Cotton
RESEARCH & DEVELOPMENT

Annual, Progress and Final Reports

REPORTS

Part 1 - Summary Details

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

CRDC Project Number: **215C**
Annual Report: ☐ Due 30-September
Progress Report: ☐ Due 31-January
Final Report: ☒ Due 30-September
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Project Title: Subsurface Drip And Furrow Experiment

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Part 3 – Final Report

1 Background to the project

Due to the size and nature of the agricultural industry in Australia the adoption of subsurface trickle irrigation (SDI) in this country has been limited due to bad experiences of early installations (Anthony, 1996). Underpinning these experiences was the failure of research at the time to fully identify and communicate the potential benefits of the drip systems (Bristow *et al.*, 2000). For these reasons it has taken twenty years for SDI to re-establish itself as a viable irrigation alternative in the Australian cotton industry.

The large body of research from Israel and the USA has indicated that substantial increase in yield and water use efficiency can be achieved through the installation on SDI for a number of crops (Camp *et al.,* 2000). In Australia some of these promised benefits have not materialised because surface irrigators here have been described as the among the most efficient water users in the world (Anthony, 1996) and poor SDI performance has been attributed to suboptimal management based on observed cotton water deficit stress (Hulme and O'Brien, 2000).

The use and management of SDI on Vertosols in Australia is poorly understood and many comparative studies have been treated with scepticism, (Hulme and O'Brien, 2000). Only two water balance studies have been conducted on the system. A study on lighter soils in the Emerald Irrigation Area, (M. McCosker, pers. comm.) demonstrated an increase in cotton yield and a doubling in WUE with SDI when compared with flood irrigation. On a Vertosol, total water used was 20-30% less with SDI, however water and nitrate fluxes (deep drainage), were significantly greater than under flood irrigation (Ian Gordon, pers. comm.).

Research by the cotton industry funded program "Minimising Pesticides in the Riverine environment" (1993-1996) found unacceptable levels of sediment and chemical pollutants in surface runoff water from furrow irrigated cotton. Carroll *et al.* (1988) identified up to 80% of erosion was associated with rainstorm events, particularly soon after flood irrigation, and pesticides and nutrients are transported with the runoff and eroded sediment.

2 Objectives of the project and the extent to which these have been achieved

2.1 Compare sub surface drip irrigation Water Use Efficiency (WUE) with furrow irrigation on heavy clay soils.

Comparison between the irrigation systems was limited in the first season due to non replication of the furrow site. Replicated sites installed by the second season provided equal comparison with the replicated SDI sites. WUE efficiency was able to be compared with and between seasons due to the similarity of the seasons and limited rainfall.

2.2 Compare environmental impact of SDI with Furrow irrigation with particular reference to runoff, sediment and chemical transport from rainstorm events

Limited comparisons of off site chemical and sediment transport were made during irrigation events, but suppositions were drawn based on managed soil conditions during the two seasons as to impacts to the environment under rainstorm conditions. However rainfall induced runoff did not occur during the two years and further research is required to quantify the effect of management and irrigation system changes.

2.3 In collaboration with RWUE adoption program identify incentives (drivers) and constraints to adoption of SDI using on farm action learning techniques

The study focussed on demonstrating irrigation management utilising scheduling techniques. The results were presented and practically demonstrated in two major workshops/farm walks in January of both seasons. Attendance and interest was overwhelming and significant questions on cost, management and installation of SDI and use of instrumentation were addressed. The RWUE Adoption Program advertised, promoted and reported on both events providing a summary of results to date, a case study and development of other publications.

2.4 Incorporate SDI into best management practise guidelines for the cotton industry

The RWUE adoption program members, the Department of Primary Industry Development Extension Officer for Cotton, Cotton Australia Liaison Officer, Netafim Australia and the Fitzroy Basin Association have promoted and publicised the results of this project. In developing documents associated with water management plan targets and natural resource management water quality targets the results of this study have been introduced in to discussions and workshops and will form part of the final documents.

3 Description and justification of the research methodology

The study was conducted at Nyang, a commercial cotton farm located 23 km east of Emerald, Queensland (23.470865 lat. and 148.330244 long.). The site is located on the higher alluvial plain described as the former floodplain of the Nogoa River. The soil is locally termed as 6AUg-9, or a Gypsic Vertosol.

An Environdata™ Weathermaster 2000 weather station located on farm, monitored rainfall, temperature, wind speed and direction, humidity and Evapotranspiration (ET_0) (Modified Penman-Monteith). Three tipping bucket rain gauges and manual rain gauges, situated at the experimental sites monitored rainfall during the two cotton seasons from 2001 to 2003.

An automated 12 mm/day SDI system was installed on a 6 ha site, consisting of twelve 0.4ha irrigation bays (16x250 m). Water, nutrients and chemicals to each bay could be individually controlled, measured and automated. Subsurface drip laterals (tape) on 1m centres were installed on 8 bays and 2 m centres on the remaining 4. The tape was buried at 40 cm, which had emitters spaced at 40 cm, delivering 0.7 L/s in the 1m spaced laterals and 1.4 L/s in the 2 m bays. Final field preparation consisted of forming flat 2m beds (<100mm high) to aid in wetting the soil above the tape, which was adapted from Arcturus Downs, an irrigated cotton and grain property on a vertosol, 80km to the south of Emerald.

The twelve irrigation bays were isolated and fitted with 0.3m diameter (dia) PVC discharge pipes and 0.4 m^3 bedload traps to quantify the contribution of cropping and irrigation management to water quality and runoff under cotton production. Three comparative furrow irrigation bays (8x500 m), were located approximately 800 m from the SDI site and also fitted with a discharge pipes (0.25 m dia). Water height during irrigation bay discharge (runoff) was measured using stilling wells housing "Dataflow" capacitance height recorders attached to the 15 discharge pipes (Figure 1). A pilot port located at the end of the discharge pipes connected individual stilling wells and allowed water levels in the stilling well to rise and fall with corresponding water levels in the pipe The Californian pipe equation (Grant and Dawson, 1997) was used to convert water height to discharge volume and each pipe had been calibrated against a V notch weir. Loggers recorded date, time, voltage from capacitance probes, and tips from tipping bucket rain gauges. Output from the loggers triggered 3 automated water quality pumping samplers when there was flow of at least 0.015 m through their associated discharge pipes (Figure 1). The 12 SDI discharge pipes were monitored in groups of six by two instrument stations (Figure 1), each consisting of 2 loggers (4 and 8 channel), solar panels, batteries, cooling system, signal converters, pluviometer, weatherproof casing, stand, ISCO 3700 automated samplers, and manual rain gauge. A single instrument station located at the furrow irrigation site was similar and monitored three discharge pipes.

Water quality samples were collected by Isco 3700 automated samplers when runoff discharged into stainless steel containers at either of the two SDI or one furrow bay. Teflon sampling tubes and suction lines at the base of the container transferred the samples to the pumping sampler so not to effect chemistry. All discharge pipes were fitted with drilled copper tube splitters at the end of the pipes and in line with the flow, gravity sampling into10 L containers. Additional water quality samples were taken by hand when runoff was occurring.

Twelve, 0.063 m siphon pipes delivered irrigation water to the furrow irrigated sites and the volume calculated by Manning's equation. Milltronics ultrasound water level sensors and Dataflow capacitance water height recorders monitored head ditch water level during irrigations.

