COMPARING APPLICATION SYSTEMS FOR COTTON IRRIGATION - WHAT ARE THE PROS AND CONS?

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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, expansion onto more marginal soils, the potential yield benefits of improved control of soil-water in the root zone, and the potential for reduced labour, fertiliser and pesticide costs have raised grower interest in alternative irrigation application techniques. 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 furrow irrigation, large mobile irrigation machines (LMIMs) and subsurface drip irrigation (SDI) within the cotton industry. 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 most 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.

Irrigation in the Cotton Industry

The Australian cotton industry is currently dominated by surface irrigation using either every furrow or alternate (skip row) furrow strategies. Both LMIMs and SDI are currently used across all cotton growing regions and industry operating conditions (eg soil types, climates, irrigation water sources). However, only 4% of the total cotton crop is currently grown using LMIMs while less than 2% is currently grown using SDI. While it seems likely that the proportion of both SDI and LMIM 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. 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 (eg. 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. As Hearn (2000) pointed out, there is a triple bonus for getting irrigation management right including:

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

The performance evaluation of in-field application systems can be divided into the two major components of water losses (ie. application efficiency) 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). The ability of the 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. However, the flexibility in timing of irrigation applications and the volume of application which can be applied may also affect the ability to utilise in season rainfall and minimise crop waterlogging. Hence, optimal irrigation system selection and management requires not only a knowledge of the characteristics of the application system but an understanding of the environment in which it operates.

What Are The Issues?

Irrigation design and management decisions are the result of a complex interaction of many variables (Table 1) 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 identify their current efficiencies and the techniques by which improved efficiencies can be achieved, and be motivated to change (Skewes and Meissner, 1998).

While agronomic benefits (ie yield/quality 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. However, there are also a range of social and economic factors which should be considered as part of the investment decision (Table 1).

Table 1. Some of the factors which typically influence irrigation design and management decisions

Factors	Examples
Agronomics	Crop responses to climatic and soil moisture variables; crop establishment, waterlogging, potential to utilise regulated deficit irrigation, cultural benefits (ie timing/nature of spraying), cultivation benefits, fertigation/chemigation benefits
Engineering	Application efficiencies, distribution uniformity, ability to utilise in-season rainfall, hydraulic design limitations on pumps, pipes and storages, supply capacities
Environment	Climate, soils, topography
Social	Skills, experience, education, labour availability,
Economic	Capital costs/availability, operating costs, maintenance requirements/costs, returns from product
Historical	Existing infrastructure, previous farming systems
Hydrological	River flow regimes, groundwater issues; surface flow harvesting
Regulatory policy	Legislation on access to river, surface and groundwater
Admin. procedures	Licence requirements, ordering of water supplies

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), increasing the effectiveness of stored soil moisture and rainfall during the season, increasing crop growth rates through reduced waterlogging, and reducing crop evapotranspiration during non-critical periods (ie deficit and/or partial root zone drying). The most effective strategy will be dependent on the individual farm, crop and management constraints. However, for cotton growers who are currently surface irrigating the options come down to the following:

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

Comparison of Factors Influencing System Selection

As with most management decisions, the choice of irrigation system used is often a result of a combination of factors. The main reasons cited in recent surveys (Raine *et al.*, 2000; Foley and Raine, 2001) include the potential for water savings, labour savings, uniformity of water application, reduced crop waterlogging, the ability to automate the system, increased yield and either fertigation or chemigation opportunities. Other issues such as the elimination of the requirement for extensive surface irrigation earthworks and ability to more readily grow crops other than cotton were also seen as factors influencing selection.

Growers often perceive that the choice of irrigation application system is the major factor influencing potential yield and operational efficiencies. However, while the choice of system has the potential to provide a range of benefits including energy, labour and capital efficiencies, it is the management practices employed which have the greatest effect on the yield and water use efficiency. This is similar to saying that it doesn't matter whether you buy an esky or a fridge, if you leave the door or lid open the beers will be hot!

To effectively compare irrigation application systems requires both systems to be operated in an optimal state. This rarely occurs under commercial conditions as growers trialling alternative application systems often have no objective measure of the optimality of their current surface irrigation practices and are typically "learning" how to appropriately manage the new application system. The problems in these comparisons have been compounded in the cotton industry by inappropriate LMIM design and installation over the last thirty years and a lack of appropriate agronomic skills for the management of SDI systems. Despite these limitations, it is possible to provide some comments on the comparative advantages and disadvantages of the various irrigation application systems currently available within the industry. A summary of the factors that should be considered in the selection process is provided in Table 2.

