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Centre Pivot and Lateral Move Machines in the Australian Cotton Industry

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Executive Summary

This document reports the findings from a survey of cotton growers irrigating with centre pivot or lateral move machines as well as equipment manufacturers and dealers of these machines. The survey included 25 face-to-face interviews and 6 telephone interviews with growers as well as interviews with the major manufacturers and dealers within the industry. The main findings were:

- Over 5300 ha of cotton is currently irrigated using centre pivot or lateral move machines.
- There are approximately 36 growers using about 75 machines across the full range of climatic, soils and water conditions experienced within the industry. Approximately 65% of the growers own two or more machines.
- All growers reported an improvement in the crop water use efficiency using centre pivots and lateral moves when compared to their own traditional surface irrigation systems. The average improvement in CWUE using centre pivots and lateral moves (average = 1.9 b/ML_{irrig}) was 0.8 bales/ML_{irrig} when compared to the grower's own traditional non-optimised surface irrigation (average = 1.1 b/ML_{irrig}).
- All growers surveyed applied less water per unit area with their machines than they applied using surface irrigation systems. 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 had limited water availability.
- Almost half (46%) of the machines operating in the industry had a managed system capacity that was less than 90% of the peak evaporative rate. Approximately 27% of the machines had a managed system capacity that was less than 70% of the peak crop water use requirement.
- Growers with plenty of available water and an adequate system capacity 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. The average yield for centre pivots and lateral moves when reported per unit area was slightly lower (0.5 b/ha or 6.4%) than traditional surface systems.
- 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.
- The vast majority of growers (93%) using centre pivot or lateral move machines installed the machine to grow crops other than cotton. Approximately 27% of growers have grown less than two crops of cotton.
- The performance of centre pivot and lateral move machines within the cotton industry is not limited by soil type or regional characteristics. Systems will work effectively on a wide range of soil types across the full spectrum of industry climatic conditions.
- The centre pivot and lateral move machines available for the cotton industry are generally appropriate and effective if designed and managed appropriately.
- The average size of the centre pivot machines in the industry is 70 ha/machine while the average size of the lateral move machines is 165 ha/machine.
- Growers reported the average capital cost of centre pivot machines as $2000/ha and lateral move machines as $1800/ha.
- Growers who use both centre pivot and lateral move machines suggest that the labour and management requirement could be as much as 80% higher for lateral moves compared to centre pivots.
- The key drivers for the adoption of centre pivot and lateral move machines were potential water savings, labour savings, yield improvements due to reduced waterlogging and better irrigation management, and improvements in germination.
- Barriers to the broader adoption of these machines within the industry include: the perception by growers using furrow techniques that these machines are not capable of supplying the volumetric capacities required to irrigate cotton, the lack of experience in the fulltime cotton growing sector regarding both water and crop management under centre pivot and lateral move machines, and the lack of dealer, supplier and extension support regarding the appropriate management of these machines for cotton production.

Key recommendations arising from the surveys include:

- There is a need for industry development and promotion of standards and guidelines on best management practices for the design and management of centre pivot and lateral move machines. In particular, better promotion of existing information on the following is required:
  - calculating appropriate system capacity requirements;
  - strategies to reduce wheel rutting and bogging;
  - management of rank crop growth; and
  - fertiliser and chemical application strategies.
- An effort is required to develop appropriate training and certification processes for users of centre pivot and lateral move machines in cotton.
- There is also a need to continue and/or expand research and development in the cotton industry on the following areas:
  - Better define system capacity requirements for growers under both full and deficit irrigation scheduling strategies using these machines.
  - Refine existing guidelines for managing the soil, crop and machine interactions under regional conditions.
  - Identify strategies for the use of centre pivot and lateral move machines to reduce water applied in pre-season and germination irrigations.
  - Quantify the benefits of installing furrow dykes and alternative LEPA technologies under the full range of industry soil and climatic conditions.

1. 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.

Surface irrigation of agricultural crops has been practiced for thousands of years. However, irrigation using pressurised systems has only been around since the early 1900s and the very first centre pivot machine was developed only in the late 1940s. By the mid-1970s, centre pivot and lateral move machines were rapidly starting to dominate the new and expanding irrigation areas in the USA and the Middle East. Centre pivots were first introduced into Australia in the 1960s with the main interest occurring in South Australia and Victoria. However, centre pivot irrigation of cotton has been undertaken in the USA since the late 1960's and in Australia since the early 1970s.

The early centre pivot and lateral move machines used in the Australian cotton industry suffered from a number of problems. The machines often suffered from inadequate capacity due to a combination of economic factors and a lack of understanding regarding the peak crop water use requirements. They were operated at high pressure, using overhead knocker sprinklers, which led to high operating costs and evaporative losses. The machines also often suffered from poor hydraulic design and excessive instantaneous water application rates leading to problems with water run-off and machine bogging. Deficiencies in grower understanding of the management practices required to use these machines also affected performance.

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. Despite the problems with the early machines and the lack of detailed local research into the design and management of these machines, the potential benefits of centre pivot and lateral move machines is increasingly being recognised within the cotton sector. The potential water use efficiency improvement, opportunities for increased flexibility and reduced labour costs, when compared to traditional surface irrigation systems, has increased recent interest in these machines. The comparatively lower system cost and typically longer life expectancy also make these machines an attractive alternative to drip irrigation. However, centre pivot and lateral move machines should not be considered as a panacea for the irrigated cotton sector.

This scoping study was commissioned by the Cotton Research and Development Corporation in an effort to better understand the existing centre pivot and lateral move irrigated sector within the industry and to identify future opportunities for research and development within this sector. This study represents the first such investigation into the use of large mobile irrigation machines in this country. The specific objectives of the study were to identify the:

- extent of current usage of large mobile irrigation machines within the Australian cotton industry;
- perceived benefits and limitations associated with the use of large mobile irrigation machines; and
- the operating constraints and situations where large mobile irrigation machines may be beneficial.

The main focus of the study was a face-to-face survey of more than 80% of the growers currently using large mobile irrigation machines within the cotton industry, as well as the major suppliers and manufacturers of these machines. Machines that were no longer working were not visited but efforts were made to obtain information on why the machines and systems failed and the lessons to be learnt from these experiences.

This report starts with a generic introduction to large mobile irrigation machines including an overview of the equipment components and performance evaluation methodologies. The main body of the report provides details of the grower and manufacturer surveys including feedback on the current operating constraints. This section is followed by grower and manufacturer identified research and development opportunities for large mobile irrigation machines in the cotton industry.

2. Background to Centre Pivot and Lateral Move Machines

Centre pivot and lateral move irrigation machines represent the largest (in both physical size and flow rate) of the mobile machines used by growers to apply water to crops and fields. The first large mobile irrigation machines (LMIMs) were developed in the late 1940s with the patenting of a "self-propelled sprinkling irrigation apparatus" by Frank Zybach in Nebraska. These early machines were manufactured by A.E. Trowbridge. Prior to this time, sprinkler irrigation was commonly performed using steel pipe and impact sprinklers, as aluminium pipe was only just becoming available. These early centre pivot machines consisted of towers that supported the pipework via suspension cable and were powered by the irrigation water pressure using hydrostatic drives at each wheel set. The right to manufacture these machines was acquired in the 1950s by Robert Daugherty who began manufacturing under the "Valley" brand name. The first Australian innovation in this arena saw the Layne and Bowler Company of the USA introduce the Australian Raincat ideas of electric motor drives, today's standard bowstring truss suspension and track drives which were later replaced with rubber tyres. During the 1960s, machines also started to be manufactured with water piston or water spinner drives rather than oil hydraulic drives. The standard machine manufactured prior to 1970 was a high-pressure unit (~80 psi at the centre) fitted with large impact sprinklers located along the top of pipe. However, the energy crisis in the early 1970s resulted in the introduction of low-pressure static plate sprinklers located on droppers below the pipe. These modifications meant that the machines could be operated at much lower pressures (<40 psi) with much lower operating costs.

By the mid-1970s, centre pivot and lateral move machines were rapidly starting to dominate the new and expanding irrigation developments in the USA and the Middle East. Of the 25.6 million hectares currently irrigated in the USA, approximately 32% (or 8.1 million hectares) is irrigated by this equipment. Centre pivots were first introduced into Australia in the 1960s with the main interest occurring in South Australia and Victoria. Centre pivot and lateral move machines currently irrigate 8-10% of the total irrigated area in Australia. Centre pivot irrigation of cotton has been undertaken in the USA since the late 1960s and in Australia since the early 1970s.

The last thirty years have seen the four main large mobile irrigation machine (LMIM) manufacturing companies based in Nebraska (Valley, Lindsay Zimmatic, T&L, and Reinke) dominate the world market for these machines. There are approximately 350 machines sold in Australia each year and there are approximately thirteen manufacturers or distributors of LMIMs currently operating in Australia. However, the majority of the machines available in Australia are manufactured in either the USA or Europe with only a handful being manufactured by Australian companies. In most cases, common components such as electric motors and gearboxes, and control panels are imported, with pipes, framework and other major structures manufactured locally. It should be noted that not all of the manufacturers build lateral move machines. In particular, USA based companies are often not interested in the manufacture of lateral move machines due to the comparatively small market size and the additional level of complexity associated with controlling and guiding these machines, yet they remain the only suppliers of lateral moves.

The expansion of the area irrigated by LMIMs in the USA resulted in a substantial research and development effort focused on the appropriate design and management practices for these machines. Much of this work was conducted by the USDA - Agricultural Research Service and the extension centres located in the State universities. Several reviews of the research work undertaken in the USA on these machines are available (Appendix 1). The most relevant work for Australian cotton growers has been undertaken by Texas A&M University in areas where cotton is grown with limited water supplies using these machines. However, very little research and development work has been conducted on LMIMs under Australian conditions.

2.1 Equipment Overview

Centre pivot systems are usually no longer than 500 metres with the most common size being around 400 metres long. Lateral move machines are not commonly used overseas and when used in other crops are rarely greater than 500 m long. However, the popularity of large machines in the cotton industry has resulted in lateral move machines of up to 1000 m in length being installed locally.

The main components of these large mobile irrigation machines (LMIMs) are the self-supporting frame spans. These structures use the water delivery pipes (located along the backbone of the span) as compression members that are held together by tie-rods acting as tension members. The pipe spans are supported at each end by a tower that incorporates gearboxes, drive wheels and either an electric or hydraulic drive motor. Emitters (either sprinkler heads or low energy precision application fittings) are attached either directly to sockets on the main pipe or suspended closer to the crop on either rigid or flexible droppers.

