APPLICATION SYSTEMS FOR COTTON IRRIGATION - ARE YOU ASKING THE RIGHT QUESTIONS AND GETTING THE ANSWERS RIGHT?

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ABSTRACT

Crop establishment and growth responses, water use efficiency, economics, labour and lifestyle are all important considerations in relation to the selection, operation and performance of in-field irrigation systems. While the cotton sector is heavily reliant on surface irrigation, considerable debate has recently occurred on the advantages and disadvantages of alternative application systems. In discussing these options, it is important to realise that no single system and management practice will be appropriate for all growers in all environments. As with all things in life, one size does not fit all! Hence, it is important to understand the nature of the alternatives and the factors which influence the performance, operation and management of each option. This paper presents results of recent studies within the cotton sector looking at the in-field irrigation performance of surface, drip and low pressure overhead spray systems. In particular, it discusses the advantages and disadvantages of the various alternative strategies using examples from both the current surface irrigation performance evaluation program and the recent scoping study into drip irrigation within the cotton industry.

INTRODUCTION

Irrigation in the Australian cotton industry has traditionally been dominated by the use of furrow irrigation practiced almost exclusively on the heavy clay soils associated with riverine flood plains. 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. However, in order to make informed investment decisions regarding irrigation application systems, it is necessary to understand the characteristics and performance of both the existing and alternative systems available.

This paper draws on the results of recent studies looking at the in-field irrigation performance of surface, drip and low pressure mobile irrigation systems within the cotton sector. However, in discussing alternative irrigation options, it is important to realise that no single application system and management practice will be appropriate for all growers in all environments. As with all things in life, one size does not fit all! Hence, it is important to understand the nature of the alternatives and the factors which influence the performance, operation and management of each option. This paper also questions some of the irrigation "myths" which have developed within the cotton industry and discusses the factors and options which should be considered in maximising the returns from an investment in irrigation application systems.

IRRIGATION APPLICATION SYSTEMS IN THE COTTON INDUSTRY

The Australian cotton industry is currently dominated by surface irrigation using either every furrow or alternate (skip row) furrow strategies. Less than 2% of the total cotton crop is currently grown using sub-surface drip irrigation (SDI) (Raine *et al*., 2000) while a similar area is currently grown using low pressure mobile systems. While it seems likely that the proportion of both SDI and low pressure mobile systems will increase over the next few years, these systems are unlikely to be a panacea for all of the irrigated cotton sector. Hence, a significant proportion of the Australian cotton industry will remain surface irrigated for some considerable period. However, even in areas for which surface irrigation remains the most sensible application strategy there are benefits to be gained from better in-field management. Many workers (Hearn 1998, 2000; Tenakoon and Milroy 2000, Dalton, 2000) have recently taken up the "*you can't manage it if you aren't measuring it*" mantra. Measuring current performance and identifying the benefits of alternative management or application system strategies should certainly be a pre-requisite to reducing the risks associated with irrigation investments.

The ability of the in-field irrigation system to apply water efficiently and uniformly to the irrigated area is a major factor influencing the agronomic and economic viability of the production system. The performance evaluation of in-field application systems can be divided into the two major components of water losses and uniformity of application. Although both components are influenced by system design and management practices, the losses are predominantly a function of management while the uniformity is predominantly a function of the system design characteristics (Solomon, 1993). However, the irrigation system is not usually expected to supply all of the moisture required for crop production as some of the crop's water requirements may be met by pre-season moisture stored in the soil profile, rainfall during the growing season, or from shallow groundwater tables. Hence, optimal irrigation management requires not only a knowledge of the characteristics of the application system but an understanding of the environment in which it operates.

Surface systems

Furrow application is the dominant form of irrigation in the Australian cotton industry. The water is most commonly distributed to the fields using head ditches and over-bank siphons. Fields are commonly laser levelled and are often greater than 1000 m in length. Set up costs for surface application systems typically range between $500-$1800/ha. While it is often claimed that the application efficiency of well designed and managed surface irrigated cotton is over 80% (Anthony, 1995) there has been little published evidence until recently to confirm or refute the widespread existence of these efficiency levels on commercial farms.

