CENTRE PIVOT AND LATERAL MOVE MACHINES IN THE AUSTRALIAN COTTON INDUSTRY

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ABSTRACT

Centre-pivot and lateral move irrigation machines represent one of the most efficient and cost-effective methods of broad-acre irrigation available to the Australian irrigation community. They have the capability to improve the overall water use efficiency of Australian irrigated agriculture in a far simpler and more cost-effective manner than other systems such as micro-irrigation, yet the level of adoption in this country generally, and the cotton industry in particular, is low. On farm surveys of both current and previous users of centre pivots and lateral moves within the Australian cotton industry were conducted to obtain information regarding on-farm irrigation infrastructure, management practices and the factors influencing adoption and operation of these machines. The manufacturers of centre pivots and lateral moves supplied to the cotton industry were also surveyed to obtain details on the recommended and implemented design, installation, operation and maintenance procedures within the industry. The results of this survey are presented and the implications for future irrigation development in the cotton industry discussed.

INTRODUCTION

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 large mobile irrigation machines. While less than 4% of the total Australian cotton crop is currently grown using large mobile irrigation machines, 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. Very little research has been undertaken within the Australian cotton industry to evaluate the performance of large mobile irrigation machines and to identify or promote appropriate design and management practices. Hence, this scoping study was commissioned by the Cotton Research and Development Corporation in an effort to better understand the performance of centre pivot and lateral move machines within the industry and to identify the opportunities for research and development within this sector.

SURVEY METHODOLOGY

On-farm surveys of both current and previous users of centre pivot and lateral move machines within the Australian cotton industry were conducted to obtain information regarding on-farm irrigation infrastructure, management practices and the factors influencing adoption and operation of these machines. The major manufacturers of centre pivots and lateral moves supplied 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 grower and the manufacturer surveys were also designed to obtain data on the:

- extent of centre pivot and lateral move machine usage within the cotton industry;
- nature of the machines currently and previously in operation;
- commercial water use and production benefits obtained using centre pivots and lateral move machines; and
- management and operation problems associated with the implementation of these machines within the cotton industry.

The surveys were conducted between July and September 2001 and involved a total of 31 interviews with growers and five interviews with the major centre pivot and lateral move irrigator dealer and supply companies. The grower survey encompassed more than 80% of large mobile irrigation machine users within the cotton industry including 16 growers from Queensland and 15 from New South Wales. The majority of the grower interviews were conducted on-farm with either the farm owner or irrigation manager. Each of the manufacturer interviews were conducted face-to-face. Where necessary, follow-up telephone interviews were undertaken to clarify or elaborate on the information provided.

INDUSTRY OVERVIEW

Approximately 5300 ha of cotton is currently irrigated using centre pivot and lateral move machines in Australia. This represents approximately 4% of the irrigated cotton area in an average year and is significantly larger than the cotton area currently irrigated by drip irrigation systems. Approximately 75 centre pivots and lateral moves are currently installed across all of the major cotton producing areas from Emerald in Queensland through to Hillston in NSW. Machines are also used in trial areas located in the Northern Territory and Western Australia. The average area irrigated by these large mobile irrigation machines (LMIMs) is approximately 93 ha with the largest single machine irrigating an area of 267 ha. The majority of LMIMs being used within the cotton industry are centre pivot machines (76%) while the remainder (24%) are lateral moves. However, the total area irrigated by lateral moves represents 45% of the total area irrigated by LMIMs due to the much larger average size (~165 ha) of these machines compared to the centre pivots (~70 ha).

The average age of the machines currently being used in the cotton industry is 10.7 years with the oldest operational machine being 23 years old. Approximately two-thirds (65%) of growers using LMIMs own two or more machines, with some growers owning up to five machines. Almost 90% of the growers responded that they would install another LMIM, with the majority of the remaining 10% having run out of country suitable for the installation of this equipment. Growers reported an average of 6.4 years of experience in using LMIMs for cotton production with 27% of the LMIM growers having produced less than two cotton crops. Only 7% of the machines were installed solely for irrigation of cotton with the rest of the growers (93%) using their machines to also irrigate other crops (normally grains or peanuts). Half (50%) of the growers surveyed obtain all of their water from surface supplies while 35% use only groundwater and the remaining growers use a mix of water sources. However, on an area basis, the proportion of surface and groundwater used is similar with approximately 40% of the area irrigated by either surface or groundwater only. Approximately half of the growers (53%) have installed LMIMs onto cracking clay soils. However, these installations account for more than 61% of the total area. Another 27% of the LMIMs are installed on clay loam soils with the remainder located on lighter textured soils.