Table 2. Comparison of irrigation application systems as used in the Australian cotton industry

(modified from Burt et al., 1999)

	Furrow	Precision furrow	Centre pivot	Lateral move	Subsurface drip
Land					
Odd-shaped fields	0	0	-	-	+
High water table	-	0	0	0	+
Undulating slopes	0	0	+	+	+
Steep slopes	-	-	0	0	+
High infiltration soils	-	0	+	+	0
Low infiltration soils	0	0	-	0	0
Highly non-uniform soils	-	-	+	+	-
Low water holding capacity soils	0	0	+	+	+
Saline soil	-	-	0	0	+
Poorly drained soil	-	0	0	0	0
Highly erodible soil	-	-	0	0	+
Low bearing capacity soil	0	0	-	-	+
Water Supply					
Groundwater supply	0	0	+	+	+
High sediment load	0	0	0	0	-
Small rate of flow available	-	-	+	+	+
Climate					
Ability to utilise in-season rainfall	-	0	+	+	+
Windy conditions	0	0	-	-	0
Social/Institutional Conditions					
Low labour availability	-	-	+	+	+
Low management skills available	0	-	-	-	-
Little technical assistance available	0	-	-	-	-
Automation potential	-	-	+	+	+
Agronomy					
Germination/crop establishment problems	0	0	+	+	-
Waterlogging	-	0	+	+	+
PRD/deficit irrigation	-	0	+	+	+
Fertigation/chemigation	0	0	+	+	+
System Characteristics					
Crop risk from system breakdown	+	+	0	0	-
Installation complexity	+	+	+	+	-
System robustness	+	+	0	0	-
Labour and management time req.	-	-	+	+	+
Environmental Concerns					
Land transformation	-	-	0	-	0
Chemical use/movement	-	-	0	0	+

(0) *indicates limited or no influence on selection,* (+) *indicates possible reason for preference,* (-) *indicates possible reason for choosing alternate method*

Yields and Water Use Efficiency

Yields and crop water use efficiencies (CWUEs) achieved with each of the irrigation application systems are primarily influenced by management strategy, system capacity and water availability. Grower survey data (Raine *et al*., 2000; Foley and Raine, 2001) has indicated that crop water use efficiencies for surface irrigation fields commonly range from 0.6-1.6 bales/ML_{irrig}(Figure 1). Growers using LMIMs who had plenty of available water and an adequate system capacity typically reported yields per unit area similar to, or greater than, traditional surface irrigation. LMIM growers with limited available water or undersized machine capacities reported lower yields per unit area compared to traditional surface irrigation. However, these growers would not have had enough water to fully irrigate the cropped area using surface irrigation. The average yield per unit area for growers using LMIMs was 0.5 bales/ha less than furrow. However, growers using LMIMs reported applying on average 3.1 ML_{irrig}/ha less than fully irrigated surface systems resulting in CWUEs ranging from 1.35 to 2.6 bales/ML_{irrig} with an average of 1.9 bales/ML_{irrig}(Figure 1). The potential to apply smaller volumes on pre-season irrigations, improved germination of crops, better utilisation of in- season rainfall and the ability to utilise deficit irrigation strategies have all been cited as reasons for the lower irrigation water use and increased CWUE with LMIMs.

Yield achieved on SDI blocks is influenced by the water management strategy adopted by the grower. Where growers focus on maximising SDI block yields (ie. growers were trying to grow large crops to pay for the SDI system) improvements of up to 2.7 bales/ha above surface irrigated fields have been achieved (Raine *et al.*, 2000). However, where growers focus 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 are similar to surface irrigated blocks. In all cases, growers have reported an increase in crop water use efficiency with an average increase of 1.29 bales/ ML_{irrig}. 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. However, the water saving differential was much smaller where optimisation of the surface irrigation had already been undertaken.

