

DRIP IRRIGATION IN THE AUSTRALIAN COTTON INDUSTRY: A SCOPING STUDY



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SR Raine, JP Foley and CR Henkel

National Centre for Engineering in Agriculture
University of Southern Queensland
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EXECUTIVE SUMMARY

This document reports the findings from a survey of drip irrigated cotton growers and equipment manufacturers conducted during May-June, 2000. The survey included 26 face-to-face interviews and three telephone interviews with growers as well as interviews with the major manufacturers, consultants and installers within the industry. The main findings were:

- The performance of drip irrigation within the cotton industry is not limited by soil type or regional characteristics. Commercial systems have been developed which will work effectively on a wide range of soil types across the full spectrum of industry climatic conditions.
- The components available for SDI in the cotton industry are generally appropriate and effective if installed properly.
- Drip systems are not inherently more efficient at water application than surface or spray systems. Badly managed drip systems may result in lower efficiencies and higher deep drainage losses than other standard systems.
- Drip systems should only be considered after serious attempts have been made to optimise existing systems. On economic grounds, investment in improved surface irrigation performance or adoption of low pressure overhead spray systems will generally provide better returns.
- The key economic drivers for adoption are comparative performance and water valuation.
- Pure economics may not be the key adoption driver – agronomic, environmental site specific and life style issues may well be more important.
- The design, installation and management of drip irrigation systems is inherently more complex than other application systems. Hence, widespread adoption will require additional training and support of both industry professionals and growers.
- Cotton SDI users can generally learn a lot about drip performance from other industries – particularly in relation to installation and management issues.
- A major barrier to the implementation of effective SDI systems in the industry is the level of training and experience of dealers and installers.

Key recommendations arising from the surveys are:

- There is a need for industry development and promotion of standards and guidelines on best management practices for SDI installation and management;
- An effort is required to develop appropriate training and certification processes for users of SDI systems in cotton;
- CRDC should initiate and/or actively support processes to facilitate registration of agricultural chemicals for use in SDI systems;
- There is a need to continue and/or expand research and development in the cotton industry regarding:
 - SDI design (emitter discharge, emitter spacing and depth, lateral configuration, germination issues) for specific soil types;
 - the identification of appropriate management practices to minimise deep drainage;
 - optimised fertiliser application quantities/times and yields on these systems; and
 - the long term sustainability including pupae control in no-rotation, no-till SDI cotton systems, particularly on hardsetting red soils.
- Economic evaluation of drip installations should include the whole of system life costs and include valid comparisons with optimised alternative application systems.

1. INTRODUCTION TO THE STUDY

Cotton production in Australia has traditionally been conducted using surface irrigation techniques on heavy clay soils. However, increasing pressures on water availability, the potential yield benefits of improved control of soil-water in the root zone, and the potential for reduced labour, fertiliser and pesticide costs has raised grower interest in alternative irrigation application techniques including low pressure overhead spray and drip irrigation systems.

While less than 2% of the total Australian cotton crop is currently grown using drip irrigation systems, it seems likely that this proportion will increase due to existing and future pressure on water availability and environmental sustainability as well as economic and political factors. Hearn (1994) states that 235000 ha of irrigated cotton are grown in Australia. Of that area, 3100 ha or 1.3% was grown under SDI in the 1999/2000 season.

It should be noted that surface irrigation of agricultural crops has been practiced for in excess of four thousand years and spray irrigation for most of the last century. By comparison, drip irrigation is the "new kid on the block" having only been commercially adopted over the last forty years. This means that drip irrigation systems, products and management practices have been rapidly evolving and that there are likely to be a range of operational issues which are yet to be fully explored.

The first drip systems were made of ceramic pipe and installed sub-surface in the 1940's. However, it was not until the late 1960's and improvements in the availability of appropriate plastics that the Israelis began to experiment with surface drip irrigation. Various forms of drip irrigation have been used in Australia for over twenty-five years. However, it has only been in the last seven years that thicker walled, new generation drip systems installed below ground have been successfully implemented in Australian cotton fields on a large scale.

Sub-surface drip irrigation (SDI) and surface drip tubes that were retrieved yearly were tried in the Australian cotton industry during the early 1980's with some resounding failures. None of these systems are operational today. These systems were essentially financed into existence, such that those growers on whose properties the systems were installed did not pay excessively for the SDI. However, these early commercial experiences suffered from a combination of poor system design, installation and management practices which influenced yield responses, water savings and product life expectancy. Similarly, research during the 1980's into the benefits of drip irrigation of cotton under Australian conditions used design and management practices more consistent with surface irrigation strategies. This work failed to recognise the significant conceptual differences in the management of drip and surface systems and hence, may have failed to fully identify the potential benefits of drip systems.

Despite these early set-backs, the potential benefits associated with drip irrigation are increasingly being recognised within the cotton sector with in excess of thirty commercial growers currently using drip irrigation. However, drip irrigation is not likely to be a panacea for all of the irrigated cotton sector. The comparatively high capital cost of these systems is certainly a factor influencing adoption. In the words of an experienced independent drip irrigation consultant "*economically speaking, drip irrigation for the cotton industry is currently right on the knife edge*". However, as a respected industry extension officer has also noted "*in a lot of instances where drip irrigation has been installed, it has nothing to do with economics. For many it is a lifestyle issue, where the grower is in a situation where both he and his irrigation system are aging, and replacement is inevitable, the perception is that drip irrigation is far more automatable than the other irrigation systems*".

This scoping study was commissioned by the Cotton Research and Development Corporation in an effort to better understand the existing drip irrigation sector within the industry and to identify future opportunities for research and development within this sector. The specific objectives of the study were to identify the:

- extent of current drip irrigation usage in the cotton industry;
- perceived benefits and limitations associated with drip irrigation usage; and
- the operating constraints and situations where drip irrigation may be beneficial.

The main focus of the study was a survey of the major drip irrigation manufacturers and nearly all of the current drip irrigators within the industry. Over 6000 kilometres were travelled visiting twenty six of the approximately thirty drip irrigation systems installed in Queensland and New South Wales. Systems that were no longer working were not visited but efforts were made to obtain information on why the systems failed and lessons to be learnt from these experiences.

Throughout the course of the interviews it has become apparent that for most drip irrigators, the adoption of drip irrigation has been an incredibly harrowing one, both emotionally and economically, as they have climbed the steep learning curve to make SDI work successfully for them. For many, there is now no choice but to make it work, and the stress of doing so must surely be counted in the overall economic cost. For many growers cropping near ecologically sensitive areas, drip irrigation and ground-rigging are seen as the only way that they are going to be capable of maintaining cotton production.

This report starts with a generic introduction to drip irrigation including performance evaluation methodologies and strategies to improve performance. The main body of the report provides details of the grower and manufacturer surveys including feedback on the current operating constraints. This section is followed by grower and manufacturer identified research and development opportunities for the drip irrigated cotton sector.

2. BACKGROUND TO DRIP IRRIGATION

Drip irrigation systems have discharge points or sufficiently small holes in sections of hose such that filtration is a primary concern (Burt and Styles, 1994). These systems commonly use low flow rates and low pressures at the emitters and are typically designed to only wet the root zone and maintain this zone at or near an optimum moisture level (James, 1988). Hence, there is a potential to conserve water losses by not irrigating the whole field. Obvious advantages of drip irrigation include a smaller wetted surface area, minimal evaporation and weed growth, and potentially improved water application uniformity within the crop root zone by better control over the location and volume of application (Hoffman and Martin, 1993). Drip systems are also commonly designed to include fertigation and automation capabilities. A typical drip irrigation configuration is shown in Figure 2.1.

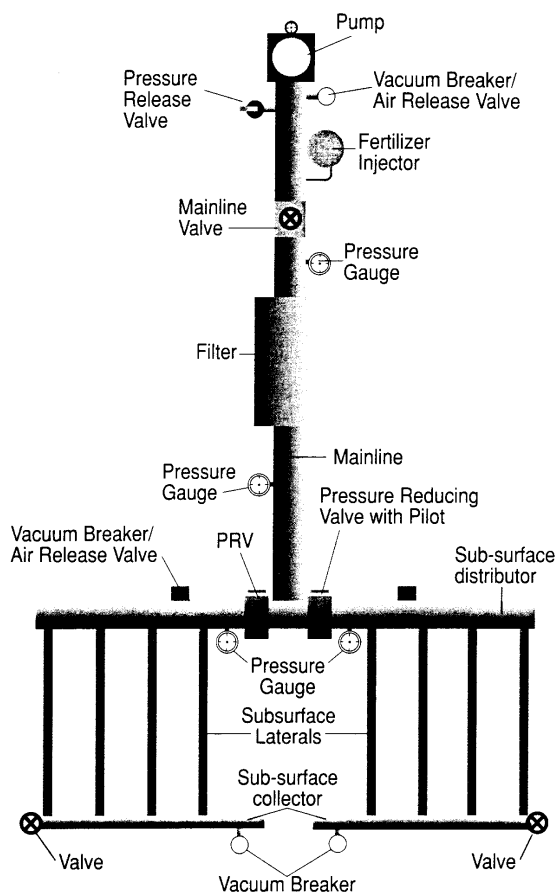


Figure 2.1: Idealised drip irrigation component layout (from *Netafim, n.d.*)

Drip systems are commonly categorised according to either their physical structure or their placement in the field (e.g. surface, subsurface or suspended). The physical structures may be either:

- flexible thin-walled drip (or trickle) tape made of polyethylene where the emitter is formed in the join, or the emitter is joined to the inside of the tape or

- drip (or trickle) tube where the structure is a thicker walled polyethylene pipe into which the separately formed emitter is inserted, welded, glued within, or attached externally to the hose.

Emitter passages can be further described as having linear, turbulent, or pressure regulating flow paths. By far the most common system in the Australian cotton industry is the thin-walled tape placed sub-surface, containing turbulent flow paths.

There have been a number of recent literature reviews on drip irrigation. Burt and Styles (1994) provide a practical guide to the design, installation and management of drip and micro-irrigation while Camp (1998) has undertaken a comprehensive review of mainly USA published research into the design and evaluation of subsurface drip irrigation. Summaries of the drip irrigation work reviewed by Camp (1998) are shown in tables 2.1 and 2.2.

Table 2.1: Summary of previous papers reporting design, evaluation, and guidelines for subsurface drip irrigation systems (from Camp, 1998)

	Design/Evaluation					Guidelines/Rec.					Economics/ Profitability	
	Uniformity	Plugging Deforma- tion	Longevity	Methods	Soil Wetting*	Design	Install	Operation (incl fert.)	Filtra- tion	Root Intrusion		Other Effects†
Ayars et al., 1995											RL, MD	
Bar-Yosef et al., 1991		X						X				
Barth, 1995											PB	
Ben-Asher & Phene, 1993					M							
Bosch et al., 1992												X
Brown et al., 1996					WP							
Bui, 1990	X	X								X	ID, MD	
Camp et al., 1997b	X	X	X	X			X	X				
Chase, 1985b		X					X				SD, ID, MD, CT	
Coelho & Or, 1996					M							
Dhuyvetter et al., 1995					M, L							X
Dirksen, 1978					M			X				X
Ghali & Svehlik, 1988					M			X			SWM	
Gibson, 1974						X		X				
Gilley & Allred, 1974a, b					M	X					SWM	
Grattan et al., 1988						X					WC	
Grimes et al., 1990					X						SC	
Hanson et al., 1997					X						SWM	
Hanson & Bendixen, 1993						X		X			SS	
Henggeler et al., 1996												X
Hills et al., 1989a	X	X						X			SC	
Hills et al., 1989b	X	X				X						
Huang et al., 1982						X					MD, RD	
Isobe, 1972						X	X	X				
Jorgensen & Norum, 1993	X					X	X	X	X			X
Knapp, 1993												
Kruse & Israeli, 1987						X	X		X			
Lamm et al., 1995c						X	X	X	X			
Lanting, 1975		X				X	X					
Mikkelsen, 1989								X			FM	
Mitchell, 1981	X		X								SC	
Mitchell & Sparks, 1982											SC, OM, RG	
Mitchell and Tilmon, 1982						X	X	X				
Mizyed & Kruse, 1989	X	X		X								
Nightingale et al., 1985								X			SC	
O'Brien et al., 1997												X
Phene et al., 1979								X			CM, WC	
Phene et al., 1992c	X		X	X								
Phene, 1995a	X						X				RG	
Phene & Ruskin, 1995						X	X	X			SC, WU	
Plaut et al., 1996						X					RG	
Rolston et al., 1979								X			CM	
Rubeiz et al., 1991								X			FM, SC	
Ruskin, 1992		X	X			X		X	X		WU, WQ	
Ruskin et al., 1990			X			X				X		
Sadler et al., 1995	X	X	X		X							
Schwankel & Prichard, 1990											SWM, EX	
Schwankel et al., 1990											SC	
Shani et al., 1996					X	X	X				SE	
Solomon & Jorgensen, 1992						X	X	X	X	X	SWM	
Thomas et al., 1974					M						EC	
Thomas et al., 1977					M, L	X					SWM	
Tollefson, 1985a						X						
Van Bavel et al., 1973					M							
Vaziri & Gibson, 1972						X						
Warrick et al., 1980					M	X						
Warrick & Shani, 1996	X	X				X	X	X			SWM	
Welsh et al., 1995							X				PB, SWM	
Zachmann & Thomas, 1973					M							
Zoldoske et al., 1995						X	X	X		X	EC	
Zoldoske & Norum, 1997	X	X				X	X	X			RG	

* Soil wetting definitions: L = laboratory measurements; M = model; WP = wetting pattern modification.

† Other effects code definitions: CM = chemical management; CT = conservation tillage; EC = emitter comparison/evaluation; EX = emitter excavation effect; FM = fertilizer management; ID = insect damage; MD = mechanical damage; OM = organic matter; PB = plastic or foil barrier; RD = rodent damage; RG = root growth; RL = row location relative to lateral location; SC = soil chemistry change, e.g. pH; SD = soil compaction; SE = seedling emergence; SS = soil salinity; SWM = soil water movement; WC = weed control; WU = use of wastewater; WQ = water quality guidelines.