Flexible mechanical and hydraulic couplings that allow the separate spans to act as individual elements connect individual spans. This ensures flexing, rotating and twisting of the joint and spans so that the machine can traverse over land contours and obstacles. Machine speed governs the volume (depth) of water applied in each pass, while system alignment is maintained via micro-switches, alignment levers and control equipment.

Centre pivots consist of a number of spans attached to a fixed centre tower containing a water supply point and power source around which the other spans and towers rotate (Figure 2.1). Lateral move machines are constructed in a similar manner to centre pivot machines except that they do not have a central, rigid supply point. Lateral move machines have the water supply point located either in the middle or at one end of the machine on a cart-tower assembly containing a mobile power plant. Lateral move machines that are supplied from open channels are provided with a large lift pump while hose supplied systems are fitted with an attachment point for connection to the water main hydrant via a flexible water delivery hose.

Figure 2.1: Centre pivot irrigation machine showing centre tower, spans, and wheel towers

Spans and Pipe Sizes

Spans commonly range in length from 34.2 m (113 ft) to 62.4 m (206 ft) with variations in exact size between different manufacturers. Span lengths are commonly limited due to the weight associated with the pipe itself and the volume of water transported. Internal diameters of the span pipes range from 135 to 247.8 mm with the most common pipe sizes being 162, 197 and 213 mm. Typical pipe wall thickness is about 2.77 mm (0.11") for these systems.

Types of Emitters

There are a wide range of emitter nozzles and application heads currently available for LMIMs. However, the application heads can generally be broadly grouped into either low energy precision application (LEPA) attachments or sprinklers. LEPA systems apply water at low pressure either directly onto the soil surface or below the crop canopy to eliminate sprinkler evaporation from the plant canopy and drastically reduce the wetted soil surface and soil surface evaporation. These systems commonly operate at very low pressures (10-20 psi) and hence, have reduced pumping energy costs. Although LEPA systems have been in existence since the mid 1980s, the adoption of these application heads in Australia has been slow.

LEPA application heads are available as either a drag sock or a combination head known as the "Quadspray" or bubbler (Figure 2.2). Both types of head are commonly suspended from the main pipe by flexible hose at either one or two crop row intervals. Drag socks come in both double and single ended sock options. Double ended socks are used in conjunction with furrow dykes or tied ridge structures to reduce the risk of washing these structures away (Figure 2.3). The "Quadspray" unit has four operating modes that allow water to be either bubbled out in a low-pressure circular sheet, sprayed horizontally (germination mode), sprayed vertically upward (chemigation mode) or dribbled out directly from the bottom (Figure 2.4). Changeover from one operational mode to another only involves a click and twist rotation.

Drag socks are replaced with static plate sprinklers for crop germination and are positioned well above the soil surface to ensure good sprinkler overlap. When using the static plate sprinklers for germination, LEPA head hose lengths need to be either reduced or slung over the pipe to gain the height typically needed for the sprinkler throw. Hence, where any LEPA system is employed, there is both a time and labour requirement after crop establishment to allow changeover from the static plate sprinklers to the LEPA heads.

(a) Drag sock (b) Quadspray in bubbler mode

Figure 2.2: Emitter options for low energy precision application

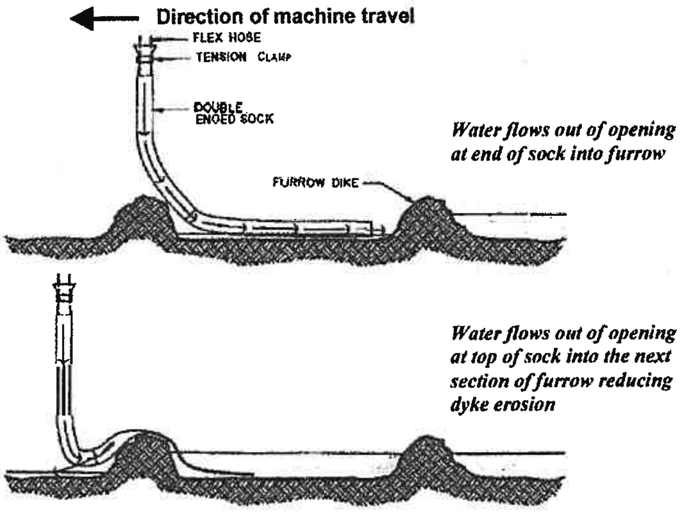


Figure 2.3: Operation of a double ended LEPA drag sock in conjunction with furrow dykes (New and Fipps, 1990)

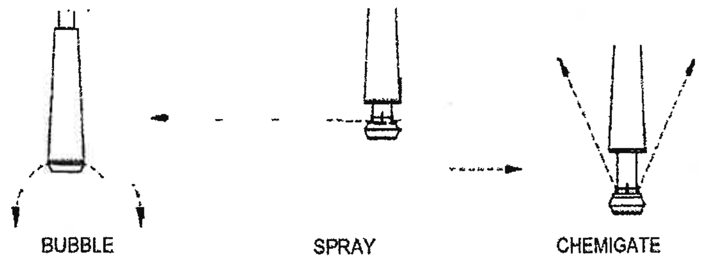


Figure 2.4: Operational modes for Quadspray LEPA heads (New and Fipps, 1990)

Sprinklers are widely used on LMIM machines and are typically offered as standard fittings. While overhead and top-of-pipe sprinklers were common on older machines, newer machines are typically configured with overcrop sprinklers which hang down from the pipe (Figure 2.5). These overcrop sprinkler heads are available as either static or moving plate sprinkler heads. Static plate heads do not have any moving parts but use a range of groove configurations upon a plate to produce the streamlets. Various static plates configurations are available to alter the number of streamlets and the angle of streamlet throw. Moving plate sprinkler heads represent the newer generation of heads that have been steadily increasing the number of streamlets while maximising throw distances.

The different types of moving plate devices available include spinners (low operating pressure but fast rotation), rotators (higher operating pressure but slower rotation) and wobblers (medium to low pressure with multi-path streamlets). All of these heads are typically suspended on rigid dropper pipes that hold the sprinkler head at spacings of 2.4-3.0 m (8-10 ft), and at a height just above the full crop height. While this form of sprinkler head and configuration is the most simple to design and use, it does suffer from the evaporative losses (particularly during peak evaporation periods) associated with soil and plant surface evaporation and these losses must be taken into account when designing the system capacity.

It is generally accepted that the replacement of older sprinkler technologies (both top-of-pipe and static head overcrop sprinklers) on existing LMIMs is a relatively simple and cost effective way of improving system performance. In general, the larger the number of streamlets produced by the emitter the smaller the droplet size and the lower the drop impact energy applied to the soil surface.

However, the lower the sprinkler head pressure, the larger the droplet size. Modern low-pressure sprinklers impart roughly 60% of the energy of old top-of-pipe high-pressure impact sprinklers (Kincaid, 1996). Hence, low pressures and large numbers of streamlets typically provide the best result in terms of reducing the instantaneous application rate, reducing the impact energy imparted to the soil and increasing the throw distance. These benefits typically minimise surface crusting and reduce run-off.

Each emitter (either sprinkler or LEPA attachment) on a centre pivot is positioned at a greater radial distance from the centre and must provide water for an increasingly sized concentric ring of field area. This is achieved by either increasing the nozzle size and maintaining the nozzle spacing or alternatively, maintaining the same nozzle size and decreasing the emitter spacing as the radius increases. Sprinkler spacing is not altered along the length of lateral move machines, with little if any increase in nozzle size.

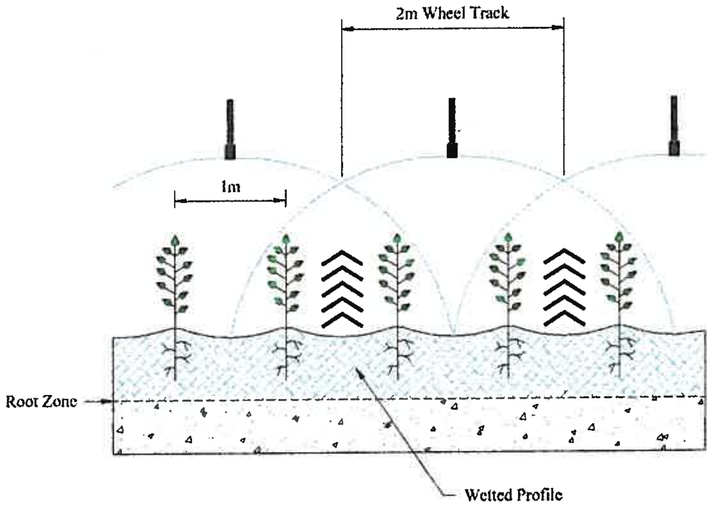


Figure 2.5: Overcrop sprinkler irrigation

Boombacks

Boombacks are used to suspend the emitters at a distance of 3-6m behind the machine towers (Figure 2.6). These optional fittings are used to improve the uniformity of sprinkler application to the crop near the towers and to reduce the potential for irrigation water intercepted by the tower (Figure 2.7) causing either rutting or bogging. Where the machine is required to move in both directions, boombacks can be fitted to both sides of the tower with the appropriate set of emitters selected using either manual or automated valves. Alternatively, a single boomback mounted on a hinged fitting can be used and swung either side of the towers depending on the direction of travel.