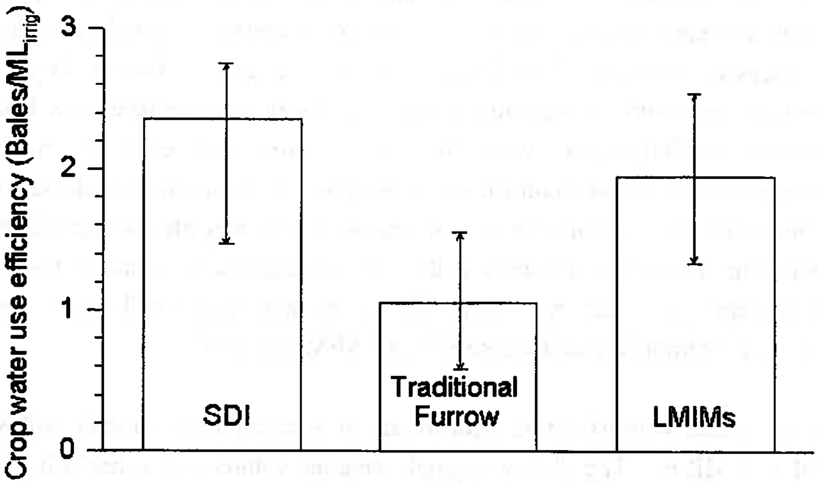

Figure 1. Crop water use efficiency (bales/ML_{irrig}) for subsurface drip irrigation, traditional furrow and LMIMs obtained from grower surveys (Cross bars represent highest and lowest values reported by growers)

System Performance

While it is often claimed that the application efficiency of well designed and managed surface irrigated cotton is over 80% (eg. Anthony, 1995) there is increasing evidence that the performance of surface irrigation on many commercial farms is highly variable. In-field measurements on over 180 irrigation events under commercial conditions have found application efficiencies of single irrigations ranging from 35-100% with seasonal efficiencies commonly between 60-85% (eg. Dalton, 2000; Dalton *et al.*, 2001; Moss *et al.*, 2001; Purcell, *pers. comm.*). One of the major reasons for low efficiencies is the correspondingly low uniformity of application associated with many furrow fields. However, these uniformities and efficiencies can often be increased by the selection of more appropriate furrow inflow rates and by pulling siphons earlier to reduce potential deep drainage losses. Optimised management of commercial surface irrigation through these simple low cost changes (ie. 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% (Dalton *et al.*, 2001; Purcell, *pers. comm.).*

The evenness of water application using SDI and LMIMs is normally much higher (distribution uniformity >90-95%) than for furrow systems (distribution uniformity ~ 60-90%) and should normally translate into smaller in-field crop yield variations with these systems. Similarly, while efficiencies are strongly influenced by management practices, well managed SDI and LMIMs commonly produce application efficiencies in excess of 90% (eg. Schneider and Howell 1995; New and Fipps, 1995). Low pressure, static plate sprinklers on LMIMS typically operate at 80-90% application efficiency while moving plate sprinklers have application efficiencies up to 95%. Low energy precision application (LEPA) socks and bubbler emitters have been found to have application efficiencies up to 98% where surface run-off is controlled.

Waterlogging

Waterlogging of cotton crops occurs due to either excessive periods of irrigation, irrigation prior to rainfall events or inappropriate drainage. Irrigation induced waterlogging is apparent near the inflow end of many surface irrigated fields and is normally associated with periods of irrigation in excess of 8-12 hours. Waterlogging may also occur at the tailend of surface irrigated fields due to poor surface drainage and excessive tailwater flows backing up over the crop. The ability to reduce irrigation induced waterlogging in surface irrigation is significant 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. An essential pre-requisite for the reduction of irrigation induced waterlogging in surface irrigation is the laser levelling (and regular re-lasering) of fields and the selection of appropriate furrow lengths, flow rates and siphon pull times. Irrigation induced waterlogging is not commonly found where SDI or LMIMs are used.

Waterlogging associated with irrigation prior to rainfall is much more common with surface irrigation than with SDI or LMIMs. The ability to apply smaller volumes of water using SDI and LMIMs during periods when rainfall events are predicted reduces the potential for root zone waterlogging and enables improved capture of rainfall in-field. However, it should be noted that while neither SDI or LMIMs require laser levelling of fields, there is still a requirement to "cut to drain" to minimise surface water ponding from rainfall.

Capital Costs

Surface irrigated fields are normally laser levelled with set up costs ranging between \$500-\$1800/ha depending on the amount of soil to be moved, the ratio of headworks to field length, and the drainage and tailwater requirements. LMIMs typically cost between \$1700 and \$2500/ha to set up and have a life expectancy in excess of 20 years depending on water quality and operational conditions. Centre pivot machines often cost between 10 and 15% more in capital costs than lateral move machines on a per hectare basis due to the larger areas normally irrigated with each lateral move machine. The capital cost of SDI systems is comparatively high (\$3500-\$4500/ha) and the life expectancy of the tape is less than 10 years. Only 10% of growers using SDI achieved a yield increase of at least 2.5 bale/ha which has been estimated as the difference required to economically justify a move to SDI. Hence, the economic benefits of moving to SDI for many growers is marginal, particularly if surface irrigation efficiencies are already high. However, if SDI is selected, the capital cost associated with ensuring adequate filtration and providing automation capability for SDI systems is normally a valuable investment. Low cost ($1500-$2000/ha) "temporary" drip systems have recently been trialled and could prove to be more economically attractive.