Table 2.2: Summary of previous papers investigating subsurface drip irrigation in field crops, including cotton (from Camp, 1998)

Crop		Lateral		Scheduling/Delivery				Water Supply§	Other Irrig. Syst.¶	Fert. Mgt.	Irrig. Water Req.	WUE	Plant Meas.	Environ. Effects
		Depth (m)	Spacing (m)	Type*	Tim-ing	Amt.	MSW†							
Alfalfa	Bui & Osgood, 1990	0.35	1.5											
Alfalfa	Kruse & Israeli, 1987	0.12-0.37	1.5	FT			PE	S						
Alfalfa	Mead et al., 1993	0.41	1.2											
Bermudagrass	Devitt & Miller, 1988	0.15	0.61, 0.91, 1.22				NP, T	SL						
Bermudagrass	Gushiken, 1995	0.15-0.30	Var.					WW						X
Corn	Adamsen, 1992	0.35-0.41	0.91	FD				SL	S		X			
Corn	Caldwell et al., 1994	0.40	1.5	FD	X	X	NP					X		X
Corn	Camp et al., 1989	0.30	0.76, 1.52	RT	X		T				X			
Corn	Coelho & Or, 1996						TDR							
Corn	Darusman et al., 1997a	0.40-0.45	1.5-3.1	FD		X	T							X
Corn	Darusman et al., 1997b	0.40-0.45	1.5	FD		X	T							X
Corn	Evert et al., 1995	0.15, 0.30	1.52				NP	M	F			X		
Corn	Evert et al., 1996	0.30	1.52		X	X	NP	IRT	SD	X		X		
Corn	Howell et al., 1997	0.30	1.5	FT	X	X	NP		SD					
Corn	Kruse & Israeli, 1987	0.12-0.37	1.5											
Corn	Lamm & Manges, 1991	0.40-0.45	1.5	FD		X	NP			X		X	X	X
Corn	Lamm et al., 1995a	0.40-0.45	1.5	FD		X					X	X	X	X
Corn	Lamm et al., 1995b	0.45	0.76-3.05	FD	X	X				X	X			
Corn	Lamm et al., 1997a	0.40-0.45	1.5-3.0	FD		X	NP					X		
Corn	Lamm et al., 1997b	0.40-0.45	1.5	FD			NP			X		X	X	X
Corn	Manges et al., 1995	0.45	0.76-3.05											
Corn	Mitchell & Sparks, 1982	0.34-0.37	0.76						SD	X				
Corn	Mitchell, 1981	0.36	0.9	FD						X				
Corn	Oron et al., 1991	0.30	0.95, 1.90					WW	SD					
Corn	Powell & Wright, 1993	0.38	0.91, 1.82, 2.74	FD		X								
Cotton	Ayars et al., 1995	0.45	1.7	Var										
Cotton	Bar-Yosef et al., 1991	0.30, 0.45							SD	X				
Cotton	Camp et al., 1997a	0.30	1.0, 2.0	RT			T	M		X				
Cotton	DeTar et al., 1994	0.38		RT					F		X			
Cotton	Fangmeier et al., 1989	0.20	1		X	X	NP	CWSI		X		X	X	
Cotton	Henggeler, 1995	0.20-0.35	1.0-3.1						F					
Cotton	Henggeler et al., 1996													
Cotton	Hutmacher et al., 1993, 1995	0.45	1.52	RT	X	X	NP	L			X		X	
Cotton	Oron et al., 1991	0.30	0.95, 1.90					WW	SD					
Cotton	Phene et al., 1992a						NP	PE	F		X			
Cotton	Plaut et al., 1985	0.40			X	X	NP	PE	SD					X
Cotton	Tollefson, 1985a	0.25	1.0	FD						X				
Cotton	Tollefson, 1985b	0.20-0.25	1.9	FD					F	X	X			
Cotton	Zetsche & Newman, 1966	0.40	1.42	R					F					
Grain sorghum	Hiler & Howell, 1973	0.20		RI				L	SD		X	X	X	
Landscape	Gushiken, 1995	0.15-0.30	Var.					WW						X
Peanut	Adamsen, 1989	0.35-0.41	0.91	FD				SL	S		X			
Pearl millet	Payne et al., 1995	0.25	0.4	FD		X						X		
Sugarcane	Huang et al., 1982	0.30				X	G	PE	F					
Sugarcane	Moore & Fitschen, 1990	0.10	2.7	FT	X	X			F					
Trees	Shrive et al., 1994	0.15				X			WW	S, SD			X	X
Turf	Gushiken, 1995	0.15-0.30	Var.					WW						X
Turf	Solomon & Jorgensen, 1992	0.10	Var.						S					
Turf	Zoldoske et al., 1995	0.20	0.46	RT										
Wheat	Oron et al., 1991	0.30	0.95, 1.90					WW	SD					
Wheat	Senock et al., 1996	0.18-0.25	0.51								X		X	
Wheat	Tollefson, 1985b	0.20-0.25	1.9	FD					F	X	X			

* Type code definitions: FD = flexible wall, dual chamber; FT = flexible wall, turbulent flow; R = rigid; RI = rigid wall, insert orifice; RT = rigid, turbulent flow; Var. = various.

† MSW = measured soil water content. Code definition: NP = neutron probe; T = tensiometer.

‡ Other code definitions: CWSI = crop water stress index; IRT = infrared thermometer; L = lysimeter; M = crop growth model; PE = pan evaporation.

§ Water supply code definitions: SL = saline/sodic; WW = waste water.

¶ Other irrigation system code definitions: F = furrow; S = sprinkler; SD = surface drip; WT = water table.

A major benefit of drip is the ability to apply small amounts of water at high frequency intervals. This provides the opportunity to maintain the soil moisture at a specified moisture deficit and changes the focus of irrigation scheduling away from "irrigating at a frequency which does not adversely affect output quantity/quality" to "irrigating on a schedule which maximises output quality/quantity". This change in emphasis may produce production benefits depending on the specific crop response to moisture stress and the specific soil moisture characteristic. However, where the crop is relatively insensitive to moisture stress and the available moisture content is high the benefits of more frequent irrigation are likely to be minor if present at all. Hence, many researchers (e.g. Hanson and Patterson, 1974; Wendt *et al.*, 1977; Bucks *et al.*, 1981) have found that drip irrigation does not increase yield compared to other application systems where both the volume and timing of the water applied for evapotranspiration is non-limiting.

Drip systems provide not only the potential to irrigate more frequently but also the ability to more readily maintain specific moisture deficits at a level below field capacity either for part or all of the irrigation season. Irrigating to maintain a specified root zone soil moisture deficit provides the opportunity for increased soil moisture storage from rainfall during the irrigation season.

The potential water application efficiency of drip irrigation systems is often quoted as greater than 90% (e.g. Golberg *et al.*, 1976; Hoffman *et al.*, 1990; Keller and Karmeli, 1975; Jensen,

1983). However, as with all irrigation systems, the ability to achieve high levels of efficiency is a function of the design, installation and management practices. For example, Shannon *et al.* (1996) found that application efficiencies under commercial drip irrigation in the Bundaberg area ranged from 30-90%.

Losses of water in drip irrigation systems principally occur through evaporation from the soil surface, surface run-off and deep drainage. Evaporation losses are generally small in subsurface irrigated systems due to a limited wetted surface area. Run-off losses are also normally small due to the low application rates. However, excessive watering periods and the use shallow subsurface drip on low infiltration soils (i.e. sodic soils) can result in appreciable tunnelling of flows to the surface creating surface ponding and the potential for localised run-off.

Deep drainage losses are often the major source of volumetric inefficiencies in drip irrigation systems with losses often being greater in subsurface systems (Sutherland, *pers comm*) . Deep drainage losses occur due to the use of excessive irrigation periods arising from either inadequate knowledge regarding the volume of water required to be applied to recharge the root zone or more commonly, appreciable non-uniformities within the application system. Drainage losses may also be associated with management of the system as maintaining the root zone at field capacity will ensure that any infiltrated rainfall will be lost direct to deep drainage.

2.1 PERFORMANCE EVALUATION

The performance of drip irrigation systems is heavily influenced by the uniformity of application. However, unlike other systems, the uniformity of drip irrigation systems is not only a function of the design characteristics but is also significantly affected by installation, maintenance and management practices. Therefore, measuring application uniformity in drip irrigation systems is an important component of performance evaluation and the assessment of the likely system longevity (Sadler *et al.*, 1995). The ASAE Standard EP458 - Field evaluation of micro-irrigation systems (ASAE, 1997) provides an outline of the most commonly adopted performance evaluation procedure.

Discharge uniformity may be assessed by measuring discharge from a number of emitters using a catch can methodology. For subsurface systems, this involves excavating the soil around the emitter and collecting the water quantity discharged (Sadler *et al.*, 1995). Trials to confirm that the excavation of the SDI emitter does not affect the emitter flow discharge rate have found that flowrates increased by only 2.8-4.0% above the discharge measured when the emitters were embedded in the soil (Sadler *et al.*, 1995). Pressure in the drip irrigation laterals is also commonly measured to identify non-uniformities due to friction losses and head differences along laterals. Pressure may be measured at the flush point or end of the lateral using a standard pressure gauge or at specific points along the lateral using a needle point pressure gauge inserted directly through the tape or tube. Where an assumption of no plugging can be made, the models used for the design and evaluation of drip irrigation systems may also be used to evaluate the application uniformity of subsurface systems based on the measured pressures and the system design characteristics (Phene *et al.*, 1992; Feng and Wu, 1990; Wu and Yue, 1991; Wu, 1992).

Root zone recharge may be measured directly using soil moisture sensors. In this case, sensors should be placed in vertical grid pattern along a radial axis from the emitter to measure both lateral and vertical soil water movement. Soil moisture sensing is also commonly used to identify deep drainage losses and variations in wetted pattern due to application rate and period of watering (Or, 1995).

A wide range of irrigation uniformity coefficients are commonly used in performance evaluation (Jensen 1983). Camp *et al.* (1997) evaluated the appropriateness of various uniformity coefficients for drip irrigation systems including the traditional Christiansen (1942) equation as used by a number of workers (e.g. Kruse, 1978; Wu *et al.*, 1979; Bralts *et al.*, 1981a&b; Solomon 1984; Nakayama and Bucks, 1986) and the ASAE Standard EP458 (ASAE, 1997b). Camp *et al.* (1997) subsequently suggested that the ASAE method should be interpreted carefully especially when plugged emitters are likely due to its smaller sample requirements. The Christensen's Uniformity Coefficient (C_u) is defined as:

$$C_u = 100\left(1 - \frac{M}{\bar{x}}\right)$$

where M is the main absolute deviation of the applied depths (or emitter discharges) x_i and is given by:

$$M = \frac{\sum |x_i - \bar{x}|}{n}$$

where \bar{x} is the mean applied depth and n is the number of measurements. For systems which have considerable variation in uniformity, there will be large variations from the mean and the coefficient will decrease. However, a very different uniformity measure, called the Emission Uniformity (E_u), is often used for drip irrigation systems:

$$E_u = (1 - 1.27e^{-0.5 C_v}) \left(\frac{q_{\min}}{q_{av}}\right)$$

where e is the number of emitters per plant, C_v is the coefficient of variation of emitter discharges due to variations in the manufacture of the emitter, q_{\min} is the minimum discharge and q_{av} is the mean discharge. Hence, E_u increases with an increasing number of emitters per plant (e) and a decreasing C_v . However, it should be noted that the range of E_u values will be much smaller than the range of discharge variations. Hence, a small decline in E_u generally represents a proportionally large variation in emitter discharge. A uniformity coefficient (C_u) of about 98% equals an emitter flow variation of approximately 10% while a uniformity coefficient of about 95% equals an emitter flow variation of approximately 20% (Howell *et al.*, 1980). The C_u is typically preferred as the measure of uniformity but the E_u is commonly used when the emitter discharges are unknown.

Extensive evaluation of drip irrigation systems have been conducted in the United States and other areas using mobile irrigation laboratories (e.g. Yurgalevitch, 1995; Hanson *et al.*, 1995; Holsambre, 1995). These studies have shown that the emission uniformities achieved under commercial conditions are often highly variable between operators. In particular, a large proportion of systems in Californian and Florida operate with E_u values of less than 80% while those in India were found to average less than 50%. Given that Howell *et al.* (1980) suggests that an E_u value of 95% equates to an approximate discharge variation of 20%, these values are not any better than those achieved with spray and surface systems. The main causes of low emission uniformities in drip irrigation systems arise from poor design and manufacture, poor pressure regulation, clogged emitters, leaking laterals, excessive watering, and non-uniform pressures. Minor causes are due to use of different sized emitters, inadequate pump pressures and missing emitters (Yurgalevitch, 1995; Hanson *et al.*, 1995).

2.2 STRATEGIES TO IMPROVE DRIP IRRIGATION PERFORMANCE

The principle strategies to improve the performance of drip irrigation systems efficiency involve the minimisation of evaporation, deep drainage losses and where present run-off. Deep drainage losses are most heavily influenced by non-uniformities within the systems which increase with system age. Hence, a significant effort is normally directed towards adopting preventive maintenance strategies to reduce the increase in system non-uniformities.

Deep drainage

Deep drainage occurs due to excessive watering periods or low uniformity of application. Matching the water application volume to the root zone moisture deficit by reducing either the frequency or duration of the irrigation is the most effective strategy to reduce deep drainage losses, particularly if pulse application strategies are being used. Greatly increased irrigation frequencies are often recommended for increased crop yields, with some authors suggesting up to eight irrigations per day for some crops. The downside of the very short irrigation intervals associated with pulsed irrigations is the decreased emission uniformity caused by the draining of laterals and submains after each event (Hanson, 1995). Similarly, it should be noted that for some crops, greater yields are not always achieved with shorter irrigation intervals. The ability to reduce the period or frequency without adverse affects of crop yields will also be a function of the uniformity within the system. In some cases, it may be necessary to improve the system uniformity before any appreciable reduction in water application volume can be achieved.

It is not uncommon to find deep drainage losses occurring during the first few irrigations of the season where subsurface drip irrigation systems are used to germinate planted seeds (Hanson, 1995). Under these conditions, excessive water is often used in an attempt to achieve the near surface saturation required for germination and establishment. In these cases, consideration should be given to the potential to either use shallower placement of the sub-surface tape (i.e. normally not greater than 250 mm) or investigate options to apply the first couple of irrigations using an alternative irrigation practice (i.e. spray or temporary surface drip lines).

Deep drainage losses also occur due to excessive irrigation periods associated with attempts to increase lateral soil-water movement into crop rows or beds. Lower discharge rates and shorter more frequent irrigations may provide an opportunity to increase lateral movement depending on soil properties. However, the wetting pattern of subsurface drip irrigation on high infiltration soils has also been successfully influenced by the placement of a continuous impermeable membrane underneath the drip line to inhibit the downward percolation of water from the emitters and provide a broad moisture front rather than a point source (Welsh *et al.*, 1995; Miller *et al.*, 2000). This system reduces downward water movement by creating a perched water table which encourages capillary movement upward and horizontally increasing the amount of water in the root zone of shallow crops. The width to depth ratio of the V shaped membrane is able to be altered for different soils to take advantage of the different capillarity of clay and sandy soils. However, in using such a system, care should be taken to ensure that the higher moisture content achieved within the root zone does not produce undesirable waterlogging effects on either root growth or nutrient availability.