YIELD AND WATER USE EFFICIENCY

Yields and crop water use efficiencies on individual farms were primarily influenced by management strategy, system capacity and water availability. Growers who had plenty of available water and an adequate system capacity typically achieved yields per unit area similar to, or greater than, traditional surface irrigation. Growers with limited available water achieved 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. All growers reported an increase in the crop water use efficiency (CWUE) compared to traditional surface irrigation systems (Figure 1) with CWUE ranging from 1.35 to 2.6 b/ML_{irrig}. The average CWUE under LMIMs was found to be 1.9 bales/ML_{irrig} which was 72% (or 0.8 b/ML_{irrig}) higher than the average CWUE achieved using traditional surface irrigation. The average CWUE was not as high as reported by growers using subsurface drip irrigation systems (Raine *et al*., 2000), which averaged 2.4 bales/ML_{irrig}. However, the LMIM results may have been influenced by the high number of LMIM growers who were inexperienced in cotton production (27% have grown less than 2 seasons of cotton) and the large proportion of machines (27%) with both a designed and managed system capacity significantly less than the capacity required to meet the peak crop water use rate. This may also have impacted on the yields when reported per unit area, which were slightly lower (0.5 b/ha or 6.4%) on average under LMIMs when compared to traditional surface systems.

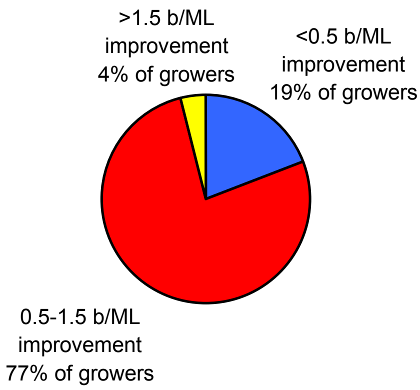
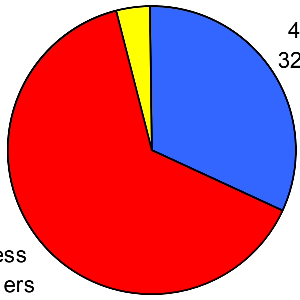


Figure 1: Increase in crop water use efficiency (in bales/ML_{irrig}) for cotton irrigated by LMIMs compared to traditional furrow systems

All of the growers surveyed applied less water per unit area with their LMIM than they applied using a surface irrigation system (Figure 2). Growers reported applying on average 3.1 ML_{irrig}/ha less than fully irrigated surface systems, however the survey results were strongly influenced by the large proportion of growers who were short of water. Only a small proportion (4%) of the growers reported applying 0-2 ML_{irrig}/ha less water while almost a third of the growers reported applying 4-6 ML_{irrig}/ha less water than their fully irrigated surface systems. The reduction in water applied is similar to the reduction in water applications (average = 2.56 ML_{irrig}/ha) reported by growers using drip systems (Raine *et al*., 2000). However, it should be noted that these water savings may well be smaller when optimisation of the surface irrigation has been undertaken.



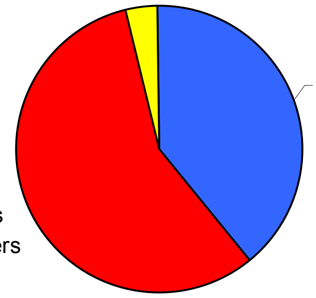


Figure 2: Difference in water applied by growers using centre pivots and lateral moves when compared to fully irrigated surface systems

GROWER PERCEPTIONS AND ISSUES DRIVING ADOPTION

There are a wide range of reasons why growers used LMIMs for irrigation of cotton. As with most management decisions, the decision is often a result of a combination of factors. However, the main reasons cited (Table 1) were the potential for water savings (93%), labour savings (85%) and reduced crop waterlogging (73%). Approximately two-thirds of growers indicated that improved uniformity of water application and the ability to automate the system was also important while approximately half the growers were interested in increased yield and either fertigation or chemigation opportunities. Other issues such as the elimination of the requirement for extensive surface irrigation earthworks was also found appealing. An experienced cotton grower reported that "return on investment" was a significant factor when he installed a lateral move machine. He commented that his lateral move had cost $1800/ha compared to a surface irrigation system costing $1300/ha and added that the lateral move could be "financed over a term" compared to the up-front capital cost of the earthworks required for surface irrigation. The ability to more readily grow a wide variety of crops other than cotton was also seen as a benefit over furrow irrigation.

Table 1: Issues driving adoption of LMIMs within the cotton industry

Issues	Responses (%)
Water saving	93
Labour saving	85
Reduce waterlogging	73
Improved water application uniformity	65
Automation	58
Increase yield	46
Fertigation & chemigation	46
Improved cotton quality	12

CHOOSING A MACHINE

The majority of LMIMs in the cotton industry (76%) are centre pivot machines. However, Australian cotton growers have recently embraced lateral move machines. This contradicts trends overseas and in other local industries where lateral move machines continue to represent only a very small proportion of the market. A major driver in machine selection is the labour requirements. Lateral move machines typically require at least 50% extra labour to manage above that required for centre pivot machines (Solomon, 1988). However, anecdotal evidence reported by the surveyed growers who use both centre pivot and lateral move machines suggests that the labour requirement could be as much as 80% higher for lateral moves compared to centre pivots. One grower's response when asked why he would prefer not to choose a lateral move machine was "*you always need to have one eye on it, just to make sure that it is actually still going properly*" while another responded by asking "*do you like to sleep at night?*". These grower comments highlight the additional labour and greater attention to detail required when looking after lateral move machines. While centre pivot machines often cost between 10 and 15% more in capital costs than lateral move machines on a per hectare basis, growers indicated that the on-going savings in labour and management costs more than compensate for the extra capital cost.

