of limitations. The reliance of IPARM on the volume balance model restricts its ability to function under non-standard furrow irrigation Gillies (2008). The surface storage approximation functions best under normal flow conditions. Hence, the model will not function correctly for fields with zero or reverse grades. Under very low grades (i.e. $S_0 < 0.0001$), the approximation of Manning's n will fail to provide realistic values of the upstream cross-sectional area under such extreme shallow grades. Additionally, Manning's n is not calibrated in IPARM so any errors in estimating n are accrued into the estimation of the Kostiakov parameters.

In contrast to IPARM, the SISCO model applies the full hydrodynamic equations for the calibration and optimisation of both the infiltration parameters and the Manning's roughness. A further advantage of SISCO is that the model allows the use of a variable depth at the inlet end of the bay (IPARM only accepts steady inflow depth). This is consistent with the behaviour of basin systems as there is no slope in the direction of water advance so the head of water at the inlet end of the bay must rise for water to advance along the bay. Thus, unlike IPARM, SISCO takes advantage of the entire suite of field data collected in the calibration process and provides a better simulation of irrigation in basins with zero slope.

The calibrated Kostiakov parameters obtained using the SISCO model are shown in Table 23. The Kostiakov parameters in SISCO were more consistent with the figures found in the literature (Table 24). Thus, infiltration parameters generated by SISCO were used for modelling both single and connected basin systems. A comparison of SISCO results and

literature figures on modified Kostiakov parameters in Summer and Autumn seasons can be seen in Table 24.

Table 23. Results of single basin modelling using SISCO - Final and Calibrated Kostiakov Parameters.

Site Name	Irrigation Features		Modified Kostiakov Parameters				Roughness
	Season	Irrigation no.	K (mm/min ^a)	a	f _o (mm/min)	C (mm)	Manning's n (s/m ^{1/3})
Deniliquin F2-B3	Spring	2 nd irrigation	34.96	0.16	0.00	0.00	0.23
		3 rd irrigation	12.27	0.16	0.00	0.00	0.22
Deniliquin F2-B4	Spring	2 nd irrigation	13.87	0.32	0.00	0.00	0.34
		3 rd irrigation	8.96	0.24	0.00	0.00	0.29
#Average (Calibrated by SISCO)			24.42	0.24	0.00	0.00	0.285

Table 24. Comparison of SISCO and literature values of the modified Kostiakov parameters for irrigations of “moist” soil (Spring) and of “dry” soil (Autumn) for the transitional red-brown earth at Deniliquin.

Site Name	Irrigation Features		Modified Kostiakov Parameters				Roughness
	Season	Number of irrigations	K (mm/min ^a)	a	f _o (mm/min)	C (mm)	Manning's n (s/m ^{1/3})
Hume (1993)	Spring	3	32.10 (24.80- 41.00)	0.12 (0.05- 0.19)	0.00	0.00	n/a
Deniliquin	Spring	4	24.42	0.24	0.00	0.00	0.285
Hume (1993)	Autumn	2	7.9 (4.90-10.9)	0.62 (0.6- 0.64)	0.00	0.00	n/a
Deniliquin	Autumn	1	11.31	0.00	0.26	0.61	0.34

5.3.5 Modelling to determine key design parameters

5.3.5.1 Basin size for flow rate and soil type: single basin

Design curves to optimise bay size for flow rate and soil type were obtained using WinSRFR for bay unit widths in the following three representative basin “types”:

1. Contour bays with no slope in the advance direction, slope across the bay of 1:2000, and surface roughness of 0.285.
2. V-bays with no slope in the advance direction, side fall to the centre axis of 1:1500 and surface roughness of 0.15.
3. Terraced bed (i.e. level furrow) systems with zero slope in both directions, a furrow spacing of 2 m, furrows 500 mm deep with bottom and top widths of 130 and 740 mm respectively, and a surface roughness of 0.10 (i.e. bare earth).

Three flow rates were modelled for each the above three layout “types”

1. Low flow 1 L/s/m width = 7.8 ML/day for a 90 m wide bay
2. Medium flow 2 L/s/m width = 15.5 ML/day for a 90 m wide bay
3. High flow 3 L/s/m width = 23.3 ML/day for a 90 m wide bay

Three soil “types” were simulated in WinSRFR for each layout and flow rate combination:

1. Transitional red brown earth (TRBE), as found at the Deniliquin site, with a threshold soil moisture deficit of 60 mm.
2. Red brown earth (RBE), typical of the Griffith site in Table 21, with a threshold soil moisture deficit of 60 mm.
3. Self-mulching clay (SMC), typical of the Kooba site in Table 21, with a threshold soil moisture deficit of 80 mm.

The design curves from this modelling show the maximum bay length and the flow depth at the inlet for typical cut-off times for each system “type” (Figure 39). The outputs of the modelling were validated by comparing the measured flow depths at the inlet with the modelled flow depths. The correlation between measured and modelled depth hydrographs in Bay 3 of the parallel contour system at Deniliquin for the Irrigation on 21st Dec 2016 are shown in Figure 38.

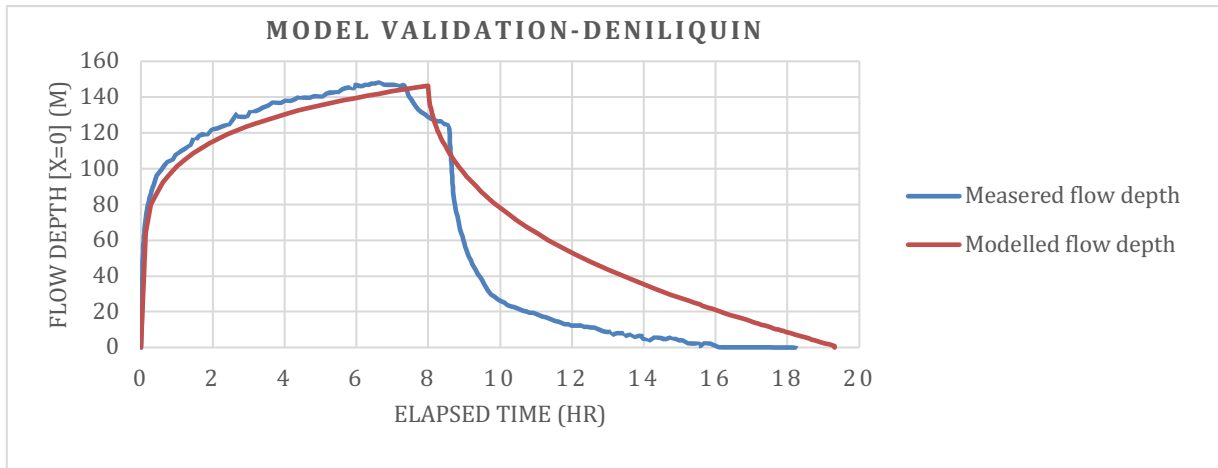


Figure 38. Measured and modelled (WinSRFR) depth hydrographs at the supply end of the Bay 3 in the parallel contour system at Deniliquin for the irrigation on the 21st December 2016.