Evaporation

Evaporation losses from subsurface drip irrigation systems is generally small due to the small (if present at all) wetted surface area. However, the movement of water to the surface through tunnelling in low infiltration soils may result in appreciable evaporation losses. Evaporation losses in sub-surface systems may be reduced by increasing the depth of tape placement or by reducing the irrigation period to reduce the potential for moisture to reach the surface. Similarly, evaporation losses may also be reduced by irrigating at night when surface temperatures are

lower or by using emitters with smaller discharge rates if evaporation is associated with water tunnelling to the surface. Where evaporation losses are significant using surface applied drip systems, it is possible to increase infiltration and reduced wetted surface area by excavating a column of soil from directly below the drip emitters and backfilling it with coarse sand. This strategy has been used to reduce evaporation losses from 30% to 4% of the applied water (Meshkat *et al.*, 1998).

Non-uniformities

Poor filtration is one of the biggest causes of drip irrigation system failure and low uniformities. Clogging of emitters by precipitates of carbonates and iron oxides, algae/bacteria growths, root intrusions, suspended materials in the water, and soil ingestion can reduce emission uniformity (Camp, 1998). Root intrusion may be deterred by herbicide impregnation of emitters (Gushiken, 1995) or the inclusion of phosphoric acid, chlorine or herbicides (e.g. treflan). Emitter design is also a factor contributing to different levels of root intrusion. Soil ingestion can be a problem where vacuum relief valves are not installed correctly. Provision for periodic flushing of these sediments from the laterals should also be installed. High flow tapes with larger orifices may be used to reduce clogging rates but higher pressure variation is normally found for any given lateral length (Hanson, 1995).

Plugging of emitters caused by physical, chemical or biological contaminants is universal and is considered to be the largest maintenance problem with drip irrigation systems (Howell *et al.*, 1983). The problem that arises is that manufacturers continue to make smaller emitters that more closely match soil infiltration rates, and consequently the potential for plugging becomes greater. Bucks and Nakayama (1980) and Nakayama *et al.* (1991) have identified water quality criteria for potential clogging hazards (Table 2.3). Similarly, there are guidelines on the type of filter to be used for various water qualities (Table 2.4). The remedies for clogging include frequent flushing of irrigation system pipes and emitter laterals and the application of chemical treatments. Acidification is used to remove precipitate contaminants (eg. white calcium carbonate or reddish brown iron oxide) where as chlorination is recommended to remove microbial growths (eg. bacterial slime). The presence of particulates (eg. sand, dirt) suggests that the filtering system should be inspected and if necessary upgraded for the water quality being used.

Table 2.3: Criteria for classifying potential clogging hazard of irrigation waters to be used in drip systems. (from Nakayama *et al.*, 1991)

Factor	Clogging Slight	Hazard Moderate	Severe
<i>Physical</i> Suspended solids (ppm)	< 50	50 – 100	> 100
<i>Chemical</i> PH	< 7.0	7.0-8.0	> 8.0
Dissolved solids	< 500	500-2000	>2000
Manganese (ppm)	<0.1	0.1-1.5	>1.5
Iron (ppm)	<0.2	0.2-1.5	>1.5
Hydrogen sulphide (ppm)	<0.2	0.2-2.0	>2.0
Biological bacteria populations (max. number/mL)	<10000	10000-50000	>50000

Table 2.4: Selection of filtration systems based on water quality
(from *Plastro Gvat*, 1989)

Nature of problem	Degree of contamination	Quantitative criterion	Type of filter				Type of control filter
			Hydrocyclone filter	Granular filter	Disc filter	Automatic screen filter	
Soil particles	Low	≤ 50 mg/l	A	B	—	C	Screen
	High	> 50 mg/l	A	B	—	C	Screen
Suspended solids	Low	≤ 50 mg/l	—	A	B	C	Disc
	High	> 50 mg/l	—	A	B	—	Disc
Algae	Low		—	B	A	C	Disc
	High		—	A	B	C	Disc
Oxidized iron and magnesium	Low	≤ 0.5 mg/l	—	B	A	A	Disc
	High	> 0.5 mg/l	—	A	B	B	Disc

3. GROWER AND MANUFACTURER SURVEYS

On-farm surveys of both current and previous drip irrigators within the cotton industry were conducted to obtain information regarding on-farm irrigation infrastructure and management practices and the factors influencing the adoption and operation of drip irrigation systems. The manufacturers of drip irrigation to the cotton industry were also surveyed to obtain details on the recommended and implemented design, installation, operation and maintenance procedures within the industry. Both the irrigator and manufacturer surveys were also designed to obtain data on the:

- areal extent of drip irrigation in the cotton industry;
- nature of the systems currently and previously in operation;
- commercial water use and production benefits obtained using drip systems; and
- to identify current management and operational problems associated with the implementation of drip irrigation systems.

The surveys were conducted over a six week period (May-June, 2000) and involved a total of 26 interviews with irrigators and six interviews with the major drip irrigation supply companies. The surveys encompassed more than 80% of drip irrigation users within the cotton industry including twelve growers from Queensland and fourteen from NSW. Each of the interviews were conducted on-farm with either the farm owner or irrigation manager. Each of the manufacturer interviews were conducted face-to-face and involved subsequent telephone follow-up. Discussions were also held with a range of dealers and individuals involved in system installation. All interviewees were advised that information provided would be treated confidentially.

3.1 INDUSTRY OVERVIEW

Approximately 3100 ha of drip irrigation is currently installed in the Australian cotton industry. These installations are owned by 31 different farm operations, ranging from smaller growers through to the major corporate operations. The systems are distributed throughout the geographical spread of the industry with fourteen systems currently installed in Queensland, sixteen in New South Wales and one system in Western Australia. All of the commercial drip systems have been installed subsurface. The average area of the drip system on each farm is approximately 90 ha with the largest single installation being 790 ha. The average age of the current installations is 2.75 years with a maximum age of seven years. At least eight farms have more than one subsurface drip irrigation (SDI) installation. In these cases, the size of the first installation ranged from 4.5 to 144 ha in size. This is consistent with USA studies (Burt and Styles, 1994) showing that farmers who are successfully expanding their areas of drip irrigations have started with trial areas of between 8 and 32 ha.

The majority (59%) of drip irrigated cotton growers use water sourced from surface supplies (Figure 3.1). Groundwater is used by approximately 45% of drip irrigators but only accounts for approximately 30% of drip irrigation water used. The other 70% of water is sourced from surface supplies. Only one grower is currently using effluent water in drip irrigation. While approximately half of the surveyed growers have installed drip irrigation onto cracking clay soils these installations account for just under 70% of the drip irrigated area (Figure 3.2). Approximately one-third of the growers have installed drip systems on to loamy soils.

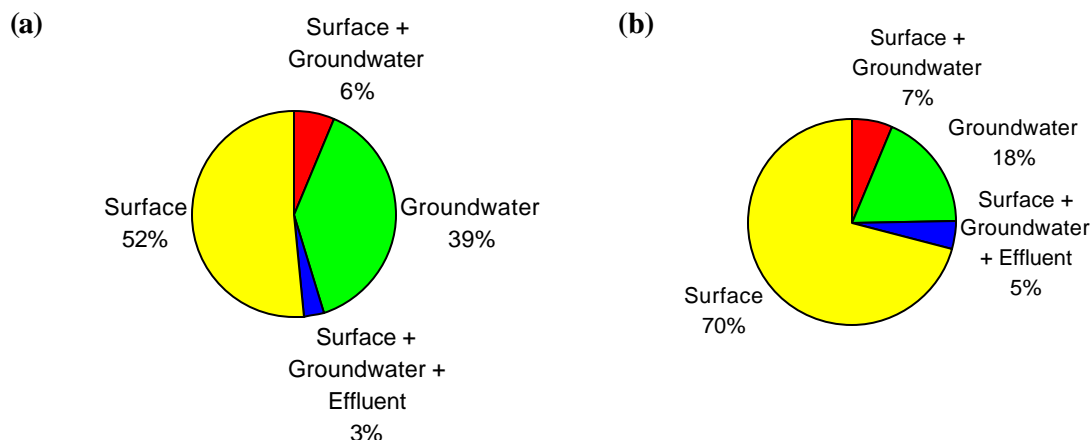


Figure 3.1: Source of water used for drip irrigation within the cotton industry by (a) number of irrigators and (b) area irrigated.

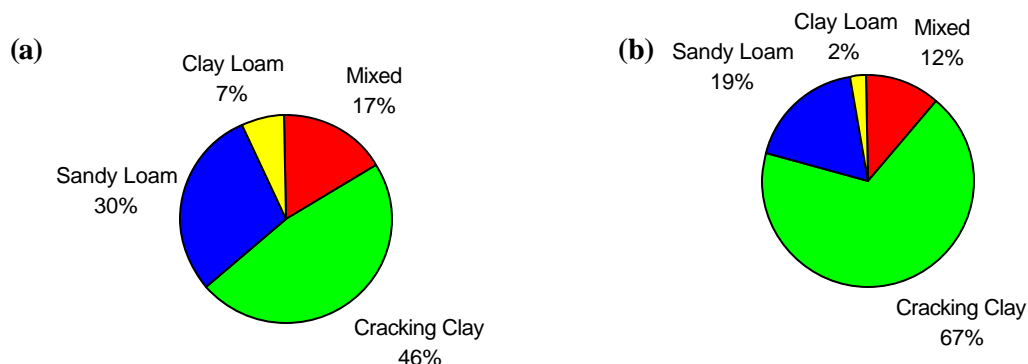


Figure 3.2: Soils used for drip irrigation within the cotton industry by (a) number of irrigators and (b) area irrigated.

3.2 SDI YIELD AND WATER USE EFFICIENCY

All cotton growers using SDI reported a decrease in water use compared to traditional furrow irrigated systems (Figure 3.3). The average reduction in irrigation water use (ML_{irrig}) associated with the operation of SDI systems compared to furrow systems was $2.56 ML_{irrig}/ha$. This represents an average 38% reduction in water application when compared with traditional non-optimised surface irrigation systems. However, it should be noted that the water saving differential may be much smaller where optimisation of the surface irrigation is undertaken. Yield achieved on SDI blocks is strongly related to the water management strategy. Where growers focus on maximising SDI block yields, improvements of up to 2.7 bales/ha above surface irrigated fields are achieved. However, where growers focused on maximising SDI water savings to enable increased production area on other fields using the saved water, the yields of the SDI blocks were not greatly different to surface irrigated blocks. In all cases, growers reported an increase in crop water use efficiency (Figure 3.4) with an average increase of 1.29 bales/ ML_{irrig} .

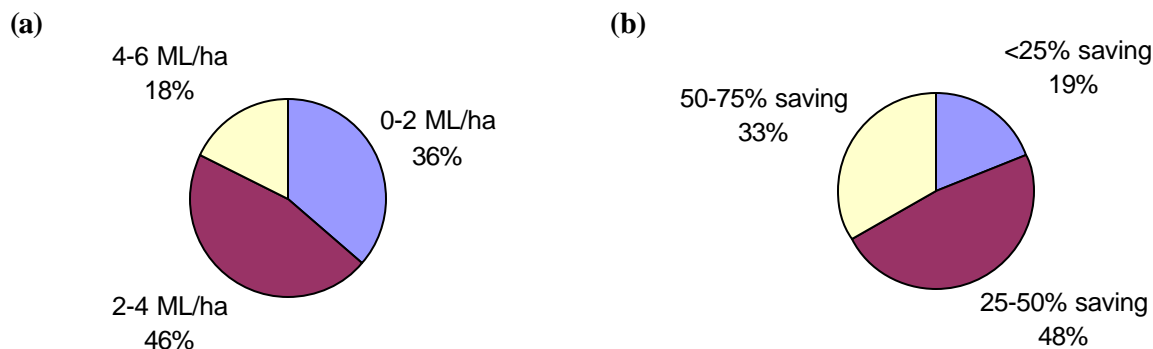


Figure 3.3: Irrigation water savings associated with drip irrigation compared to furrow systems reported by cotton growers as (a) an absolute volume (ML/ha) and (b) a percent saving compared to irrigation water applied used by the furrow system.

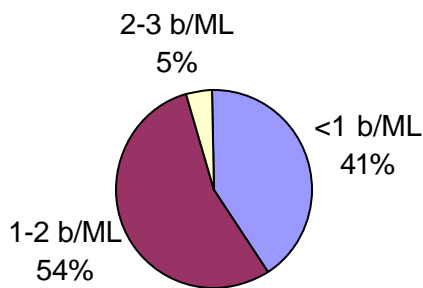


Figure 3.4: Increase in water use efficiency (bales/ML) between cotton irrigated by SDI and furrow

GROWER COMMENTS ON THE ADVANTAGES OF DRIP IRRIGATION

- Water savings evident.
- Increased yields or the same yield with less water (increased water use efficiency)
- Land not suited to surface irrigation is now productive with drip and in the majority of cases, with no increase in allocation.
- Increased yield associated with reduced waterlogging on heavy clay soils.
- Labour savings – not only in irrigation but less crop management time (less sprays, less cultivation).
- Automation has created labour and water savings.
- Creates an ability to double crop with less water.
- Fertigation has enabled the use of less fertiliser – not in all cases as some skeptical about the decrease.
- Less cultivation passes and ground rig applications.
- Able to cultivate or use ground rigs during irrigation cycles.
- Crop management (height & bush size) easily managed with water control
- More efficient use of rainfall with less runoff.
- The improved soil structure has meant the use of less powerful machinery operations and hence, a cost saving.

3.3 ISSUES DRIVING ADOPTION OF DRIP IRRIGATION IN THE COTTON INDUSTRY

There are a wide range of reasons why the existing drip irrigation systems have been installed in the cotton industry. As with most management decisions, it is often a combination of factors which leads cotton growers to make a decision to install drip irrigation systems. All growers surveyed indicated that the potential to increase crop yield was a factor influencing on their decision while approximately 70% of growers also indicated that water and labour efficiencies were also important (Table 3.1). The cost of labour and the relatively simple automation capability of drip systems was a major driver in the adoption of drip by smaller growers. Thirty-eight percent of the systems have been installed in an effort to reduce water applications either because the farms are already short of water or the growers intend to use the water savings in irrigating additional area. Twenty-four percent of growers were motivated by the potential of SDI to increase yields in specific fields, particularly on marginal country (usually with hardsetting red soils) that had not responded well to the destructive wetting and drying cycles associated with both furrow and spray irrigation. Some growers have installed drip systems into environmentally sensitive areas, such as river zones, so that they could maintain dry spray paths and use ground rigs for pest control. However, it should also be noted that a small number of drip systems have been installed principally as show pieces for the various drip installers and drip manufacturing companies while others appear to have been installed principally for political and/or social reasons (ie. in an attempt to be seen to be doing the right thing).