CHOOSING AN EMITTER SYSTEM

Almost all the current LMIM growers (96%) use static plate sprinklers to germinate and establish cotton. However, approximately half of these growers (48%) then use LEPA socks or bubblers after crop establishment to apply the majority of irrigations. Only 4% of the growers are using moving plate sprinklers throughout the main growing period of the crop. This proportion is closely related to machine age with older machines more commonly fitted with the static plates. There is a potential to improve the performance of the machines fitted with static plates by either conversion to moving plate heads with better wind fighting capabilities and lower instantaneous application rates or low energy precision application heads.

Low Energy Precision Application Emitters

Low Energy Precision Application (LEPA) emitters are commonly regarded as providing improved control over water application and reduced evaporative losses. Approximately 40% of the growers used "Quadspray" (i.e. bubbler) heads while the rest used drag socks. LEPA emitters are normally spaced to apply water every second row. However, on soils with low infiltration rates or on large pivots where nozzle flow-rates are high, on option to reduce run-off is to space the LEPA heads between every row rather than every second row. Hence, LEPA machines commonly use non-standard main pipe with outlets at spacings of 0.75m (30"), 1.5m (60") or 2m (80") rather than the standard 2.75m (8') and 3.05m (10'). Not all LMIM manufacturers supply LEPA pipe, with some designers preferring to use standard outlet spacings with extra tees, furrow arms and fittings to split flow and provide water to multiple LEPA emitters from a single outlet.

Approximately 20% of the LMIM growers who were using LEPA emitters also used alternate row furrow dyking to reduce surface run-off. The rest of the growers using LEPA were simply using drag socks or bubbler technology during normal crop irrigation without any furrow dykes. Growers not using furrow dykes on cracking clay soils indicated that they believed that dropping water into the cracks would be just as effective as furrow dyking. Growers who have successfully implemented furrow dyking in conjunction with LEPA emitters were convinced that the system improved irrigation water control and performance. Benefits included allowing irrigation on sloping country without runoff, and an increase in the capture of rainfall within the field. One grower indicated that dyking in conjunction with double length hoses adjacent to the towers also helped to keep water away from the wheel-tracks. LEPA also made it possible to ground rig cotton on dry traffic lanes soon after the machine had finished its run. A number of growers reported that the use of single ended drag socks eroded furrow dykes. However, where double ended drag socks were used, dyke erosion using LEPA was not a problem. Another benefit of LEPA cited by growers is the ability to apply chemicals at the same time as the irrigation is being applied because the plant canopy is not being wetted. In these cases, pesticide is applied either through separate chemigation spray lines attached to the machines or by traditional aerial application. One grower indicated that a significant advantage of LEPA was the ability to apply very small amounts of water (6 mm) at very high frequencies (twice daily), in a manner similar to SDI irrigation. However, most growers were applying 20-30 mm per pass on cracking clay soils to retain a smaller wetted soil volume.

Overcrop Sprinklers

Overcrop sprinkler irrigation is the older irrigation technology, and is most widely used in the form of modern static plates, spinners, wobblers and rotators, with very little old high pressure impact sprinklers still in existence. Approximately half (52%) of the LMIM growers used overcrop sprinklers throughout the whole season. Nearly all of these growers used static plate sprinklers. Growers using the sprinklers believed overcrop sprinklers were easier to manage as they didn't have to align sprinkler heads with crop rows and wheel tracks, did not have to change heads after germination, and there was less likelihood of damage due to high winds. Growers on hardsetting soils with low infiltration rates indicated that low pressure multi-stream overcrop sprinklers were the most appropriate emitters for their soil as the high instantaneous application rates associated with LEPA emitters resulted in significant run-off and furrow dyking was difficult to successfully implement. Problems were encountered using overcrop sprinklers where it was necessary to apply non-rain fast pesticides, and delay irrigation for 0.5 day just prior, and 1 day immediately after spraying. These delays may cause a deficit in the irrigation schedule that is difficult to catch up in peak season, particularly for low managed system capacity machines. No LMIM grower indicated that they had observed either decreased yields due to sprinkler wetting of cotton pollen or decreased fibre quality due to boll rots.