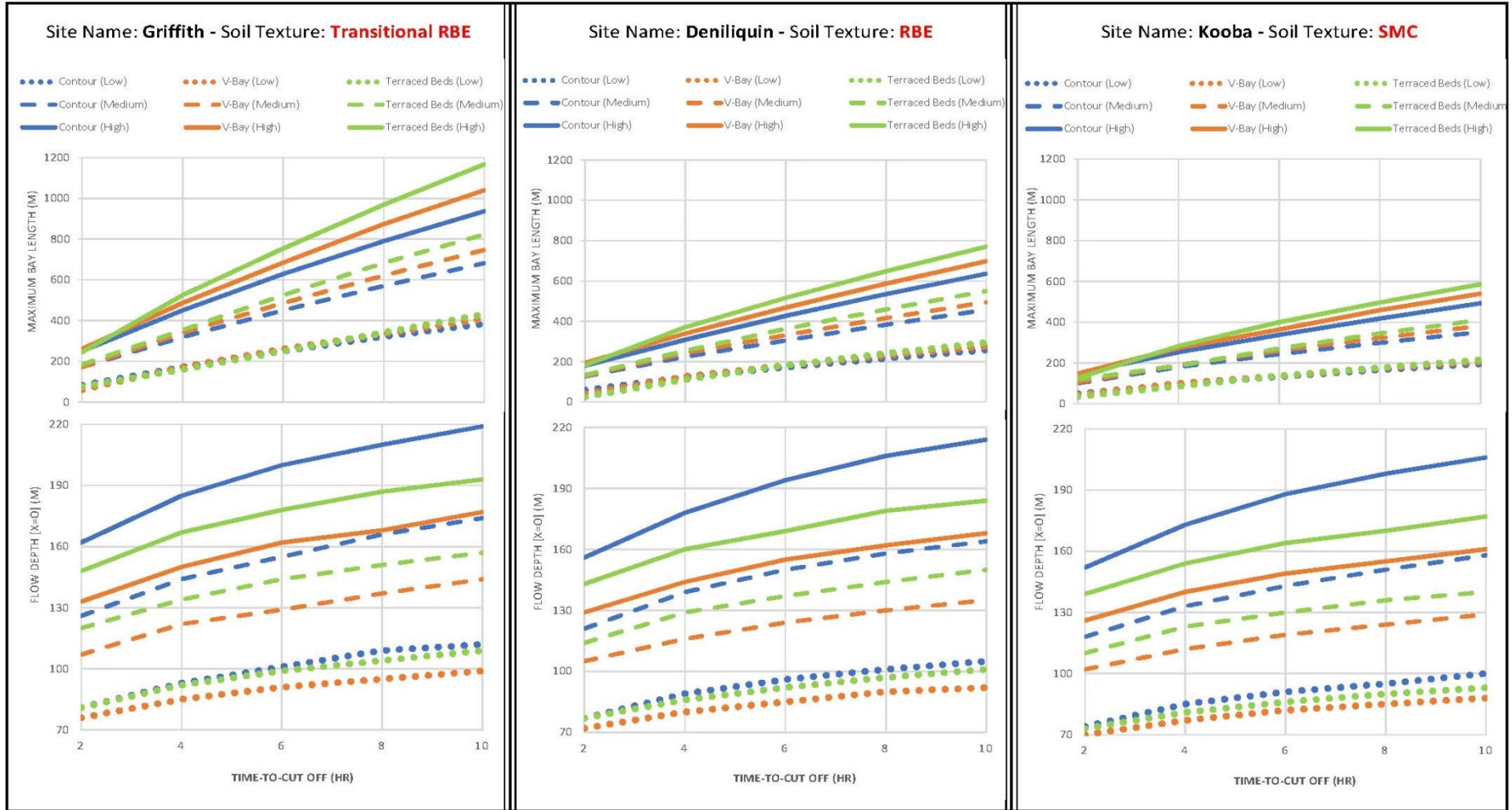


Figure 39. Design curves showing bay length and water depth at the inlet end of single basins from WinSRFR modelling. Curves are shown for each combination of three common basin types (Parallel Contour, V-Bay Contour and Level Furrow (Terraced Beds) systems), three soil types (TRBE = transitional red brown earth; RBE = red brown earth; SMC = self mulching clay) and three inflow rates (Low = 1 L/s/m width; Medium = 2 L/s/m width; High = 3 L/s/m width).

5.3.5.2 Minimum terrace step: connected basin

In basin systems supplied and drained using a side-ditch, drainage from a bay augments the supply to the adjoining downstream bay, increasing the inflow rate. However, as the water level rises in the lower bay this slows the recession in the higher bay by reducing the head differential across the control structure. This slows the inflow rate to the downstream bay.

Investigation and modelling of hydraulically connected basin systems has begun, with trials of the B2B model to assess its capabilities. The output from two model runs using B2B are shown in Figure 41 and Figure 42 and show the following two scenarios that have been run to evaluate the models limitations:

- a) Terraced beds in bays with “uneven” bay widths and level furrows.
- b) Terraced beds in bays with “even” bay widths and level furrows.

A medium flow rate (15 ML/day) and the infiltration parameters typical of a TRBE (Deniliquin, Table 21) were used for both scenarios.

Water depth at the inlet during irrigation of Bays 2,3 and 4 in the contour system at Deniliquin on the 21st December 2016 and water depths at the inlet in three bays of a level furrow system modelled by B2B are shown in Figure 40, Figure 41 and Figure 42, respectively. Although from different system “types”, they are useful for comparative purposes as they are both irrigated and drained using a side-ditch.

It can be seen that there is a degree of consistency between measured (Figure 40) and simulated (Figure 41 and Figure 42) water depth during the advance phase. However, the recession curve simulated by the B2B model is considerably different to the field observations. In the B2B simulation, all water runs off the bay without water backing up and impeding drainage to the point where the water depth in the draining bay starts to rise, which can be seen happening in Figure 40.

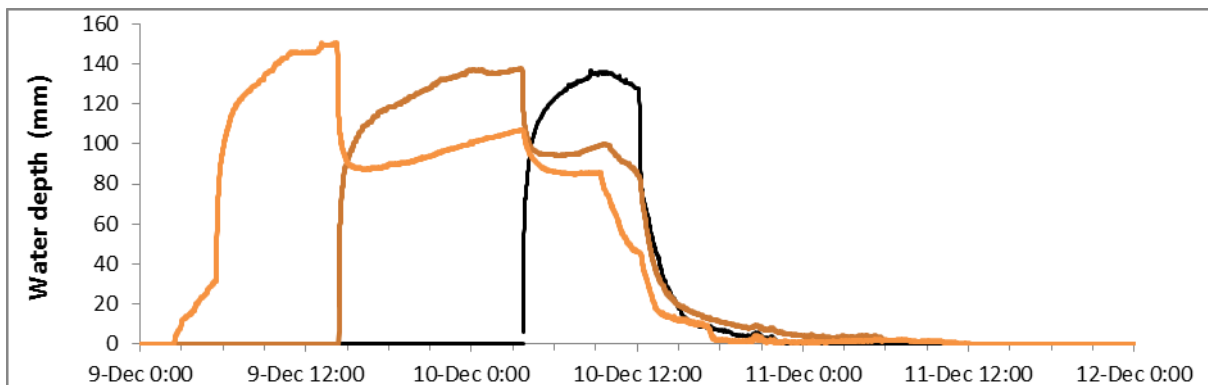


Figure 40: Depth hydrographs at the inlet end of bays 2, 3 and 4 of the parallel contour layout at Deniliquin during the irrigation on the 9th December 2016 when all bays were watered and drained using the side-ditch.