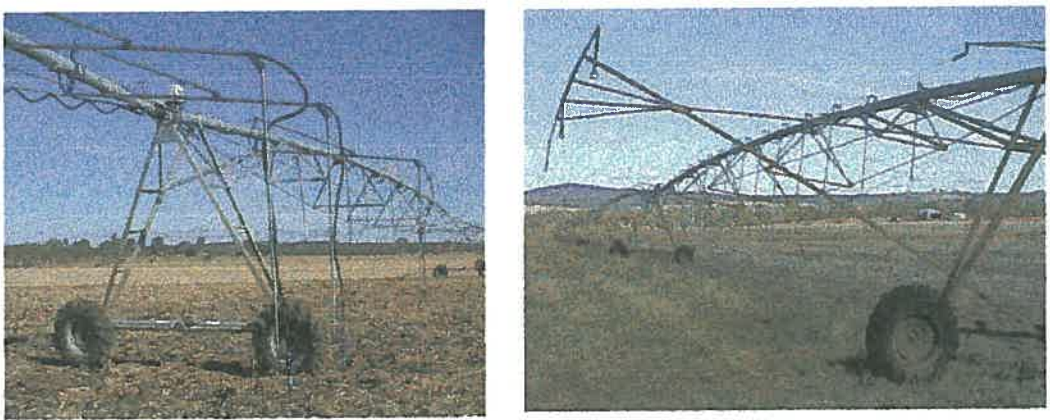


Figure 2.6: Fixed and swivel mounted boombacks for LMIMs

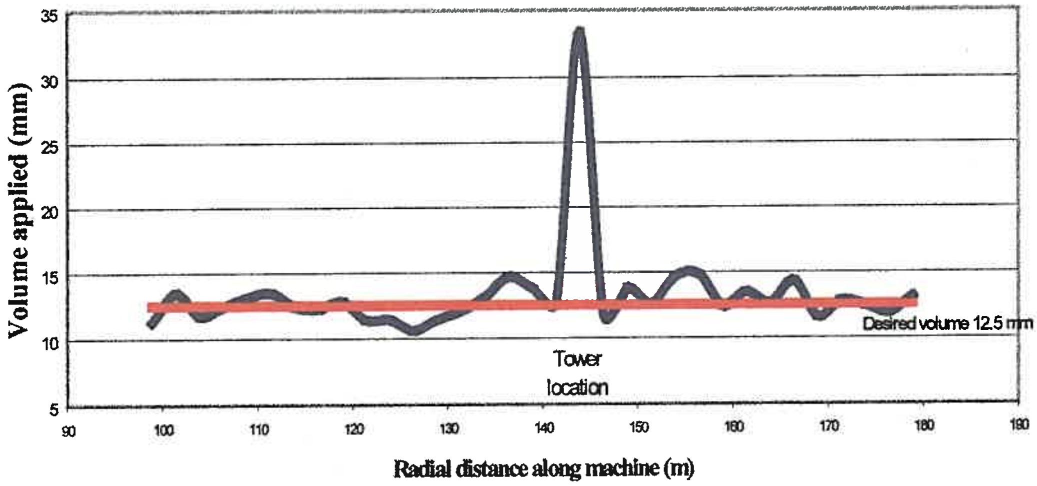


Figure 2.7: Field test results showing three times the normal amount of water being applied around the tower through interception of sprinkler water by tower structure (Foley, 2000)

Tyres and wheel sizes

LMIMs represent a considerable investment in tyres and wheels. Hence, growers should also ensure that they have the necessary equipment to re-inflate, replace or otherwise repair tyres on the machine. This typically involves having spare tyres, along with lightweight jacks and blocks. Larger tyre sizes are sold as options to reduce wheel rut formation. Common tyre sizes for centre pivot and lateral move machines include 14.9"x24", 16.9"x24", 16.9"x28" and 11.2"x38". However, these sizes result in ground pressures for a wet 48 m span (weight ~ 3750 kg) with a 100 mm deep wheel rut of 12.9, 11.4, 10.8 and 14.6 psi, respectively. Hence, while there are some differences in ground pressure associated with changes in tyre size, larger tyres do not generally reduce rutting as much as boom-backs which reduce the wetting of the wheel-track area. Larger wheel and tyre sizes also increase loading upon gearboxes and drive trains. Tyre wheel combinations can also be purchased in sizes up to 18.4"x28", 16.9"x34" and 16.9"x38". However, manufacturers do not normally like to supply these larger sizes because of the higher drive train loads involved.

High-speed ratios are also sometimes sold as solutions to wheel rutting problems. However, high-speed drive-train combinations may produce start-up torques that are greater than the design specification for the machine leading to increased occurrences of motor burnout. Gearbox failures are also often the result of overloading the machine drive-train. Larger width tyres may result in tyre centrelines that overhang from the gearbox attachment points thus increasing the risk of failure. Where larger and wider tyres are used, the power loom size and hydraulic lines should be increased in capacity to cope with the greater power requirements.

Automation

Control panels vary in complexity depending on requirements. Where necessary, all functions can be manually controlled. Features that are commonly available include machine remote control using either computers or mobile phones with voice feedback and programs to apply varying amounts of water over different periods. It is possible to program the machines to stop where required or vary the application across the field. For lateral move machines, it is possible to progressively apply lighter amounts of water and then to reverse direction at the end of the field applying increasingly larger amounts of water. Pressure switches are commonly incorporated to stop pumps when pipes burst (i.e. on low pressure) or to start the machine moving when water pressure builds up. Hydraulically driven machines often employ electric over hydraulic controls to perform the more complex tasks of automation. Automation is essential to take full advantage of the LMIMs capacities. While automation may increase the machine complexity, it can substantially reduce the time involved in management and provides the level of control required to maximise the return on investment.

Chemigation

Chemigation using LMIMs can be conducted in two distinct ways. Chemical can be injected into the irrigation water in the main pipe for distribution through the emitters with the water. Products that can be distributed in the irrigation include fertilisers, herbicides, insecticides, and fungicides. Alternatively, chemigation can be conducted using a separate system of distribution pipework with spray heads suspended underneath the LMIM truss rods to enable the application of chemical with or without irrigation water.

2.2 Measuring the Performance of Large Mobile Irrigation Machines

The three most important measures of LMIM performance are application rate, uniformity of application and application efficiency. This section explains the importance of each measure and outlines the design and management factors that influence the relevant machine performance variable.

2.2.1 Application rate

Four measures of the application rate are important: the design system capacity, the managed system capacity, the average application rate (AAR) and the instantaneous application rate (IAR). These measures differ primarily in the time scale being considered with the system capacity measures commonly reported as volumes applied per day or week, the average application rate reported as volumes per hour, and instantaneous rates reported as volumes per second. It should be noted that manufacturers and dealers commonly report the design system capacity, which is not the same as the managed system capacity.

Design system capacity

The design system capacity is calculated as the volume of water that the machine could deliver in a day divided by the irrigated area and is normally reported in mm/day. For example, it is not unusual for a machine to have a designed system capacity of 12 mm/day. This does not imply that 12 mm is applied in each irrigation event. Rather, growers would typically apply between 25 and 50 mm per pass to reduce plant and soil surface evaporative losses common with smaller applications. However, a 12 mm/day machine applying 50 mm in a single pass, would mean that the machine requires a little more than 4 days to irrigate the full area. The designed system capacity measure normally assumes that the machine is operating for between 22 and 24 hours every day.

Managed system capacity

The managed system capacity (or effective application rate) is calculated as the volume of water actually applied during an irrigation cycle divided by the irrigated area and hence, is most often measured over a period of days and reported in units of mm/day. The volume applied during the cycle is calculated using the pump flow rate, pumping duty and the period of the irrigation cycle. The managed system capacity will normally be less than the designed system capacity as management requirements commonly reduce the period of time that the machine is operating. For example, if a grower only has the machine running for only six out of every seven days, to allow for pesticide spraying or other cultural practices, then a machine with a designed system capacity of 12 mm/day would have a managed system capacity of 12 mm/day x (6 / 7 days) = 10.3 mm/day.

Part-circle, relocatable centre pivots and lateral move machines normally have a reduced managed system capacity compared to full circle centre pivot machines with the same pump capacity. This reduction is due to:

- block and hydrant changes reducing pumping opportunity time;
- non-irrigation during periods of peak water requirement to allow in-field activities; and
- pump flow-rate variation due to variable operating conditions.

Other issues that could affect the managed system capacity include:

- high LMIM ground speeds resulting in more block changes and a reduced pumping opportunity time;
- irrigating an area greater than appropriate for crop, soil, and location; and
- management using soil water banking for suitable crops allows lower managed system capacity.

The design and management issues associated with the system capacity are often not well understood by Australian growers using these machines and account for many of the perceived failures of these machines.

Average application rate

The average application rate (AAR) is the average depth of water applied to the irrigated field during the irrigation. The AAR is calculated by dividing the emitter flow rate (in litres per hour) by the wetted soil surface area (in square metres). The AAR is normally reported in millimetres applied per hour to allow for a direct comparison with soil infiltration rates. AAR is altered when emitter wetted area or flow rate is changed. The wetted area is affected by sprinkler height, wind, and sprinkler impact plate changes. Nozzle pressure, nozzle size and sprinkler spacing affect individual sprinkler flow rates.

The introduction of low-pressure fixed sprinkler plate technology in the 1960s and 1970s resulted in increases in AARs because the area wetted by the sprinklers were smaller than the previously higher pressure sprinklers. However, the more recent development of rotators, wobblers, spinners and other moving plate sprinklers, have resulted in a substantial decrease in AARs due to the larger throw and greater average droplet diameter of these emitters.

For centre pivot machines, the highest AAR is found at the outer end of the machine. AAR will always be greatest at the outer ends of centre pivots equipped with only one type of emitter and nozzle, as individual emitter flow rates increase in response to the larger annular area irrigated. The AAR of lateral move machines will be lower than the AAR at the outer ends of centre pivots. Individual emitter flow rates on a lateral move will be much smaller than an emitter located on the outer end of a centre pivot that has a similar irrigated area and managed system capacity. Considerable research in the USA has been conducted upon the common mismatch of AAR and soil infiltration rates at the outer ends of centre pivot machines. For example, Scherer (1998) showed that sprinklers that throw to a radius of 10 metres, sited on the end of a 400 metre long centre pivot, produce average and peak application rates in the order of 40 and 50 mm/hr, respectively. When these AARs are compared to the 5 mm/hr average infiltration rates common for many clay soils, the resultant excess water must be temporarily stored in surface roughness or runoff is inevitable. This is supported by a range of work which suggests that the AAR associated with low pressure sprinklers on the outer ends of centre pivots will commonly exceed the infiltration rate of all soils except sands (eg. King and Kincaid, 2001; Kincaid *et al.*, 2000). Other options to reduce surface run-off under these conditions include retaining crop stubble, using spreader bars to increase separation between emitters and using long throw spray emitters.

Instantaneous application rate

The instantaneous application rate (IAR) describes the rate at which water is applied by an individual streamlet from an emitter head to a very small area of irrigated field (eg. hundredths of square metre). The time scale under consideration for determination of IAR is in the range of seconds and the IAR is typically 1.3-1.5 times greater than the AAR (Kincaid *et al.*, 2000). High IARs are commonly recorded where streamlets from static plate sprinklers impact upon a small portion of irrigated field during the stop cycle of electrically driven centre pivots. However, there will be zones of high IAR within the wetted area of every sprinkler pattern.

IARs under LMIMs are rarely measured in the field. However, the genesis of larger runoff issues is contained in this small area and time scale. Puddling of the soil surface begins from the impact of the streamlets, and is rapidly followed by soil surface sealing though the rearrangement of the destroyed soil crumbs. Most LMIMs in this country are equipped with rotating, spinning and oscillating plate sprinklers that overcome the high IAR by not having individual streamlets that apply water to any one point. Irrigator concern regarding droplet impact energy (Stillmunkes and James, 1982) creating soil crusting issues during germination has led manufacturers to develop germination specific sprinklers.