MACHINERY DESIGN & INSTALLATION ISSUES

Over half of the LMIM growers surveyed (56%) indicated that they would like to make changes to the design of their LMIM on future possible installations. A wide variety of design issues were identified by growers ranging from problems with system capacity, operating pressures, field slope, soil type and sprinkler packages. The broad perceptions of the performance of centre pivots and lateral moves in the Australian cotton industry is closely related to design and management problems associated with some of the first machines used in the industry. Early centre pivots were successfully sold to growers, particularly in central Queensland and northern NSW, with little understanding of the crop requirements and the necessary system capacities required for each region. One grower claimed pivots were originally presented as 50 ha machines, but in some instances up to three additional spans were sold increasing irrigated area to 100 ha without any change in pumping or system capacity. This sales technique significantly improved the $/ha price, but gave growers little chance of crop success (when measured in bales/ha) with system capacities at roughly half the local peak crop water use. As a consequence, it is the belief of some growers that "it is impossible to supply sufficient water to cotton irrigated with a centre pivot". Unfortunately, there are still many growers with LMIMs that are designed or managed with capacities substantially below peak crop water requirements. While cotton can handle continuing small deficits, other grain and legume crops that are commonly grown under these same machines must have capacities to match the relevant peak crop water use.

Design and Managed System Capacities

The design capacity of machines in the cotton industry ranged from 5.5 to 13.3 mm/day with the managed capacity ranging from 4.5 to 12.8 mm/day. Only 78% of machines had design capacities which were greater than 90% of the average peak evaporative rate recorded in the region where the machine was operating and only 54% of machines were operated to provide managed capacities above 90% of the average peak evaporative rates (Figure 3). However, crop factors relating cotton water use to the evaporation rates commonly ranges from 1.0-1.2 and the application efficiency for overcrop sprinklers is rarely greater than 90% during the peak season. Using these figures, only 12.5% of the LMIMs in the cotton industry have a managed capacity able to supply the full crop water use requirements during the peak growing season.

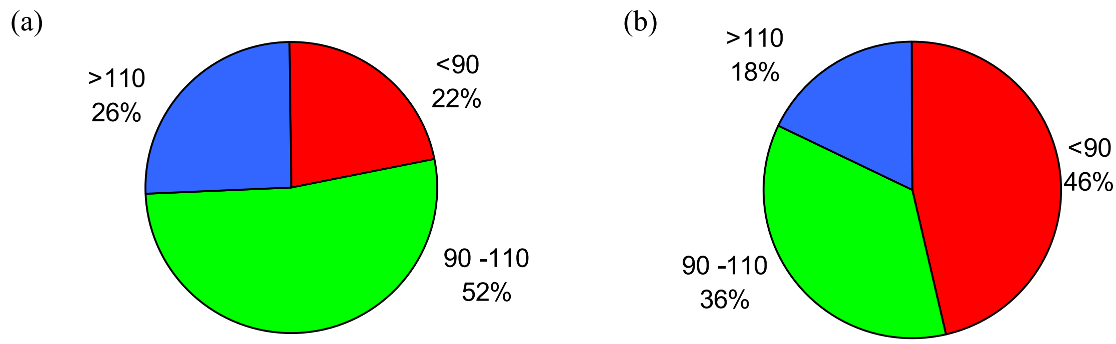


Figure 3: (a) Designed and (b) managed system capacities expressed as a percentage of the average regional peak evaporation rates (in January)

Some growers with inadequate system capacities using machines fitted with overcrop sprinklers reported difficulties in managing pesticide spraying and irrigation, particularly during the peak demand period. In these cases, growers needed to allow the crop canopy to dry for half a day and then not irrigate the crop for a day to allow the pesticide to be effective, resulting in a further decrease in the volume of irrigation water able to be applied. No relationship was found between the ability of the managed capacity to meet the peak evaporation demand and the yield per unit area achieved (Figure 4). However, systems with a low managed capacity were found to produce slightly higher crop water use efficiencies (bales/ML_{irrig}) due to either the supplementary nature of the irrigation applied or the deliberate application of a regulated deficit irrigation strategy. Regulated deficit irrigation strategies involve actively managing crop stress to reduce vegetative growth and improve the CWUE (bales/ML). This is typically achieved by maintaining a continual soil-water deficit during the growing period to hold the crop growth at between 4.5 & 5.0 nodes above white flower.

Experienced LMIM cotton growers indicated that they could achieve high crop water use efficiencies with machines that had low managed capacities by utilising either soil water banking or regulated deficit irrigation strategies. However, a greater level of crop management was required in these cases. One grower stated that his return on investment for LMIMs was better for low system capacity machines when used in conjunction with regulated deficit irrigation strategies. In this case, the grower indicated that reducing his capacity by 25% allowed him to irrigate a significantly greater crop area and total yield with the same volume of water, albeit at a slightly higher risk. However, when growers were asked about whether they were managing the system using a regulated deficit irrigation strategy, only 10% either understood or were actively implementing this strategy.