Early research (eg. Yule and Keefer, 1984; Douglas *et al*. 1996) using short furrow lengths under high levels of management and control, identified single irrigation efficiencies in excess of 80%. However, more recent measurements (eg. Dalton, 2000; Moss *et al*., 2001) under commercial operating conditions (long furrows and water inflow periods) have found application efficiencies of single irrigations ranging from 35-99% with seasonal efficiencies commonly between 60-85%. In these studies, deep drainage was identified as a major source of water loss (commonly 1-2 ML/season) and is consistent with results reported by a range of studies conducted in different areas of the cotton industry (eg. Willis *et al.* 1997**;** Douglas 1998**;** Ringrose-Voase *et al***.** 1998**;** Zischke and Gordon, 2000; Silburn and Montgomery, 2001).

The cotton industry has moved slowly to capitalise on the potential gains to be made from improved in-field irrigation management. While the industry has invested heavily in the investigation of the problems associated with inappropriate irrigation management such as groundwater rise, salinity, tailwater recycling, off-farm sediment and pollutants, it has been slow to grasp the opportunities for improvements in yield and reductions in costs associated with improved surface irrigation management. As Hearn (2000) pointed out, there is a triple bonus for getting in-field surface irrigation management right including:

- minimising yield losses from waterlogging;
- saving water lost in deep drainage, increasing WUE and allowing more cotton to be grown; and
- conserving the resource base, by minimising the risk of salinity and thus enhancing sustainability.

There are also benefits associated with reduced pumping and operating costs. The various techniques to improve the on-farm application efficiency of surface irrigation practices can be broadly grouped according to whether they modify the soil, water (eg. application/scheduling) or design parameters. Substantial agronomic benefits are also possible through improved management of surface irrigation. The ability to reduce irrigation cut-off times (ie siphon pull times) can substantially reduce the incidence of irrigation induced waterlogging with measurements (eg. Hodgson 1982) and anecdotal observations (Dalton *pers comm*.; Spragge *pers comm.*) suggesting that inappropriate surface irrigation strategies commonly account for losses of up to 1 bale/ha/season and could be as high as 2-3 bales/ha/season under adverse conditions.

While most growers readily accept the benefits associated with the timing of irrigation applications, few recognise that true scheduling involves not only the timing of applications but also the management of application volumes to match deficits and minimise losses. Dalton (2000) points out that irrigation deficits are typically highly variable but are rarely measured. Irrigation practices are even less frequently adjusted in response to these variable deficits. However, products and services (eg. Aquatech Pty Ltd, Irrimate Services, Dalton Consulting; RWUE extension officers) are now commercially available to enable both field designers and irrigators to determine the irrigation management variables (in particular, siphon flow rate and pull times) that provide the best field and seasonal efficiencies under conditions of significant spatial and temporal variation in soil infiltration characteristics.

Optimised management of commercial surface irrigation through simple low cost changes (eg. SIRMOD revised flow rates and times to cut-off) have been found to improve application efficiencies for single irrigations by as much as 30% and to improve seasonal application efficiencies by up to 15%. Other management strategies that have been proven effective overseas but have not received significant interest in this country include cut-back flows and surge irrigation. All are worthy of further investigation in appropriate situations.

Other future opportunities to improve surface irrigation performance include the manipulation of soil infiltration properties along the length of the field by selective compaction or amelioration, variation of the furrow slope or furrow shape along the length of the field and variation of the flow rate continuously during the irrigation. Simulation models (eg. SIRMOD) have indicated that such strategies might be feasible but there are many practical problems to be solved before implementation will be possible.

Subsurface Drip systems

A recent scoping study of sub-surface drip irrigation (SDI) in the cotton industry (Raine *et al*. 2000) reported that SDI is currently used across the full geographic range of Australian cotton producing regions (Table 1) and has been adopted for a wide range of reasons. Nearly all of the SDI irrigators experienced some problems in the design, installation, operation, maintenance or management of their SDI systems. More than half of the growers (55%) reported installation 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. However, most growers acknowledged that with the benefit of experience none of these issues should have been a problem.