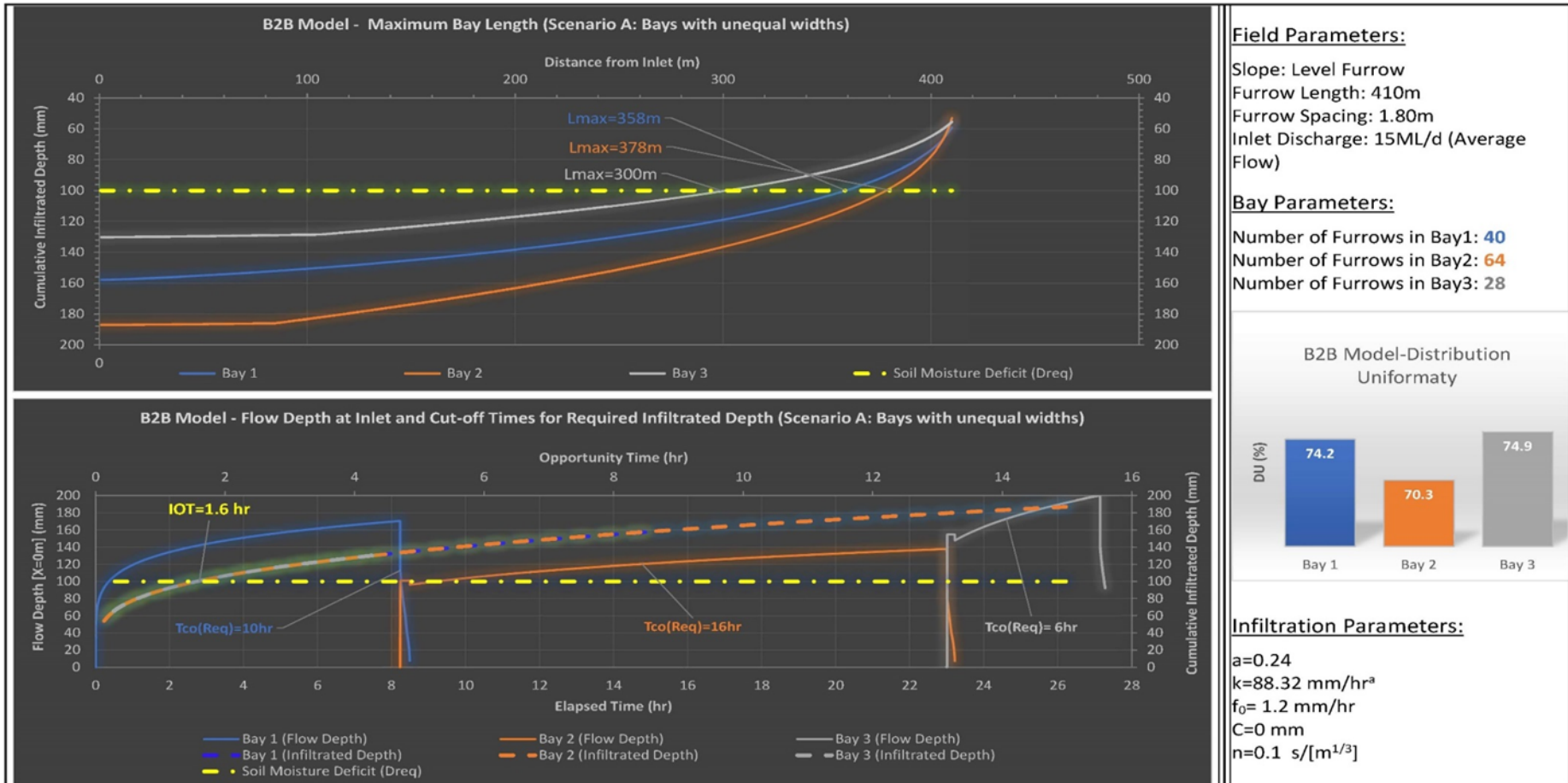


Figure 41: B2B Design Curves for Terraced Beds with bays of **unequal width** showing the maximum bay length for a given infiltrated depth (top) and the water height at the inlet in each of the three bays during the course of the simulated irrigation (bottom). The effect of the unequal bay sizes on the modelled distribution uniformity is seen in the bar graph to the right.

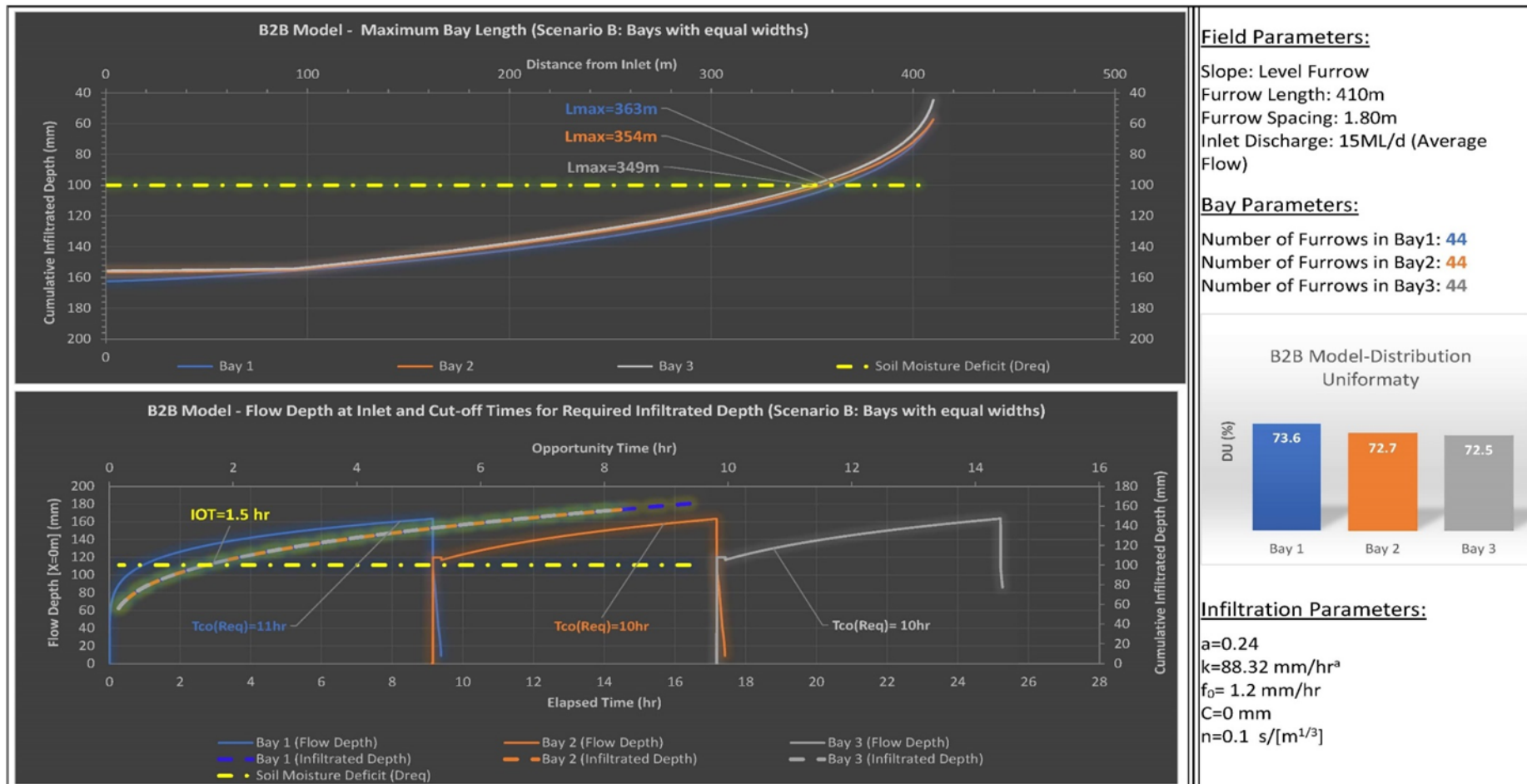


Figure 42: B2B Design Curves for Terraced Beds with bays of **equal width** showing the maximum bay length for a given infiltrated depth (top) and the water height at the inlet in each of the three bays during the course of the simulated irrigation (bottom).