2.2.2 Uniformity of application

Uniformity of application refers to how evenly the irrigation water is applied across the field. In fields not watered uniformly, some parts will be irrigated to the desired depth, while other parts will be either under or over irrigated. These non-uniformities lead to yield variation across the irrigated area resulting in differences in economic return for different portions of the field (Solomon, 1988). The factors that contribute to non-uniformity include:

- the emitter spacing, nozzle operating pressure, and emitter configuration;
- nozzle size and selection with location along machine;
- nozzle height, angle and wear;
- machine movement including step size and its consistency;
- flow rate variations due to discontinuous end-gun operation, and variations in pump duty; and
- runoff from high application rates.

Large nozzle gun sprinklers, which are commonly positioned on the ends of LMIMs, are also often responsible for the poor uniformity performance of application (Molle, 1999). Poor uniformity around wheel towers on LMIMs is also a common problem as growers and distributors often employ inappropriate techniques to reduce wheel bogging, resulting in lower uniformity and application rates in the vicinity of the wheel towers to reduce the probability of wheel bogging.

As LMIMs do not irrigate all parts of the field at any one instant, they must apply the same depth of water along their travel path and machine length to irrigate uniformly. This requires a different evaluation methodology from that employed on static sprinkler systems. Measurements are commonly taken along one or two transects across their travel path. However, this always results in an underestimate of the uniformity as no measure of the variation along the direction of travel is obtained. To adequately determine uniformity across the whole field, monitoring is necessary along the full travel path of the machine.

While standards for testing the spatial uniformity are available (e.g. ISO11595; ASAE S436) there is still some debate over the appropriateness of the methodology employed in these standards. Dependence of uniformity measures upon sampling spacings (for catch-can layouts) has been discussed by Smith and Black (1991). On the basis of sampling theory, they recommended that catch can spacings should be of the order of ¼ of the sprinkler spacing (Smith, 1995). Bremond and Molle (1995) likewise analysed catch-can spacing and determined that assessment errors could be minimized and catch-can spacings maximized when 5 m spacings were used for LMIMs with sprinkler wetted diameters of 20 metres.

Two coefficients (i.e. DU and C_u) are commonly used to express the uniformity of irrigation systems. The Distribution Uniformity (DU) is an empirical index that is calculated as the ratio, expressed as a percentage, of the mean of the lowest one-quarter of applied depths and the mean of all applied depths :

$$DU(\%) = \frac{\overline{x}_{lowquarter}}{\overline{x}} * 100$$

where $\overline{x}_{lowquarter}$ equals the mean of the lowest 25% of individual catch-can depths and $\overline{x}$ equals the mean of all individual catch-can depths. The uniformity of application for solid set impact sprinklers has traditionally been considered acceptable if the calculated DU is greater than 75%. However, Bremond and Molle (1995), Heermann (1991) and Yonts *et al.* (2000b) have suggested that DU should be greater than 90% for LMIMs to be considered to be performing well.

The Uniformity Coefficient (C_u) was first proposed by Christiansen (1942) and is defined as :

$$C_u = 100(1 - \frac{M}{\overline{x}})$$

where M is the mean absolute deviation of the applied water depths x_i (or catch-can depths from sampling grid) and is given by :

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

where $\overline{x}$ is the mean applied depth and n is the number of measurements. For systems that have a considerable variation in uniformity, there will be large variations from the mean and the coefficient will decrease. Solid set sprinkler systems which have a C_u less than 86% would typically be viewed as under-performing while LMIMs would be expected to have a C_u greater than 90% to be considered acceptable.

Heermann and Hein (1968) proposed a measure of application uniformity that should be used specifically for centre pivot machines. In this measure, the applied depths are weighted according to their radial position along the length of the machine, to allow for the different annular area represented by each depth. The modified Heermann and Hein (1968) coefficient of uniformity can be written as:

$$C_u = 100\left[1.0 - \frac{\sum_s S_s |D_s - \overline{D}|}{\sum_s D_s S_s}\right]$$

where D_s is the applied water depth for one collector position, $\overline{D}$ is the average applied water depth for all collectors, and S_s is the distance to equally spaced collectors.

Marek *et al.* (1986) and Bremond and Molle (1995) introduced other areal weighted uniformity coefficients specifically for centre pivot machines. Both of these methods use the square of the differences from the mean, rather than mean deviation as used by Heermann and Hein (1968). These methods emphasise any significant deviations from the mean and are useful in highlighting the poor performance of broken or blocked emitter nozzles. A number of researchers (e.g. Heermann, 1994, Smith, 2000) have also suggested that representing the irrigation variation using a cumulative irrigation depth distribution curve may better describe the performance of an irrigation system than the use of a simple coefficient.

2.2.3 Application efficiency

The *application efficiency* (AE) is a measure of the losses associated with applying water to a field. It is calculated as the ratio, expressed as a percentage, of the volume of irrigation water stored in the root zone divided by the volume of water supplied to the field inlet (IAA, 1998). The loss mechanisms that decrease application efficiency for LMIMs include:

- sprinkler loss of fine water droplets;
- evaporative losses from either the soil surface or plant surfaces;
- run-off from the irrigated field; and
- deep drainage.

As with other forms of irrigation, runoff and deep drainage are most commonly associated with poor management and system operation. However, wind drift and evaporative losses are strongly influenced by emitter selection, nozzle size, operation pressures, emitter location in relation to the crop canopy and weather conditions. A large number for studies have been conducted in the USA (eg. Silva and James, 1988; McLean *et al.*, 2000; Yonts *et al.*, 2000a&b) to quantify evaporative losses under a range of conditions and compare the efficiency of the various emitter options. Older style low angle, high pressure, impact sprinklers located above the pipe have been found to commonly operate with efficiencies of 70-85% (eg. Schneider and Howell, 1999; Harrison and Tyson, 1995). However, low pressure, static plate sprinklers commonly operate at between 80-90% application efficiency while the moving plate sprinklers have application efficiencies up to 95%. LEPA socks and bubbler emitters have been found to have application efficiencies up to 98% where surface run-off is controlled. However, up to 50% runoff has been found (Schneider, 2000) where LEPA systems are operated under adverse conditions without furrow dyking.

Evaporative losses are not well understood by Australian growers using irrigation. Drift and evaporation losses of sprinkler droplets (Figure 2.8) using a typical LMIM sprinkler configuration (nozzle pressure=138 kPa, nozzle diameter=4.7625 mm) are commonly reported as less than 5% and rarely greater than approximately 8%, even under extreme weather conditions (RH% = 10, DB = 43°C, wind speed = 19 km/hr) (eg. Frost and Schwalen, 1960). Similarly, evaporation losses from the crop canopy surfaces may be as small as 1-2% (New and Fipps, 1995; Yonts *et al.*, 2000a) and are commonly reported as less than 8% (Schneider and Howell, 1999). Hence, moving the emitter into or below the crop canopy may not necessarily increase application efficiency dramatically and may result in greater runoff water losses due to the increased IAR associated with the smaller wetted area.

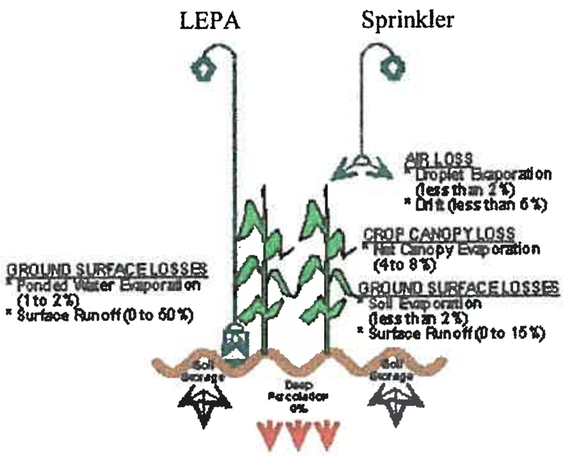


Figure 2.8: Illustration of the water loss pathways for LEPA and sprinkler application methods under LMIMs (from Schneider 1999)

3. Grower and Manufacturer Surveys

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.

3.1 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 (Figure 3.1). 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).

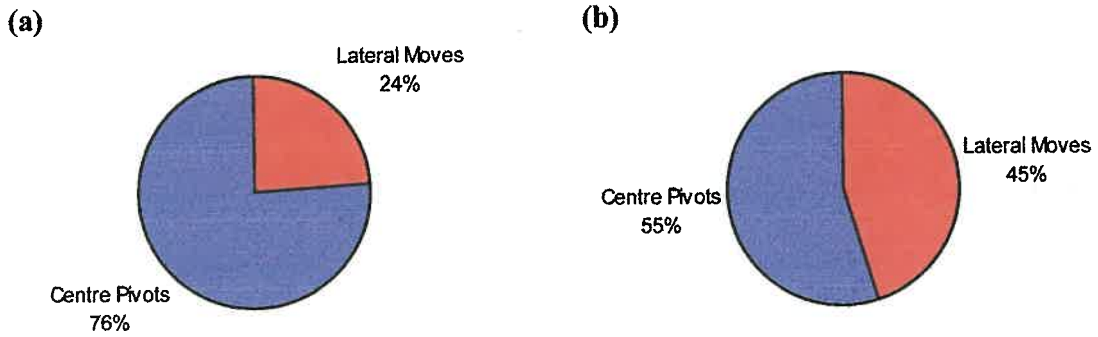


Figure 3.1: Type of large mobile irrigation machine used within the cotton industry by (a) number of machines and (b) area irrigated

Half (50%) of the growers surveyed obtain all of their water from surface supplies (Figure 3.2) 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 (Figure 3.3). Another 27% of the LMIMs are installed on clay loam soils with the remainder located on lighter textured soils.