All sites were managed uniformly, except for irrigation applications. The farmer managed the furrow irrigated sites in the same manner as the rest of the property for the first season. In the second season furrow irrigation events were optimised based on SIRMOD model outputs. Water level in the head ditch was raised in the second season, increasing flow rate by 1 L/s and reducing irrigation time to only fill the soil moisture deficit. Insect control and growth regulation (1 Pix application) was the same across all treatments. However in the second season, Pix was applied only to those treatments that required it.

All crop nutrients were supplied by the drip system in the first season, however in the second season all nutrients were applied before planting, with the exception of a single Boron application and 4 weekly Urea (N) applications mid-season.

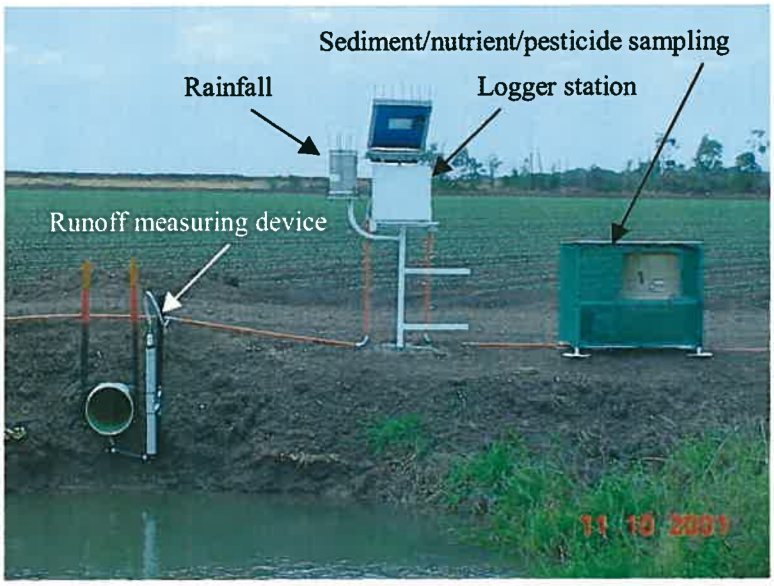

Figure 1 . 6ha SDI field instrument monitoring station and 0.42ha SDI bay discharge pipe instrumented to measure irrigation and rainfall runoff for sediment, nutrient and pesticides.

Accumulated heat units after planting (HUAP) were used to manage crop factors (K_c) and related growth stages to determine crop evapotranspiration (ET_c) from daily ET_0. Four daily irrigation treatments, 50, 75, 90, and 120% of ET_c (equates to 6, 8, 10 and 12 mm/day during peak demand) randomised in 3 blocks were applied to the twelve SDI bays (second season 120% application was reduced to 105% and peak daily applications were capped at 6, 8, 10 and 12 mm/day). The various irrigation levels in 3 replicates provided a means to determine water use efficiency of cotton under deficit irrigation, manipulate soil profile condition to increase in crop rainfall storage and therefore decrease environmental impacts. The 3 * 0.42 ha furrow irrigation bays provided comparison with the SDI blocks and optimisation of furrow irrigation management.

Generally, in the first season, daily irrigation was automated, volumes adjusted every 3 to 5 days according to daily evaporation rates and applied during the day. In the second season applications were automated and adjusted daily on a three day rolling average, applied exclusively at night and capped at predetermined levels. An in-line water meter measured total applied water and the SDI computerised controller monitored individual block volumes.

Soil water content was monitored by 3 Enviroscan soil moisture probe systems, consisting of 15 moisture probes (1 in each furrow irrigated bay and 1 in each of the SDI bays). Probes were located either in the plant line adjacent to an emitter, approximately 0.1 m from the 1 m spaced drip tape or 0.5 m from the 2 m spaced tape in each plot, and 20 m from the end of each furrow site. However, in the second season the centre of each SDI probe location was triangulated at 0.1 m from the tape and 0.1 m from an emitter. Probe calibration was for the adjacent cotton property on similar soil. Individual probes were site specific calibrated to daily applied irrigation volumes. Drainage below the active root zone was calculated by difference between, applied water, crop water use and tail water, that is, the water not accounted for was presumed to be lost below the root zone.

WUE, yield, and lint quality of Ingard™ cotton, planted on 2m wide flat beds (<100 mm high) were assessed over two seasons in fifteen 0.4 ha sites (irrigation bays). A commercial harvester was weighed after each of the centre 8 rows (0.2 ha) of each bay was harvested and after unloading. Bay guard rows (0.2ha) were harvested and weighed separately. Yield was then calculated using a Gin turnout factor of 36% in 2001/02 and 43% in 2002/03 (Turnout factor = percentage weight of lint in harvested cotton, after seed, trash and impurities are removed). Grab samples from each site were taken from the harvester for lint quality analysis. After harvest, 1 m^2 in three rows from each site were assessed for field losses.

Statistical analysis of results was determine by GenStat 6.1, "General Analysis of Variance" with level of significance set at 5%.

4 Research Results

4.1 Rainfall and soil transport

Rainfall was very low for both 2001/02 and 2002/03 seasons recording 78 and 10 mm respectively. Therefore runoff was limited to either tail water from furrow irrigations or minor rainfall events in the over-irrigated 120% SDI treatment, and to a very minor extent in the 90% treatment. As a result, soil and chemical transport only occurred on these sites.

Total soil loss for the 2001/02 season on the furrow irrigated site was 5.97 t/ha and 2.53 t/ha for the 120% SDI treatment (Figure 2a). In the second season no sediment transport was detected in the SDI, however soil loss in the furrow increased to 12.71 t/ha (Figure 2b), as a result of the increased flow rate and equivalent total tail water volume to the previous season. Average sediment concentration for each irrigation event was 4.2 and 5.2 g/L for 2001/02 and 2002/03 seasons respectively. However unequal replication, differences in individual furrow tail water volume, and differences in length of irrigation between years made sediment concentration comparisons difficult.

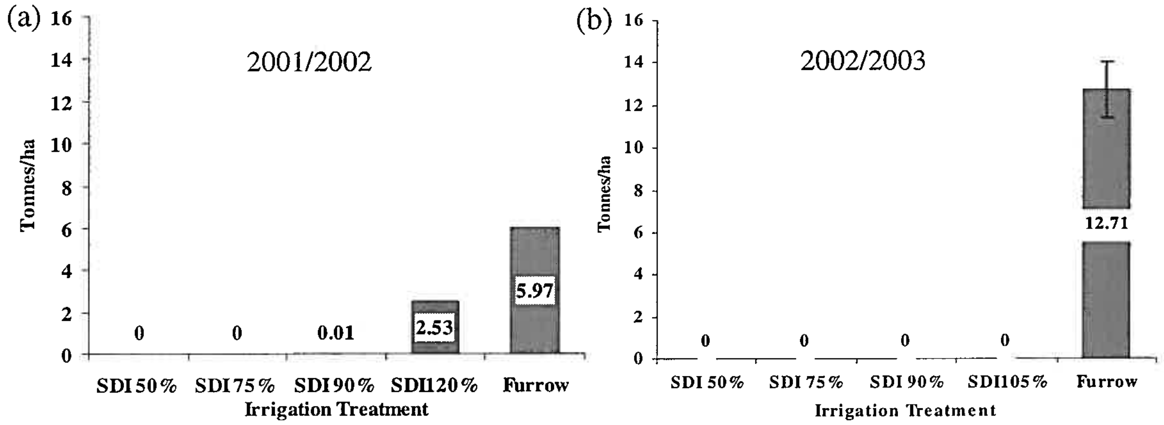

Figure 2. Soil loss in tonnes/ha from all sites for all rainfall and irrigation events for the cotton seasons between 2001 and 2003. Soil loss in season 2001/2002 was from single non replicated sites.