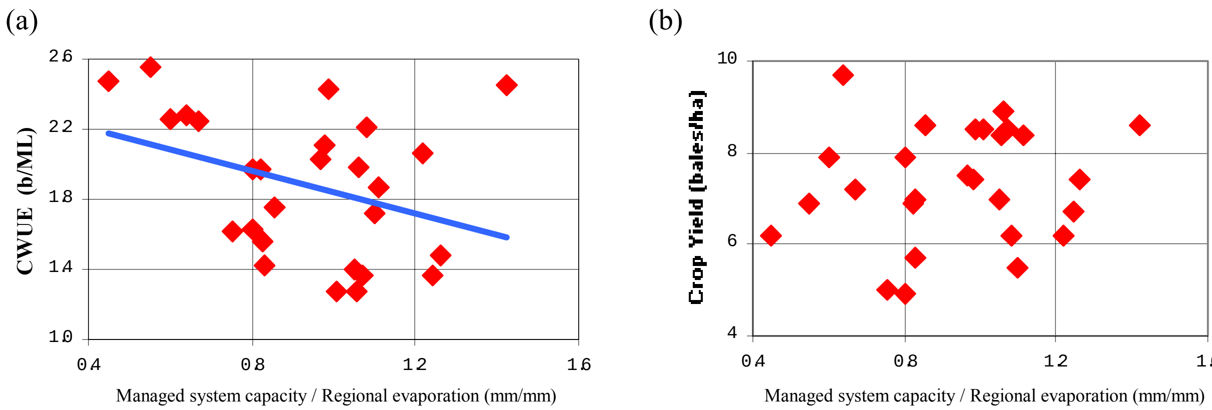


Figure 4: Relationship between managed system capacity and (a) crop water use efficiency and (b) yield per unit area

Farming in Circles

Approximately 50% of the growers who irrigate with centre pivot machines were planting and cultivating in circles to match the alignment of their centre pivot wheel tracks. These growers often explained that the transition from "square" farming wasn't easy but that they now prefer this layout. The remaining half of the centre pivot growers preferred the simplicity of farming "up and back on the flat" as they believed it resulted in less complication for all farming operations. Age of the machine and choice of emitter appeared to be a factor with newer machines more commonly fitted with LEPA emitters and farmed in a circle. Many growers either use very low beds or no beds at all when farming straight through the circle. Where beds or furrows were used by growers cultivating "up and back on the square" under centre pivots, some problems with premature gearbox failure were reported. This was a particular concern with "flimsier" towable gearboxes fitted to some brands of machines as these gearboxes were not designed to continuously cross hills. In these cases, growers indicated that beds should be aligned with the direction of travel.

Operating Pressures and Running Costs

Nearly 60% of growers operate machines that have a supply point or centre pressure in excess of 30 psi. A major desire with experienced growers was to change to lower operating pressures at the same flowrate as they had observed that the higher system pressures were adding unnecessarily high costs to operating the LMIM. Excessive operating pressures at the supply point or centre cause higher running costs. LMIMs using low-pressure sprinklers at 10 psi, should have centre pressures no greater than 22 psi. Centre fed channel supply lateral moves are commonly now supplied with pump pressures at or below 28 psi. When correctly designed, these machines should cost around $10/ML in diesel costs for pumping and machine movement. A LMIM operating at 50 psi will cost ~$10/ML extra to run than a machine operating at 25 psi. For an irrigated area of 250 ha and a total of 4.5 ML/ha pumped, this excess pressure will cost an additional $11,250 per crop.

Water Quality and Pipe Corrosion

Pipe corrosion was a concern for 25% of LMIM growers. In particular, water quality issues in central Queensland and the Border Rivers region of northern NSW have caused a number of failures where the main pipes have been corroded and now contain pin-holes. In these cases, the water quality (particularly pH) was very poor with one grower installing a sacrificial anode to provide 10-year machine life. A small number of growers blamed poor assembly by the dealer for corrosion. In these cases, incorrectly sized and/or fitted rubber gaskets were used to seal the main pipes in the span, with the inner gasket diameter being much smaller than the pipe size resulting in water being trapped within the pipe. Ensuring that water does not remain in the pipes at any stage will minimise corrosion where water quality is poor. Many growers have installed span drains with extended hoses to remove drainage water from the wheel tower area. A number of growers using surface water sources indicated that coarse filtration was necessary to stop nozzle blockage. Growers operating channel supplied lateral move machines indicated that it was essential to use suction filters to minimise the uptake of grass, sticks and cotton trash. A popular type of suction filter reported by growers being used in open channels are self-cleaning rotary screens where clean water jets or brushes are used to remove trash from the moving rotary screens.