5.4 Focus Area 4

Investigate the economic impact of investment in irrigation development on whole-farm profitability

5.4.1 Economic impact of the adoption of new surface irrigation development

Generally, the case studies are demonstrations of potential returns from either investment in irrigation infrastructure or investment in recommended layouts (Table 25). The marginal rates of return vary widely, this is due to the different levels of capital expenditure and the impact on the gross margin returns.

For all crops, water productivity within the irrigation system is improved with either improved irrigation efficiency or improved layout such as a terraced side-ditch. This influences the positive economic returns shown in the case studies.

Rice growers can change to terraced side-ditch layouts and double cropping farming systems and realise good returns. Growers can incorporate winter crops (wheat and canola) into their production system to gain an acceptable return on investment.

Investment in recommended layouts has been shown by the case study growers to both improve yields and reduce water use in cotton and maize production systems. These returns have been sufficient to gain acceptable marginal returns on capital investment in layout changes.

Table 25: Summary of the results from the economic analysis from the six case studies.

Case Study	Previous System Description	New System Description	Change & Benefit Description	Capital Cost & Area Developed	Average Gross Margin Net Benefit (Cost)	Marginal Return on Capital Invested	Discounted Cashflow Return (NPV at 7%)
Murrumbidgee 1	Furrow-Cotton / Winter Crop (F-Co/WC)	Furrow-Cotton / Winter Crop (F-Co/WC)	Automation and Earthworks Water logistic efficiency, more cotton area grown.	\$237,500 250 ha \$950/ha	\$195,429	66%	\$1,712,723
Murrumbidgee 2	Furrow-Maize (F-M) + Contour-Rice double crop (C-R/dc)	TerrBank-Cotton (TB-Co)	Change in layout. Labour efficient and machinery efficient	\$3,520,000 1600 ha \$2,200/ha	\$1,144,201	26%	\$3,879,822
Murray 1	Contour-Rice double crop (C-R/dc)	Contour-Rice double crop (C-R/dc) + TerrBank-Cotton / Maize (TB-Co/M)	Part change layout. New system allows more flexibility in crop rotations and crops that can be grown.	\$454,050 150 ha \$3,027/ha	\$129,097	23%	\$490,284
Murray 2	Contour-Rice / Winter Crop (C-R/WC)	TerrBank-Rice double crop (TB-R/dc)	Change in layout. More crops in shorter period, water use down	\$862,860 360 ha \$2,397/ha	\$150,564	14%	\$365,277
Victoria 1	BorChk-Maize / Winter Crop (BC-M/WC)	BorChk-Maize / Winter Crop (BC-M/WC)	Re-lasered, channel upgrades, bigger border check. More maize area, efficiency, yields up, water use down	\$1,210,000 550 ha \$2,200/ha	\$890,077	59%	\$6,358,422
Victoria 2	BorChk-Maize / Winter Crop (BC-M/WC)	BorChk-Maize / Winter Crop (BC-M/WC)	Re-lasered, total automation, infrastructure upgrades. More maize area, efficiency, yields up, water use down	\$675,000 250 ha \$2,700/ha	\$123,402	15%	\$754,071

6.0 Outcomes

6.1 Focus Area 1

Fostering collaboration and partnerships to facilitate the adoption of research findings

The Participatory Action Research methodology was beneficial for growers within the southern connected regions (discussed in Section 5.1). The PAR approach was also beneficial for the regions because it enabled the collaboration of research, development and extension skills across several organisations. The collaboration enabled a significant level of knowledge output from the project through farmer journals, newsletters, information sheets, workshop and field day presentations as well as scientific journal and conference papers (detailed in Section 8.2).

Growers in the Murrumbidgee Valley are eager to see the results from the longer irrigation deficit at the IREC key learning site to consider the impact of the irrigation deficit on lint yield and quality. The long irrigation deficit potentially exposes cotton to risk associated with prolonged and excessive heat that can occur during late January/early February. However, this regime may offer an irrigation management strategy in seasons with low water allocation.

The work at the ICC key learning site has highlighted issues with fast watering on lighter soil types. The co-operator at this site and one other grower have now adopted the short deficit irrigation used in the field experiment as their standard practice, as a direct result of the project's findings.

The work at the SG key learning site demonstrated that short season rice followed immediately with short season wheat did not provide sufficient time to enable grain harvest of the wheat. Alternative winter crop types with shorter growth durations, such as barley and canola, should be considered if production of grain is the desired outcome of the double cropping production system.

A new partnership between the NSW DPI and Deakin University, School of Engineering has commenced that will see the development of novel technology for improving surface irrigation management and performance once the current project determines optimal design parameters.

6.2 Focus Area 2

Investigate irrigation and nitrogen management strategies to improve water productivity in cotton, maize and rice farming systems

6.2.1 Key learning site 1

Grower group: Irrigation Research and Extension Committee, Whitton NSW.

Focus crop: cotton.

6.2.1.1 Experiment 1

Irrigation-nitrogen rate interaction

Treatment effects on crop N uptake and lint yield were observed according to irrigation deficit and fertiliser N rate separately. However, there was no interaction observed between crop N uptake and nitrogen rate regime. An 8% increase in yield was observed when the sub-surface drip system watered every day compared to every second day. Although reliable water use data was not available, the effect is likely caused by increased amounts of water application than differences in the frequency of irrigation. The sub-surface drip system did not perform sufficiently well enough to run the experiment as originally intended i.e to keep the total amount of water applied over the reproductive period constant whilst changing the irrigation frequency.

Overall, the two irrigation treatments were not sufficiently different enough to impose differences in soil conditions, such that plant demand for water and nutrients were met differently. These limitations were the reason for the experiment being discontinued at Whitton and moved to Point Farms, Darlington Point, NSW for the remaining 2 years of the project.

Using multi-spectral imagery from drone platforms as tools for cotton management

Although not within the main objectives of the project, remote sensing of N concentration in cotton by means of multispectral imagery from a drone was shown in experiment 1 and 2 to be possible. Information gained from this research established new insights into the use of these technologies for improved fertiliser management, growth regulation, defoliation applications and yield prediction.

Vegetation indices including information from the red-edge band (region between the red and near-infrared bands) such as NDRE and particularly SCCCI showed potential to track in-season cotton N concentration. SCCCI correlated well with petiole N content, highlighting the SCCCI measurements as an alternative method to determine the N status of the crop. However, results showed that the relationship between SCCCI and petiole N content can be affected by the plant water status this must be taken into consideration when attempting to use this methodology and requires further investigation.

SCCCI increased in the standard and long deficit treatments compared to the short irrigation deficit. The opposite was observed for NDVI, which is an index more related with plant biomass and can be affected by wilting and plant growth. These results, supported by the stomatal conductance measurements from the site, suggest that these vegetation indices could be used as plant water stress indicators. Further research is needed to better study

the reliability of vegetation indices to monitor water stress and the accuracy of using SCCC1 as a proxy for petiole N content.

6.2.1.2 Experiment 2

At this stage of the season, with all field experiments yet to have the final uptake, development and lint yield measurements taken, comprehensive conclusions cannot be made. However, the field experiments have provided the following indicative results.

More frequent surface irrigation (short deficit) during the flowering, fruit development and following the reproductive stage for SICOT 746 BRF Bollgard 3 cotton was found to increase crop biomass and lint yield production on a red brown earth soil type (*Chromosol*) in the Murrumbidgee Valley, NSW. In the highest yielding short interval treatment (~ 7 day interval), soil matric potential was -40 kPa at 23 cm soil depth immediately prior to irrigation.