Table 3.1: Issues driving cotton grower decisions to install drip irrigation

ISSUE	Responses (%)
Increased crop yield	100
Water savings	71
Labour savings	71
Water limited – major issue	38
Fertigation and chemigation	29
Reduced waterlogging	24
Soil type/field shape/slope	24
Automation	21
Improved crop quality	13
Land limited – major issue	13
Improved water distribution down field	4

MANUFACTURER COMMENTS ON THE PERCEIVED BARRIERS TO THE ACCEPTANCE OF DRIP IN THE COTTON INDUSTRY

- Grower perception of the cost/hectare versus achievable benefits. Early uncontrolled trials did not demonstrate the benefits from drip irrigation, mainly through farmer lack of interest and supplier/manufacture inability to properly service and control the trials.
- The most talked about benefits are yield and water use efficiency but there is little mention of the total drip concept as a farm management tool.
- The cotton industry conferences have not moved towards discussing irrigation systems except for surface irrigation. The industry talks water balance & efficiency but does not compare to other systems.
- There is a perceived acceptance by growers that the water use efficiency of surface irrigation is high and that there is little water use efficiency benefit from drip irrigation.
- There is a lack of controlled trials (independent studies) which look at the total drip irrigation management system inclusive of the individual aspects of drip (eg. fertigation, chemigation, wetting patterns, labour, automation and agronomic factors).
- Constable's research has had a impact on acceptance
- In the early stages of marketing and even to some extent today, there is a barrier in terms of the grower's and his employees' ability and willingness to learn about the management of the drip irrigation system.
- Growers require better knowledge of the operating constraints associated with SDI systems to ensure that they are able to ask the appropriate questions in order to evaluate supplier's quotations.
- Growers need to learn and obtain the ability to put the knowledge into practice to ensure the best results or even ensure a result.
- Growers see a large and difficult operation & management problem, installation problem, maintenance problem and perceive a mystical or radical science associated with drip irrigation.
- Farmers perceive the failure of the some early drip irrigators in the cotton industry as due to the failure of drip irrigation rather than the financial failure of these enterprises due to a range of factors.
- There is a need for the industry to push for registration of chemical usage through drip irrigation. This is seen as a barrier even though most drip growers do currently use chemigation.

3.4 DESIGN AND LAYOUT PRACTICES

Nearly all the irrigators surveyed indicated that they have experienced problems at some stage in either the design, installation, operation or maintenance of their drip systems. However, it should be noted that installation of many systems has involved a high degree of design, installation and management experimentation. Growers indicated that none of these problems have been insurmountable and that, while there is always room for improvement, they were generally satisfied with their system performance. This is reinforced by approximately 57% of the drip irrigators interviewed indicating an interest in expanding their existing SDI area.

Supply capacity

Older SDI installations were typically designed to deliver around 14 mm/day to the crop. However, both manufacturers and growers have been pushing lower design capacities with more recent installations being commonly set up to deliver approximately 12 mm/day. A number of experienced drip irrigators have reduced supply design capacity to 10 mm/day with some contemplating 6-8 mm/day capacities in conjunction with deficit irrigation strategies during periods of peak demand. Systems with smaller design capacities have reduced capital costs because of the lower flow rate and smaller pipeline and valve capacity requirements. A change in design capacity from 12 mm/day to 8 mm/day provides an opportunity to reduce the capital cost of pumps and filters by one third and overall costs by approximately 20%. However, this would require many growers to change their operating strategy to incorporate deficit irrigation practices.

Filtration and filtration capacity

Both manufacturers and growers have indicated that the filtration capacity of approximately 20% of existing cotton SDI systems is inadequate. Filtration typically requires the use of a final filter mesh size that is 7-10 times smaller than the smallest dimension of the tape emitter. However, the industry's understanding of filter set capacity under commercial conditions has principally been based on USA and Israeli experiences. The drip irrigation industries in both of these countries rely heavily on underground water where as a significant proportion (~70% by area; Figure 3.1) of the Australian cotton industry relies on surface water often with high sediment loads and much poorer quality. Hence, while the final mesh size used in the filtration units is typically appropriate, the capacity of the filtration set can be taxed due to excessively frequent flushing of the filter set. High impurity loads, may also create inflated pressure differentials causing impurities to be forced through the filtration media and possible blockage of emitters and system failure.

Filter system capacities are being commonly being installed at the upper end of the "manufacturer's recommended maximum capacity". This often does not leave sufficient margin for errors in the estimation of the water quality or seasonal variations in the water quality (surface water). Inadequately sized filtration systems create an unacceptable increase in the number and frequency of back flushing cycles. When an individual filter is undergoing flushing it is off line. Hence, if flushing of the filter sets occurs for a significant proportion of the irrigation period, the overall capacity of the filtration system can be reduced dramatically. Where the water quality is poor, the capacity of the filter system should be designed to handle the required design flow rate when one of the filters is flushing. In this case, smaller individual filter sets have the benefit of producing a smaller reduction in overall flow rate during flushing and shorter flushing periods. However, a greater number of these smaller units are required to achieve the same overall filtration capacity. Hence, the selection of the appropriate configuration of filters requires an assessment of the water quality, the filtration capacity required, and both the capital and operating cost of alternative configurations. This information has not been well promoted within the industry to date and appears to be the main reason for some undersizing of filtration capacity.

Slimes or biological growths may build up in sub-mains and laterals even after highly quality filtration (200 mesh) and have the capacity to move through the system and plug emitters. Frequent application of biocides (e.g. free chlorine) is necessary to reduce build up in susceptible waters along with the use of scour valves on supply and sub-mains mains to remove contaminant growths.

Back siphoning may also cause emitter blockage where systems are not designed or installed appropriately. As the water drains from the drip tape, a vacuum is created which, if not released, results in soil being sucked into the emitter. The inadequate number and location of air vacuum breaker valves is a significant cause of emitter problems, particularly in fields that are not graded as low points can block the air from relieving the vacuum.

Tape flushing capacity

The tape flushing capacity of the drip system is a critical area of design that impacts on the system performance and life expectancy. Some SDI designers have recently started using block distribution uniformities of greater than 92.5% to ensure adequate flushing velocity uniformity throughout the system. However, in some cases in the cotton industry, SDI systems appear to have been installed with inadequate flushing main capacities and with flushing valves which are too small. In these cases, while the piping and valving apparently operate well, the inability to

achieve adequate velocities at the lower ends of the tape lines results in deposition, decreases in flow volumes and eventually, total blockage. This will produce slightly higher back pressures in the mains which may also affect system performance. Retro-fitting of larger valves and increasing the number of valve may solve some flushing problems. Velocities to effectively flush and scour tapes are in the range of 0.4 to 0.6 m/s and no amount of flushing in an inadequately designed system will provide an extended system life. This is one of the areas that appears to be least understood by both growers and manufacturers in the design process and will continue to provide difficulties to those growers with under-designed systems.

Pumps

Early drip irrigation pump installations typically consisted of single large pumps and electric motors. Availability of parts for these systems was also poor as these pumps were not high turnover items. Newer installations are typically based on multiple pump/motor combinations providing easier replacement and serviceability. There has also be a recent tendency to provide some additional pump capacity within the system to allow adequate irrigation in the event of a single pump or motor failure and allow for pump wear. However, another method to closely match irrigation and flushing flowrates to pump capacity as well as account for impeller wear over time is to use variable frequency drives on a single pump/motor combination in the set.

Infield tape placement

The majority of drip irrigators in the cotton industry install the tape at two metre intervals (figures 3.5 & 3.6) on a 1:2 drip tape:crop row ratio (Figure 3.7). However, approximately one third of growers install tape on a 1:1 tape:crop row ratio. This represents a significant dichotomy in the perceived benefits of the alternative spacing strategies and is presumably also influenced by the higher (~33%) cost of the 1:1 systems. The majority of tape is installed at a depth of between 250 and 350 mm (Figure 3.7). Regional differences in tape placement were observed with growers in NSW generally installing the tape deeper than Queensland growers. Tape depth affects the wetting pattern in relation to plant depth and root uptake with deeper tape placement on lighter textured soils observed to produce germination problems in systems with 1:2 tape:crop row ratios. There is also a greater potential for deep drainage with increasing depth of tape placement.

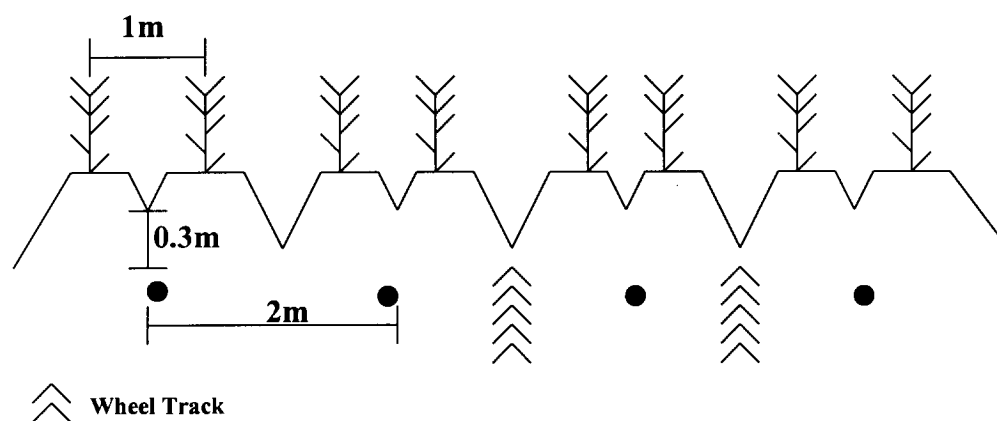


Figure 3.5: Typical sub-surface drip irrigation tape placement in cotton

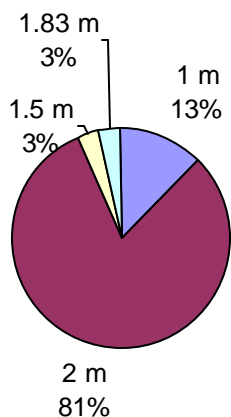


Figure 3.6: Proportion of drip irrigation layouts at various drip line spacings (in metres)

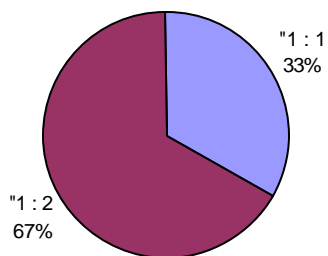


Figure 3.7: Proportion of growers using either 1:2 or 1:1 tape lateral spacing versus crop row spacing

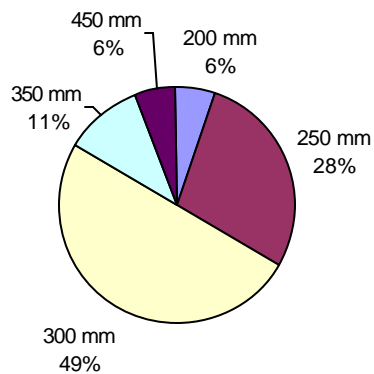


Figure 3.8: Proportion of drip irrigation layouts at various tape placement depths (in mm)

MANUFACTURER COMMENTS ON TAPE REQUIREMENTS

- The minimum wall thickness that should be used for SDI systems is 15 Mil.
- Emitter output & emitter spacing need to be considered with soil type and length of run to prevent emitter blockages and achieve good wetting patterns and crop growth.
- The uniformity of emission (flow variation) throughout a field should be in the range of not less than +/- 10%. Ideal $E_U > 92.5\%$.

Problems encountered with design and installation

Almost two thirds of the surveyed growers indicated that they would make some changes to their design prior to the installation of their next SDI system (Table 3.2). A wide variety of design issues were identified by growers ranging from problems with the field orientation, the inappropriate location of sub-mains and vacuum breaker valves, inadequate selection of lateral lengths, as well as inadequate filtration and tape flushing capacity. A major concern raised by both growers and manufacturers was system life expectancy with many of the currently installed drip irrigation systems not expected to achieve the desired design life expectancy of 7-15 years. However, a large number of these growers recognised that the lower system life expectancy was because the designs of the systems were premised or altered, often at their own request, to achieve a lower capital and installation cost. Problems may also arise where local dealers, who generally lack adequate technical skills in SDI system design, installation and operation, alter manufacturer design layouts (e.g. reducing filtration and flushing capacities/sizes) and/or delete system components (e.g. vacuum break valves) from the designs without consultation with the designer. Forty five percent of the surveyed growers indicated that the level of knowledge displayed by the dealer/installer adversely affected either the design or installation of their system. Design changes typically resulted in a reduction in system performance, increasing operating expenses and reducing system life expectancy.

Table 3.2: Design and installation issues identified by cotton growers with drip irrigation

Design/Installation Issues	Responses (%)
Would improve design next time	62
Tape misalignment	55
Dealer/installer lack of knowledge	45
Incorrect or uneven tape depth	42
Surface drainage inappropriate/inadequate	34
Trouble with joiners/tape/risers	31
Troubles with sticks, roots and stumps	28
Inadequate flushing main/valve sizes	28
Trouble with insect/mice holes just after installation	17

Many of the SDI systems have also been designed and installed without the water supply being tested for impurities to enable appropriate selection of the filtration system and maintenance program. Similarly, the soil physical properties are rarely evaluated adequately to enable appropriate selection of the lateral and row spacings, and the emitter flow rates and spacings. The main reason provided by manufacturers for the lack of prior field investigation is that growers are not prepared to pay the costs of the required analyses. However, the cost of the analyses is often insignificant compared to the overall system costs and the potential problems associated with inadequate evaluations may be difficult to remedy once the system is in place below the ground.

A number of SDI installation problems were reported by growers. More than half of the surveyed growers (55%) reported problems with tape alignment while 42% reported problems with tape depth control. Other installation problems include the damage to, or incorrect attachment of, laterals to sub-main risers, the incorrect laying of tape (twisting, kinking, incorrect symmetry of the tape) or incorrect trench backfilling. Approximately one third of growers (31%) reported joiner or riser problems. This is consistent with reports from installers that the early slip ring joiners were a problem, particularly in the cracking clay soils because the shrinking and swelling moved the ring and loosened the joint. Subsequent attempts at using tie wires on seamed tapes were unsuccessful due to leakage along the seams associated with inadequate tie-wire tightness. However, more recent systems have reported a significant reduction in joiner problems where tie wires have been used on seamless tape and threaded joiners used on seamed tapes.

GROWER ADVICE ON DESIGN AND INSTALLATION

- The survey for the drip irrigation design should be conducted comprehensively to ensure that all low spots and high spots are located, in particular crest points for the possible positioning of sub-mains.
- Before installation, the land (whether new or old) should be well prepared to remove all stumps, roots, sticks and rocks. Land should be ripped in both directions to break hard pans & remove stumps before it is rotary-hoed or cultivated to remove large clods of soil.
- The area should be land levelled to remove melon holes and crests.
- The installation of the tape should be only done after the row direction has been ripped at least twice to just below the depth at which the tape must be laid.
- Flushing mains require more valves. The areas to be flushed need to be decreased in size to allow more efficient flushing.
- Sub-mains require flushing valves on the end to ensure cleaning of the sub-main or passage of water to allow cleaning.