Table 1: Drip irrigation in the Australian Cotton industry (as at March 2000)

Total SDI Area	~ 3100 ha
Farming enterprises using drip	> 31 farms
Average farm area under drip	~90 ha (max 790 ha)
Average age of existing drip installations	~2.8 years (max 7 years)
Size of initial drip installation	4.5-144 ha
Drip water source (by volume)	70% surface, 30% groundwater
Soil types	70% cracking clays, 30% loams

All cotton growers using SDI reported a decrease in water use (average saved = 2.56 ML_{irrig}/ha or 38% of applied water) compared to traditional furrow irrigated systems (Figure 1a). However, the water saving differential was much smaller where optimisation of the surface irrigation had already been undertaken. Yield achieved on SDI blocks is strongly related to the water management strategy. Where growers focus on maximising SDI block yields (ie. growers that were “land short”), 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 (ie growers were “water short”), 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 1b) with an average increase of 1.29 bales/ ML_{irrig}.

A number of SDI systems in the cotton industry appear to have been installed with inadequate flushing main capacities and/or with flushing valves which restrict flushing water flow rates. In these cases, while the piping and valving apparently operate well, the inability to achieve adequate velocities at the lower end of the tape line results in deposition, decreases in flow volumes and eventually emitter blockage. This will produce slightly higher back pressures in the mains which will also affect emitter rates elsewhere in the block.

Germination remains one of the biggest challenges for SDI users, especially when used on an alternate tape line spacing (i.e. tape spacing is twice crop row spacing). 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. A small proportion (11%) of drip irrigators have followed the lead of United States and Israeli SDI users, by using furrow or spray irrigation to germinate crops and then irrigating with SDI after establishment. The full project report (Raine *et al*., 2000) provides further details on these and other common problematic areas including supply and filtration capacities, tape placement, scheduling, and chemigation. Table 2 provides a summary of the main SDI study findings.

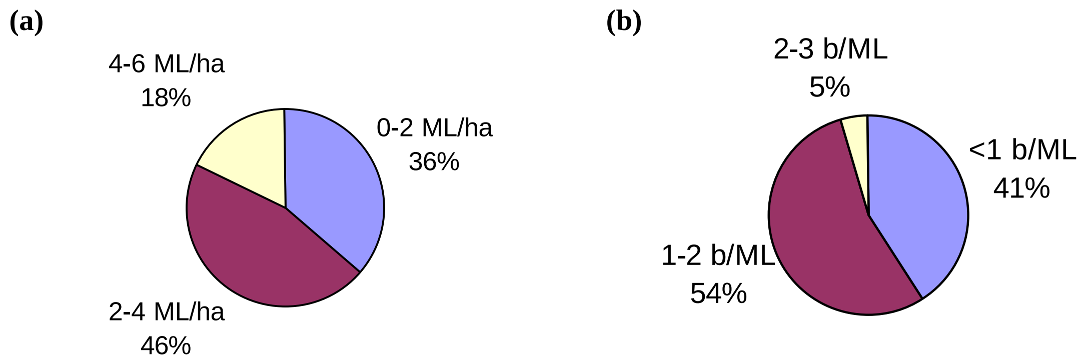

Figure 1: Proportion of SDI irrigators achieving each level of (a) water savings and (b) increase in water use efficiency (bales/ML) when compared to furrow irrigation systems

Table 2 Main findings arising from the scoping study of SDI within the cotton industry

- The performance of drip irrigation within the cotton industry is not limited by soil type or regional characteristics.
- The system 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.
- Economics may not be the key to adoption – agronomic, environmental site specific and life style issues may well be more important.
- The main economic drivers for adoption are comparative performance and water valuation.
- 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 successful SDI systems in the industry is the level of training and experience of dealers and installers.

The SDI 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.

On economic terms alone, drip irrigation is rarely justified. Where an SDI system costs ~$3800 to install, it would need to yield at least 1.25 bales/ha more than furrow irrigation to make it economical viable. This yield differential would increase to more than 2.5 bales/ha for systems that cost around $5000/ha. However, only approximately 10% of SDI irrigators indicated that they were achieving a yield differential of more than 2.5 bales/ha. Hence, 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 both the grower and his irrigation system are ageing, and replacement is inevitable, the perception is that drip irrigation is far more automatable than the other irrigation systems*". For growers cropping near ecologically sensitive areas, drip irrigation and ground-rigging are also often seen as the only way that they are going to be capable of maintaining cotton production.