Yield diminished as irrigation interval increased to 14 (standard deficit), and 19 days (long deficit) (-70kPa and -110 kPa). Comparison of yield between the three treatments indicated 8% higher yield and 9% lower yield in the short and long deficits respectively compared with the standard irrigation deficit.

Water use efficiency was marginally higher in the shorter deficit as a result of the yield increase. The data indicate that it may be advantageous to shorten irrigation intervals to 7 days during periods of high crop water demand.

The higher rate of fertiliser N (270 kg N ha⁻¹) increased yield by between 6–10% compared with a reduced rate (180 kg N ha⁻¹) with the greatest increases being seen in the short irrigation deficit, although with no statistical significance.

The standard practise of 14 day watering with the reduced rate of fertiliser is considered the most nitrogen efficient treatment with an internal NUE of 10.1.

The short deficit delayed maturity of the crop by approximately 4–10 days when compared to standard and longer deficits respectively and this extended out to 19 and 28 days to harvest due to repeated weekly rain events and overcast conditions throughout May, 2017.

Irrigation deficit affected micronaire, yellowness, maturity and moisture content of the lint although not to the extent of price penalties. Nitrogen and the interaction of the two factors had no effect on lint quality.

Irrigation practice at the site is not providing water logged conditions that would result in N loss.

6.2.2 Key Learning Site 2

Grower group: Southern Growers, Jerilderie, NSW

Focus crop: Rice

There was no yield loss when rice was grown on beds compared to the traditional flat surface layout. However, beds offered better drainage that allowed the soil to return to oxidised conditions sooner following drainage. The oxidised soil conditions provide better seedbed conditions for winter crops planted immediately following the rice crop.

Flush finishing rice post-flowering during the grain filling period improved soil oxidation compared to the standard practice of permanent water through to normal draining time. This has potential to improve establishment conditions for subsequent winter crops within the rice farming system. However, the impact on rice grain yield and quality requires further investigation due to potential yield loss risk. If the risk can be mitigated there could be potential yield improvements for crops sown straight after rice, increasing total water productivity in the cropping system.

6.2.3 Key Learning Site 3

Grower group: Irrigated Cropping Council, Numurkah, Victoria

Focus crop: Maize

In this particular soil type of Northern Victoria, which is a well-drained loam to clay loam, placing 75% of total crop N application up front provided productivity benefits with contrasting grain yield results from year to year for irrigation deficit.

Shorter irrigation deficits (5 days; -40 kPa) fully refilled the soil profile and provided some plant stress protection at critical reproductive growth stages when air temperatures were 38–40+ °C compared with standard 7 day irrigation frequency. However, using this strategy throughout the crop duration may increase water use and needs to be carefully managed.

The fast watering afforded by the flexibility of the automated irrigation system did not adequately refill the soil water when the standard irrigation deficit was used. The relationship between irrigation opportunity time and infiltration needs to be understood as new irrigation systems are developed that aim to maximise the efficiency of the water applied by minimising deep percolation and surface runoff. In this system the application of real-time logging of matric potential provided irrigation scheduling at an appropriate frequency, especially for the short irrigation deficit which equated to irrigation at approximate 5 day intervals.

The study has provided practical opportunities for farmers to learn how an automated surface irrigation system with border check layout in maize can potentially be run differently from year to year according to seasonal conditions to provide more consistent long term production.

6.3 Focus Area 3

Develop best practice design guidelines for basin surface irrigation

Systems

The review and evaluation of available hydraulic models found:

1. SISCO was the only model which could simulate a rising head of water at the inlet end of the bay as well as a variable inflow rate. It was used with the field data to determine infiltration characteristics and surface roughness.

2. WinSRFR was the only model capable of simulating zero slope in all the basin types examined. It was used to determine the most appropriate bay size for a given flow rate and soil type.
3. B2B was the only model capable of simulating linked bays. It was used to determine the minimum slope for side-ditch systems.

Infiltration parameters and surface roughness values of soils typically found under basin systems in southern NSW were determined. Further work is required to validate the use of these values for designing basin layouts and to provide greater confidence in recommendations.

Design curves for determining the bay size for a given inflow rate and soil type were obtained using WinSRFR modelling. Further work is required to:

1. Simulate the recession phase in typical basin systems so that recommendations can be made based on a total opportunity time.
2. Validate the WinSRFR model outputs using a separate dataset from that used to calibrate it.

A key finding from the modelling of single basins is that advance and recession need to be modelled separately in these systems. This is because advance is determined by inflow rate and surface roughness along the long axis of bays, whereas recession is determined by slope and roughness across the width of bays.

The other key outcome was confirmation of the hydraulic connection between bays that occurs through side-ditches on flat grades (< 1:1000) and the effect this has in prolonging drainage times and reducing control over application depths.

Flows into basins connected through a side-ditch were successfully simulated using the B2B model. However, there is a significant difference between measured and simulated drainage in these systems. This is attributed to the assumptions in the model regarding the calculation of discharge during the recession phase and assumptions of a level water surface and free drainage from the bay. Further work is required to specifically target this aspect of the B2B model and improve it so that it can be used to determine minimum paddock slopes where drainage is not impeded in side-ditch systems.

Other key areas in which additional research into the B2B model and simulating side-ditch systems is required include:

1. Extension of the B2B model to accommodate alternative interconnecting structures;
2. Development of methods for measuring discharge recession;
3. Extension of the B2B model to accommodate other bay surface configurations (i.e. contour and V-bay).

6.4 Focus Area 4

Investigate the economic impact of investment in irrigation development on whole-farm profitability

The case studies show that economic returns can be positive from investment in either improved irrigation layout or improved irrigation infrastructure.

However, individual development and financial plans are essential for each case before investing in any capital development. The marginal rates of return vary widely, this is due to the different levels of capital expenditure and the impact of this on the gross margin returns.

For all crops, water productivity within the irrigation system is improved with either improved irrigation efficiency or improved layout such as terraced bankless. This influences the positive economic returns shown in the case studies.

The results are likely to be different for farms with markedly different resources or enterprise rotations to those of the representative case study farms. Growers should analyse their own set of resources and the best case for change for their individual circumstances. This also includes implications for tax and available rebates and grants for the development options being considered. The optimal development investment and timeline is an individual business decision and advice from finance professionals and financiers should be considered early in the planning stages.

7.0 Conclusion

7.1 Collaboration, communication and adoption

In total seven grower group and extension organisations were brought together by this project. The collaborators included IREC, ICC, SG, CottonInfo, Murray Local Land Services, Rice Extension and Riverina Local Land Services. All were involved in the planning of project activities ensuring relevance for their respective industries.

This collaboration also created a direct pathway for the presentation and dissemination of project results from project field experiments.

Functional and productive collaboration between research, extension, grower groups and industry has been a key outcome of this project. Each of the organisations involved are expected to seek opportunities to continue these relationships and build on the achievements established within the project.

As a result of these field days and tours, a small number of growers from the Riverina, northern NSW and northern Victoria have changed irrigation layouts and installed automated surface irrigation systems, with plans to convert more of their irrigation layouts.

In northern Victoria two growers have changed their irrigation management and nitrogen application in maize production. The changes have resulted in greater profitability through increased yields due to improved nitrogen use efficiency and plant health.

In southern NSW irrigators have installed raised beds and are exploring double cropping options in rice. Raised beds are essential in the double cropping program as they assist with winter drainage. Whole farm profitability is increased by growing three crops in two years.