Approximately one third of drip irrigators indicated that surface drainage in their drip irrigated fields was inadequate and that grading should have been undertaken prior to installation. Similarly, twenty eight percent of growers also reported other problems with land preparation prior to installation including the inadequate removal of roots, sticks and hardpans. Hence, as with all products, growers should conduct their own assessment of the reliability and experience of the supply and installation companies.

Field layouts and farming practicalities are also important, given that the system will be in the ground for a long time. Risers, submains and valves that are placed high off the ground

have been found to create problems for groundrigs, cultivating rigs and other in-field equipment. PVC pipes and fittings have also been found to suffer ultraviolet degradation. Hence, exposed pipes and fittings should be painted to reduce cracking. HDPE risers are not commonly used in the industry but were reported as being more durable and robust when nudged with a boll buggy or cultivator.

SUMMARY OF MANUFACTURER/SUPPLIER COMMENTS ON THE DRIP IRRIGATION PRODUCTS AND SERVICES PROVIDED

- All manufacturing companies are on a comparative equal footing with no major performance or economic differences in product. Labyrinth research and drip efficiency research (emitter uniformity & emission uniformity) are so well advanced that in general, the companies surveyed do not have any outstanding advantages over another product. Although this is currently the case, the industry should be warned against companies that may move into the sector to “deliver, cheap and nasty tape”. For example, the tape used in short-term horticultural (vegetable) crops is not the tape to be used in a SDI system.
- Superior performance should be gained by the service provided, design efficiency, installation supervision and guarantees, irrigation operation & management guidelines and back-up service.
- Some companies do have an agronomic technical back-up service but as with most manufacturers/suppliers insufficient “feet on the ground” creates shortages to cover the whole industry. Hence, there is a reliance on local dealers (who may not be adequately qualified) to cover shortfalls. There are insufficient irrigation dealers (currently only three) throughout the cotton industry that are experienced with the design, installation and the operation and management of sub-surface drip irrigation systems.
- For drip irrigation to be successful, it is necessary for the farm owner/cotton grower, farm manager, irrigation manager and the farm agronomist (employee or consultant) to all have an interest in the drip concept and be willing to learn the appropriate management requirements.

3.5 MANAGEMENT PRACTICES

Germination

Germination remains one of the biggest challenges for SDI, especially when used on an alternate tape line spacings (i.e. 1:2 tape:crop row systems). While 44% of the SDI area is currently germinated using the SDI system alone, another 45% of the total SDI area relies heavily on rainfall to some extent for crop establishment (Figure 3.9). Germination using SDI is nearly always difficult unless the tape is placed directly in the plant line. However, because of the additional cost associated with 1:1 systems, this practice will continue to be less popular within the Australian cotton industry. A small proportion (11%) of drip irrigators have followed the lead of USA and Israeli SDI users, by using furrow or spray irrigation to germinate crops and then irrigating with SDI after establishment. A number of Australian growers also reported contemplating the use of lateral move irrigators for germination of SDI areas. In this system, the SDI fields would be germinated with the lateral move spray irrigator before being subsequently irrigated using the SDI. The lateral move irrigator would then be used to irrigate other adjacent crop areas without SDI.

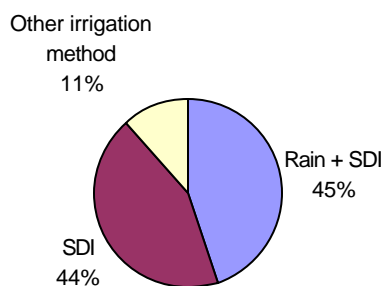


Figure 3.9: Strategies adopted for the germination of SDI cotton area.

Scheduling

Appropriate scheduling of SDI is critical if the benefits of the additional capital investment associated with drip installation are to be realised. In excess of 85% of drip irrigators rely to some extent on an objective measure of soil moisture within the root zone (Figure 3.10). However, a significant proportion of the irrigators (57%) use more than one scheduling tool. This suggests that there is a high degree of uncertainty amongst growers in relation to the appropriate tools, techniques and strategies for scheduling drip irrigation. Many of the survey growers also use visual midday stress observations of the crop to confirm soil moisture readings and scheduling decisions.

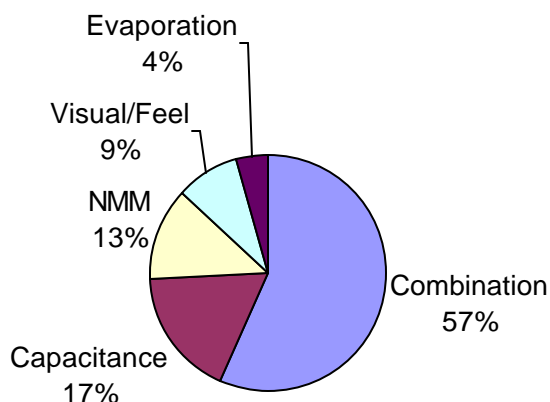


Figure 3.10: Scheduling tools used by drip irrigators in the cotton industry

Fertiliser usage and chemigation

More than half of the irrigators surveyed use less fertiliser under drip irrigation than under traditional surface irrigation (Figure 3.11). Only 9% reported an increase in fertiliser usage while 35% have not changed their fertiliser applications. The drip irrigation systems have also been widely used to apply chemicals during the season with approximately half of the growers (52%) indicating that they have applied either treflan or lorsban (neither of which is currently registered in all States for application in this industry) through the system and 39% indicating that they have applied other chemicals through the system (Figure 3.12).

Three main types of chemical injector systems are used in the industry:

- venturi systems are commonly installed in conjunction with large poly tanks for fertiliser input. Smaller, secondary venturi systems are used for chemical input. Minibulks and other dry break delivery systems are now being used for herbicides and acids and are capable of being injected directly into the systems using smaller venturi systems;
- 33 mL Dosatron pulse type units used for small volume chemical and acid injection; and
- plastic bodied "fire-fighter" style pumps that are capable of delivering larger flows at moderate pressures directly into the supply mains.

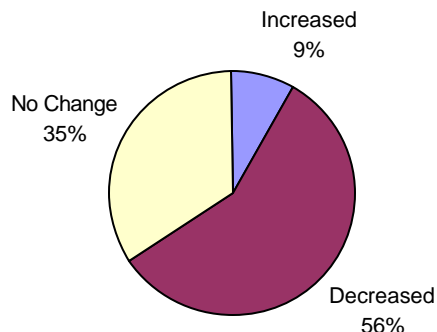


Figure 3.11: Fertiliser usage with drip irrigation compared to surface irrigation

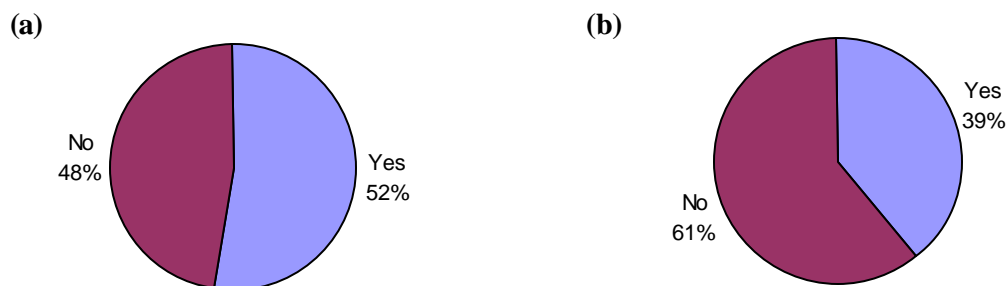


Figure 3.12: Do you apply (a) Treflan and/or Lorsban or (b) other chemicals through drip irrigation?

Crop Stress Management

Pix use within the drip irrigated sector reflects a dichotomy in water and crop management strategy adopted by these irrigators. Seventeen percent of the drip irrigators reported an increase in pix use due to their adoption of strategies which maximise yield per unit area (i.e. give the crop plenty of fertiliser and water and induce stress using pix). However, almost half of the drip irrigators indicated that they were currently using less pix on their drip irrigated crops than on their surface irrigated crops (Figure 3.13). Approximately 10% of these growers deliberately managed their drip irrigation strategy to reduce water use and induce crop stress. The rest of

these growers appear to use less pix as a result of inadvertently stressing the crop as part of their crop scheduling practice.

Only one grower indicated that they actively managed their SDI system to moisture stress the crop throughout the growing season in an attempt to improve crop water use efficiency. This form of deficit irrigation is relatively common in Israeli SDI cotton systems and has recently shown some potential under Australian conditions (Figure 3.14). However, when growers were asked about managing soil-water under continual deficits to hold crop growth at 4.5-5 nodes above white flower (NAWF) most indicated that they were not currently confident enough to risk the crop to that level (ie. ‘it would be running too close to the edge’’).

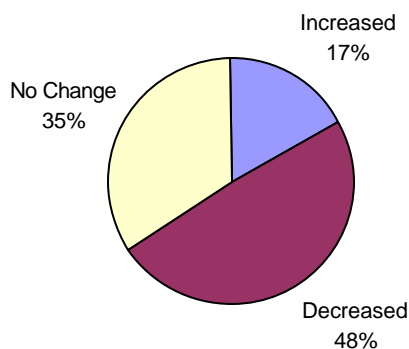


Figure 3.13: Pix usage with drip irrigation compared to surface irrigation

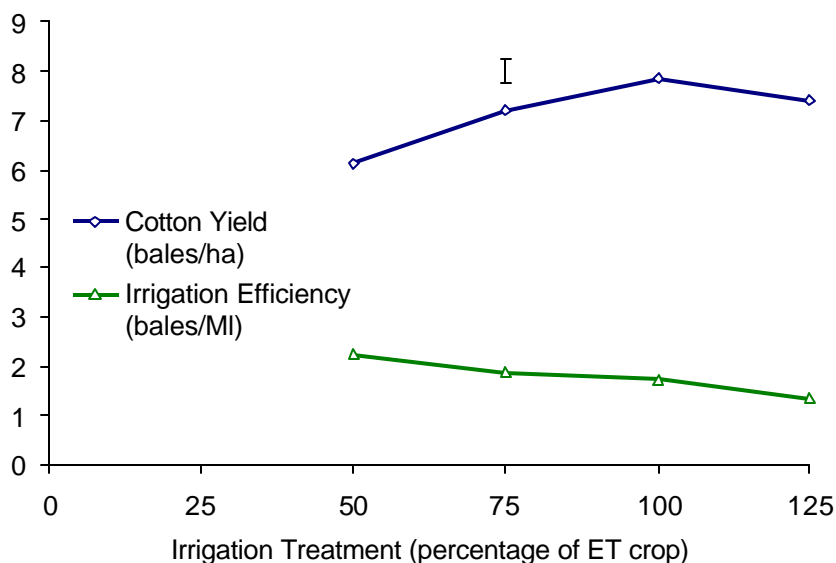


Figure 3.14: Cotton yield measured from picker harvested weights (assuming 38% turnout and 227 kg/bale) and irrigation efficiency. Bar is for 5% lsd for cotton yield. (from Hulme and O’Brien, 2000)

In-field rainfall run-off

One of the commonly perceived benefits of drip irrigation is the potential to capture rainfall during the crop season due to a reduced wetted zone and the ability to deficit irrigate. While only a small proportion of irrigators used deficit irrigation, almost three quarters of the irrigators surveyed believed that drip irrigation had reduced the surface run-off under rainfall compared to surface irrigated land (Figure 3.15). No grower identified an increase in run-off due to drip irrigation. However, there has not yet been any on-farm measurements to confirm these observations.

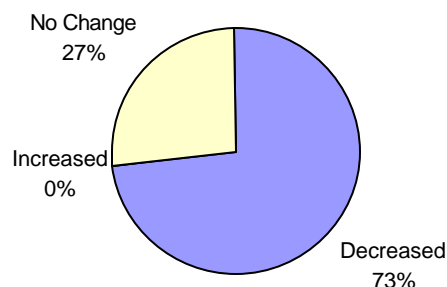


Figure 3.15: Surface run-off from rainfall on drip irrigated areas compared to surface irrigated areas.

3.5 ECONOMICS OF DRIP IRRIGATION

The subsurface drip irrigation systems currently operating in the cotton industry typically cost between \$3500 and \$4500 per hectare to install. However, some systems have cost up to \$7500/ha. Yield improvements achieved by SDI when compared with traditional surface irrigation are strongly influenced by the level of optimisation of the existing surface irrigation and the SDI management strategy adopted by the grower. Where growers attempt to reduce total water use in SDI fields to enable additional water to be applied elsewhere, only minimal improvements (and in some cases, decreases) in yield were achieved. However, where growers attempt to maximise yield on the SDI fields, improvements of up to 2.7 bales/ha are being achieved (Figure 3.16). Hence, the economic assessments of SDI systems need to incorporate the various management drivers by including the value of extra yield (achieved either on the SDI block or blocks irrigated with SDI water savings), the capital value of the water saved by the adoption of SDI, savings in labour, fertiliser and tillage costs, as well as the lifestyle benefits.

Growers who believe that the most significant economic benefit of SDI over furrow systems is yield improvement typically need to yield at least 1.25 bales/ha more from SDI compared to furrow irrigation for SDI systems costing approximately \$3800 to install. This yield differential increases to more than 2.5 bales/ha for systems that cost around \$5000/ha. However, only approximately 10% (ie. 2 out of 21 who responded to this question) of the SDI irrigators indicated that they were achieving a yield differential of more than 2.5 bales/ha. Approximately 25% of growers were achieving between 1.5 and 2.0 bales/ha extra while another 25% were either not achieving any significant yield increase or getting a reduced yield in their SDI blocks

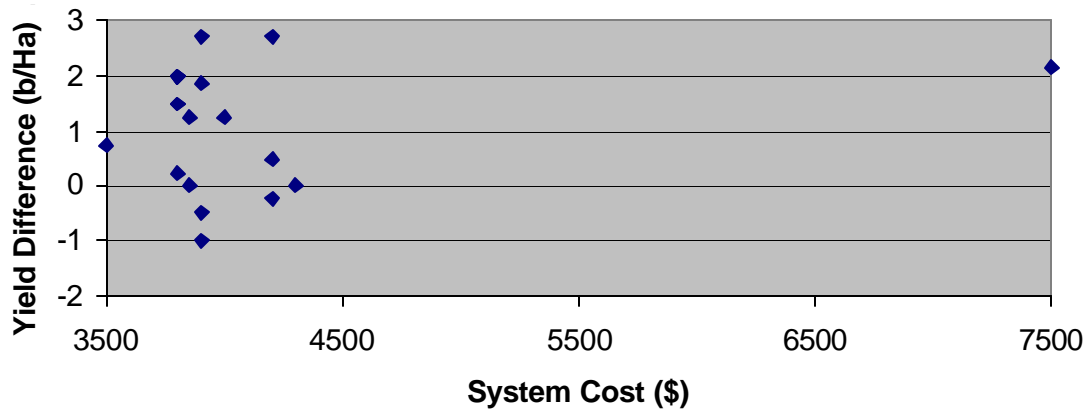


Figure 3.16: Yield differential between SDI and traditional furrow irrigation for cotton growers with both furrow and drip systems

compared with their furrow blocks. In these cases, growers indicated that the benefits of reduced water use on SDI fields were obtained through increased production area using the saved water on other fields or through labour and crop management benefits.