Low pressure mobile systems

Approximately 35 centre pivot and lateral move irrigation machines are currently being used within the Australian cotton industry. These machines typically irrigate an area of between 50-250 ha each. While centre pivot machines are usually no longer than 400-500 m, the popularity of large systems has resulted in a number of lateral move machines being installed with lengths of around 1000 m. Low pressure mobile systems typically cost between $2000 and $2500/ha to set up and have a life expectancy in excess of 20 years. The application efficiency of low pressure mobile machines is strongly influenced by management. However, well designed and operated machines commonly produce application efficiencies in excess of 90% (eg. Schneider and Howell 1995; New and Fipps, 1995). Anecdotal evidence from Australian cotton growers using these machines indicate that they have reduced water usage typically by about 15-20% and obtained a yield benefit of approximately 1.2 bales/ML when compared to conventional furrow irrigation practices.

The total area of cotton under centre pivots and lateral moves currently represents only ~2% of the industry. However, this contrasts with both the broader Queensland irrigated cropping sector, in which these machines account for approximately 10% of the area, and the USA where these machines account for in excess of 30% of the irrigated area (~8 million ha). The low adoption rate in the Australian cotton industry is most likely attributable to misconceptions regarding the reliability and capacity of the machines to meet the required peak seasonal crop water use requirements, concerns over water losses through evaporation of the spray droplets, and perceived potential problems over soil surface crusting and reduce seedling emergence due to droplet impact energies. However, preliminary investigations of a number of machines over various cropping sectors have shown that simple design and management errors are most often the cause of any machine failures or cropping difficulties.

One advantage of mobile irrigation machines is the ability to vary the application method (ie. spray plates or LEPA) and volumes applied in response to agronomic demands and rain. This reduces the potential for crop waterlogging and increases the effectiveness of in-season rainfall. It also provides the capability to utilize regulated deficit irrigation strategies during the later part of the season to maximize the cotton agronomic response to water stress. Using spray plates, water can also be applied to the soil surface providing high germination rates with relatively small application volumes compared to SDI or surface systems. Application volumes can also be varied to allow cultivation and ground rig spraying between waterings. Other advantages of low pressure mobile systems include the ability to fertigate, all terrain mobility, as well as reduced labour and lifestyle issues due to easier management.

Mobile irrigation machines do not irrigate all parts of the field at any one instant, but must apply the same depth of water along their travel path and their machine length, to irrigate uniformly. Those factors that contribute to non-uniformity are the nozzle size selection, nozzle size increments, nozzle height and wear, sprinkler spacing, nozzle operating pressure, and sprinkler configuration (DeBoer and Monnens, 1993). Machine movement including step size and its consistency, and flow-rate variation due to discontinuous end-gun operation, incorrect adjustment of gate valves and changing water heights in supply dams and bores will also affect machine uniformity.

Management of these systems is also critical as the system capacity (ie volume that can be applied/week) is affected by the pump duty cycle and the start time of the cycle. Systems are commonly designed to meet the peak season crop water use requirements. However, during these periods it is necessary to closely match the application volume to the crop requirements as over application will result in water losses and areas of the crop being water stressed before the next irrigation. In practice, this occurs where the application volume is greater that the readily available soil deficit resulting in water inefficiencies and periods of crop stress between waterings.

The CRDC has recently commissioned a scoping study on the performance and operating experiences of growers using low pressure mobile machines in the cotton industry. It is expected that the results from this study will be available by the end of the year.

WHAT ARE THE ISSUES?