7.2 Plant and management interactions

Irrigation and nitrogen management in irrigated cotton

Shortening the irrigation interval and increasing the application of fertiliser N applied to the crop produced significant increases in lint yield. However, direct increases in crop profitability were not realised due to complex interactions with the development of the crop. These interactions delay the harvest maturity of the crop and increase the risk of encountering fewer daily hours of favourable harvesting conditions as well as a higher risk of wet weather during harvest which could potentially impact the ginning process.

Double cropping in a rice farming system

Double cropping has the potential to improve water productivity in rice farming systems, but further work is required to find:

- more suitable, short(er) season winter crops and varieties
- easier, quicker and lower cost methods of dealing with high rice stubble loads to allow timely sowing of the winter crop
- the feasibility of seeding a winter crop/pasture into a flush irrigated rice crop prior to rice harvest.

Manipulation of rice water management, by early drainage of permanent water, and flushing water to maintain soil water near field capacity, returned the soil to aerobic conditions earlier

than conventional end-of-season water management. These conditions are more favourable for the establishment and growth of subsequent winter crops. However this water management regime comes with a risk for grain yield loss in the rice crop and, therefore, requires further investigation before such a management practice can be recommended.

Beds within rice bays offered better drainage that returned the upper layers of the soil profile to aerobic conditions suitable for winter cropping earlier than conventional flat-surface layouts.

The ability to supply adequate crop nutrition, particularly nitrogen and phosphorus, following a rice crop, remains a significant issue to overcome in order to maximise the return from the winter crop and thereby maximise water productivity in rice farming systems.

Irrigation and nitrogen management in irrigated maize

Reducing the irrigation deficit on red soils to between -20 to -40 kPa, and applying the majority of fertiliser-N prior to planting, can improve maize grain yield and profitability.

7.3 Hydrology for improved basin irrigation design

Field data showed that opportunity times of 30–40 hours are common in commercial, side-ditch basin systems on flat terrain (slopes < 1:1000). Eliminating the hydraulic connection between bays, which occurs through the side-ditch and watering and draining bays, cut opportunity times to around 15 hours and reduced water run-off volumes by 65%.

The WinSRFR hydraulic model was used to produce design charts for single basins. Maximum irrigation bay size (i.e. length) was determined for irrigation events with cut-off times of 2, 4, 6, 8 and 10 hours for high, medium and low flow rates on three common soil types. The model outputs were validated using the field data collected from commercial fields.

The B2B showed the variability in application depth between bays and the lack of precision inherent in side-ditch systems. However, further development of the model is required as it does not simulate recession in inter-connected, side-ditch systems. When completed, B2B will be used to determine minimum paddock slopes (i.e. the terrace step) for a range of bay size, storage volume, soil type and roughness combinations. The model will provide additional detail to the field data which demonstrated a minimum terrace of 150 mm was needed to ensure unimpeded drainage in side-ditch systems.

7.4 Economics of system modernisation

Water productivity in irrigated rice, cotton and maize crops, is increased by both improved irrigation infrastructure or improved layout, for example through the implementation of a terraced side-ditch system. Positive economic returns demonstrated in project case studies were influenced by reduced water use and therefore lower water costs, or higher yields achieved with the same or less total water use.

The project demonstrated that changing to a terraced side-ditch layout and double cropping can realise good returns for rice growers. Production systems can be modified to target the most suitable soil types, and additionally growers can incorporate winter crops (e.g. wheat

and canola) into their production system through double cropping to gain an acceptable return on investment.

For cotton and maize growers, the case studies showed that investment in recommended layouts can both improve yields and reduce water use resulting in acceptable marginal returns on capital investment.

8.0 Extension opportunities

8.1 Recommendations for future work

- Coordinated investment allowing a farming system approach, and the involvement of research and development agencies directly with grower groups, should be continued to maintain scientific intellectual capacity within southern connected regions.
- The impact of system flexibility on plant development, and yield and system profitability, resulting from automating irrigation management, needs to be further understood.
- Further investigation is needed into the risks in rice farming systems associated with changes to water management, suitable crop and variety options for double cropping, and the implications for improved water productivity.
- Development of autonomous irrigation offers further improvement in water productivity and the suitability of various autonomous irrigation options needs to be investigated for each of the farming systems within the southern connected regions.

8.2 Media and communications material

8.2.1 Farmer journals and newsletters

IREC Farmers' Newsletter 194 Autumn 2016 – [Introduction to the Maximising on-farm irrigation profitability project](#)

IREC Farmers' Newsletter 194 Autumn 2016 – [Field Station update](#)

ICC Newsletter Autumn 2016 – Introduction to the Maximising on-farm irrigation profitability project

IREC Farmers' Newsletter 195 Rice R&D Edition 2016 – [New tools for measuring and managing variability](#)

IREC Farmers' Newsletter No 196 Summer 2016 – [Remote sensing of nitrogen status in cotton](#)

IREC Farmers' Newsletter No 196 Summer 2016 – [Lifting maize yield with new management practices](#)

Upstream News IREC e-newsletter, [January 2017](#) – Maximising on-farm irrigation profitability project update

ICC Newsletter Autumn 2017 – Lifting maize yields with new management practices

IREC Farmers' Newsletter 197 Autumn 2017 – [Exposure to northern irrigation research and farms](#)

Southern Growers Newsletter, June 2017 - [Maximising on-farm irrigation profitability](#)

IREC Farmers' Newsletter 198 Spring 2017 – [Maximising on-farm irrigation profitability](#)

IREC Farmers' Newsletter 199 Autumn 2018 – [Ideas and exchanges from irrigators in the north](#)

8.2.2 Workshop and Field day presentations

Rice R&D Update August 2015 – Introduction to the Maximising on-farm irrigation profitability project

IREC Field Station Field Day April 2016, IREC Key Learning Site (Plate 6)

GRDC Update - Griffith, July 2016: Using satellites and drones for water and nitrogen decision making.

GRDC Update - Moama, July 2016: The impact of irrigation and N management on N uptake and yield in maize.

GRDC Update - Moama, July 2016: Using satellites and drones for water and nitrogen decision making

PA Workshop, Driving productivity on your farm - Griffith, July 2016: Remote sensing paddock analysis through drones, satellites and wireless technology

Rice R&D Update – Yanco, August 2016: Tools for managing and measuring variability.

Rice R&D Update - Yanco, August 2016: The impact of irrigation field layout and water management on soil redox

Southern cotton research review meeting – September 2016: The impact of irrigation management and N rate on N uptake and lint yield in irrigated cotton

ICC Field Day ICC variety Field Site, October 2016: Drones for irrigation and nutrient management.

2017 Maximising On-Farm Irrigation Profitability Northern Tour

2017 Smarter Irrigation for Profit: Maximising Irrigation Profitability Farm Walk: IREC KLS Field Day - Point Farms (Plate 7).

2017 Exploring how to Increase Irrigated Cropping Profitability, September 27 – Southern Growers Field day

Southern cotton research review meeting - September 2017: The impact of irrigation management and N rate on N uptake and lint yield in irrigated cotton

2017 ICC Field day

The Optimising Irrigation and Nitrogen Research Tour, CottonInfo – February 2018.

2018 Maximising On-Farm Irrigation Profitability Northern Tour.

2018 Southern Growers Summer Crop Options and Systems Field Day – March 8



Plate 6: Field Day participants hearing all about the Maximising On-Farm Irrigation Profitability project at the 2016 IREC Field Station Field Day (photo Iva Quarisa).



Plate 7: Inspecting the cotton during the 2017 Smarter Irrigation for Profit: Maximising Irrigation Profitability Farm Walk at the IREC Key Learning Site Field Day Point Farms (photo Iva Quarisa).