4.2 Nutrient and chemical transport

During the first 5 of 7 furrow irrigations in 2001/02, approximately 9% (18 kg/ha) of the pre-applied nitrogen was removed in tail water, with no further losses during the remaining 2 irrigations, however Total N (TN) concentration in the first irrigation after inter row cultivation was 50 times greater than ANZECC guideline value of 0.75 mg/l, all be it in a concentrated flow (Figure 3). Small quantities of TN were lost off the wettest SDI treatments that continually discharged due to over-watering and some rainfall (Appendix A, Figure 1a). Total P (TP) tended to be similar to that of TN with considerable losses off the furrow site in the majority of irrigation events, but in contrast with TN increased with each event to 160 g/ha (Appendix A, Figure 1c).

Herbicides such as Trifluralin (Treflan), Prometryn, Fluometuron (active constituents of Cottagard), Diuron and Atrazine were also removed from the furrow and wettest SDI treatments (Table 1). In the first irrigation, a small amount of trifluralin (6.2μg/L) (12% of ANZECC values) was removed with no further losses detected in later irrigations, but the others chemicals continued to move offsite in varying quantities (Appendix A, Figure 1b, d, f, & h,). Insecticides such as Dimethoate and Endosulphin were also transported offsite in considerable quantities from the furrow and 90 and 120% SDI treatments (Appendix A, Figure 1e, & g.). The chemicals Diuron, Atrazine and Endosulphin were not applied in this season, although they were mobilised and transported offsite. Chemical offsite movement was not associated with time of application, except after tillage in early November 2001, when it tended to increase (Appendix A, Figure 1 and Figure 3). Mean concentration of chemicals, except Atrazine in all samples taken from SDI sites during the 2001/02 season ranged from twice to 16 times higher than furrow irrigated samples (Table 1). Mean sample concentration for chemicals listed in Table 1, with the exception of Atrazine exceeded the 2000 ANZECC guidelines for fresh water ecosystems.

There was no offsite movement of sediment or chemicals from the driest SDI treatments and no losses due to rain induced runoff on the furrow either, because the soil was dry during all minor rainfall events. Data for the second season was not available at the writing of this report, but will be reported in subsequent articles.

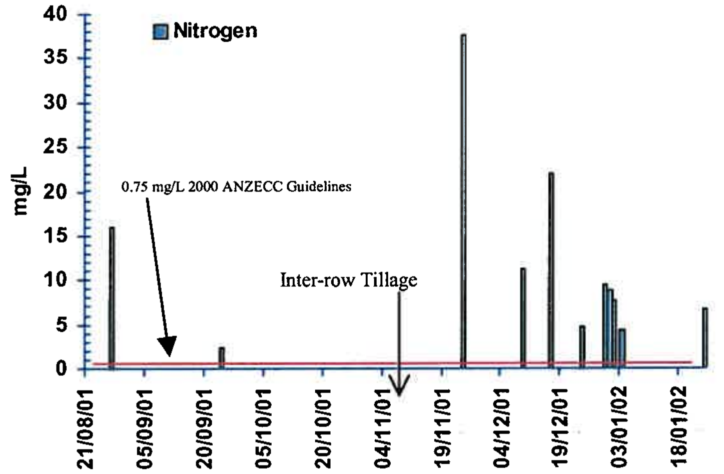

Figure 3. Total Nitrogen concentration from all sites for all runoff and irrigation events for the cotton season 2001/02 compared with the 2000 ANZECC guidelines and the timing of inter-row tillage.

Table 1. Chemical concentration – mean and range of samples collected from rainfall and irrigation for furrow irrigation and SDI sites in relation to 2000 ANZECC guidelines for fresh and marine water quality.

Chemical	**Furrow**			**SDI**			**ANZECC Guideline trigger values**	
							Level of protection (% species)	
	Mean ug/l	**Min ug/l**	**Max ug/l**	**Mean ug/l**	**Min ug/l**	**Max ug/l**	**99%**	**80%**
Atrazine	0.08	0.03	0.11	0.06	0.03	0.10	0.70	150.00
Diuron	0.40	0.21	0.67	2.01	0.04	9.68	0.02	160.00
Endosulphin	0.37	0.15	0.64	0.69	0.54	0.90	0.03	1.08
Fluometuron	1.50	0.17	4.20	9.51	1.66	23.60	NA	NA
Prometryn	0.12	0.04	0.22	1.96	0.11	8.70	NA	NA
Dimethoate	1.20	0.40	2.00	2.53	0.60	4.80	0.10	0.30

4.3 Water balance

In general, the various irrigation levels induced varying levels of plant growth. The smaller cotton plants in the 50 and 75% treatments used less water and consumption increased with increasing plant size in the wetter treatments, but yield tended to decrease due to waterlogging in the wettest of SDI treatments and furrow irrigated sites in the first season. In each season the driest SDI treatment received 42 and 35% less water respectively than the wettest on average, which the crop utilised to the fullest extent and maintain relatively dry soil profiles. In comparison to the furrow sites, the 50% SDI treatments received on average 43% less water per ha (54% if tail water is included) (Figure 4a). The 75% SDI treatment received 36% less water than the furrow, excluding tail water (with tail-water 49%).

During the first season soil in the driest treatments received 25% and 18% less water than the 90% treatments, in which the profile was constantly full or near full, and therefore these drier treatments had the capacity to store ~140mm and 100mm of in-season rainfall respectively. The second season was hotter with seasonal ET up by 294 mm and only 10 mm of effective rainfall. Consequently potential rainfall storage in the 50 and 75% treatments was 230 and 76 mm respectively in comparison to the 90% SDI treatments (Figure 4b). Although applied water and consumption increased on the previous seasons' levels, the difference in water use between years was not significant ($P \leq 0.05$). Irrigation water consumption between 1 and 2 m spaced laterals was also not significantly different.

Irrigation application to the 120% treatments was reduced to 105% of ET_c in the second season and therefore, no runoff was recorded (also due to limited rain) compared to the previous season (Figure 4b).

Deep drainage in the first season was substantial at 118 mm and 46 mm (16 and 6% of applied water) for the furrow and wettest SDI sites respectively (Figure 4a). In the 2002/03 season optimisation of the furrow irrigated sites and reduction of the 120% SDI treatment to 105% of ET_c, reduced drainage below the root zone to close to zero (Figure 4b).

By pushing irrigation water through faster (increasing flow rate by 1 L/s on average) tail water remained similar to the previous year, leaving scope for further optimisation. Tail water was 20 and 28% of applied water for the 2001/02 and 2002/03 seasons respectively, even though total volume of applied furrow irrigation water was reduced by 1.9 ML/ha (189 mm) in the second season. Excluding tail water, a total of 2.2 ML/ha was saved through optimisation of each furrow irrigation. The 75% treatments received 5% less than the furrow excluding tailwater, 22% including tailwater.