One alternative approach to drip irrigation within the industry involves the use of SDI to irrigate areas which would not normally be considered appropriate for cropping. These soils are typically either lighter in texture or have poor structural properties. This land is difficult to furrow irrigated and in many instances would not handle spray irrigation, due to poor surface structure and associated infiltration issues. However, use of this marginal land, although potentially economic due to low land purchase costs, must still be capable of sustainable production over the longer term. This ability to maintain yields on these poor soils in the longer term is yet to be confirmed. However, advances in no-till cotton growing and the use of ameliorants including micro-fine gypsum, water retaining polymers and the use of polyacrylamides and green manures or semi-matured cereal stubble may help the structure of these soils and provide them with stability throughout the wetting and drying cycles associated with cotton production.

Some of the larger corporate growers indicated that they are currently reassessing their SDI expansion plans. The recent improvement in their understanding of furrow irrigation systems has resulted in them increasing yields using these systems (principally via system capability and irrigation cycle time improvements). These growers are also assessing the potential to reduce water use on their existing furrow systems (ie. through more appropriate flow rates, cut-off times and furrow lengths) at comparatively minor cost. Hence, the prospect of reduced yield and water use differential between their SDI and surface irrigated fields has meant these growers are starting to question the economic benefits of future SDI investment.

MANUFACTURER COMMENTS ON THE ECONOMICS OF DRIP IRRIGATION

- General consensus from manufacturers/suppliers is that the typical cost for a fully installed SDI system inclusive of automation should be approximately \$4500 to \$5500 per hectare. This amount will deliver a system which if installed, operated, managed & maintained effectively should provide a minimum of 10 years life (existing irrigators are discussing and requesting a minimum 10 year life span)
- Automation is an excellent farm management tool reducing labour and improving control. The cost per hectare (\$/ha) of automatic controllers, valves and accessories is negligible when compared to the total cost. The benefits of automation typically far outweigh the cost.

4. FUTURE WORK

The existing drip irrigation installations in the cotton industry represent less than 1.5% of the industry. While this area is comparatively small, the systems have been installed over a wide range of soils, climatic and operational conditions ranging from northern Western Australia, through central Queensland to south western New South Wales. Even though there is a divergence of crop management strategies within the drip irrigated cotton sector, all of the current drip installations reported improvements in water use efficiency over traditional surface irrigation practices. The average crop water use efficiency improvement was 1.29 bales/ML_{irrig} with an average water reduction of 38% compared to traditional non-optimised surface irrigated systems. These results suggest that SDI technology could be successfully used in most areas of the existing cotton irrigation sector. However, the major factors affecting the adoption of drip irrigation are the high capital cost of the components and installation, and grower understanding of how to profitably use SDI as a farm management tool. Neither of these constraints is likely to change dramatically in the near future without external intervention.

The grower and manufacturer surveys raised a range of drip irrigation issues which could be considered for further investigation or promotion within the industry.

- There appeared to be a high level of variability in grower knowledge in relation to the requirements for installation and operation of their drip systems. Guidelines for both the installation and operation of SDI systems in cotton should be developed or better promoted (in cases where they already exist) within the industry. Extension of existing knowledge to growers and consultants, and availability of independent irrigation consultants that are capable of trouble-shooting designs, installations, operation and maintenance would also assist the industry.
- A significant number of drip irrigation growers indicated that they currently use chemicals which have are not currently registered for use in cotton. Hence, there is an urgent need to encourage the registration of these chemicals within the industry.
- The hydraulic design principles of drip irrigation are well established but operational problems have been encountered with lower cost systems “designed for a price”. This suggests that there is a need for greater awareness by growers within the industry of the trade-offs between capital expenditure, system performance and operating costs. This may require an independent evaluation of the full costs (ie. capital, operating, labour, management) associated with lower cost systems.
- Further work is required to quantify the actual yield/water differentials between drip and other irrigation systems. While there is no doubt that drip is more water efficient than other non-optimised systems, what is the magnitude of water savings (if any) when compared to optimised surface or other irrigation application (ie. lateral moves, centre pivots, LEPA) systems? It would appear that comparable improvements in water use efficiency and yield could be achieved at much lower cost through modification and/or adoption of these alternative systems.
- There appears to be some confusion regarding the potential to use drip irrigation for crop stress management either to improve seasonal water use efficiency or reduce the need for pix. Further work is required to confirm and promote the benefits of deficit irrigation on the potential to increase crop water use efficiency as well as capture and utilise within season rainfall events. The potential benefits associated with specific water stress periods on the requirement for pix usage should also be evaluated.
- One area where growers may be able to sensibly reduce the capital cost of drip irrigation systems is the potential to reduce overall system capacity. Current systems are routinely designed to supply 12 mm/day. However, some growers are considering installing 8 mm/day

systems with the expectation that the readily available soil moisture reserves will be required to be used during peak demand periods. While this may work effectively where the soils have a significant moisture reserve and the peak demand period is comparatively short, it would not be appropriate for all areas of the industry. Hence, further work is required to define capacity requirements (mm/day) for areas of different rainfall and probability. Similarly, growers who are prepared to reduce the area grown during drought periods could benefit from higher overall yields during better rainfall years by installing systems with of lower capacity. However, further work is required to quantify the relationships between rainfall reliability, system capacity, economic returns and the grower's risk strategies.

- A significant number of existing drip systems have been installed on marginal soils with poor structural properties. It also seems likely that drip will continue to be used in areas which are difficult to irrigate with other systems. However, the irrigation of these marginal soils raises questions regarding the long term sustainability of crop production in these areas due to the potential for structural degradation and the associated problems of poor water movement and root penetration. Pupae control through tillage on hardsetting soils and the use of no-till stubble retention systems that are able to improve the soil moisture characteristics are likely to be essential for the long term sustainability of cotton production in these areas.
- Many of the existing systems have been designed without evaluation of soil wetting patterns and crop root requirements. Similarly, the appropriateness of dual row versus single row installations on various soils and the consequent effects of emitter flow rates, depths and spacings are not well understood within the industry. Further work is required to evaluate soil moisture movement on the range of soils encountered and the development of appropriate guidelines.

GROWER FEEDBACK ON FUTURE CRDC ACTIVITIES IN DRIP IRRIGATION

- CRDC should develop a greater awareness of the benefits that have arisen from drip irrigation and also how some of the benefits can contribute to environmentally acceptable farming methods (eg. runoff, fertiliser decreases, less sprays, ground rig usage etc).
- CRDC should lobby the Governments on these issues and aim to impress the improvements in BMP that can be achieved with drip.
- There is a need for CRDC to prepare booklets for farmers on guidelines and instructions for the effective design, installation and management of SDI systems
- Research into soil type vs lateral spacing vs emitter flow rate vs emitter spacing vs depth of tape.
- Need more detail on fertigation and maintenance requirements.
- Would like chemicals registered and developed for the control of pests, diseases and weeds in drip irrigation. CRDC should not only research this but should lobby chemical companies to develop chemicals suitable for drip use.
- CRDC should also be lobbying for financial assistance or incentives to install drip. For small farmers this could be in the form of long term fixed or low interest loans for the purchase of drip irrigation systems. For larger farms or corporations it could be in the form of taxation incentives.

MANUFACTURER/SUPPLIER FEEDBACK ON FUTURE CRDC ACTIVITIES IN DRIP IRRIGATION

- There is not only a need for the industry to become involved with drip irrigation R&D but there is a need for the R&D to be inclusive of extension (ie RD & E).
- There is a need for cotton industry extension relative to the SDI system in terms of – requirements, quality, costs & grower awareness of system requirements
- There is a need for all better dissemination to both growers and manufacturers of all drip irrigation research in cotton.
- There is a need for R&D on the concept of total drip irrigation with the positives and negatives being published. This R&D must be independent of manufacturers – they can help but they must not be seen to influence or own the outcomes/results.
- There is a need to research the following for SDI systems (or if it has already been done then to publish the data):
 - Soil effects wetting patterns and wetting up cycles;
 - Scheduling drip in various soils and with a range irrigation requirements; and
 - Fertigation – methodology and crop growth as a function of various fertiliser & irrigation scheduling strategies.

5. REFERENCES

- ASAE (1997). Field evaluation of micro-irrigation systems. *ASAE Standard*: EP458. St. Joseph, MI.
- Bralts, V.F., Wu, I., and Gitlin, H.M. (1981a). Manufacturing variation in drip irrigation uniformity. *Trans. ASAE* 24:113-119.
- Bralts, V.F., Wu, I. and Gitlin, H.M. (1981b). Drip irrigation uniformity considering emitter plugging. *Trans. ASAE* 24:1234-1240.
- Bucks, D.A., Erie, L.J., French, O.F., Nakayama, F.S., and Pew, W.D. (1981). Sub surface trickle irrigation management with multiple cropping. *Amer. Soc. Agr. Eng.* Nov-Dec. p1482-9.
- Burt, C.M., and Styles, S.W. (1994). Drip and micro-irrigation for tree, vine, and row crops. Irrigation Training and Research Centre. Cal Poly, San Luis Obispo, CA.
- Camp, C.R. (1998). Subsurface drip irrigation : a review. *Trans. ASAE* 41(5):1353-1367.
- Camp, C.R., Sadler, E.J., and Busscher, W.J. (1997). A comparison of uniformity measures for drip irrigation systems. *Trans. ASAE* 40:1010-1020.
- Christiansen, J.E. (1942). Hydraulics of sprinkling systems for irrigation. *Trans. Amer. Soc. Civ. Eng.* 107:221-239.
- Ellis, J.E., Kruse, E.G., McSay, A.E., Neale, C.M.U., and Horn, R.A. (1986). A comparison of five irrigation methods on onions. *HortScience* 21:1349-51.
- Feng, J. and Wu, I.P. (1990). A simple computerized drip irrigation design. *Proc. 3rd Nat. Irrig. Symp., ASAE Publ. No. 04-90.* p348-353. St. Joseph, MI.
- Goldberg, D., Gornat, B. and Rimón, D. (1976). Drip irrigation, principles, design and agricultural practices. Drip Irrigation Scientific Publications. Kfar Shmaryahu, Israel.
- Gushiken, E.C. (1995). Irrigating with reclaimed water through permanent subsurface drip irrigation systems. In *Proc. 5th Int'l. Microirrigation Congress*, ed. F.R. Lamm, p269-271. ASAE., St. Joseph, MI.
- Hanson, E.G. and Patterson, T.C. (1974). Vegetable production and a water-use efficiency as influenced by drip, sprinkler, and subsurface and furrow irrigation methods. *N.M. Agr. Expt. Station. J. A.* 523.
- Hanson, B., Bowers, W., Davidoff, B., Kasapligil, D., Carvajal, A. and Bendixen, W. (1995). Field Performance of Microirrigation Systems. *Proc. 5th Int. Microirrigation Congress*, F.R. Lamm (ed), p769-74. St. Joseph, MI.
- Hoffman, G.J. and Martin, D.L. (1993). Engineering systems to enhance irrigation performance. *Irrig. Sci.* 14:53-63.
- Hoffman, G.J., Howell, T.A. and Solomon, K.H. (1990). Management of farm irrigation systems. ASAE Monograph, ASAE, St. Joseph, MI. 100 pp.
- Holsambre, D.G. (1995). Status of drip irrigation systems in Maharashtra *Proc. 5th Int. Microirrigation Congress*, F.R. Lamm (ed), p497-501. St. Joseph, MI.
- Howell, T.A., Stevenson, D.S., Summerland, B.C., Aljibury, F.K., Gitlin, H.M., Warrick, A.W., and Raats, P.A.C. (1980). Design and operation of trickle (drip) systems. In *Design and operation of farm irrigation systems.* M.E. Jensen (ed). *ASAE Monograph* 3, 663-717.

- Hulme, P. and O'Brien, B. (2000). Investigation of irrigation management of drip irrigated cotton soil to maximise yield. Unpublished.
- James, L.G. (1988). Principles of farm irrigation system design. Wiley, New York.
- Jensen, M.E. (ed) (1983). Design and operation of farm irrigation systems. *ASAE Monograph 3*, St. Joseph, MI.
- Keller, J. and Karmeli, D. (1975). Trickle irrigation design. Rain Bird Manufacturing Co., Glendora, CA. 133 pp.
- Kruse, E.G. (1978). Describing irrigation efficiency and uniformity. *J. Irrig. Drain. Div. ASCE* 104(IR):35-41.
- Meshkat, M., Warner, R.C., and Workman, S.R. (1998). Comparison of water and temperature distribution profiles under sand tube irrigation. *Trans. ASAE* 4:1657-63.
- Miller, M.L., Charlesworth, P.B., Katupitiya, A., and Muirhead, W.A. (2000). A comparison of new and conventional subsurface drip irrigation systems using pulsed and continuous irrigation management. In *Water - Essential for Life. Proc. Nat. Conf. Irrigation Association Australia. 23-5th May*. Melbourne.
- Nakayama, F.S. and Bucks, D.A. (1986). *Trickle Irrigation for Crop Production – Design, Operation and Management*, Developments in Agricultural Engineering 9. Elsevier. New York., NY. 383 pp.
- Nakayama, F.S. et al. (1991). Water Quality in drip/trickle irrigation: A review. *Irrig. Sci.* 12:187-92.
- Or, D. (1995). Soil water sensor placement and interpretation for drip irrigation management in heterogenous soils, *Proc. Fifth Int. Micro-irrigation Congress*. p214-21. ASAE, Orlando, Fl.
- Phene, C.J., Yue, R., Wu, I., Ayars, J.E., Schoneman, R.A. and Meso, B. (1992). Distribution Uniformity of subsurface drip irrigation systems. *ASAE Paper No. 92-2569*. St. Joseph, MI.
- Pruitt, W.O., Fereres, E., Henderson, D.W., and Hagan, R.M. (1984). Evapotranspiration losses of tomatoes under drip and furrow irrigation. *Calif. Agr.* 38(5&6):10-11.
- Sadler, J.E., Camp, C.R., and Busscher, W.J. (1995). Emitter flow rate changes caused by excavating subsurface microirrigation tubing. *Proc. 5th Int. Microirrigation Congress*, F.R. Lamm (ed), p763-8. St. Joseph, MI.
- Shannon, E.L., McDougall, A., Kelsey, K. and Hussey, B. (1996). Watercheck - a coordinated extension program for improving irrigation efficiency on Australian cane farms. *Proc. Aust. Soc. Sugar Cane Tech.* 18:113-8.
- Solomon, K.H. (1984). Yield related interpretations of irrigation uniformity and efficiency measures. *Irrig. Sci.* 5:161-172.
- Sutherland, P. (*pers comm*). Irrigation Development Officer, Bureau of Sugar Experiment Stations, Ayr. March 2000.
- Thorburn, P.J. Sweeney, C.A. and Bristow, K.L. (1998). Production and environmental benefits of trickle irrigation for sugarcane: a review. *Proc. Aust. Soc. Sugar Cane Tech.* 20:118-125.
- Welsh, D.F., Kreuter, U.P. and Byles, J.D. (1995). Enhancing subsurface drip irrigation through vector flow. In *Proc. Fifth Int. Micro-irrigation Congress*. ASAE, Orlando, Fl.