Wheel Rutting and Bogging

More than three-quarters (79%) of LMIM growers reported experiencing some wheel rutting problems with most indicating that it was only a problem in the first few years of operation due to inexperience and poor machine design. This was because most of the machines were supplied without appropriate options to address wheel rutting and very little information had previously been provided regarding management practices to address these issues. However, the majority of growers indicated that wheel rutting and bogging was no longer a major problem in their irrigation management. A wide range of machine modifications or management practices are currently being used by growers to successfully reduce the incidence of wheel rutting and bogging (Figure 5). While no one method dominated the solutions used, the techniques most commonly used included 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 were firm. Other options include using "rut fillers" where the tower drags opposing discs, provide raised and graded road or the use of polyacrylamides sprayed onto the wheel tracks.

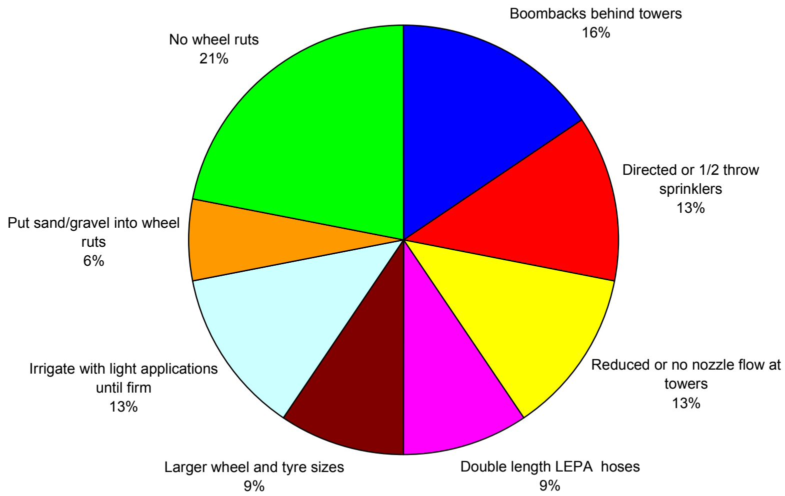


Figure 5: Options used by growers to reduce wheel ruts and tower bogging

There appears to be an inaccurate perception amongst the broader cotton industry that LMIMs do not reliably irrigate on heavy cotton soils due to wheel rutting and bogging. However, this perception is based on the experiences of growers over a quarter of a century ago. The machines initially used in the 1970s were equipped with top-of-pipe impact sprinklers, on towers with small tyre sizes and towable gearboxes, in cropping situations where the pivot had to be moved long distances between separate circles/pads for each irrigation. Growers that were involved at the time are now saying that they had a relatively poor understanding of the water depths applied by the pivot during each irrigation and the overall crop water use requirement. The top-of-pipe sprinklers provided little control over where water was applied and wheel-ruts were quick to develop. A large number of the towable gearboxes failed, and the replacement downtime was added to by the time taken to shift these units from one circle to the next for each irrigation period. However, the introduction of low-pressure spray and LEPA systems along with the various design and management options to prevent wheel rutting mean that these issues generally represent minor concerns in current cotton production systems.

Field Drainage

A significant number of growers (83%) installed machines onto new country without levelling or drainage. This represents a significant cost saving over traditional furrow irrigation systems. Levelling of fields in conjunction with the installation of the LMIMs was undertaken by 10% of growers while the remaining 7% of growers had installed LMIMs on fields that had previously been levelled for furrow irrigation. However, some growers who had not previously levelled indicated that in future they would cut to drain, especially in low spots of fields. Many LMIM growers indicated that they preferred to think of themselves "as dryland growers, who can apply water when they want". They also indicated that because they did not have to run the paddocks at a saturated level at any time, there was a reduced requirement for levelling and drainage infrastructure.

AGRONOMIC ISSUES

Crop Germination

One of the greatest benefits of LMIMs acknowledged by cotton growers is the ability of LMIMs to provide high rates of even germination. The benefit of being able to complement any rainfall to ensure that the best possible germination is achieved was also perceived as a benefit. While most growers (87%) used the LMIM for germination, a small proportion of growers (13%) relied solely on rainfall primarily because of water availability limitations. All growers surveyed reported using some form of sprinkler plate over the germination period with almost half of the growers then changing the emitter to either LEPA socks or bubblers after crop establishment. However, the practice of pre-watering and post-watering depended on soil characteristics. Where the soil had a reasonable tilth and the water could be applied gently and uniformly to the planted seed zone, growers indicated that they applied water only after the crop had been planted to reduce the amount of water moving past the root-zone. These growers reported significant water savings by reducing the amount of water applied prior to crop planting and the volume of water applied during establishment. However, growers on heavy clay soils typically applied comparatively large applications prior to planting to "wet everything up". This approach is derived from the practice in furrow irrigation systems of applying large amounts of water prior to the crop being planted. In this case, the surface is allowed to dry and planting occurs into the moist soil. Some growers on hardsetting soils indicated that they were unable to water directly after planting as a crust would form, limiting the ability of the plant to emerge. However, one option employed by other growers with these hardsetting soils was to operate their LMIM at higher speeds to apply light applications at more frequent intervals in an attempt to maintain surface moisture and reduce crust development.