8.2.3 Scientific Journal and conference papers:

Irrigation Australia Limited international conference and exhibition. 24th May 2016 – Maximising on-farm irrigation profitability.

Ballester, Carlos, Hornbuckle, John, Brinkhoff, James, Smith, John and Quayle, Wendy 2017, Assessment of in-season cotton nitrogen status and lint yield prediction from unmanned aerial system imagery, Remote sensing, vol. 9, no. 11, pp. 1-18, doi: 10.3390/rs9111149.

J. Brinkhoff, J. Hornbuckle, W. Quayle, C. Ballester-Lurbe and T. Dowling, "WiField, an IEEE 802.11-based agricultural sensor data gathering and logging platform," Submitted to the International Conference on Sensing Technology, 2017.

North SH, Brinkhoff J and Quayle W (2017) Continuous monitoring of soil redox to compare layouts for post rice crops. International Temperate Rice Conference, 7–8 March 2017, Griffith NSW. <http://www.itrconference.com/f.ashx/Oral-Abstracts/Sam-North-Continuous-Monitoring-of-Soil-Redox-Potential-to-Compare-Layouts-for-Post.pdf>

Quayle, W.C. Hill, J., Ballester, C. Smith, J., Brinkhoff, J. Hornbuckle, J. (2017) Irrigation nitrogen interactions in southern cotton. Cotton Research Conference, 15-17 September, 2017, Canberra. https://www.conferenceonline.com/site_templet/images/group0/site70/ConferenceBook2017_Small.pdf

Zoriatseyan N, North S and Chua L (2018) Modelling of basin surface irrigation systems in the southern Murray-Darling basin to develop design guidelines. Irrigation Australia Ltd Conference, 13-15 June 2018, Sydney (in press)

8.2.4 Information Sheets and flyers

North S (2018) Growing wheat straight after rice. Primefact 1617. NSW DPI, Orange.

Smarter Irrigation for Profit - Maximising Irrigation Profitability Fact Sheet.

Crop 4 Profit and PISC Meeting Delegates 22nd March, 2017 – one page flyer.

8.2.5 Social Media

Over 100 Facebook and Twitter posts were made by IREC, ICC, Southern Growers & Deakin University CeRRF with over 2070 Twitter followers and over 600 Facebook likes combined.

Examples of the social media posts during project events and photos from events are provided in Plate 8 to Plate 11.



IREC @IRECNSW · 7 Feb 2017

Southern valleys well represented @GwydirValley irrigation research field day on maximising irrigation profitability tour



3 9

Plate 8: Social media post during one of the farm visits that formed the basis of the 2017 Maximising on-farm irrigation profitability project northern NSW farm tour.



CeRRF_Griffith @CeRRF_Griffith · 8 Feb 2017

Working with a good looking corn crop in Northern VIC Short irrigation schedule, 60% fert upfront @IrrigatedCC @mollerpeter #cropforprofit



2 7

Plate 9: Social media post highlighting the activities at the Irrigated Cropping Council Key Learning Site in northern Victoria. Source: Deakin University Centre for Rural and Regional Futures.

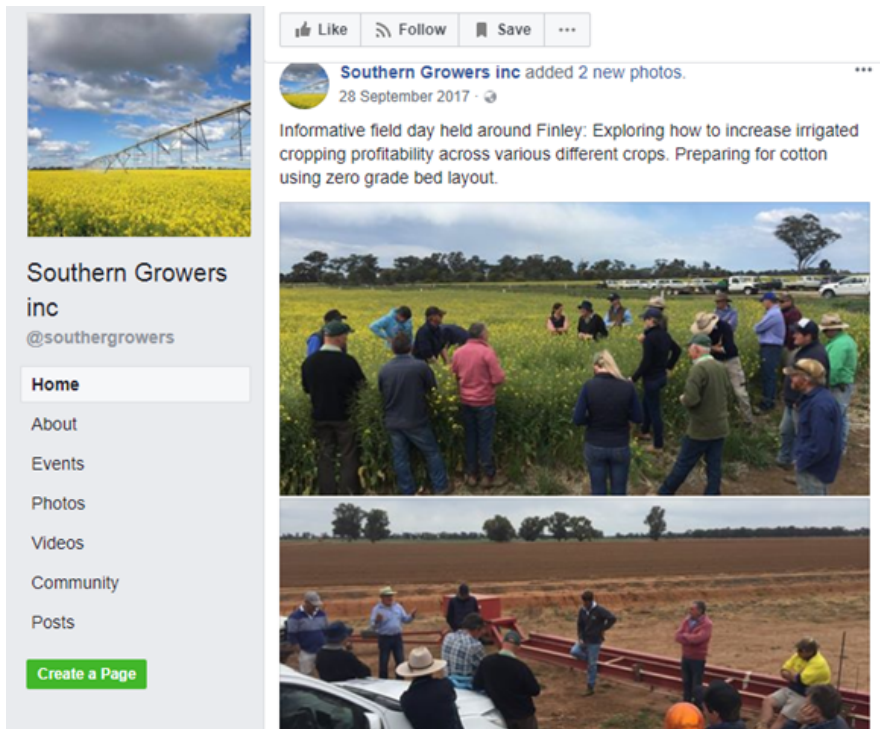


Plate 10: Social media pots during the Southern Growers field day that included their Maximising on-farm irrigation profitability key learning site.



Plate 11: Irrigated Cropping Council twitter post from their 2017 crop walk that included their Maximising on-farm irrigation profitability key learning site.

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10.0 Executive Summary

Farmers manage about 4000 gigalitres (GL) of water diverted for irrigation in the connected systems of southern NSW and northern Victoria. Profitability on irrigation farms is primarily determined by the income the farmer is able to generate from each megalitre (ML) of water accessed and the management of the costs associated with water use and other inputs including nutrients, labour and capital.

Water is the most limiting resource for all irrigation industries including the cotton, rice, grains and dairy sectors. More effective utilisation of the water resource will increase farm profitability and productivity per megalitre of water. Improving water management and water and nutrient productivity through the adoption of better designed and more flexible irrigation layouts will help to improve the economic viability of the irrigation sector.

This research project was undertaken in response to a priority focus identified by three grower groups, the Irrigated Research and Extension Committee (IREC), the Irrigated Cropping Council (ICC) and Southern Growers (SG). The grower groups, who have a combined membership of approximately 900 irrigation farmers, identified that improving the efficiency and flexibility of broadacre irrigation systems was crucial to maximising profitability.

These broadacre irrigators are seeking alternative irrigation systems that are labour, water and energy efficient and increase the productivity of each megalitre of water used. However, the systems must retain the advantages of existing systems (low capital and energy requirements), while allowing for faster watering (decreasing accessions and increasing water productivity) and better drainage (decreasing waterlogging and improving crop productivity).

The objective of the project was to develop profitable, sustainable broadacre irrigation systems that increase the profitability and flexibility of farming systems in the southern connected regions of the Murray Darling Basin (MDB).

To realise this objective, the project was divided into four focus areas:

- 1) working with growers in Participatory Action Research to prioritise research direction, inform project activities, and provide a pathway for extension
- 2) assessing the ability to apply defined irrigation depths with scheduled application, and determining the potential of precision irrigation to reduce deep drainage and waterlogging risks, while increasing nutrient and water productivity in broadacre surface irrigation systems
- 3) developing irrigation design criteria to enable the use of precision irrigation in basin surface irrigation systems
- 4) investigating the economic impact of irrigation system and infrastructure redevelopment on whole farm profitability and return on investment

The project was a collaboration between two key research organisations, NSW Department of Primary Industries and Deakin University Centre for Rural and Regional Futures, and three grower groups, IREC, ICC and SG, located within the southern connected systems of the Murray Darling Basin. A participatory action research approach was used by the project proponents, with a steering committee comprised of representatives from the three grower groups, extension organisations (Murray and Riverina Local Land Services), industries within the region (rice, cotton and grains), and the research team. The steering committee

determined the research priorities, ensured the relevance of the research, and assisted in the communication of research findings.