Irrigation efficiencies (IE), expressed as a ratio of crop water use and applied irrigation water (less tail water), were poor in the furrow irrigated system in the first season at 81%. After optimisation during the 2002/03 season, and accounting for tail water reuse, the ratio improved to 100% (Figure 4). All SDI irrigation treatments were around 100% efficient for both seasons, except the 120% treatment in 2001/02 season at 86% (tail water not recycled).

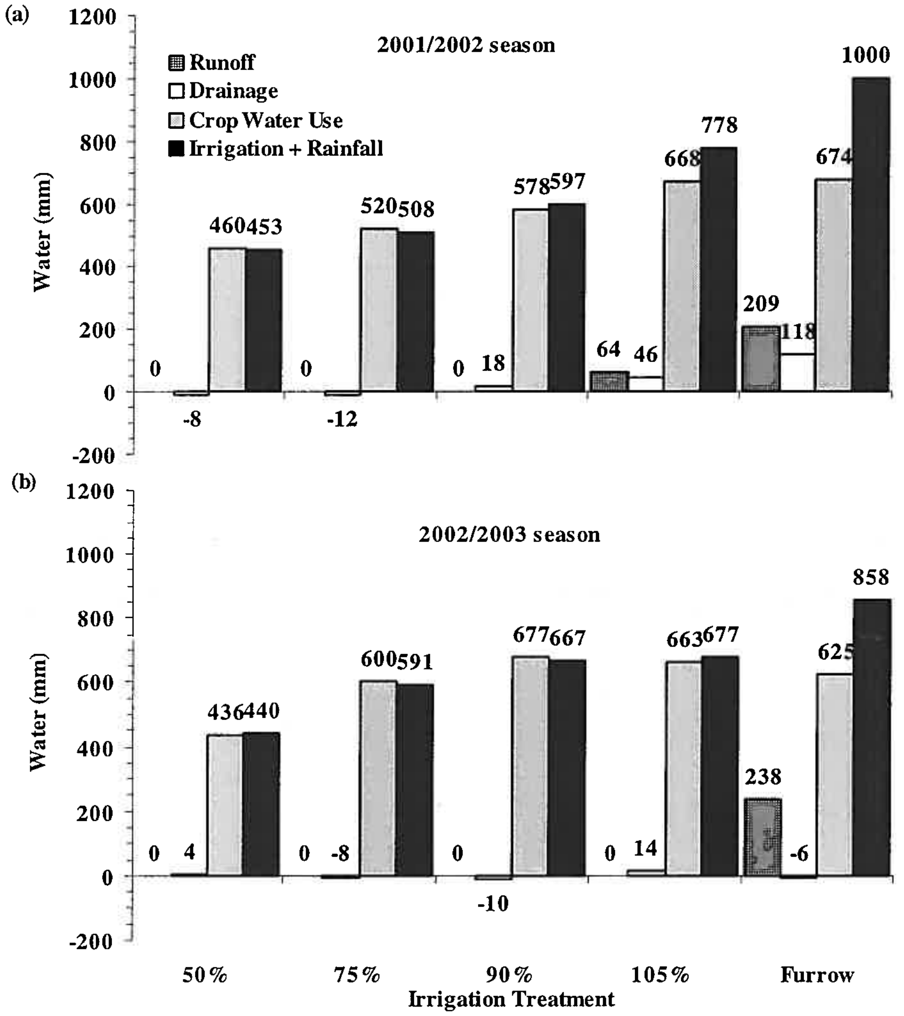

Figure 4. Comparison of water balances for the cotton seasons 2001/02 (a) and 2002/03 (b).

4.4 Water use efficiency and yield

Generally WUE decreased with increasing volume of applied irrigation water in the SDI and it followed a similar trend in the second season (Figure 5). Furrow irrigation WUE was low in the first season, but increased twofold in the second season (Figure 5). However over the two years, mean furrow irrigation WUE was not significantly different from the three driest SDI treatments (Table 2), nor was it significantly different between years ($P \leq 0.05$). Within the SDI system, biennial WUE means were significantly different between the two wettest and the two driest irrigation levels (Table 2). The 105/120% and 90% treatment WUE means were also significantly different by 0.2 bales/ML (Figure 5).

Biennial mean yield was significantly different ($P \leq 0.05$) between the furrow irrigated sites and all SDI treatments, and 50% treatments were significantly different from all other SDI treatments. The 75, 90 and 105/120% treatments did not differ in yield (Table 2), although irrigation levels were considerably different (Figure 4). In the 2002/03 season, furrow irrigated yield increased substantially on the previous season by 1.5 bales/ha, while yield in the driest SDI treatment (50%) was reduced by 1.4 bales/ha (Figure 5). There was no significant difference in mean yield between years over all treatments because of the increase in furrow yield, but within the SDI system a mean seasonal decrease of 0.433 bales/ha was significant, generally due to yield decrease in 50% SDI treatments (Figure 5).

Field losses ranged from 6-11% over all treatments for both seasons. The implications were not considered significant and outside the scope of this study and the values were not added to total yield.

Table 2. WUE and yield biennial treatment means for the two cotton seasons over the period 2001-2003.

Irrigation Treatment Biennial means 2001-2003	**SDI 50%**	**SDI 75%**	**SDI 90%**	**SDI 105/120%**	**Furrow**
WUE bales/ML	1.649^{a}	1.518^{ab}	1.317^{bc}	1.133^{c}	1.479^{ab}
Bales/ha	7.243^{a}	8.226^{b}	8.259^{b}	8.087^{b}	9.822^{c}

WUE bales/ML l.s.d. = 0.245. Bales/ha l.s.d. = 0.628. Mean values followed by the same letter are not significantly different at ($P \leq 0.05$).

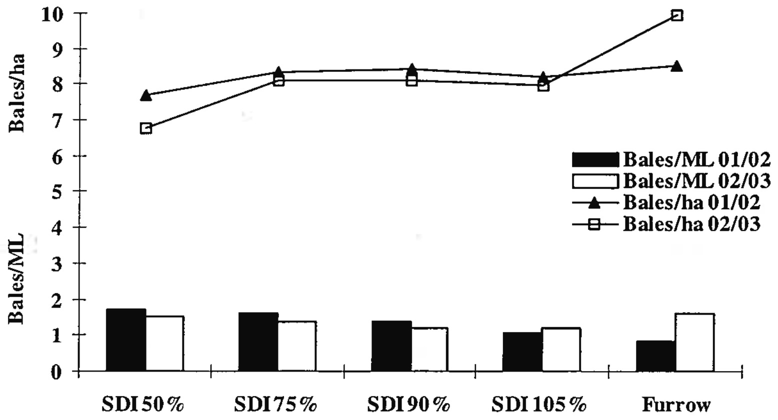

Figure 5. WUE, (based on rainfall, applied water less tail water) and lint yield for the cropping seasons 2001/02 and 2002/03. (SDI 120% was changed to 105% in season 02/03). L.s.d of biennial treatment means calculated at $P \leq 0.05$.