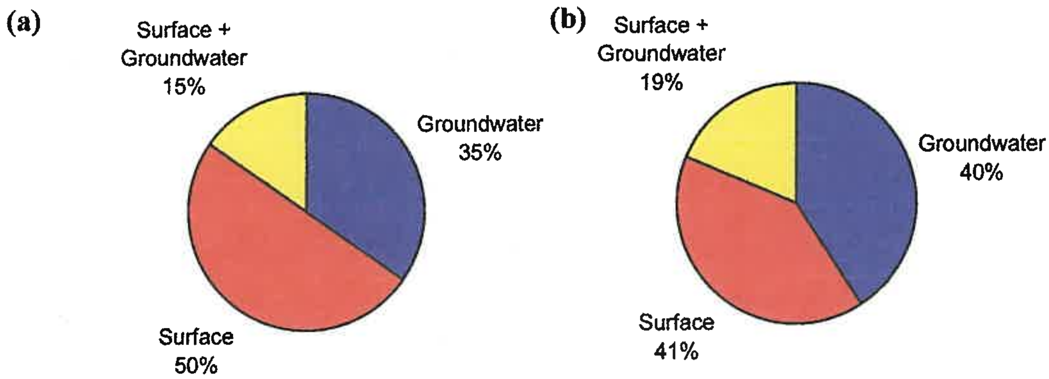


Figure 3.2: Source of water used for LMIMs within the cotton industry by (a) number of machines and (b) area irrigated

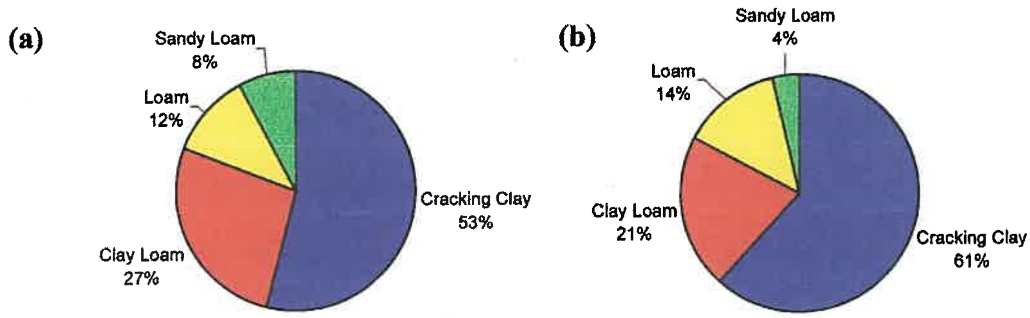


Figure 3.3: Soils irrigated with LMIMs within the cotton industry by (a) number of machines and (b) area irrigated

3.2 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 3.4) with CWUE ranging from 1.35 to 2.6 b/ML_{irrig} (Figure 3.5). 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 (Figure 3.5). 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 <2 crops) 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.

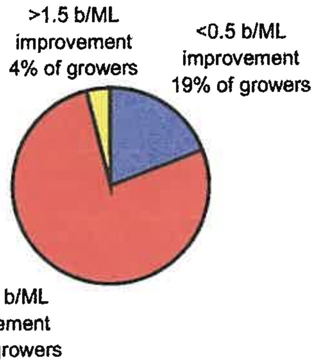


Figure 3.4: Increase in crop water use efficiency (in bales/ML_{irrig}) for cotton irrigated by LMIMs compared to traditional furrow systems

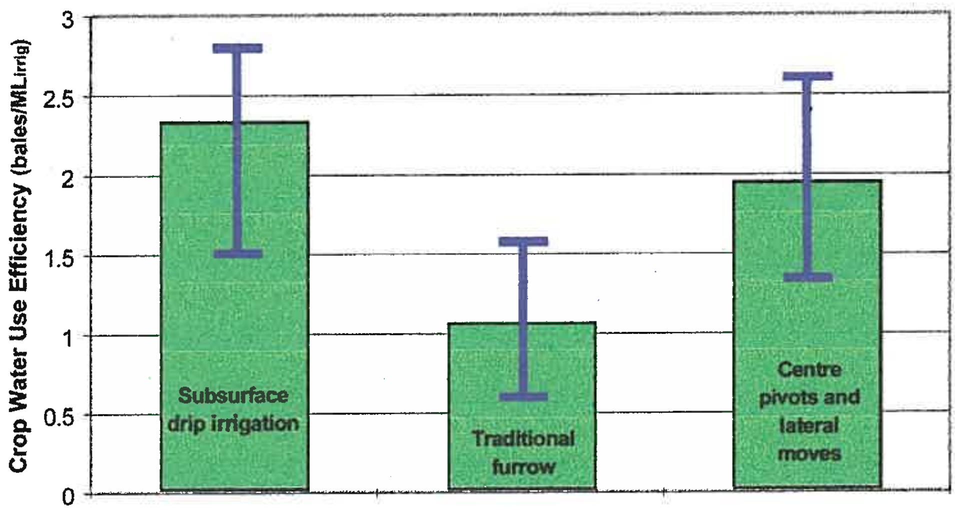
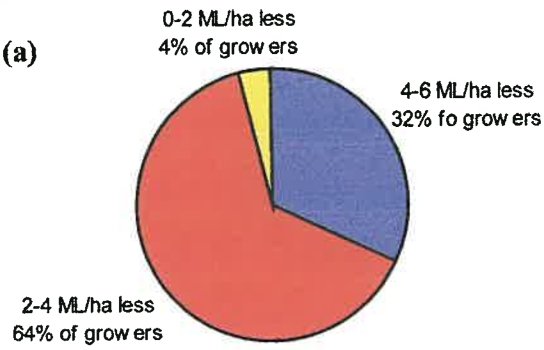


Figure 3.5: Crop water use efficiency (bales/ML_{irrig}) for subsurface drip irrigation, traditional furrow and LMIMs

Cross bars represent highest and lowest values reported by growers.

All of the growers surveyed applied less water per unit area with their LMIM than they applied using a surface irrigation system (Figure 3.6). 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.

(a)



(b)

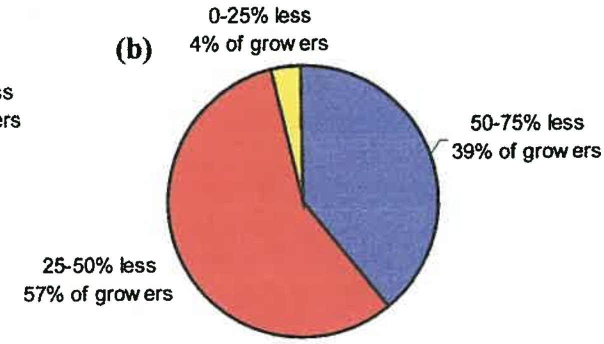


Figure 3.6: Difference in water applied by growers using centre pivots and lateral moves when compared to fully irrigated surface systems

3.3 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 3.1) 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 3.1: 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

GROWER COMMENTS ON ADVANTAGES OF CENTRE PIVOT AND LATERAL MOVE MACHINES

- "I'm saving a 'cruiser every two years and two blokes wages compared to managing a furrow system"
- "One of the best things about these machines is the ability to spray while LEPA irrigating"
- "Best thing - Gemstar applied through the machine & 1 Tracer is all I sprayed for 7 bales/ha"
- "Waterlogging is a thing of the past. If there is a front coming, I only put on 1 inch, instead of 2 inches and see what rain I get"

3.4 Choosing a Machine

The majority of LMIMs in the cotton industry (76%) are centre pivot machines (Figure 3.1). 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. The major differences between centre pivot and lateral move machines are shown in Table 3.2.

Table 3.2: Typical characteristics of centre pivot and lateral move machines

Centre Pivot	Lateral Move
Circular layout	*Rectangular layout*
Higher capital cost (commonly 10-15%)	*Lower capital cost*
Low labour requirement	*Higher labour requirement (>50%)*
Pipeline supplied	*Can be channel supplied*
Driest ground always immediately in front of machine	*Driest ground typically at opposite end of field from machine*
Very high instantaneous application rates at outer end of machine	*Uniform instantaneous application rates across the machine*

A major driver in machine selection is the labour requirements (Table 3.1). 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.

While there are increased labour costs associated with running lateral move machines, there are some savings associated with farming larger areas "on the square". One argument for lateral move machines over centre pivot machines is their ability to fully utilise fields that have already been developed as square or rectangular blocks. Their capacity to cover larger areas than centre pivots is due to the manner in which the water is supplied across the machine. The largest lateral move machines utilise ditch fed centre supply systems that have on-board pumps taking water from a central supply channel. As these systems are centre fed, they only require a pipe size that is able to supply half of the total flowrate to each side of the machine. In comparison, the outer half of any centre pivot supplies exactly ¾ of the water to the irrigated field, and roughly half the water is used in the outer ¼ of a centre pivot. It should also be noted that for a given system capacity and area, individual nozzle flowrates are normally smaller on lateral move machines than those on the outer spans of an equivalent centre pivot machine. Several growers indicated that they selected lateral move machines because of the perceived ease of use with respect to farming management of LEPA systems.

Concerns are commonly expressed regarding the "loss" of land associated with the use of centre pivot machines. However, nearly all of the growers surveyed indicated that their production was water limited and not land limited. In these cases, the "loss" of land is irrelevant as the production potential and highest returns are achieved by optimising the cotton production (and returns) based on a per unit water basis (i.e. b/ML) rather than a per unit area basis (i.e. b/ha). However, where production is land limited, or new installations are being planned, economies in land and water delivery infrastructure can be achieved by using a nested approach to the location of multiple centre pivot machines (Figure 3.7). Alternatively, new generation corner units are available for centre pivot machines from some manufacturers.

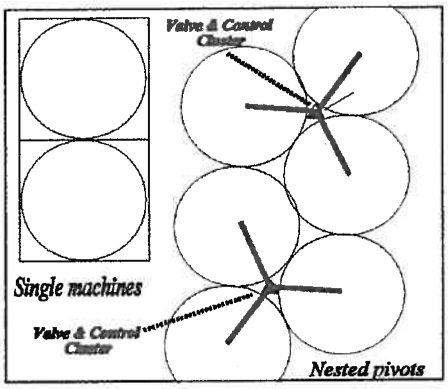


Figure 3.7: Layout of centre pivots in single and nested configurations that allow a greater usage of field area without using corner systems (Evans, 1999)

Experienced lateral move growers and designers aim for the longest single feed channel possible without cross roads to simplify the ease of management and minimise the most labour intensive operations. These long channel runs are split into two or three smaller blocks on either side of the channel for any one crop. Centre feed lateral move growers stated that only one variety, planted at one time, should be planted on parallel blocks on opposite sides of the channel, so that they can be scheduled together. A number of growers using lateral move machines have very long runs (6+ km) of which only small sections are used for any one season. This allows crop rotation and the opportunity to include different crops throughout the year.

3.5 Choosing an Emitter System

Almost all the current LMIM growers (96%) use static plate sprinklers to germinate and establish cotton (Figure 3.8). However, approximately half of these growers (48%) then use LEPA socks or bubblers after crop establishment to apply the majority of irrigations (Figure 3.8). 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 LEPA heads.