- Wendt, C.W., Onken, A. B., Wilke, O.C., Hargrove, R., Bausch, W., and Barnes, L. (1977). Effect of irrigation system on the water requirements of sweet corn. *Soil Sci. Soc. Am. J.* 41:785-8.
- Wu, I.P. (1992). Energy gradient line approach for direct calculation in drip irrigation design. *Irrig. Sci.* 13:21-29.
- Wu, I.P., Howell, T.A., and Hiler, E.A. (1979). Hydraulic design of drip irrigation systems. *Hawaii Agric. Exp. Sta. Tech. Bull.* 105. Univ. of Hawaii, Honolulu.
- Wu, I.P. and Yue, R. (1991). Drip irrigation design using energy gradient line approach. *ASAE Paper No.* 91-2154. St. Joseph, MI.
- Yurgalevitch, C.M., Tenny, L.S., and Ulmer, D.S. (1995). The current status of microirrigation systems in Dade County. *Proc. 5th Int. Microirrigation Congress*, F.R. Lamm (ed), p331-5. St. Joseph, MI.

APPENDIX A DRIP MANUFACTURER SURVEY FORM

SCOPING STUDY INTO DRIP IRRIGATION WITHIN THE AUSTRALIAN COTTON INDUSTRY

Drip Tape / Tube Manufacturers Survey & Questionnaire

CONSULTANTS: National Centre for Engineering in Agriculture (NCEA) *on behalf of the Cotton Research and Development Corporation*

The purpose of this section of the scoping study is to obtain details of drip irrigation installations on cotton farms relative to design, installation, operation and maintenance. In addition it is hoped through dialogue to ascertain the perceived benefits of the system and to detail if those benefits have been realised. This study is not a comparison of companies, installers or growers. It is solely a means of determining the relative merits of drip irrigation in the cotton industry and advise CRDC on the requirement for possible future research needs.

DRIP TAPE MANUFACTURER

COMPANY NAME:

ADDRESS:

TELEPHONE: FAX:

MOBILE: E-MAIL:

NAME OF CONTACT FOR REFERENCE:

As a drip manufacturer / supplier, do you supply the following services?

- | | | |
|--|--------|-------|
| • Design of the drip irrigation system | a) Yes | b) No |
| • Installation of the irrigation system | a) Yes | b) No |
| • Supervision of the installation of the system | a) Yes | b) No |
| • Supply irrigation scheduling advice | a) Yes | b) No |
| • Supply Agronomic Advice (fertigation programs, Cotton plant water stress periods, soil water regime vs crop growth data) | a) Yes | b) No |
| • Maintenance advice and programs | a) Yes | b) No |
| • Training Programs for operation & maintenance | a) Yes | b) No |

MARKETING OF DRIP IRRIGATION SYSTEMS TO THE COTTON INDUSTRY

Suppliers have been marketing DRIP IRRIGATION to the Australian Cotton Industry for the last 10 to 15 years, UPTAKE by cotton growers has been SLOW, and the NUMBER of systems is still LOW. As a supplier/manufacturer, what do you see as the PERCEIVED BARRIERS to a large percentage of growers accepting and adopting SUB-SURFACE DRIP IRRIGATION SYSTEMS in cotton.

Please List :

.....
.....
.....
.....

Are the barriers uniform from COTTON GROWING REGION to REGION?

- a) Yes
- b) No

What do you as a SUPPLIER / MANUFACTURER think that the COTTON INDUSTRY should be doing in Research & Development (R&D) to overcome these BARRIERS?

Detail :

.....

.....

.....

In your endeavour to capture THE COTTON MARKET, as a company what has been your MARKETING STRATEGY over the years?

i.e. : trials, cheaper prices, design etc. Please detail (Positive & Negative)

.....

.....

.....

.....

DRIP IRRIGATION ECONOMICS

Sub-surface drip irrigation systems costs seem to range from around \$2000/ha to \$7500/ha. For a long, effective and efficient life-span in a sub-surface drip system, what investment range in DOLLARS / HECTARE should growers be expecting to spend on a total system (rule of thumb) :

..... \$/ha up to \$/ha

For this system, what is the EXPECTED LIFE SPAN, in years? years
(i.e. for the above amount of money, how long will it last)

As a general guide to the COST of DRIP IRRIGATION COMPONENTS in cotton, what is the cost per hectare of a sub-surface drip system for cotton:
Please list as follows (\$/ha):

Including Installation: \$/ha. Excluding Installation: \$/ha

In-field cost only (i.e. as a guide to expansion, total costs excluding filtration and pump sets and supply mains) :
..... \$/ha

Some SDI systems have been quoted at exceptionally low costs (\$2000/ha). Given that sub-surface drip irrigation system have specialised components (e.g. flushing manifolds, vacuum breakers, air release valves, sub-mains & valves sized to suit flushing flowrates), in your opinion, can the system be installed at a lower cost per hectare without being detrimental to its life expectancy?
a) Yes b) No

If a cotton grower was solely cost oriented, what irrigation components of the drip system, if any, could be removed from the system before longevity and efficiency is affected?
(use of layflat on surface for mains, submains and flushing mains, simpler filtration because of good water quality, reduced system capacity-mm/day, automation removed)

Please list :

.....
.....
.....

With regard to the emitter, does the emission uniformity of the emitter correspond to an IAA rating:
a) Yes b) No c) Not know

What IAA Category Rating do your emitters satisfy, if any?
a) Category A OR b) Category B

Does your emitter operate with a flow labyrinth? a) Yes b) No

If YES, please give a description of your labyrinth and the actual or perceived advantage over other manufacturers.
.....
.....
.....

What TYPE of Emitter Outlet is used?

- Hole
- Slit
- Flap PLEASE TICK
- Slit with Flap
- Emitter installed internally to the tape

Do you have a Pressure Compensating Tape used in the cotton industry? a) Yes b) No

IF YES, are longer lengths of lateral run able to be achieved with the compensated tape:

- a) Yes
- b) No

Does the use of a pressure compensated tape increase the cost of drip installation?

- a) Yes
- b) No

Is your drip tape / tube or emitter protected to prevent

- a) Root Intrusion with a chemical or mechanical root guard
 - b) Insect Intrusion into the emitter hole, ie ants
 - c) Soil & Water Suck Back at the time of irrigation closure / stoppage
- PLEASE TICK

FUTURE EXTENSION & BACK-UP SERVICE

Do you provide a back-up service to the customer? a) Yes b) No

If No, WHY NOT:

.....

.....

For what period of time is this service provided?

- a) 6 months
- b) 12 months
- c) for one season
- d) for two seasons
- e) unlimited

What is included in this Extension & Back-up Service (periodic retraining, troubleshooting and problem solving) ?

.....

.....

.....

.....

DETAILS OF FARM INSTALLATIONS

Farm Installation Number: Area of Installation: hectares

Farm Name / Company Name:

Name of Farm Owner: Telephone:

Name of Farm Manager: Telephone:

Name of Irrigation Manager: Telephone:

Name of Agronomist / Consultant: Telephone:

History of NEGOTIATION between GROWER and SUPPLIER / MANUFACTURER

- What was the reason given by this grower for his interest in installing a drip irrigation system?

.....

.....

.....

- What benefits did the cotton grower perceive as being attainable from drip irrigation?

Increased Crop Yield?	Labour Saving?	Water Saving?
Improved Cotton Quality?	Automation?	Fertigation & Chemigation?
Improved water distribution down field		Reduced waterlogging?

- What perceived benefits did you as a drip irrigation supplier believe were achievable in this instance?

Increased Crop Yield?	Labour Saving?	Water Saving?
Improved cotton Quality?	Automation?	Fertigation & Chemigation?
Improved water distribution down field?		Reduced waterlogging?

- Has the cotton grower achieved the expected benefits: a) Yes b) No c) Uncertain

- If NO, then WHY NOT?
-
-

DRIP TAPE / TUBE INSTALLED

Was this DESIGN LAYOUT done by the MANUFACTURER'S DESIGN TEAM:

a) Yes b) No

If NO – Who did the system design (local supplier, grower) :

.....

Was this installation set up as a grower trial site? a) Yes b) No

Was this installation set up with the filtration and pump set-ups designed for future expansion? (That is, to cater for a larger irrigation area.)

a) Yes b) No

Is the drip line: a) Tape OR b) Tube

Actual Wall Thickness of Tape / Tube used: 6 Mil, 8 Mil, 10 Mil, 12 Mil, 15 Mil, 20Mil, Other.....

Diameter of Tape / Tube used: 16mm; 22mm; 25mm; 28mm; 32mm; 35mm; 40mm; Other.....

Emitter Flow Rate: lph Emitter Spacing: metre (m)

With regard to lateral length and design selection, what flow rate per metre was selected for this installation?

Flow Rate per metre: lph/metre

For this installation what is the tape operating pressure range (kPa , psi, bar):

FIELD LAYOUT

For this installation:

Is the tape installed: a) Surface OR b) Sub-surface (below ground)

If sub-surface, What Depth below soil surface: (cm)

Is the cotton crop planted on a) 2 m BEDS b) 1 m HILLS / FURROWS c) BROADACRE

Are the ROWS OF COTTON planted at 1 metre spacing? a) Yes b) No

If NO, what spacing? (metres)

What is the TAPE LATERAL SPACING (metres) :

COTTON CROP ROW SPACING: Please draw a furrow profile with dimensions BELOW:

What is lateral design flow variation: a) ± 5%; b) ± 7.5% c) ± 10%

Is the system designed with a ± pressure & flow variation within the length of the SUBMAIN?

a) Yes b) No

If YES, what is the variation? ±PRESSURE (kPa) ±.....FLOW (lph)

What is the maximum length of run of tape installed with this design: metres

Is there a flowmeter installed in this drip system? a) Yes b) No

How many pressure measurement points are installed and describe their positions

.....
.....

VALVES

How are the sub-block and flushing valves operated : a) Manually OR b) Automatically

If the system is automatic, are the valves operated by electric cable or hydraulic tube?

a) Yes b) No

Please give reasoning behind selection (including possible operational concerns for either)?

.....
.....
.....

Brand Name: Type:

Are AIR RELEASE VALVES / VACUUM BREAKERS used in the irrigation system?

a) Yes b) No

If YES, Where are they positioned? PLEASE TICK

- Within the high point of the lateral
- At the sub-main
- Within the main irrigation line
- Or at high points only

How many air-release valves / vacuum breakers were used in the drip layout?

Was the size of the air release valve and/or vacuum breaker selected to allow the entry, to the sub-main & tape, of the required volume of air to negate suck back of soil & water into the emitter?

a) Yes b) No

If NO, how do you prevent Soil & Water Suck Back into the Dripper / Emitter?

Please give a brief description.

.....
.....
.....

SURFACE SOIL DESCRIPTION

For this installation describe the soil :

- Cracking Clay
- Clay
- Clay loam PLEASE TICK
- Loam
- Sandy clay loam

Soil Colour a) Red b) Black c) Brown d) Grey e) Other :

Was the whole sub-block a consistent soil type Yes No

SUB SOIL DESCRIPTION:

If an inspection of the sub-soil was done during sampling, WAS THERE A DISTINCT (B) HORIZON:

a) Yes b) No c) Uncertain/Unknown

Sub-soil Type / Description:

- Cracking Clay
• Clay
• Clay loam PLEASE TICK
• Loam
• Sandy clay loam

Sub-soil Colour : a) Red b) Black c) Brown d) Grey e) Yellow
f) Mottled (blue/grey) g) Other If Other, Please Specify:

Are there sand lenses present in the soil horizons:

a) Yes b) No c) Uncertain/Unknown

IF YES – What Depth?cm

Is there a compacted layer within the soil profile:

a) Yes b) No c) Uncertain/Unknown

IF YES – What Depth?cm

SUPPLY WATER QUALITY

Water Source: a) Channel b) Bore / Underground c) Dam d) River

Was the Water Source Tested for Impurities: a) Yes b) No c) Don't Know

Was the water source tested for the following impurities?

Please tick if YES and if possible give a contaminant VALUE in ppm or mg/l

- Algal
• Bacterial
• Suspended solids
• Colloidal clays
• Chemical
• Bicarbonates
• Carbonates
• Iron
• Other minerals
• Other Impurities – WHAT

If NO, WHY WAS THE WATER NOT TESTED:

.....

FILTRATION SYSTEM

A) Primary Filtration System:

Sand Automatic Back-flushing a) Pressure b) Time
 Gravel Manual Back-flushing
 Other Media Type
 Mesh / Disc Mesh Size:

What is the capacity of the filter bank VERSUS the maximum irrigation flow rate:

MAX Irrigation flow rate: lph Filter Bank Capacity: lph

B) Secondary Filtration System:

Disc Filtration (Arkal / Amiad filters)
 Steel Mesh Screen with Nylon Sleeve
 Mesh Size:
 Automatic Back-flushing a) Pressure b) Time
 Manual Back-flushing

C) Sub-main & Lateral Flushing:

Sub-surface drip installations are best maintained when the system has the ability to FLUSH THE SUB-MAINS AND LATERALS regularly by increasing the VOLUME, VELOCITY and (with in reason) PRESSURE of water flow to remove SEDIMENT etc.

Was the sizing of the supply sub-main, flushing manifold and valves designed for irrigation flow rates or flushing flow rate capacity?

a) Yes b) No

If No, WHY NOT:
.....
.....

If the above answer is YES, has the flushing system been successful in decreasing or negating the blockage of emitters?

a) Yes b) No

If the answer to the DESIGN question above was NO, have problems of emitter blockage arisen?

a) Yes b) No

What flushing velocity you design for in the lateral tape? (m/sec)

What is the flushing cycle programme (timing, duration and number of blocks and the ratio between area of irrigation / area of flushing) ?

.....

D) Sub-main / Lateral Connection

During the FLUSHING PROCESS the joining / connection mechanism or method used to connect the tape lateral to the sub-main has failed in some instances, due to the increased FLOWS, VELOCITY AND PRESSURES used to flush the sub-main and laterals.

Has this been a problem with your connection system? a) Yes b) No

If YES, has the system of connection been rectified? a) Yes b) No

Please give a description of the connector used between lateral and sub-main. PREFERRABLY A DRAWING (or provide brochure)

FERTIGATION / CHEMIGATION

Is the system designed and installed with equipment to enable the application of fertilisers and chemicals through the drip tape during an irrigation cycle?

a) Yes b) No

If No, WHY NOT:
.....
.....