Labour

A major driver in the adoption of LMIMs and SDI is the substantial reduction in labour associated with these systems compared to furrow. However, while the labour time requirement for these systems can be as little as 10% of the labour required to manage traditional surface irrigation systems, the level of agronomic management skill required to effectively operate these systems is much higher. The majority (76%) of LMIMs in the cotton industry are centre pivot machines. A major driver in LMIM selection is the labour requirement with lateral move machines typically requiring 50-80% more labour to manage (ie. channel/hose changes, guidance system maintenance, re-fuelling operations) compared to centre pivot machines.

Operating Costs

Pumping and maintenance costs associated with pressurised application systems are commonly perceived as a major barrier to the adoption of these systems. However, modern LMIMs 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. SDI systems also operate at low emitter pressures (ie 70–138 kPa) and require comparable pumping costs.

Agronomic Control and Management

SDI and LMIMs provide substantial benefits in the timing of ground rig spraying and in-field cultivation practices as these systems can apply smaller irrigation volumes than furrow systems meaning that the period between irrigation and subsequent spraying or cultivation activities can be relatively short. Concerns over LMIMs affecting boll formation and lint quality are unfounded under Australian conditions with no grower using LMIMs reporting reduced lint quality. The use of low energy precision application emitters (ie socks and bubblers) on these machines means that the irrigation water is normally applied beneath the plant canopy and the flowers and bolls are not routinely wet. Where overcrop sprinklers are used, the common approach of applying irrigation water no more frequently than every third day to a particular part of the field means that the flowers and bolls are able to completely dry between irrigations.

Fertigation and Chemigation

Fertigation through surface irrigation systems is typically achieved by fertiliser additions to distribution channels. However, difficulty in fertiliser dissolution, transient surface water ponding affecting denitrification and the non-uniformity of surface irrigation applications mean that the effectiveness of these additions is often questioned. By comparison, fertigation and chemigation can be easily implemented using both LMIMs and SDI systems. The injection systems used to mix fertilisers and chemicals into irrigation water for application by LMIMs and SDI systems can be accurately controlled and the high uniformities of application ensure that the fertiliser/chemical is evenly applied to the crop. LMIMs have the advantage of being able to apply chemicals onto the crop canopy with very small volumes of water. LMIMs can also be fitted with a separate chemical distribution pipeline to enable crop spraying without the chemical being mixed with the irrigation water.

Other Factors

One advantage of LMIMs is the ability to vary the application method (ie. spray plates or LEPA) and volumes applied in response to agronomic demands and rain. Using spray plates, water can be applied to the soil surface providing high germination rates with relatively small application volumes compared to SDI or surface systems. A major benefit of lateral move machines over centre pivot machines is their ability to fully utilise fields that have already been developed as square or rectangular blocks and the perceived ease of use with respect to the use of LEPA systems. More than three-quarters of growers using LMIMs have reported (Foley and Raine, 2001) experiencing some wheel rutting problems during the first few years of LMIM operation due to inexperience and poor machine design. However, the majority of growers have overcome these difficulties through a range of machine modifications and management practices including the use of boom backs, ½ throw sprinklers or reduced flow rates near towers, double length LEPA hoses or the application of lighter irrigations until the wheel tracks are firm.

Nearly all SDI irrigators have experienced some problems in the design, installation, operation, maintenance or management of their systems. However, most growers acknowledged that with the benefit of experience none of these issues should have been a problem. 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. Germination also 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).

Conclusions

The performance of many existing surface irrigation systems in the cotton industry is highly variable and may not be as efficient as commonly perceived within the industry. This should be seen as an opportunity to improve production through the modification of management and/or design practices which minimise crop waterlogging and improve application efficiencies. However, there are a wide range of farm specific factors which should be considered in deciding whether it is more appropriate to improve the performance of the existing surface system or invest in alternative irrigation infrastructure. In most cases where the key objective is simply an improvement of application efficiency and/or a reduction in irrigation induced waterlogging, the most cost effective option will be to work towards improving the performance of the existing surface irrigation system. However, where greater control and flexibility in irrigation management is desired, significant additional benefits can be achieved by investing in either LMIMs or SDI systems. In these cases, the comparatively lower cost and longer life expectancy of LMIMs makes these machines more attractive for growers moving away from surface irrigation. However, the flexibility in SDI design layouts and the additional environmental and management benefits associated with SDI systems will continue to make these systems attractive to individual growers in selected areas.

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