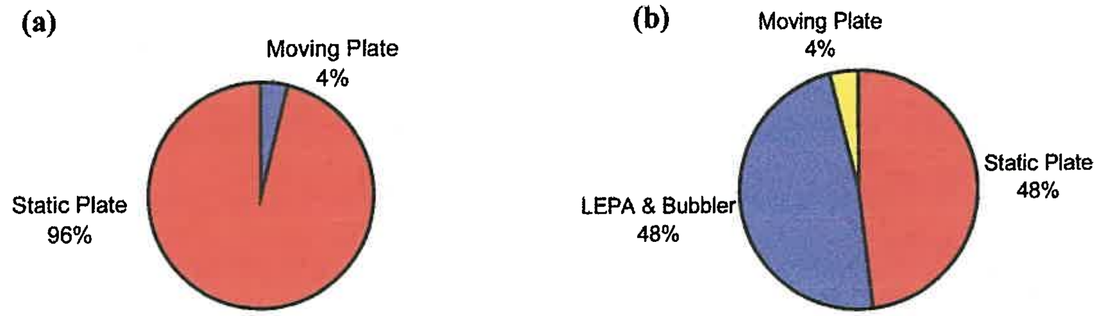


Figure 3.8: Types of emitter heads used for (a) germination of the crop and (b) irrigation of the crop after establishment

GROWER COMMENTS ON SELECTING AN EMITTER

- "Use sprinkler plates for germination and then fit LEPA socks once cotton is established"
- "I like the Quadspray head as it is easy to change between the sprinkler plates and low energy bubbler"
- "Use low impact sprinklers such as spinners on soils susceptible to crusting"
- "There is a need to have more outlets near the end of the centre pivot to improve application rate and better match the infiltration rate of the soil"
- "Use LEPA heads with furrows and dykes to achieve optimum application uniformity"
- "Long LEPA socks in furrows are the most effective method for eliminating wheel rutting"

3.5.1 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. An introduction to the various emitter options, configurations and operation of these systems has been provided in Section 2.1. 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.

3.5.2 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 (Figure 3.8). 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.

MANUFACTURER COMMENTS ON EMITTER SELECTION

- "When choosing a sprinkler package the crop type, soil type, row spacing, span spacing, pivot pressure, pump duty and topography all need to be considered."
- "Sprinkler operating pressures between 10-20 psi should be used to improve efficiency."
- "Sprinkler packages are sold with 10-20 psi regulators when there is any considerable field slope."
- "LEPA heads should be placed beneath the canopy between alternate rows."
- "The Quadspray is highly suitable for cotton as it has the ability to be adjusted from a plate outlet at germination to a bubbler setting once the crop is established. It also has a chemigation mode."
- "Boom backs, ½ sprinklers and extra long LEPA hoses should be used near towers to reduce the potential for wheel rutting."

3.5.3 Pressure Regulators

Pressure regulators located at the individual emitters were used by 58% of LMIM growers to improve the uniformity of application along the machine. Pressure regulators even out LMIM nozzle operating pressures on fields with elevation differences, particularly where low operating pressures are used (Figure 3.9). However, the supply pressure must increase slightly (21-35 kPa or 3-5 psi) to effectively operate the pressure regulators and this will increase pumping costs. When low pressure nozzle packages (6 & 10 psi) are installed, pressure regulators are mandatory.

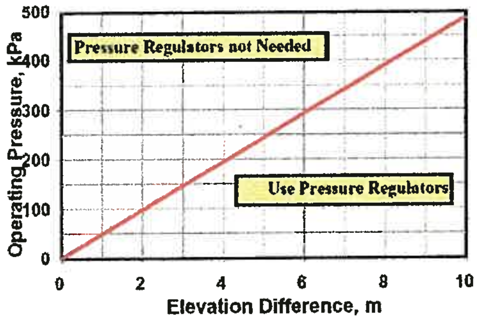


Figure 3.9: The effect of field elevation and nozzle operating pressure on the requirement for pressure regulation of LMIMs

3.5.4 Effect of Soil Infiltration on Emitter Selection

Growers who installed their LMIM on hard-setting soils with low infiltration suggested that it was important to consider soil type when selecting a suitable irrigation site. They suggested that existing static plate sprinkler packages should be changed over to low pressure multi-stream or moving plate sprinklers to overcome crusting issues. Retrofitting of newer sprinkler packages is a quick, economical and effective method of substantially improving the irrigation performance of existing LMIM installations.

Table 3.3: Options to reduce runoff where sprinkler application rates exceed soil infiltration rates

Use long throw multi-stream low pressure sprinklers
Use sprinkler spreader bars
Use furrow dykes or tied ridges to hold water where it falls
Keep soil surface rough, not smooth as for furrow irrigation
Conduct aggressive inter-row in-crop cultivations
Retain standing wheat stubble

3.6 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.

3.6.1 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 3.10). 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.

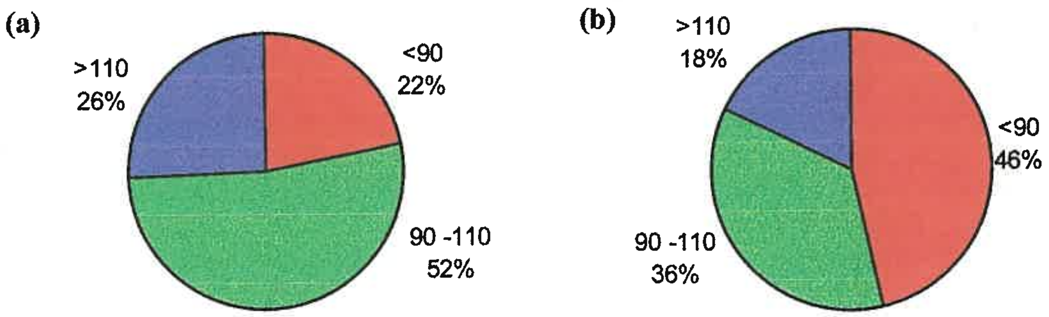


Figure 3.10: (a) Designed and (b) managed system capacities expressed as a percentage of the average regional peak evaporation rates (in January)

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.

GROWER COMMENTS ON SYSTEM CAPACITY

- "A poor system design capacity will cause lower crop yield"
- "As the system capacity goes down, management levels must increase to overcome the deficit"
- "Costs are not that great to go from an adequate to a secure system"
- "Must weigh up risk vs. system capacity & cost"
- "As the system cost is reduced during buying, pipe sizes are reduced and running costs will go up"

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 3.11). However, undersized capacity systems 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.

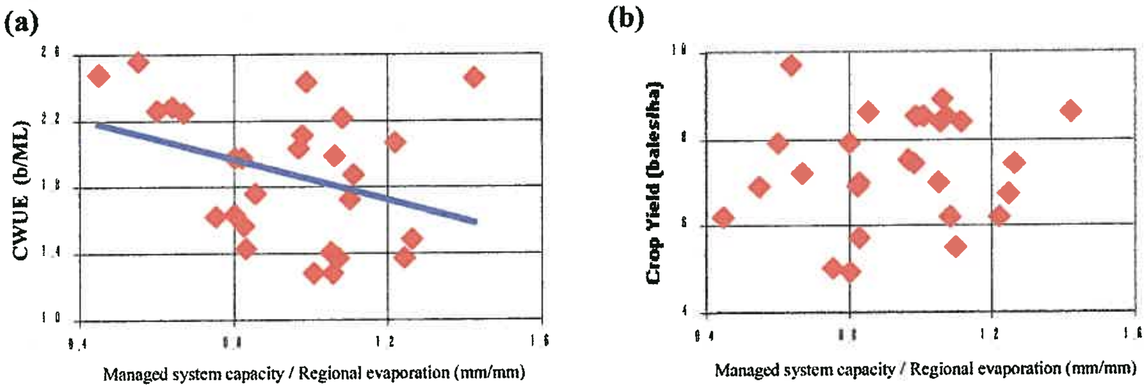


Figure 3.11: Relationship between managed system capacity and (a) crop water use efficiency and (b) yield per unit area

3.6.2 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.

Centre pivot growers farming in a circle indicated that they generally run the LMIM over the field without applying irrigation water, to mark out the field with the wheel-tracks, and then use these wheel tracks as a guess-row guide on either end of each span. Equipment sizes are selected as a fraction of the span size, with the most common combinations being 8 m wide planters, 24 m wide spray rigs and 48 m wide irrigation spans. Furrows are lined up down the side of the tractor using marks on the front axle rather than over the front bonnet. In the USA, where this method of field cultivation is common on spans that do not quite match farming equipment width multiples, growers adjust markers to allow small variations in guess row width on each pass.

Either one or two wide roads into the centre commonly provide machinery access to a field that is farmed in a circle. Where a single access road is used, farming is conducted around the full circle where as the use of two access roads splits the field into two semicircles. In most cases, the wide access road area includes some crop rows that have been planted parallel to the machine and are picked first to enable harvesting access to the circles. In picking the full circle configuration, the centre pivot is parked in the centre of the extra wide access road. The harvester travels around the full circle and ends up on the opposite side of the centre pivot where boll buggies and pickers unload at the module builders.

With two roads to the centre point and two semicircular fields, the centre pivot can be parked upon the semicircle that is not being picked, sprayed or cultivated, after which the centre pivot is moved to the other semicircle. At harvest, pickers follow the semicircle and meet the module builders on the access road and module pad/drain combination. However, care should be taken to place modules on one access road only so that the centre pivot can be moved to the other field without moving the modules.

Where a single access road is being used, drainage should be setup with a single field slope so that the lowest point in the field is at the outer end of the access road and module pad/drain combination. Water should also be able to run around the circle in the furrows and into this area. Two slope fields should be set up with two access roads and so that the pivot centre is located on either the high ridge line or low valley line. In either case, fields should drain around the circles to the access road and module pad/drain combination.

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.

When using a single centre pivot machine across multiple circles, some growers shift the centre pivot by dragging the centre and power supply with a tractor at the same speed as the centre pivot outer towers would normally move, so that the whole machine acts like a lateral move. The operation can take roughly the same time as turning all the gearboxes, moving the machine and turning all the gearboxes back. Growers who have tried to use one centre pivot across multiple circles in the one season have usually had great difficulty keeping up with peak crop water use and usually resort to purchasing one centre pivot machine per circle.

GROWER COMMENTS ON FARMING IN CIRCLES

- "With centre pivots it is easier to layout the traditional square field. But planting in line with the LMIM improves crop management"
- "Planting in line with a centre pivot is made easier with suitable GPS guidance equipment."
- "Guidance can be achieved by aligning the LMIM wheel tracks with implements"
- "When planting in circles, cotton picking is achieved by planting access rows into the centre. This is picked first allowing an area for a module builder and space to turn the picker into the next row."

3.6.3 Operating Pressures and Running Costs

Nearly 60% of growers operate machines that have a supply point or centre pressure in excess of 30 psi (Figure 3.12). 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.

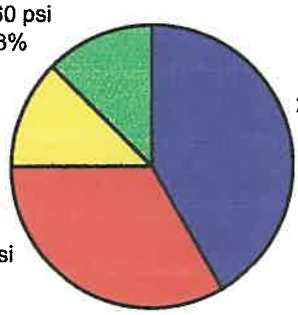


Figure 3.12: Operating pressure at centre for centre pivots or at supply point for lateral moves

3.6.4 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.