Irrigation design and management decisions are the result of a complex interaction of many variables (Table 3) which are rarely consistent between individuals. For example, irrigation management is often expected to maximise efficiencies and minimise the labour and capital requirements of the particular irrigation system without adversely affecting the growing environment for the plant (Walker and Skogerboe, 1987). In trying to improve irrigation efficiencies, it is necessary for irrigators to understand the concept of irrigation efficiency, identify their current efficiencies and the techniques by which the efficiency can be achieved, and be motivated to change (Skewes and Meissner, 1998). Hence, a principal objective of evaluating an irrigation system is to identify alternatives that may be both effective and feasible in improving the system's performance (Walker and Skogerboe, 1987).

Table 3. Some of the factors which typically influence irrigation design and management decisions

Factors	Examples
Agronomics	Crop responses to climatic and soil moisture variables; waterlogging, regulated deficit irrigation
Environment	Climate, soils, topography
Social	Experience, education, labour availability
Economic	Capital availability, operating costs, returns from product
Historical	Existing infrastructure, previous farming systems
Hydrological	River flow regimes, groundwater issues; surface flow harvesting
Engineering constraints	Hydraulic design limitations on pumps, pipes and storages, supply capacities
Regulatory policy	Legislation on access to river, surface and groundwater
Administrative procedures	Licencing requirements, ordering of water supplies

While agronomic benefits (ie yield increases) are commonly the major driver of irrigation performance improvements, water savings at the field scale may be obtained by:

- maximising the pre-season soil moisture storage;
- minimising evaporation losses;
- minimising crop transpiration while maintaining agronomic and economic goals;
- maximising net effective precipitation during the growing season;
- improving the application efficiency of the irrigation application system; and
- reducing deep percolation to only that necessary for leaching.

Hence, the choice of application system and management strategy adopted will greatly influence the agronomic and engineering performance of irrigation (Table 4). However, there are also a range of social and economic factors which should be considered as part of the investment decision.

QUESTIONING THE MYTHS

As with any industry, a range of irrigation related myths have developed within the cotton industry. These myths (or “sacred cows”) are typically based on either outdated technology or the inappropriate application of either “scientific” data or farm observations. Unfortunately, it is often difficult to identify the myths from the fact. Hence, questioning of the current status should be conducted in a positive and constructive manner in an effort to identify opportunities and not to entrench industry dogma. It should also be conducted in a manner that is focused on identifying the reliability and applicability of the information for our own purposes and not to avoid the issues raised. Some of the most common irrigation myths currently being touted within the cotton industry are discussed below.

Cracking clay soils don’t leak!

All soils are permeable and have the ability to produce deep drainage under the right conditions. Cracking clay soils are certainly regarded as having low permeability rates compared to most other soils. However, where water is applied to the surface for long enough they will certainly leak. This major industry misconception arose from research during the 1980s which only looked at a limited number of soils in select areas using relatively short furrow lengths. The soils investigated may also have been structural degraded due to compaction induced by the cultural practices of the period. However, over the last 15-20 years, the industry has expanded onto a greater range of soils types (not all soils are the same!), furrow lengths have

Table 4. Some of the issues which should be considered as part of evaluating investments in irrigation application systems

Factor	Issue
Agronomics	Crop establishment Waterlogging effects Cultural benefits (ie timing/nature of spraying) Cultivation benefits Potential to utilise regulated deficit irrigation Fertigation/chemigation opportunities
Engineering Performance	Application efficiency Distribution uniformity Ability to utilise in-crop rainfall
Economics	Capital costs Operating costs Maintenance requirements/costs
Labour	Operating requirements/costs Training/experience required
Lifestyle	Automation, remote sensing/control Irrigating without others knowing

increased dramatically in some cases and better tillage and cultural practices have improved the structure of many of the soils. Hearn (2000) observed that there has been a significant body of recent research (eg. Willis *et al*., 1997; Douglas, 1998; Ringrose-Voase *et al.*, 1998; Young 1998; Hulugalle and Weaver, 2000) which as demonstrated the potential for appreciable drainage on cracking clay soils. Recent volume balance (eg. Dalton, 2000) and detailed lysimeter (eg. Zilkche and Gordon, 2000, Moss *et al*., 2001) research has demonstrated that cracking clay soils can leak up to 1-2 mm/day and commonly have deep drainage losses of up to 2 ML/ha/season (Silburn and Montgomery, 2001). This represents a substantial contribution to yearly drainage rates and may be contributing to accelerated local groundwater rises but also represents lost productivity and profitability opportunities.