4.5 Cotton Quality

Biennial cotton quality treatment means were not significantly different between irrigation level or method with the exception of cotton fibre length (l.s.d. = 0.03328 at $P \leq 0.05$) in furrow treatments (Table 3). Seasonal differences (between years) were significant in all parameters with the exception of cotton fibre strength (Table 3).

Table 3. Cotton quality parameter treatment means for each season 2001/2002 and 2002/2003 with l.s.d. of biennial means.

Cotton Quality	Season	Biennial l.s.d.	SDI 50%	SDI 75%	SDI 90%	SDI 105/120%	Furrow
Length	01/02^a	0.0211	1.06	1.12	1.13	1.10	1.12
	02/03^b		1.12	1.12	1.11	1.14	1.17
Uniformity	01/02^a	0.520	83.20	84.37	84.83	83.60	84.40
	02/03^b		82.95	82.67	82.67	83.07	83.70
Short Fibre Index	01/02^a	0.709	7.13	6.40	6.33	7.20	5.30
	02/03^b		8.40	9.13	9.43	8.90	8.00
Strength	01/02^a	0.858	26.63	28.53	28.90	28.00	30.20
	02/03^a		29.85	28.87	29.13	29.47	30.17
Elongation	01/02^a	0.2440	9.40	8.90	9.00	9.57	8.90
	02/03^b		5.60	5.50	5.43	5.40	5.87
Micronair	01/02^a	0.1729	4.67	4.53	4.40	4.47	4.40
	02/03^b		4.30	4.73	4.77	4.93	4.87

Seasons followed by the same letter are not significantly different based on biennial cotton quality means at ($P \leq 0.05$).

4.6 Earliness

The driest SDI treatment was ready for harvest 4 weeks prior to wettest treatments and 3weeks earlier than the furrow irrigated sites in 2001/02 season (Table 4). In 2002/03 earliness between the driest SDI treatment and the furrow irrigated sites was 16 days.

Table 4. Earliness of each treatment, indicated by readiness for defoliation and harvest.

Treatment	Defoliated	Ready for harvest
50%	9/1/2002	23/1/2002
75%	23/1/2002	6/2/2002
Furrow	30/1/2002	13/2/2002
90 & 120%	7/2/2002	21/2/2002

5 Discussion

5.1 Environmental impacts

In the Emerald Irrigation Area (EIA) tail water is reticulated on farm and many farms have the capacity to retain 25 mm of runoff within farming systems and in a dry season sediment chemical and nutrient transport is restricted to tail water. However, as this data shows considerable amounts of sediment and chemical are removed off fields, which are then deposited into various parts of delivery and recovery infrastructure during non-optimised furrow irrigation events. In comparison, SDI under deficit irrigation management, runoff, sediment or chemical movement was not detected.

Soil loss in the first season was similar to that found in previous studies on conventional cotton irrigation under dry conditions (Waters, 2001). In the second season under optimised furrow irrigations, soil loss increased two fold due to increased application rates and production of a similar volume of tail water. The RWUE adoption program and other research has demonstrated that these soil losses could be reduced by further irrigation optimisation (reduction of tailwater) and application of irrigation water flocculants (Waters, 2000). Therefore as demonstrated in this project, it would seem necessary to adopt these and or other complimentary soil loss/erosion minimisation strategies under irrigation optimisation conditions. Under dry weather conditions all soil was retained in SDI fields where irrigation levels were maintained at or below 75% of daily ET_c. Generally soil loss in the over-watered SDI sites was generated by the constant irrigation water outflow from saturated soil in each bay. This situation was rectified by the second season by reducing daily irrigation by 15% in the wettest treatment and the increased evaporative demand of the following season. In general the manipulation of soil moisture condition provided a considerable buffer to the effects of rainstorms, should they have occurred. Soil moisture manipulation in SDI was managed by deficit irrigation techniques which cannot be practiced under furrow irrigation on a commercial scale and therefore a buffer to rainstorm effects is created only by chance, should it rain when the profile is only partially full.

Throughout both seasons, the furrow irrigation system shed amounts of chemical, and nutrient which seemed to increase after tillage events. Chemicals such as, Diuron, Atrazine and Endosulphin were not applied yet were mobilised by tillage and sampled in tail water. Early in-crop tillage also affected chemical movement in the SDI, but only in the wettest treatments (full moisture profile) after rainfall. However, a late season rainfall event caused considerable chemical offsite movement on the wettest SDI. This suggested a major rainfall event on an over-watered SDI system could have greater impact than one on a non-optimised furrow irrigated system, because the soil store of residual chemical in SDI systems could be larger. However a similar situation would arise in an optimised furrow irrigation system that had produced limited tail water during the season.

This water quality sampling data relates to single dry season, but with similar indications from a second dry season. The samples were taken from concentrated flows before it was diluted in return drains and therefore were well above fresh water aquatic ecosystem guidelines. But should it rain on moist soil, especially in a non-reticulated system, significant quantities of sediment, nutrients and chemicals could leave the farm and contaminate riverine systems. An SDI system managed under deficit irrigation techniques has the potential to store in-crop rainfall and could have considerable advantage over mismanaged SDI and furrow irrigation in terms of reduction of environmental impacts under rainstorm conditions. An issue of concern is the remobilisation of chemicals attached to clay particles, either in field or deposited elsewhere in the system, after tillage or high flow events. A number of these chemicals had not been used for some years, yet were measured in high concentrations.

5.2 Water use efficiency

Considerable water savings were made with the SDI system in both seasons and the optimised furrow system in the second season. Based on data from two seasons, viable cotton could be grown with 5 ML/ha on this soil type with a SDI system, whereas under fully optimised furrow irrigation 6.2 ML/ha would be required. In a season where there was substantial rainfall, the required volume of irrigated water would be less. But the SDI would have distinct advantages over furrow irrigation depending on soil condition at the time of rainfall events. But there are losses such as additional pumping, seepage in infrastructure, labour and logistics associated with furrow irrigation when attempting to fully optimise furrow irrigation water use, which makes it difficult to achieve and comparisons with SDI equally as difficult. Also, a small percentage of the unaccounted for water, used to estimate drainage below the root zone in this study, is associated with soil conditions, site calibration, instrument characteristics, and water extraction patterns, and therefore a more definitive measurement of deep drainage losses is required.

The data suggests that cotton can adapt to low levels of irrigation without appreciable loss of yield under SDI. Generally what water is applied, cotton uses and yield increases, up to a point where the soil becomes wet enough to allow drainage below the active root zone and waterlogging begins to reduce yield. Under deficit irrigation, WUE increases considerably, yet yield remains constant at daily application rates between 75% and 90% of ET_c, which in this project was equivalent to 8–10 mm of daily irrigation during peak demand. Yield is maintained even though moisture content in a considerable volume of soil remains near wilting point, which provides rainfall storage potential and limits the possibility of runoff, offsite and groundwater contamination for the majority of a cropping season. In most furrow irrigation systems, plant available water and soil moisture condition cannot be manipulated in this way, and generally for 3–5 days, seven to eight times in a cropping season, the profile is above field capacity and very susceptible to runoff events and groundwater contamination from summer rainfall. Under conventional furrow irrigation, considerable volumes of water are lost below the root zone, as was shown in the first season of this project, which could have serious consequences for ground water contamination, rising water tables and/or increased soil salinity.