LMIMs can be purchased with pipe options including polythene lining, epoxy coating, aluminium, and stainless steel to overcome a range of water quality issues. Some growers with machines whose pipe integrity has already been compromised have fitted PVC or HDPE pipe underneath the original galvanised pipe. The quality of galvanising associated with the various brands of machines is highly variable. Where water quality is a concern, growers should consider selecting machines with the highest zinc weight per square metre. While definitive water quality guidelines for LMIMs are not available, the pH of the supply water appears to be a major factor in corrosion. Where the pH of the supply water is less than 6.5 or greater than 7.6, galvanised pipes should be avoided and the use of alternate pipe or lining materials considered. Alternate pipe linings typically add a minimum of 15% to the capital cost for galvanized LMIMs.

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.

3.6.5 Power Supply and Control Systems

Approximately two-thirds (65%) of the growers surveyed powered their pumps using diesel engines while the remainder used electric motors. The power supply for lateral move machines was always provided by on-board diesel driven alternators, with centre pivots being driven in equal proportion by mains power and diesel alternator sets, depending upon the availability of mains power infrastructure. Unlike the USA, Australian centre pivot users rarely have adequate quantities of good quality groundwater available at the centre of the circle. This means that growers in this country typically pump water either considerable distances through pipelines from surface supplies, or from bores located considerable distances from the centre of the circle.

All growers had some level of automation capability on their machines. However, only 10% of growers had control systems that consisted of more than timer and pressure control shut-off options. Where present, more advanced control systems were seen to be a major factor reducing labour levels and improving the flexibility of irrigation management. Automated control panels, while increasing machine complexity, were used by growers with lateral moves to reverse machine direction of movement at the end of the block and continue irrigation. They were also used by growers to change channels, traverse across roads and continue irrigation, and shutdown when the irrigation was completed. Some growers programmed controllers to apply reduced volumes immediately after rainfall and then gradually increase the applied depth until the normal irrigation schedule was achieved. However, many growers indicated that prospective LMIM purchasers should install an automated system that was as simple as possible, as extra equipment complexity was a major cause of breakdowns.

3.6.6 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 3.13). 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.

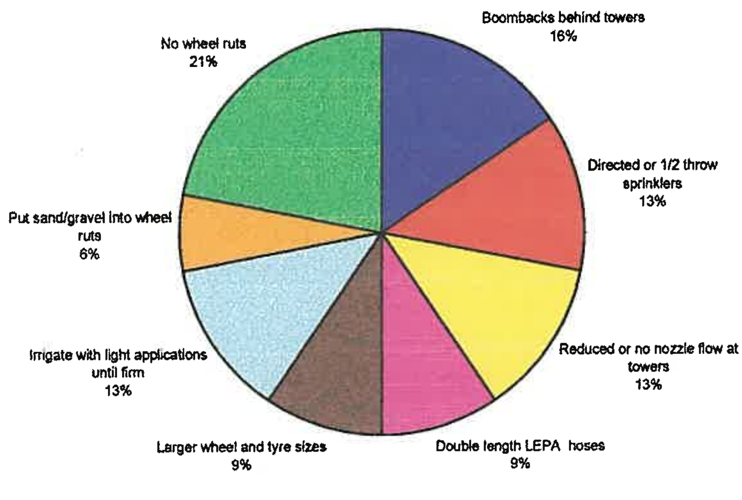


Figure 3.13: Options used by growers to reduce wheel ruts and tower bogging

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.

3.6.7 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.

MANUFACTURER AND DEALER COMMENTS ON SYSTEM DESIGN

- "As a national dealer/manufacturer we supply the following services: design of irrigation system, installation of irrigation system, supervision of the installation of the system and servicing advice. But we do not provide scheduling and agronomic advice"
- "System capacity design is based on information supplied by the grower and local irrigation dealer or information supplied by the local agronomist."
- "We design to water use requirements as requested by growers and local dealers."
- "Design of main supply line and pump are the responsibility of the local irrigation dealer. To assist design, the national dealer/manufacturer will supply operating pressure at intake of LMIM and the required flow rate."
- "Agronomy, fertigation, chemigation and irrigation scheduling is the responsibility of agronomists and irrigation specialists."
- "We prefer that the grower understands 'water holding capacity' of their soil so we can design to this."
- "Maximum area of effective coverage for a centre pivot and lateral move machine is limited by the maximum instantaneous application rates that can be applied without run off occurring."
- "When designing a machine we require the following information; crop type, irrigated area, evaporation and infiltration losses, full or supplementary irrigation and who is operating the system."
- "Pressure requirement at intake and flow rate are determined after crop requirements have been determined i.e.; soil type, crop factor and evaporation rates."
- "Peak crop water use is determined with evaporation pan data, soil type, crop factor and root depth."
- "Maximum design area is limited by water flow rate, span pipe size and mains power."

3.7 Agronomic Issues

3.7.1 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 used the LMIM for germination, a small proportion of growers relied solely on rainfall primarily because of water availability limitations (Figure 3.14). 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.

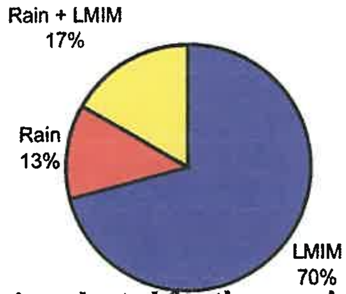


Figure 3.14: Strategies adopted for the germination of cotton by LMIM

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.

3.7.2 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 (Section 3.6.1). 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 in Figures 3.4 and 3.5 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 (Figure 3.15). The most popular methods were neutron probes (NMM) 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.

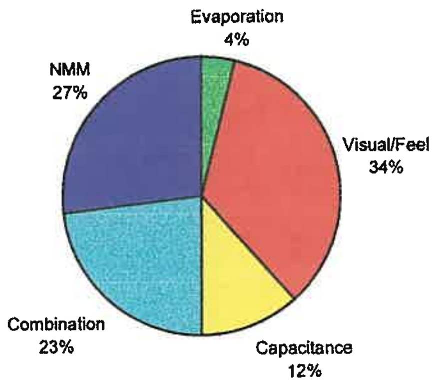


Figure 3.15: Methods used to schedule irrigations under LMIMs

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 3.16). 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

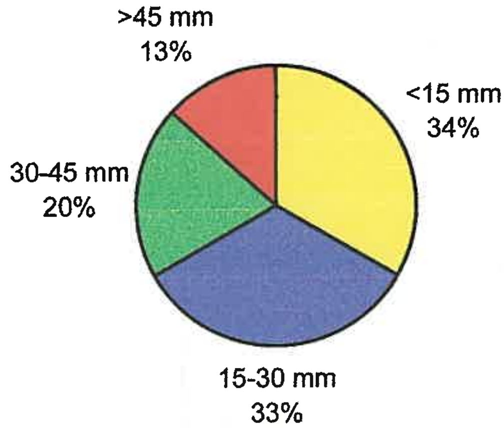


Figure 3.16: Depth of water typically applied to cotton crops in a single pass by LMIMs

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 with previous horticultural experience 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.

3.7.3 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 (Figure 3.17). More than two-thirds of LMIM growers (69%) indicated that they had decreased their pre-season fertiliser application (Figure 3.17). 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.

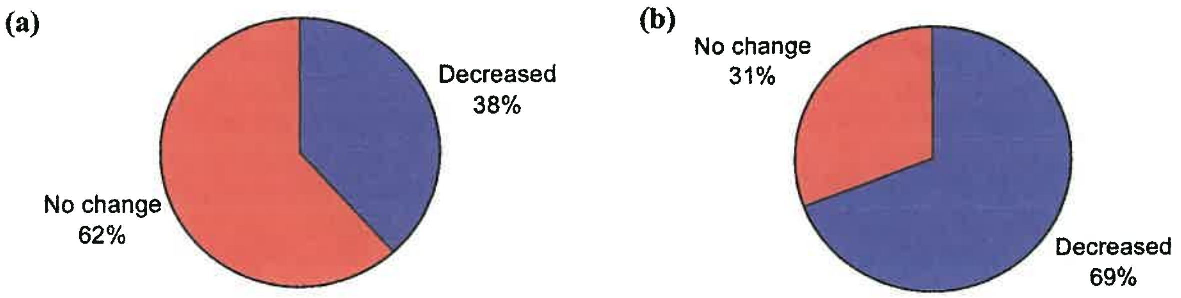


Figure 3.17: Comparison of fertiliser usage with LMIM compared to traditional surface irrigation expressed as (a) total seasonal usage and (b) pre-season fertiliser usage

Urea is the dominant fertiliser applied through the LMIMs. However, one grower indicated that he was also applying phosphorus and potassium, while another had applied chelated zinc through the machine. Fertigation with LMIMs is typically conducted using either:

- a high pressure pump to inject the fertiliser into the mainline from a large plastic dilution and mixing tank; or
- for channel fed lateral move machines, options adopted by growers included using a urea buggy to feed the fertiliser into the start of the channel or towing an "N buggy" behind the machine. Systems where the buggy was towed behind the machine experienced difficulties when the lateral move changed direction.

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. The relative corrosive potential for a range of fertilisers is shown in Table 3.4. Chemigation through LMIMs was routinely conducted by 14% of growers (Figure 3.18). 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 (Figure 3.18). 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.

Table 3.4: Relative corrosion of galvanized iron after 4 days immersion in solution of 12 kg of fertiliser in 100 litres of water (New and Fipps, 1995)

Fertilizer Type	Solution pH	Relative Corrosion
Calcium Nitrate	5.6	Moderate
Sodium Nitrate	8.6	Slight
Ammonium Nitrate	5.9	Severe
Ammonium Sulphate	5.0	High
Urea	7.6	Slight
Phosphoric Acid	0.4	Severe
DAP	8.0	Slight
17-17-10	7.3	Moderate

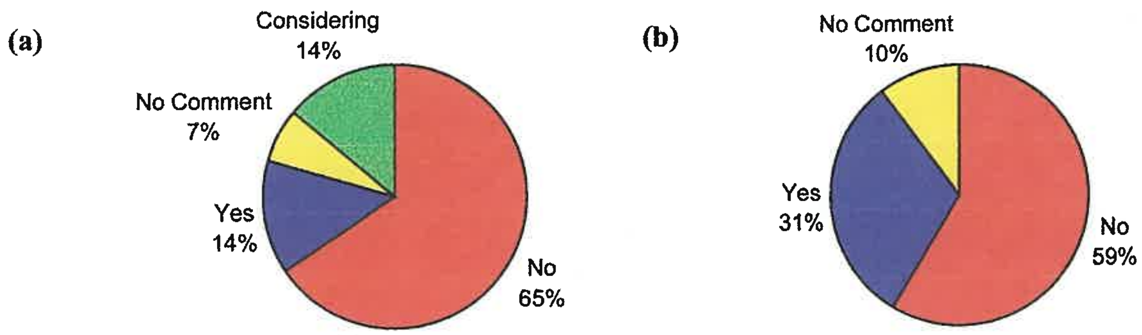


Figure 3.18: Have you (a) applied 'Gemstar' through your LMIM? or (b) changed your insect management?