I have a recycling system so I must be an efficient irrigator

Irrespective of the type of irrigation system and associated infrastructure, the major factor influencing irrigation efficiency is the way in which the irrigation is managed. This is analogous to the saying "*the most dangerous nut in the car is the one behind the wheel*". Certainly a poorly designed and installed irrigation system will never have an acceptable performance. However, there are many well designed and installed systems which are operated inefficiently by applying the water for excessive periods which results in either deep drainage losses or crop losses through waterlogging. The most common example is where irrigations are conducted for excessive periods to fit with labour shifts (ie 12 hour runs) on the assumption that there will be no inefficiencies because the run-off water will be captured by the tailwater system. Similarly, some water (up to 5%) may be lost in the recycling process through increased evaporation and deep drainage within the channel systems.

The only option to improve irrigation efficiency is drip

There are many well designed and managed surface irrigation systems which are operating with infield application efficiencies in excess 90%. Hence, if the existing surface system is suffering from low application efficiency, one sensible alternative could be to investigate an investment in upgrading the design and/or management of the surface system. Similarly, there are also alternative application systems in the form of low pressure mobile systems which typically have a lower setup cost and longer life expectancy than current drip systems.

Centre pivots or lateral moves are not an option for cotton in Australia

A wide range of myths exist regarding the appropriateness and operational requirements of centre pivots and lateral moves for cotton production. Concerns commonly voiced include: the potential for bogging of towers, waste of corner areas when using pivots, inability to cultivate in circles, excessive evaporation losses, high pressures and consequent operating expenses, and increased crop disease. Each of these issues is addressed separately below. While most of these concerns have arisen from adverse early experiences, it should be noted that the level of Australian cotton industry experience in the use of these machines has increased dramatically in the last 5 years. Current users of centre pivot and lateral machines in the cotton industry are reporting substantial yield increases over traditional furrow irrigation practices particularly due to improved control over the timing and volume of water applications.

Tower Bogging – Bogging should only ever be a concern where the soil is wet due to either rainfall or the irrigation itself. If the soil is wet enough to bog the machine due to rainfall, the question should be asked as to why you are irrigating under this conditions? Irrespective of whether SDI or low pressure application systems are used, fields should also be cut to ensure adequate surface drainage, particularly in high intensity summer rainfall dominant areas. Where the machine is adequately designed, there is no reason for wheeled areas to be wet due to the irrigation practices. The most common method to eliminate wetting of the wheeled areas by the irrigation itself is to fit the machine with structures (called "boom backs") which shift the spray nozzles to behind the tower wheels. This ensures that the wheeled areas are not wet prior to trafficking and hence, eliminate bogging concerns. On LEPA machines, hose lengths near the towers can be increased (ie commonly doubled) so that the water emits well behind the towers. Another solution involves modifying the nozzle and sprinkler selection to eliminate water throw onto the towers and reduce throw onto the tracked area.

Wastage of corner areas with centre pivots – The majority of the Australian cotton industry is water limited and in most years, water limitations mean that many farms are only capable of irrigating a proportion of the farm. Hence, the inability to irrigate corner land is often not the most limiting factor influencing the total area irrigated. It should also be noted that the corner land is not "lost" but is still available to be dryland farmed. However, where corner areas are required to be irrigated, several options exist including the use of corner units which have improved dramatically in reliability and performance over the last few years. For large developments involving multiple pivots, it is also possible to reduce corner areas by the use of nested circles with triangulated centre locations.

Loss of corner areas is the most common reason growers give for choosing lateral moves over centre pivot machines. However, it should be noted that lateral move machines have a number of substantial disadvantages when compared with centre pivots including a higher level of machine complexity, an increased guidance risk, an increased management requirement and an increased labour requirement (estimated as 3 times larger).

Cultivation in circles – There is no necessity for centre pivot irrigators to cultivate in circles. Many irrigators continue to use a parallel row direction under centre pivot irrigators and completely ignore the wheel tracks in their planting and cultivation practice. The towers will find their own path around the field and the loss of plant area is typically negligible. However, some irrigators are reporting that with improvements in tractor guidance, cultivating in circles is not difficult.