As demonstrated in this project ,waterlogging can be considerably reduced, and water use efficiencies can approach and surpass that of SDI. By irrigating to the soil deficit, increasing flow rate and discontinuing irrigation before tail water is produced, water loss to drainage below the active root zone is removed, waterlogged conditions were not evident and yield increased substantially on the previous season.

Consequently WUE for the furrow irrigated sites was above expectations. The SDI on the other hand although very water efficient, was hampered by a less than optimal yield. In the first season, water stress in the early growth phases caused poor floral initiation in the driest treatments and therefore low final yield. In the second season water stress was not an issue. Low yield was attributed to fertiliser application and poor fertiliser use. Excessive fruit load early in the season, placed demands on the plant that could not be met because of unavailable nutrients, hence final yield and WUE were lower than anticipated. Cotton quality was effected by the difference between seasons and the inefficient use of fertiliser in the SDI, and not due to differences between the two irrigation systems. Symptoms and/or effects of adverse conditions having been anticipated or recognised can be rectified simply in SDI systems, but not so easily under furrow irrigation. Although this is common knowledge to experienced users of SDI, it would seem for SDI to out perform a well managed furrow irrigated system on heavy clays, 1/3 of total fertiliser requirement is applied before planting and the remaining 2/3 applied on a weekly basis through the drip system for the majority of crop life, especially under deficit irrigation where low moisture limits nutrient uptake.

Based on the second seasons data, cotton WUE and Yield on heavy clays under SDI are comparable with well managed furrow irrigated systems (5% difference in applied water). Where SDI can outperform furrow irrigation is on lighter soils, and areas of unsuitable topography where furrow irrigation function and efficiencies are known to be poor. This is not to say that SDI does not work on heavy clays, it will out perform or at least equal furrow irrigation if the correct agronomic requirements are met.

5.3 Incentives and constraints to adoption of SDI

5.3.1 Water use

Considerable water savings are made with SDI, in comparison to conventional furrow irrigation. residual water could be used to grow winter crops, saved for following cotton seasons or traded, and/or returned for environmental flows. Should the price of water increase significantly SDI may become a more viable option on this basis alone, although optimisation of furrow and other delivery systems such as centre pivot can also be very efficient. Deficit irrigation management techniques also induced earliness, which could have significant savings in terms of pest control (reduced number of sprays) and could also improve planting windows for winter crops and/or opportunity cropping to enhance cover and minimise erosion.

5.3.2 Adjustment to conditions

The correct balance of soil aeration, nutrition and available soil moisture to maximise production can be achieved under SDI by close monitoring of soil conditions in relation to plant needs and climate driving the processes. Water can be successfully used to control growth. Less vegetative matter reduces the number of insects, as there is less shade and increased air movement around the foliage. Consequently the smaller plants offer increased chemical efficacy and the number of sprays required in a season could be reduced.

5.3.3 SDI System Design

5.3.3.1 Capacity

The installed SDI system can deliver 12 mm of water per day, but the data suggests that a more than adequate crop can be produced on a system designed to deliver 8 mm/day. Based on current results, 6 mm per day could be sufficient to produce an average crop. Therefore a system based on 8 mm capacity would be adequate, considerably reducing installation costs by ~20% (Netafim Australia pers. comm.). Cost reductions are achieved through smaller diameter piping and smaller pump. Naturally, risks are higher using low capacity systems, but considering the two seasons were the hottest and driest for some considerable time, under normal conditions the perceived risks could be easily managed.

5.3.3.2 Lateral spacing

The data suggests that there was no significant difference between the crops grown on lateral spacings of 2 m or 1m. Germination and establishment were not hampered by the wider configuration, however bed design has a considerable impact on the ability of the wider configuration to “wet up” the soil profile to the surface of the planting zone. Heavier soils, such as those in this trial, are not susceptible to moisture subbing problems, compared to that experienced on lighter soils. In conjunction with low flat 2 m beds, row configuration could be adjusted so that the plant rows are planted closer to the tape (75 cm row spacing) with 125 cm furrow spacing. (30/50 inch combination) on lighter soils, but this could also be beneficial on heavy soils, by reducing wetting up time and irrigation volume. System costs are significantly reduced by ~30% if only half the tape is used in comparison to those systems installed on a 1m configuration, (Netafim Australia pers. comm.).

Although systems are designed to suit site-specific characteristics, systems can also be design for differing levels of management. That is, if the concepts of deficit irrigation are understood and well practiced the systems can be further downsized to deliver lower volumes of water, reducing capital costs, with acceptable risk levels and without loss of yield. However system function is dependant on soil condition, topography and row and bed configuration, and as found in this study, management and knowledge. Therefore if costs are minimised by installing laterals at wider spacings, bed configuration and row spacing should be adjusted to compensate for inherent characteristics of the soils moisture subbing ability, with a commensurate increase in management intensity.

5.3.3.3 Runoff

In a dry season sediment, chemical and nutrient transport is restricted to tail water. In most cases all tail water is reticulated around EIA farms and many have the capacity to retain 25mm or more of rainfall within their farm reticulation systems. However considerable amounts of silt and chemical are removed off fields and deposited into various parts of the delivery and recovery infrastructure. In comparison, SDI systems under deficit irrigation, soil erosion and chemical transport does not occurs, as a consequence, bed and furrow shape is retained throughout the season. In furrow irrigation systems, even under minimum till, considerable ridge and furrow reshaping is required to prepare for the following season compared to no adjustment in the SDI.

5.3.4 Constraints to adoption of SDI

Apart from the cost of installation and return to capital that constrains most prospective adopters, management and maintenance of SDI systems are technically demanding for the uninitiated. The decision to install such a system requires a considerable paradigm shift from furrow irrigation management and a significant grasp on site-specific soil/water interaction, plant responses and scheduling of irrigation events.

The latter is probably important to all irrigators, but is mandatory for SDI users and in addition, the degree of difficulty increases as clay content decreases (lighter soils). Therefore the system may not be initially suited to the many, but with adequate training, considerable backup service and appropriate documentation, the adoption rate may increase. The most common question asked during the project related to the cost of the system, questions about all other benefits, impacts, efficiencies were not common.

5.3.4.1 Instrumentation

This and previous studies have shown that with precise measurement of water and nutrients, yields can be improved. Reduction of stress in the vegetative stage through to bud formation is critical for final yield. Crop monitoring prior to the first irrigation to avoid moisture stress in these early growth periods is essential. Therefore applying irrigation water from a historical standpoint or daily ET data is not sufficient, as daily irrigation assessment is related to previous events not the current situation. This methodology can over-water the crop with no gain in yield and contribute to offsite transport of sediment, chemicals and nutrients. To apply irrigation water based on daily water use as monitored by soil moisture probes without site-specific calibration is also not recommended. Nevertheless, with practice, over a number of seasons, daily plant water use can be related to the volume of water applied/required relative to each year. But soil structural characteristics change, which affect probe sensors and irrigation water is again applied in response to historical data, not the plants requirement for the current day.