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 types so that they can obtain high machine speeds and an ability to apply the chemicals quickly with their LMIM over the entire field.

3.8 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 (see section 3.3). 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.*, 1999). 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 (see section 3.6.3).

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 (Figure 3.19) and only marginally related to the yields per unit area achieved (Figure 3.20). There was also a poor relationship between the machine cost per unit area and the system capacity of the machines (Figure 3.21). 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.

The effect of management practice and water availability on performance is highlighted in the results for the two lowest cost ($1250/ha and $1500/ha) machines surveyed (Figures 3.19-3.21). The lowest cost machine in the industry ($1250/ha) was designed and managed with an inadequate capacity, resulting in a significant decrease in the yield per unit area (Figure 3.18) but producing one of the highest crop water use efficiencies (~2.4 b/ML_{irrig}) reported. However, the $1500/ha machine was designed and managed with adequate capacity to meet the peak crop water use demands, produced a yield per unit area similar to traditional surface irrigation and a crop water use efficiency of only 1.29 b/ML_{irrig}.

Manufacturers and dealers indicated that centre pivots should range in price from about $1500/ha for 100 ha machines to $3300/ha for 15 ha machines. This wide range of machine costs is strongly associated with the length of the centre pivot, with longer centre pivots resulting in a cheaper capital cost per hectare. However, the upper limit for centre pivot length is influenced by the system capacity and the potential for run-off due to the mismatch between the application rate of the emitters located on the outer spans of the machine and the soil's infiltration rate. Growers are often tempted to install excessively long pivots due to the lower capital cost per hectare. However, there is only a limited range of machine design and management options (eg. Table 3.3) available to minimise run-off from long machines and the cost of implementing these practices should be considered in the decision. The location of the water supply will also influence the capital cost of centre pivot installation with shallow groundwater accessible close to the centre of the pivot requiring shorter pipe lengths and smaller pumps.

Manufacturers indicated that the cost per hectare for lateral move machines will typically range from $1300/ha for 100 ha and larger machines to $3500/ha for 15ha machines. The capital costs of lateral move machines are closely related to the ratio of the machine length and the supply channel length. As increases in the supply channel length are cheaper than increases in machine length, the longer the run, the cheaper the machine per hectare. However, the channel length is often constrained by normal channel height restrictions across sloping land. Hence, the cheapest and simplest lateral move machines to manage typically have long unhindered supply channels. It should also be noted that lateral move machines with the same pumping capacity but operating in different regions may require different channel run lengths to maintain a system capacity proportional to the peak crop water use in each region. The management of large lateral move machines typically requires at least one part-time skilled operator with labour requirements increasing dramatically with the intensity of crop management and level of automation available.

Pipe sizes are commonly the first item to be reduced when dealers and growers attempt to reduce the capital outlay of LMIMs during the purchasing process. For example, the majority of dealers and suppliers would rather provide smaller pipe sizes (eg 6 5/8" dia.), as this is the most common pipe size, rather than supply larger pipe sizes (eg 8-10" dia.), which would have substantially lowered operating pressures and pumping costs. However, small reductions in capital price per hectare are paid for time and again through increased running costs for the life of the machine. Hence, growers should request indicative operating costs for the various hydraulic design options provided by the LMIM dealers or manufacturers.

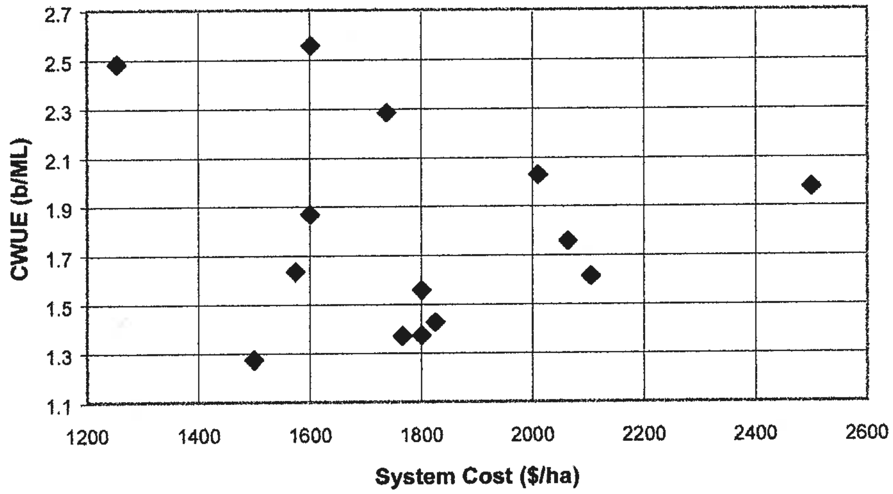


Figure 3.19: Effect of LMIM machine cost on the crop water use efficiency (b/ML$_{irrig}$)

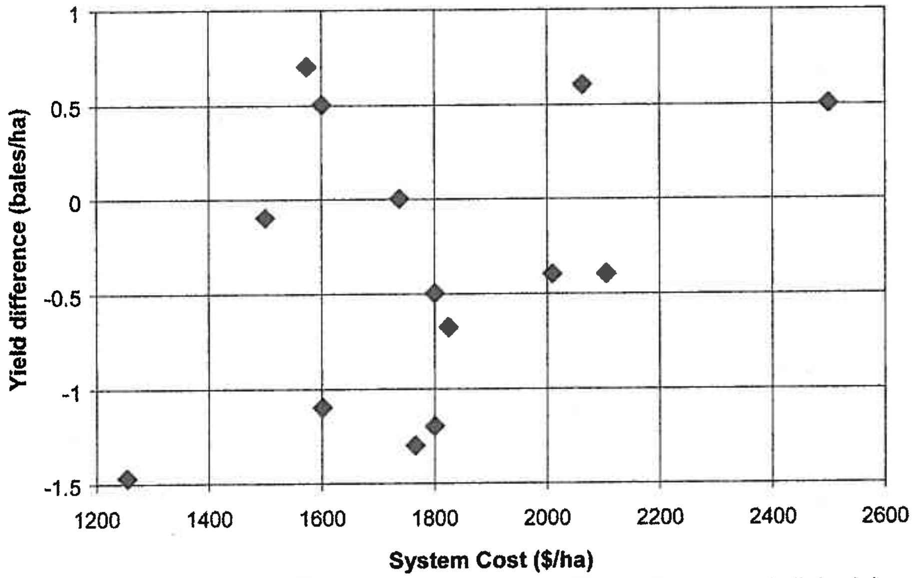


Figure 3.20: Effect of LMIM machine cost on yield differential (b/ha) between LMIM and traditional furrow irrigation

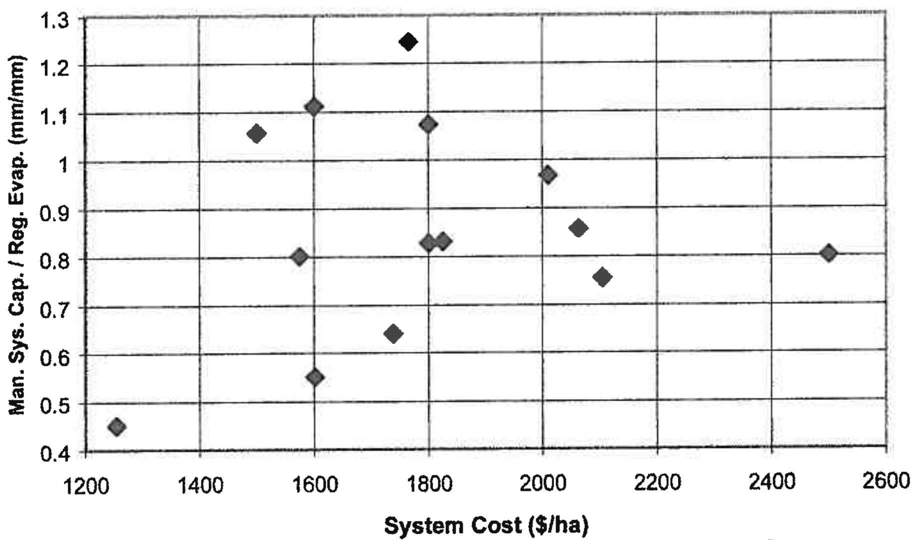


Figure 3.21: Effect of LMIM machine cost on the relationship between managed system capacity and regional evaporation

4. 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, 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.

The grower and manufacturer surveys 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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Appendix 1 Suggested Further Reading

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Appendix 2 Glossary of Terms

AE Application efficiency: a measure of the losses associated with applying water to a field. It is calculated as the ratio, expressed as a percentage, of the volume of irrigation water stored in the root zone divided by the volume of water supplied to the field inlet

AAR Average application rate: the average depth of water applied to the irrigated field during a single irrigation event. The AAR is calculated by dividing the emitter flow rate by the wetted soil surface area, normally reported in mm/hr.

Boombacks Structures used to suspend the emitters at a distance of 3-6m behind the machine towers to reduce wheel rutting and bogging

C_u Christensen's uniformity coefficient defined as:

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

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

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

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

CWUE Crop water use efficiency, commonly reported in units of bales/ML of either total water applied or irrigation water applied

Design system capacity
The volume of water that the machine could deliver in a day (if operating continuously) divided by the irrigated area, normally reported in mm/day

D_u Distribution uniformity defined as:

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

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

EAR Effective application rate (same as managed system capacity)

LEPA Low energy precision application: used to refer to the application of water either within the crop canopy or directly onto the soil surface using either quadspray bubbler or sock emitters

LMIM Large mobile irrigation machines (ie centre pivots and lateral moves)

Managed system capacity (or effective application rate)
Calculated as the volume of water actually applied during an irrigation cycle divided by the irrigated area. Often measured over a period of days and reported in units of mm/day. The managed system capacity will normally be less than the designed system capacity as management requirements commonly reduce the period of time that the machine is operating.

SDI subsurface drip irrigation

Appendix 3 Typical System Costs and Life Expectancies for Irrigation Application Systems

Irrigation System Type	Approx. Cost ($/ha)	Expected Life (yrs)
Furrow w/head-ditch & siphon	1800	10+
Lateral move w/channel * #	1900	20+
Centre pivot pipe/pump/motor** #	2500	20+
Subsurface drip inc. pump, pipe & filters #	4500	7+
Disposable subsurface drip #	1500	3+

* - includes gravity fed channel ~1.5 times length of LM run; ** - includes pump/motor and pipe ~1.5 times CP length
# no levelling costs included