Losses from evaporation – Many growers perceive that evaporative losses from centre pivots and laterals consume up to 30% of the water applied. However, an extensive range of studies (eg. Dadiao and Wallender, 1985; Frost and Schwalen, 1960; Silva and James, 1988; McLean *et al*., 2000; Solomon *et al*., 1985; Yonts *et al*., 2000) has demonstrated that evaporation losses from these machines are commonly in the order of 2-3% of the applied water rising to approximately 8% under extreme temperature, humidity and wind conditions. Where sprinklers are used, there is also a misconception that moving the sprinklers to within the canopy substantially reduces evaporative losses. However, recent work (Yonts *et al*., 2000) shows that water savings of only 1 to 2 % can be expected when moving the sprinkler from just above the canopy to within the canopy. Surface run-off from low pressure mobile machines should also normally be negligible. However, problems may be encountered where LEPA configurations are used on steep slopes without the use of furrow dikes. In these cases, one option is to dike only the furrows in which the LEPA socks travel (every second one) and leave the alternate furrows flat for wheel tracks.

Excessive operating expense – Modern low pressure mobile systems typically operate with nozzle pressures between 70 kPa (10 psi) and 138 kPa (20 psi) and normally require <240 kPa (35 psi) at the system centre. Fuel costs associated with pumping and movement for these machines typically range from $13-$25/ML.

Crop disease incidence - While spray nozzles may be used to germinate the cotton crop, these nozzles are not commonly used throughout the season. Most commonly LEPA or sock emitters which do not wet leaves and buds are used throughout the majority of the season. Disease pressures under these conditions have been reported to be no greater than under surface irrigation.

WHAT ARE YOUR OPTIONS?

The strategies to improve water use efficiency revolve around the central themes of reducing losses out of the system (i.e. evaporation, deep drainage, run-off), reducing crop evapotranspiration during non-critical periods, and increasing the effectiveness of stored soil moisture and rainfall during the season. The most effective strategy will be dependent on the individual farm, crop and management constraints. However, for most surface irrigated cotton growers the options come down to the following:

(a) Do nothing (ie. remain with existing furrow design/management);
(b) Invest in precision surface irrigation (ie re-designed fields with optimised surface irrigation management practices);
(c) Invest in either centre pivots or lateral move machines;
(d) Invest in a drip irrigation system.

A summary of the advantages and disadvantages of each is provided in table 5.

Table 5. Comparison of irrigation application systems for cotton production

Option	Advantages	Disadvantages
Do nothing (ie. existing surface irrigation)	• No additional capital or operating costs	• Potential yield/profit opportunities forgone
Precision surface irrigation	• Reduced waterlogging (increase yield ~ 1 b/ha) • Reduced deep drainage and tailwater losses (seasonally up to ~15%)	• Existing furrow costs + $100-500/ha • Modelling/field instrumentation required • Possible increased labour costs
Centre pivot or lateral moves	• In-field water application commonly reduced by up to 30% • Yield increase commonly up to 1.2 b/ML • Automation/chemigation	• Cost ~ $2000-$2500/ha • Life expectancy ~ 20 years
Subsurface drip systems	• Increase in crop water use by an average of 1.29 bales/ML_{irrig} (either reduced water application by average 38% or increased yield by average 2.7 b/ha) • Automation/chemigation • High flexibility for cultural practices	• Cost ~$3500-$4500/ha • Life expectancy ~ 10 years

CONCLUSIONS

Existing surface irrigation systems may not be as efficient as perceived within the industry. This should be seen as an opportunity not as a political hindrance. Options for improved in-field irrigation performance are not limited to changing to drip systems. Significant improvements can be made through better monitoring of surface irrigation performance and modification of design and/or management practices to minimise crop waterlogging, deep drainage losses and tailwater losses. There is also significant potential for improved control of water and crop management through the installation of either centre pivot or lateral move machines which can be accomplished with lower cost and have a greater life expectancy than drip systems. However, there are other benefits of drip which may continue to make it attractive in some areas and to individual growers.

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