In terms of probe placement, triangulation in relation to the emitter is a reasonable approach so that a sensors centre point is level with and within 100-140mm from the tape at 45° to an emitter. (That is <100mm away from an emitter and <100mm along the tape from an emitter). Adapting to the required instrumentation or simply interpreting the data could be a constraint to adoption of SDI and other precision application systems. There are other scheduling methods adopted successfully by producers, as reported in a survey of cotton producers (McHugh 2001), but these manual and automated methods can be equally challenging when optimising irrigation.

5.3.4.2 Installation

Site history and soil condition have significant impacts on SDI, site inspection and considerable sampling is required to establish conditions prior to installation and design. Although this site was extensively "worked" (Deep ripped, cross ripped, laser levelled and rotary hoed) prior to installation, it was done when the soil was above the plastic limit and thus caused more soil degradation than it ameliorated. As SDI lends itself to a control traffic (permanent bed) farming zero till (permanent bed) system, it would be prudent to adopt some measure of traffic/tillage minimisation some years prior to the installation of SDI to facilitate soil preparation and increase subbing ability of the soil. There is anecdotal evidence that subbing increases significantly as the soil ages after SDI installation and so to the irrigation efficiency of the system. The costs of landplaning, soil degradation through prior preparation and observed poor performance in the early years after installation could be restrictive to adoption.

5.4 Incorporation of SDI into BMP guidelines for the cotton industry

The results from the trial were demonstrated at two workshops/farm walks and reported widely on radio. The key producers and members of peak bodies who attended the farm walks were able to take away effective management strategies and options to adopt and or promote the effectiveness of SDI and deficit irrigation. The results of this work have been offered into discussion and accepted in natural resource management workshops, water management planning workshops and water quality target setting forums. The project although small in scale has moved SDI and its benefits into public view in the Emerald Irrigation Area. The results have been recognised by peak bodies in the Fitzroy Basin as being beneficial to best management practices in the cotton industry, especially in relation to natural resource management and water quality.

6 Assessment of likely impact of results and conclusions of the project

The agricultural industry in the Fitzroy Basin has received considerable criticism because of off-site movement of contaminants into riverine systems. However adoption of practices to demonstrate minimisation of contamination is limited with the exception of closed reticulation systems in the EIA. But chemicals and sediment are still being transported into the drainage systems and await mobilisation from future rainstorm events.

This project has highlighted the stark contrast between two irrigation systems and how each can be managed to minimise offsite impacts and save considerable volumes of water. The optimisation of furrow irrigation events saved water and improved yields to an extent that surpassed SDI, which is achievable only on this soil type. This result highlighted the amount of skill, experience and knowledge necessary to operate SDI successfully. The cost of installing a SDI system and managing it to protect the environment, will be a significant deterrent to adoption and perhaps this technology should be reserved for marginal soils in difficult terrain.

Over the period of the study erosion rates of 5-13 t/ha were measured under conventional cotton production practices experiencing dry conditions. As demonstrated in other forms of agriculture, rates of this magnitude result in long term yield reduction. Similar effects could be expected if these erosion rates continue in cotton production, especially under rainstorm conditions where these volumes can increase 3-4 fold. The mobilisation of chemicals that were applied in some preceding season, but not recently, by tillage and tail water production, highlights the problem when rainstorms and high flow events mobilise sediment in reticulation infrastructure, drainage and riverine systems. It indicates that high concentrations will be experienced for years to come, long after producers have ceased use of particular chemicals or adopted minimisation strategies.

There are a number of proven alternative management options to improve environmental management, many of which must be used concurrently and in unison with irrigation systems. These results have identified strategic management practices that can be applied to irrigation systems which offer benefits to cotton producers who are looking to move toward BMP, ISO14001 and environmental management system (EMS) accreditation.

This study has demonstrated that:

- Non-optimised furrow irrigated systems and poorly managed SDI systems could have significant adverse impacts on the environment from tail water and rainstorm events.
- The production of tail water mobilises and transports significant concentrations of sediment, chemicals and nutrients offsite.
- Irrigation based on >90% of daily evapotranspiration rates of cotton could cause excessive drainage below the active root zone and groundwater contamination in this soil type.
- Deficit irrigation techniques are required to reduce offsite impacts and maximise rainfall storage in SDI systems.
- Reduction of crop water requirements by up to 25% based on ET_{crop} does not reduce cotton yield or quality.
- Under conditions described in this project SDI cotton yields were surpassed by furrow irrigation yields, whereas WUE was similar over two seasons.
- Incentives identified that promote adoption of SDI in cotton production were outweighed by constraints such as; installation cost, knowledge barriers and technical demands.

7 Description of "project intellectual property"

Nil

8 List of publications arising from the project

Bhattarai, S.P., McHugh, J., Lotz, G.B., and Midmore, D.J., Water-Yield production function: Physiological basis for cotton grown on Subsurface Drip Irrigation in heavy clay soils at Central Queensland, Australia. In: Proceedings of the 3rd World Cotton Research Conference. Cape Town, South Africa, March. 2003.

Bhattarai, S.P., McHugh, J., Lotz, G.B., and Midmore, D.J., Studying the economic and physiological basis for cotton production on Subsurface Drip Irrigation in the heavy clay soils of central Queensland, Australia: An analysis of water-lint production function. In: Proceedings of the 2nd International Congress of Plant Physiology. New Delhi, India, January 2003.

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McHugh, A.D., Lotz, G.B., Sub-Surface Drip irrigation on a Vertosol under Cotton: Increased Water Use Efficiency and Reduced Off-Farm Environmental Impacts. In: Proceedings of the Rural Water Use Efficiency Workshop. Bardon Conference Centre - Brisbane, April 2003, pp 43-49.

9 Recommendations for further research

This study has shown that irrigation management and or manipulation of soil surface and profile condition could have a significant influence on water quality, riverine and groundwater contamination. Therefore the irrigation management techniques and technology impacts need to be assessed at irrigation area, sub-catchment scale, in concert with other minimisation practices especially in irrigation areas without a reticulation system on difficult soils, such as the Dawson Valley Irrigation Area (DVIA) and the west bank of the EIA. A commercial scale research site in either of these areas would provide essential data on economic viability of SDI systems and how it assists in meeting regional water quality targets.

If SDI and fully optimised furrow irrigation systems are to provide the expected benefits, there is a clear need to make better use of soil properties, profile condition, monitoring, instrumentation and technology transfer. The aim is to ensure that sediment, nutrients and chemicals are held within the cropping zone over a range of climatic and catchment conditions, utilising an integrated approach to environmental management systems.

In this project, drainage below the root zone was estimated by the volume of water that could not be accounted for, that is by difference. Quantifiable methods are required to determine water loss through drainage when water is applied above crop requirements. Generally, if all furrow irrigated fields were optimally irrigated, then drainage below the root zone would be minimised during irrigation. However as this is not the case, research and demonstration of the linkages between WUE and deep drainage is required.

In two seasons rainfall was very low, so there is still a need to understand what volumes of runoff are generated from these two irrigation systems when they are optimally managed to increase rainfall infiltration and infield storage during rainstorm events.