Large scale field research experiments were conducted at Key Learning Sites (KLS) that were established in connection with each of the grower groups. The sites were located with IREC in the Murrumbidgee Irrigation Area (MIA) targeting irrigation and nitrogen management in cotton, with Southern Growers in the Murray Valley (MV) of NSW targeting double cropping in rice farming systems, and with ICC in northern Victoria focusing on irrigation and nitrogen management in maize grown in an automated border-check surface irrigation system.

The differences in each of the KLS ensured an appropriate mix of irrigation layouts, crops and soils types were examined providing growers in each location with relevant research.

Best practice recommendations do not exist for the basin irrigation systems currently being developed by irrigation farmers. Matching bay size to a given inflow rate and soil type, and determining the minimum field slope for a specific bay size, surface geometry, inflow rate and surface roughness, are two critical design considerations to ensure that new irrigation developments allow more precise application of irrigation water. A modelling approach (with initial outputs compared to field data collected across a range of basin systems and soil types) was adopted because it is too costly and impractical to evaluate the range of irrigation systems necessary to answer these two questions using field studies.

The aim of the economic component of the project was to determine the benefits compared to the disadvantages of investing in new irrigation development. Detailed financial information was collected across six case study farms (two with each grower group involved in the project), to enable gross margin, whole farm returns, marginal rate of return on capital investment, and discounted cash flow benefit (cost) financial analyses of each of the irrigation developments investigated by this project. . Three of the case studies involved changes from a side-ditch delivery contour layout to either a terraced bankless layout or a border check layout. The other three case studies retained the existing layouts (furrow or border check) but invested in efficiency gains such as channel improvements and automation.

The cotton (MIA, IREC) and maize (northern Victoria, ICC) sites focused on the interaction between irrigation and nitrogen (N) management in siphon and automated border check surface irrigation systems, although with varying aims. Different irrigation deficits were used to impose different irrigation management treatments at both sites. Different N fertiliser application rates and timing of application of the same total N application rate were used to impose N management differences at the cotton and maize sites respectively.

Reducing the irrigation deficit, resulting in more frequent irrigation, increased crop N uptake in both cotton and maize, and increased the lint yield in cotton and grain yield in maize, by 5 percent and 16 percent respectively when compared to grower standard practice results. However, in cotton increasing irrigation frequency also added to the management costs of the crop at the end of the season and increased the risk of weather impacting on the quality and harvest time of the crop. In maize the yield advantage of the small irrigation deficit over the grower standard practice highlighted that in fast watering automated systems, where more precise application of water is occurring, understanding soil infiltration capacity is important in ensuring soil water used by the plant is adequately replaced during each irrigation event.

The grower standard practice in maize resulted in plant water use greater than was being replaced with irrigation using the automated irrigation system, which negatively impacted grain yield.

Cotton lint yield increased when the N fertiliser application rate was increased from 180 kg N/ha to 270 kg N/ha. Crop N uptake also increased across the N fertiliser application range and there was no change in the internal nitrogen use efficiency, indicating that across the fertiliser N rates used the same amount of lint was being produced relative to the amount of N that was taken up by the crop.

Maize grain yield was increased by applying most (60%) of the targeted total N application rate prior to planting the crop, compared to applying only 30% pre-plant and the remainder over four applications in-crop prior to tassling. Reducing the irrigation deficit on red soils to between -20 to -40 kPa matric potential and applying the majority of fertiliser N prior to planting the crop, are two management strategies within a fast-watering automated border check irrigation system to improve maize grain yield and profitability.

Irrigation needs to be carefully managed and adapted with smaller irrigation deficits to ensure water efficiency is not reduced in both siphon and automated border check irrigation systems.

Rice grain yield was not significantly reduced when grown on beds within the rice layout. However, beds provided quicker drainage and returned the soil to aerobic conditions more quickly following draining, providing better soil conditions for subsequent winter crops. Short season rice grown in combination with short season wheat did not allow enough time for the wheat crop to produce the second grain crop in a calendar year, highlighting that not all crop types and/or varieties will be suitable for double cropping within the rice farming system.

Early drainage of water from the rice crop post-flowering, followed by flushing water through the crop based on a predetermined irrigation deficit until the crop matures, provided more favourable soil conditions for a subsequent winter crop. However, there is significant risk of rice grain yield loss due to moisture stress at this stage and significantly more investigation is required before any recommendations can be made.

Design charts for determining an optimum bay size for cut-off times less than 10 hours in three basin types (contours, V-bays and terraced beds) on three typical soil types for three flow rates (1 L/s/m bay width, 2 L/s/m bay width and 3 L/s/m bay width) were obtained using the WinSRFR model. The field data collected across the basin types and soil types validated the model outputs and highlighted the deficiencies of side-ditch systems in paddocks with field grades less than 1:1000. The hydraulic connection between bays created through the side-ditch is the principle cause of the lack of precision with water application and extended opportunity times (i.e. slow drainage) observed in side-ditch, basin irrigation systems. Both the field data and the modelling showed marked reductions in irrigation opportunity times are possible when drainage from bays is not impeded by water backing up in a side-ditch. Further development of the B2B model is required to determine the minimum paddock slope at which side-ditch systems operate effectively under a range of bay size, storage volume, soil type and surface roughness combinations. Guidelines for side-ditch system construction are essential for the development of basin systems that allow more precise application of irrigation water and cost-effective automation. For the rice industry this will allow the adoption of flush-irrigation, while for the cotton industry it will give confidence in the adoption of terraced, side-ditch systems to reduce labour costs associated with siphon irrigation. In

the interim, the field data indicates that a minimum terrace of 150 mm should ensure unimpeded drainage in side-ditch systems.

The economic case studies have highlighted that economic returns following the redevelopment of irrigation layouts or upgrading of irrigation infrastructure can be positive. However, individual development and financial plans are essential for each case before investing in any capital development. Marginal rates of return on capital invested vary widely, due to the different types of development, the levels of capital expenditure and the impact on the gross margin returns.

Water productivity in irrigated rice, cotton and maize crops, is increased by either improved irrigation infrastructure or improved layout, for example through the implementation of a terraced bankless system. Positive economic returns demonstrated in project case studies were influenced by reduced water use and therefore lower water costs, or higher yields achieved with the same or less total water use.

Rice growers can change to terraced bankless and double cropping systems and realise good returns. Growers can then incorporate winter crops (such as wheat and canola) into their production system to gain an acceptable return on investment.

Investment in recommended layouts has been shown by the growers in the case studies to improve yields and reduce water use in both cotton and maize. These returns have been sufficient to gain acceptable marginal returns on capital investment in layout changes.

The Participatory Action Research approach and the formation of a Steering Committee ensured the grower groups, extension organisations and industry representatives were informed throughout the project. The steering committee met formally twice per year. One meeting consisted of a tour to each of the key learning sites and the other formed the basis of an annual results review and planning meeting.

The grower groups' involvement enabled the project to regularly present the latest results to growers by attending group activities such as field days and meetings. Over 900 grower and industry personnel received new information published by the project in newsletter articles and factsheets and distributed utilising the grower group networks.

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