Does the grower use an efficient fertigation programme: a) Yes b) No

If No, WHY NOT:
.....

Fertigation injection points :

Does the fertigation / chemigation system have more than one injection point into supply mains to allow injection of fertiliser and acid to stop precipitates forming and depositing?

a) Yes b) No

If No, WHY NOT and HOW MANY injection points are in the design?

.....

Is the fertigation / chemigation inlet to the irrigation flow manifold provided with a separate filter system?

a) Yes b) No

If No, WHY NOT:

- a) Yes
- b) No

With respect to the IRRIGATION SCHEDULE RECOMMENDED AND IMPLEMENTED. Please specify and detail the irrigation schedule recommended by you and the schedule implemented by the grower (timing and amounts)

.....

.....

Is the irrigation schedule modified using:

- a) Evaporation Pan
- b) Neutron probe
- c) Enviro Scan
- d) Tensiometer
- e) Raingauge
- f) Other

If other – What is the system:

If the above answer was No, WHY NOT and WHAT Irrigation Scheduling was applied:

.....

.....

SEED GERMINATION

How does the grower achieve SEED GERMINATION?

Does the grower use :

- a) Sub-surface Drip (SDI)
- b) Sprinkler
- c) Furrow / Surface
- d) Timely rainfall

If SDI is used, does he irrigate before or after planting? a) Before b) After

Does the depth of the drip tape, the soil type and the distance between tape and seed allow a high level of germination? (vertical and horizontal soil water movement, evenness from point emitters)

- a) Yes
- b) No

If the answer is NO – Please give a detailed description of the problem (e.g. water piping straight to surface, complete field saturation necessary)

.....

.....

Did you, the supplier / manufacturer, understand that wetting-up problems may occur with the use of sub-surface drip tape installations?

- a) Yes
- b) No

If NO, what steps were / are taken by you to minimise the possibility of wetting up problems occurring, either at germination or during normal irrigation cycles? (ie design changes via emitter spacing, emitter flow rates etc). A BRIEF DESCRIPTION if applicable.

.....

.....

OPERATIONAL PROBLEMS

What Operational Problems have been encountered (Y/N) ?

- a) Degrading Water Quality / Poor Filtration – leading to excessive back-flushing
- b) Insect and Pest Problems Please CIRCLE relevant INSECT / PEST

Ants	Pigs
Cricket	Foxes
Borers	White ants
Mice	Rats
Other	
- c) Ineffective wetting pattern because of soil type?
- d) Incorrect sub-surface lateral / tape positioning – down the row?
- e) Lateral / Tape placed at an incorrect depth, thus giving ineffective uptake of water?
- f) Uneven depth of tape placement due to poor installation technique or machinery?
- g) Blocking of the emitters with plant roots?
- h) Blocking of the emitters with soil or other foreign bodies?
- i) In ability to wet up for planting / seed germination?
- j) Other – please specify.....
.....

Is the DRIP IRRIGATION SYSTEM NOW OPERATING EFFECTIVELY to the customer's satisfaction?

- a) Yes b) No

TRAINING

Was a System Operation and Irrigation Application TRAINING COURSE and / or ON-SITE DEMONSTRATION offered by the supplier / manufacturer?

- a) Yes b) No

Was the training course / programme accepted by the grower / owner? a) Yes b) No

If NO for either of the above questions, PLEASE give an explanation:
.....

When a training course was offered and accepted, WHO WAS IN ATTENDANCE?

- a) Grower / Owner b) Farm Manager c) Irrigation Manager d) Agronomic Consultant
- e) Irrigation System Operator f) All of the above

MAINTENANCE & OPERATION PROCEDURES & PROGRAMMES

Did the supplier provide an in-season maintenance programme to the grower /owner?

APPENDIX B DRIP IRRIGATOR SURVEY FORM

SCOPING STUDY INTO DRIP IRRIGATION WITHIN THE AUSTRALIAN COTTON INDUSTRY

Drip Irrigator Survey & Questionnaire

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The purpose of this section of the scoping study is to obtain details of drip irrigation installations on cotton farms relative to design, installation, operation and maintenance. In addition it is hoped through dialogue to ascertain the perceived benefits of the system and to detail if those benefits have been realised. This study is not a comparison of companies, installers or growers. It is solely a means of determining the relative merits of drip irrigation in the cotton industry and advise CRDC on the requirement for possible future research needs.

DETAILS OF FARM INSTALLATIONS

Farm Installation Number: Area of Installation: hectares

Farm Name / Company Name:

Name of Farm Owner: Telephone:

Name of Farm Manager: Telephone:

Name of Irrigation Manager: Telephone:

Name of Agronomist / Consultant: Telephone:

IRRIGATION AND CROP MANAGEMENT

Irrigation Operation

- How long have you had a drip system for? years
- How many years experience have you or your staff had with drip irrigation (SDI) in cotton?
..... years
- What's the irrigation time cycle that you run with your drip (on-time/off-time, 12/12, 6/6/6/6, 8/8/8)?
Cycle time.....
- How often are you running the drip system?(every day, every third day)
- When you use SDI do you like to see the water wetting the surface? (This may be the only clue that it is working in the field at all) Yes No
- How do you determine how much water to apply? (mm or ML/ha)

-
- What is the volume of water you apply with your furrow system? ML
 - How is this gauged or measured? (Flow meter / Allocation / pump capacity)
 - What is the volume of water you apply with sub-surface drip? ML
 - Does your SDI system include Flow meters and Pressure Gauges?
 Yes No If NO, Why not?
 - Is the volume of water applied, measured using a Flow Meter or is it gauged by some other method?
 Yes No Explain:
 - Do you use pressure points as a measure of blockages in the system?
 Yes No Explain:
 - Do you use your flow meter to assess the change in supply to your drip block?
 Yes No Explain:
 - Do you notice water movement coming to the surface from your SDI drip system?
 Yes No Explain:
-
- How are you achieving germination in your drip irrigation block?
 SDI system? Rainfall? Furrow Irrigation? Spray / LEPA?
 - Are you using an irrigation scheduling tool now, that you weren't using when the system was first installed?
 Tensiometer Neutron Probe Enviro-Scan Other:
 - Does your SDI system include in-field filters at the sub-mains?..... Yes No
- If either YES or NO, please explain the reasons behind the decision to implement or delete:

- Did your water supply have any particular problems that you had to cater for in terms of filter set capacity and / or chemical addition? (iron, carbonates, colloidal clay)
 Yes No If YES, Explain:
-
- Does your Primary Filtration System have automatic back flushing?
 Yes No
 - Does your Filter System Capacity handle the seasonal variations in water quality efficiently?
 Yes No

- At any time when irrigating, does your filter system back-flush at intervals that would affect the volume of water applied to the crop?

..... Yes No If YES, Please explain:

.....

Runoff Management

- Do you have to run the tail-water pumps for longer or shorter periods of time during periods of rainfall runoff from SDI blocks?

..... Yes No Explain:

.....

- Do you think that SDI can negate / diminish the effects of water-logging in cotton?

..... Yes No Explain:

.....

- What wetting pattern do you think your emitters are making in the soil? (soil type)

Explanation:

.....

- Can you see or feel a change in your soil structure in your SDI block?

..... Yes No Cannot Determine

Crop Management

- Is the crop growth (height & bush size) similar in both your furrow and SDI fields?

..... Yes No

Please explain similarities / differences:

.....

- What amount / volume of Pix (Mepiquat chloride) do you use on your furrow and SDI irrigation blocks? Detail as how many litres per ha or how many sprays and at what rate?

Furrow: litres / ha OR No. of sprays: Spray rate:

SDI: Litres / ha Or No. of Sprays: Spray Rate:

- Did you initially have to use a lot more Pix on your SDI block?

..... Yes No

- Could you run a regulated deficit irrigation program with this crop and this system?
(i.e. growth control of the plant through plant mapping with it running at 4-4.5 NAWF, or using intensive soil moisture monitoring of the crop and keeping it partially droughted)

..... Yes No

Explanation:
.....

Fertiliser Use

- Do you fertigate (apply fertiliser through the SDI system)? Yes No

If NO, Your reasons:

.....
If YES, please detail what fertilizers / amounts / number of units of each / how often are the fertilizers applied (every irrigation, weekly, fortnightly, monthly):

(N P K [N – urea – <biuret or non-b>, Phosphoric Acid, Chlorine, Any Micronutrients {Zn, B, Mn, Mg, Co} applied)

.....
.....

- *If you do fertigate, have you altered the total amount of fertiliser applied to the crop?*

..... *Increased* *Decreased**No change*

- Has fertigation allowed you to change the pre-season application of fertiliser?

..... *Increased* *Decreased**No change*

Incidence of Weeds and Herbicide Use

- Is the number of inter-row cultivations and shielded or banded sprayer passes different on your SDI cotton blocks to that applied to your furrow irrigated blocks? (increased/decreased)

..... Yes No If YES, What are the numbers? SDI Furrow

- Do you apply Treflan through your system? Yes No Something else.....

If YES, at what rate is the chemical applied? Litres / ha

Insecticide Use

- Do you experience pest and / or insect damage to the tape? Yes No

- How many drip tape joiners would you use per year? Number:Per Area

- Do you try and control those insects that chew the drip tape?

..... Yes No If YES, what chemicals? (Lorsban, Regent or Other/s)

- Application of chemical for the control of crickets etc to protect tape? Yes No
- Application of chemical for the control of roots into the emitters? Yes No
- If YES to the above, how often do you apply the maintenance programme for each of the above?
 - Chlorine / Phosphoric Acid for cleaning:
 - Chemical for the control of pests & insects that damage tape:
 - Chemical for the control of root intrusion into the emitters:
- What cost per ha per year (estimate) is your SDI system running cost? \$/ha/yr
- What are your furrow systems repair costs running into (estimate)? \$/ha/yr
- Do you run the SDI System for short periods during the off-season?
 - Yes No Please explain:
 -
- Do you run a MAINTENANCE PROGRAMME during the off-season to ensure continued cleanliness of the system (tape), and control of roots, insects & pests?
 - Yes No Please describe:
 -
- Do you implement a heavy CHLORINATION & PHOSPHORIC ACID dosage at the end of the irrigation season and before the start of the next irrigation season?
 - Yes No Please detail:

History of GROWER consideration of / decision to PROCEED with an SDI SYSTEM:

- What benefits did you the cotton grower perceive as being attainable from drip irrigation?

Increased Crop Yield?	Labour Saving?	Water Saving?
Improved Cotton Quality?	Automation?	Fertigation & Chemigation?
Improved water distribution down field?		Reduced waterlogging?
- Have you achieved the expected benefits: a) Yes b) No c) Uncertain
- If NO, then WHY NOT?
-

Initial Purchase Decisions

- What was the basis for you taking on a sub-surface drip system as an irrigation method? (Consideration of: neighbor / friend / relative has some, industry talk, water shortages, management possibilities in crop and labour)? Please detail below:

.....

- Are you land limited or water limited in terms of production expansion?

.....

- Was this a major influence on your decision to implement and SDI System?

..... Yes No Please explain:

.....

Design and Installation Process

- Who did the design? (Installer / Manufacturer / Grower)

- Did you have any input into the design? Yes No

Please explain the reasons for either a YES or a NO:

.....

- Was the SDI system installed as you had hoped? Yes No

If NO, What were the differences?

.....

- Are you happy with the system as it is installed? Yes No

- Were there irrigation parts removed from the plan before installation?

..... Yes No Uncertain

- Why were they removed?

- You decided to remove to help with the budget? Yes No

- The installation contractor decided to alter the design? Yes No

- You altered the design? Yes No

- Were you involved in the installation process? Yes No

- Did you have any installation problems due to soil preparation issues , i.e. roots, sticks & stumps, soil hard pans & effective cultivation to below tape installation depth?

..... Yes No If NO, why not?

- Did you install the SDI System over (i) furrow irrigation developed country, or (ii) new country without levelling & tail-drains, or (iii) new land with levelling & tail-drains?

.....

- What alterations, if any, to the plan or design would you make to future design layouts?

.....

- What would you do differently at installation, next time?

.....

- What parts of the irrigation system would you leave out next time to save on the irrigation costs and / or installation costs, if any?

.....

- In your opinion, will the removal of these parts from the system, affect the efficiency of the irrigation operation, maintenance of the system or longevity of the system?

..... Yes No If YES, why delete parts?

.....

- Are you satisfied with the initial contact, service, design, installation & backup service you have been provided by the following?

- The local irrigation distributor or agent? Yes No

Please detail:

- Are your satisfied with the manufacturer of the drip tape? Yes No

Please detail:

.....

- Are your satisfied with the designer of the system, be that the local distributor or the manufacturer / supplier?

..... Yes No

Please detail:

.....

- Are your satisfied with the installation company or person? Yes No

Please detail:

.....

The Future and the Broader Picture

- Are there plans for SDI expansion? How much will you put in next time? ha
- What is the biggest horror story you have? Please detail:
.....
.....
- What is the biggest problem you have had with the drip system?
Please detail:
.....
- What is the best story / scenario of the SDI System?
Please detail:
.....
- With regard to the overall SDI System, i.e. from design to operation to water application to maintenance, what would you do differently next time?
.....
- What tips would you give to growers who were about to install SDI?
.....
.....
- What RESEARCH work should CRDC be funding for Drip System Irrigators?
.....
.....
- What question haven't I asked?
.....
.....
- Is there anything else, that you as the grower OR irrigation manager / supervisor wish to add?
.....
.....

APPENDIX C GLOSSARY OF TERMS

C_u Christensen's Uniformity Coefficient defined as:

$$C_u = 100\left(1 - \frac{M}{\bar{x}}\right)$$

where M is the main absolute deviation of the applied depths (or emitter discharges) x_i and is given by:

$$M = \frac{\sum |x_i - \bar{x}|}{n}$$

where \bar{x} is the mean applied depth and n is the number of measurements.

D_u Distribution Uniformity defined as:

$$DU (\%) = \frac{M_{25}}{M} * 100$$

where M is the mean of all emitter discharge readings and M_{25} is the mean of the lowest 25% of discharges.

E_u Emission Uniformity defined as:

$$E_u = (1 - 1.27e^{-0.5C_v})\left(\frac{q_{\min}}{q_{av}}\right)$$

where e is the number of emitters per plant, C_v is the coefficient of variation of emitter discharges due to variations in the manufacture of the emitter, q_{\min} is the minimum discharge and q_{av} is the mean discharge.

mesh size number for filter sizes, used like gauge numbers

micron there is a thousand micron to a millimetre and one million micron to a metre.
25.4 microns = 1 mil.

mil Used when referring to the thickness of the tape product. It is equal to one/thousandth of an inch, also called a "thou" or so many "thou". For example 15 mil is equal to 375 micron, this being the most common tape thickness used for SDI in cotton industry.

SDI subsurface drip irrigation system.