Scheduling

Appropriate scheduling is important as it is closely related to crop yield potentials. Excessive watering may lead to rank growth while inadequate watering may lead to excessive moisture stress. The majority of the LMIMs currently operating within the cotton industry have a limited potential to meet their peak crop water requirements. This creates a risk of easily falling behind and introducing crop stress if the system is not well managed. For systems with adequate capacity, there is also a potential for growers to create ideal growing conditions resulting in rank growth. While traditional approaches to scheduling irrigations on cotton in Australia are focused on minimising crop stress, the crop water use efficiency (b/ML_{irrig}) results presented above suggest that there may be significant benefits associated with growing cotton using a regulated deficit irrigation strategy. This is similar to the approach currently used by growers who only have sufficient water for supplementary irrigations, where the crop is always a little dry, but not excessively stressed. It is also similar to the scheduling focus currently being widely adopted in the USA and Israel. Cotton's potential to maintain yield under continuing light application of water stress, gives it high water use efficiency potential. However, managing the crop to ensure that excessive stress is not applied requires extra plant growth monitoring and a detailed understanding of the crop physiology. Approximately two-thirds (66%) of growers reported using an objective measure of irrigation scheduling with a wide variety of techniques being used. The most popular methods were neutron probes followed by a combination of evaporation data and other methods. Several growers reported concerns on the usefulness of soil moisture measurements in undulating country as soil characteristics and hence, moisture content varied widely throughout the irrigated area. One grower indicated that he used a capacitance probe with a telemetry rain gauge but with experience has determined the need to always do a visual inspection of key areas before deciding when to irrigate. The ability to apply smaller volumes of water in a single irrigation and hence, make better use of in crop rainfall was also cited as a major benefit of these machines.

The average volume of water applied in each irrigation is 26.3 mm (range 7-65 mm). While one-third of growers typically apply less than 15 mm in a single pass, 13% of growers are applying more than 45 mm in each pass (Figure 6). Hence, it is evident that some agronomists in the industry are caught in the surface irrigation paradigm and end up advising growers to apply more water than is required. The lack of irrigation induced waterlogging often associated with traditional surface irrigation practices means that crops under

LMIMs aren't held back as much as surface irrigated crops. This is believed to be the main reason for approximately 20% of LMIM growers experiencing excessive rank growth. Irrigation schedules and application volumes can and should be modified to maintain a desired level of crop stress. The use of more determinant cotton varieties under LMIMs may also aid in the control of rank and excessive growth where water and Pix control is lacking. However, where the crop has been encouraged to grow without either moisture or waterlogging stress, growers have reported the ability to finish crops earlier with significant reductions in the amount of chemical used during the season. Only one grower indicated he actively managed his LMIM using a deficit irrigation strategy throughout the growing season in an attempt to improve crop water use efficiency and reduce excessive crop growth. Three LMIM growers indicated that the cheapness and ready availability of advice with regard to growth regulators meant that they preferred not to worry about regulating crop growth by moisture stress.

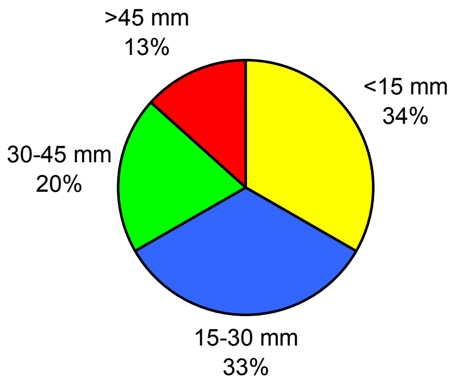


Figure 6: Depth of water typically applied to cotton crops in a single pass by LMIMs

Fertiliser Usage and Chemigation

Forty-five percent (45%) of growers had applied fertiliser through their LMIM with 38% reporting a decrease in the total fertiliser applied to the crop compared with applications for traditional surface irrigated fields. More than two-thirds of LMIM growers (69%) indicated that they had decreased their pre-season fertiliser application. No grower reported increased fertiliser use when compared to traditional surface irrigation. Several growers also indicated that LMIMs provided an increased ability to time the application of fertiliser, improving both the management of labour, machinery and water as well as the efficiency of fertiliser uptake. No grower expressed concerns regarding the potential for accelerated corrosion due to fertigation through the galvanised pipes. However, where fertigation is practiced, it is important to ensure that the fertiliser is adequately flushed and drained from the system. Chemigation through LMIMs was routinely conducted by 14% of growers. These growers reported success using 'Gemstar' with one grower also using 'Dipel'. One grower indicated that the only chemicals used in producing a 7 b/ha crop were 'Gemstar' applied through the machine and 'Tracer' applied normally. Significant improvements in the efficacy of 'Gemstar' were reported when cotton was regularly chemigated at rates as low as 5% of label rate with 10 mm of irrigation water. While 79% of growers were not currently using chemigation, 14% were actively considering implementing this practice in the near future. Almost one-third of growers (31%) indicated that the use of LMIMs changed their insect management strategies. In particular, one grower suggested that the overcrop spray assisted in washing eggs off the cotton plants early in the season. However, there were also concerns regarding the potential for overcrop sprays to wash chemicals off mature plants late in the season. This was not a concern for LEPA users who were not wetting the crop canopy during irrigation. Manufacturers and dealers indicated that increasing numbers of growers were setting up their LMIMs with the capacity to chemigate through separate spray systems that are hung underneath the main trusses of the system. In these cases, growers are specifying high-speed electric motors and gearboxes with large diameter tyres so that they can obtain high machine speeds and an ability to apply the chemicals quickly with their LMIM over the entire field.