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Appendix 1

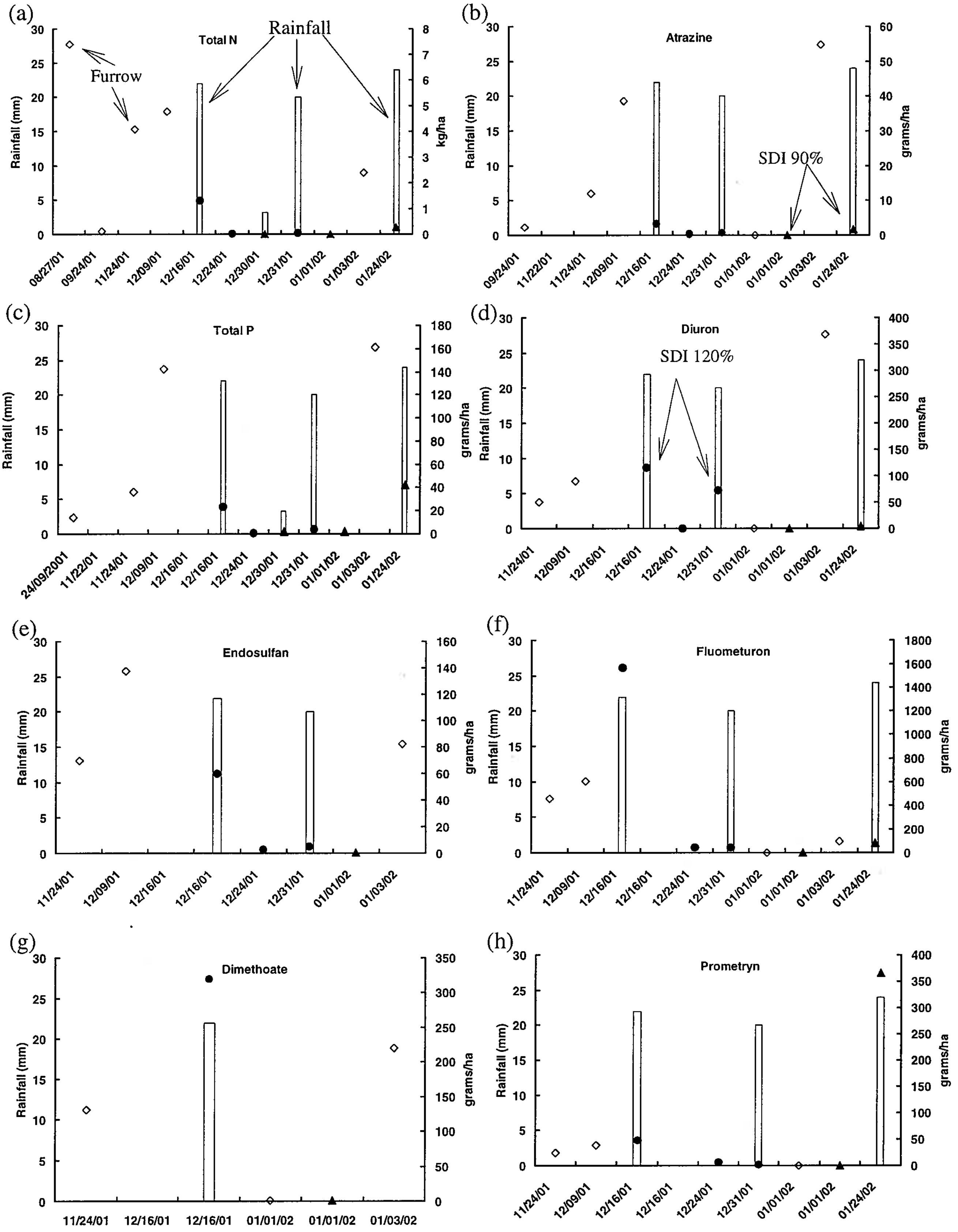

Figure 1. Nutrient and chemical concentrations of samples collected from each rainfall and irrigation event for furrow and subsurface irrigated sites for the 2001/2002 cotton season. Dates are expressed in mm/dd/yy. ◇ = furrow irrigation, ● = 120% SDI, ▲ = 90% SDI.

Part 4 – Final Report Executive Summary

Use and management of subsurface drip irrigation (SDI) on heavy clay soils is poorly understood, with no definitive water balance study conducted on systems. Research has also found unacceptable levels of sediment and chemical pollutants in surface runoff water from furrow irrigated cotton.
The objectives were to:

- Compare water use efficiency (WUE), sediment, runoff and chemical content of runoff between SDI and furrow irrigation on a Vertosol, near Emerald, Queensland.
- Identify incentives and constraints to adoption of SDI.
- Incorporate SDI into BMP guidelines for the cotton industry.

The aim was to manipulate soil profile moisture condition, thus increasing the potential for rainfall storage in the soil, consequently reducing runoff and offsite impacts. The farmer managed the furrow sites as per the rest of the farm in the first season. In the second season each furrow irrigation was optimised to increase WUE.

Offsite impacts were restricted to irrigation events (No runoff from rain). Significant transport of sediment occurred from the furrow sites (6-13 tonnes/ha) with no soil loss from the three driest SDI treatments. Chemical and nutrient concentration levels were unacceptable during each irrigation event.
Optimised furrow irrigation reduced drainage below the root zone, doubled WUE and enhanced yield by 1 bale/ha and achieved a total water saving of 2.2 ML/ha on the first season. Reduction of irrigation by 25%, in SDI did not reduce yield or cotton quality and achieved a total water saving of 1.8 ML/ha over two years. Non-optimised furrow irrigated systems and poorly managed SDI systems have significant adverse impacts on the environment from tail water and drainage below the root zone. Changes in land and irrigation management practises increased the soil storage capacity for in crop rainfall.

This project has highlighted irrigation management strategies to minimise offsite impacts and save considerable volumes of water. However the measured erosion rates, even under dry conditions, will result in long term yield reduction which could be exacerbated under rainstorm events. Therefore, all irrigation systems must be operated in concert with other erosion minimisation strategies. The optimisation of furrow irrigation events saved water and improved yields that surpassed SDI, but highlighted the amount of skill, experience and knowledge necessary to operate SDI successfully. The cost of SDI systems and management of it are significant deterrents to adoption and therefore it requires significant training and financial incentives. Generally this technology should be reserved for marginal soils. These results have identified strategic practices which offer benefits to cotton producers moving toward BMP, ISO14001 and environmental management system (EMS) accreditation.

Irrigation management techniques and technology impacts need to be assessed at irrigation area, sub-catchment scale, in concert with other contamination minimisation strategies, especially in irrigation areas with marginal soils and runoff containment issues. A commercial scale research site would provide essential data on economic viability of SDI systems and how it assists in meeting regional water quality targets.
If SDI and fully optimised furrow irrigation systems are to provide the expected benefits, there is a clear need to make better use of soil properties, profile condition, monitoring, instrumentation and technology transfer. The aim of new research could identify and demonstrate how sediment, nutrients and chemicals can be held within the cropping zone over a range of climatic and catchment conditions, utilising an integrated approach to environmental management systems.
Quantifiable methods are required to determine water loss through deep drainage when water is applied above crop requirements. Generally, if all fields were optimally irrigated, drainage below the root zone would be minimised during irrigation. However as this is not the case, research needs to demonstrate the linkages between WUE and deep drainage.
In two seasons rainfall was very low, so there is still a need to understand what volumes of runoff are generated from these two irrigation systems when they are optimally managed to increase rainfall infiltration and infield storage during rainstorm events.