ECONOMICS OF LARGE MOBILE IRRIGATION MACHINES

The economic evaluation of irrigation application systems should encompass the capital, labour, pumping, maintenance and other operating costs. Growers reported that significantly less labour was required to operate and maintain LMIMs compared to traditional surface irrigation. Figures reported from the USA indicate that the labour required for surface irrigation is six-ten times greater than that required for LMIMs (Burt *et al.*, 1995). Growers reported that lateral moves required 50-80% more labour than centre pivots to manage. Diesel pumping costs for well designed machines should be in the order of $10-20/ML. The capital cost of LMIMs used in the Australian cotton industry ranged from $1250/ha to $2500/ha. The cost per unit area of the machines was not related to the crop water use efficiency (b/ML) achieved and only marginally related to the yields per unit area achieved. There was also a poor relationship between the machine cost per unit area and the system capacity of the machines. This suggests that (a) more expensive machines do not necessarily provide greater system capacities and (b) crop water use efficiency and yields are more strongly influenced by management strategy and water availability than by the system price.

CONCLUSIONS AND FUTURE WORK

Large mobile irrigation machines are currently being used by cotton growers across the full range of soil and climatic conditions experienced by the Australian industry. All of the growers surveyed reported an increase in crop water use efficiency when compared to traditional surface irrigation. Growers in this study reported an average 72% increase in crop water use efficiency (bales/ML_{irrig}), an average reduction in water applied (ML/ha) of 44% and an average decrease in yield per unit area (bales/ha) of 6.4% using centre pivot and lateral move machines compared to traditional furrow irrigation methods. These results are consistent with those reported in an earlier study on subsurface drip irrigation in the cotton industry (Raine *et al.*, 2000) and suggest that there is a potential to improve the industry's crop water use efficiency and production. However, the potential increases in crop water use efficiency that have been highlighted by these studies reflect less on the technology associated with the pressurised systems and more on the approach of the individual cotton growers to crop and water management. Hence, a high priority should be placed on undertaking work to identify, and encourage adoption of, optimisation of existing surface irrigation systems and irrigation strategies that maximise crop water use efficiency. An assessment of the range of physical and economic conditions under which cotton crop growth can be better managed via irrigation should also be undertaken. This study raised a range of issues associated with irrigation using LMIMs, which should be considered for further investigation or promotion within the industry:

- There needs to be better dissemination to agronomists and growers of previous work conducted on crop growth management and waterlogging, particularly with respect to water use efficiency. In particular, there is a need for better information on the control of plant growth and frugal use of water resources using regulated deficit irrigation strategies to improve crop water use efficiencies (b/ML_{irrig}) and increase returns on investment.
- There is a need for the development of materials and dissemination of information to assist growers to understand the implications of LMIM design and managed system capacities on crop production and risk. This material should include information on peak regional evaporative rates and peak crop water use requirements in each of the cotton growing regions.
- The benefits and limitations of LEPA emitters should be explored and promoted as appropriate. Research needs to be conducted on the benefits of furrow dykes under Australian soils and conditions including the optimisation of dyke lengths and volumetric capacity. Work also needs to be undertaken to identify if the use of LEPA with furrow dykes raises the risk of deep drainage due to the localised ponding of the water application.
- Further training of agronomists and growers in the industry is required, particularly in relation to plant-water relationships and the differences in crop management requirements under the various irrigation systems.
- There is a need to identify strategies for the use of centre pivot and lateral move machines to reduce water applied in pre-season and germination irrigations.
- Only limited information on fertigation and chemigation options for LMIMs is currently available. Some limited work may need to be conducted to assess the effectiveness of the various application systems and chemical options. However, growers indicated that the development of information sheets on fertigation and chemigation (particularly pesticide) options would be beneficial.
- Information on the existing solutions to the problems of wheel rutting and bogging need to be better extended across LMIM growers and prospective purchasers of this equipment.
- The skill level necessary for the successful management of LMIMs should be fostered and enhanced through appropriate training of personnel.

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