Growing Cotton Under Sprinkler Irrigation

A report for:

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Executive Summary

Cotton grown under Centre Pivot and Lateral Move (CPLM) irrigation systems employing traditional full tillage raised bed cotton farming systems will give poor yield and water use efficiency results.

Ground cover, in the form of specialised cover crops or previous year's cereal stubble, is crucial to achieving high yielding, highly water efficient cotton crops. Ground cover material must have enough lignin and cellulose to resist decomposition until after row closure in the cotton crop. Planting cotton into fields with high ground cover residue loads is possible, but requires specialised equipment and separate farming systems to traditional, full tillage, raised bed cotton systems. Principles widely adopted in dryland cropping systems can be adapted to growing cotton under CPLM machines with specialist tools and correct planter set up. Zero-till cotton, grown on the flat can be achieved utilising new Bollgard 3 genetics, however tillage may still be required to control ratoon cotton.

Sprinkler selection is very important in delivering water to the soil efficiently. Sprinkler selection will have the greatest influence in machine performance, for minimal cost. Irrigation scheduling is very different to traditional cotton farming systems. However, the same decision-making tools are relevant for furrow and sprinkler irrigated crops. Machine maintenance is of the highest importance because, if the machine breaks down, there is zero capacity to irrigate the crop. Preventative pre-season maintenance can minimise down-time during the season and help prevent severe water stress.

Strip tilling is a new technique to Australian farming systems that has delivered significant yield increases in corn crops in the United States. Strip tilling is a precision agriculture tool and beneficial in a cotton system under CPLM, because it rips directly below the plant line, applies fertilizer at depth directly below the roots, prepares a seed bed, and moves trash out of the plant line in one pass, while retaining full ground cover between rows.

Table of Contents

Table of Figures

Foreword

Cotton has been grown in Australia since the late 1960's, with the first crop being grown at Wee Waa in the North West of New South Wales. Furrow Irrigation has almost been exclusively used to irrigate cotton in Australia since the industry was born. However, since the Murray Darling Basin Plan was introduced, in conjunction with government incentives to swap irrigation water rights for water saving infrastructure, more cotton is being irrigated using alternative systems.

Farmers in the Macquarie Valley, including my own family, invested heavily in water-saving infrastructure, primarily as overhead sprinkler irrigation systems in the form of Centre Pivots and Lateral Moves (CPLM). These new, capital and energy intensive forms of irrigation did not deliver the promised results of increased yields and reduced water input using existing full tillage furrow irrigated farming methods. It was obvious that farmers would have to change techniques in order to achieve better yields and water-use efficiency in the future.

I started changing our farming technique to better suit overhead irrigation, however I could see the benefit in visiting farming regions with decades of experience would extrapolate the speed of our learning and lead to success. I was awarded a Nuffield Scholarship sponsored by Cotton Australia and the Cotton Research and Development Cooperation to investigate other farming techniques that could help growers achieve their goals of increased yield and reduced water use using new overhead sprinkler irrigation infrastructure. My Nuffield journey took me to United States, Canada, Brazil, Israel, Mexico, New Zealand, France, England, and parts of Australia.

Acknowledgements

I would like to thank Cotton Australia and the Cotton Research and Development Corporation (and by extension the levy-paying Cotton Growers of Australia) for their support. Without the forward- thinking attitudes within the cotton industry this research would not be possible. The financial support has been significant and I hope my findings will give a healthy return on the investment the industry has ploughed into me.

I would like to thank the Nuffield organisation for its extensive support and administration of such a wonderful opportunity for young farmers in facilitating worldwide contacts and unrivalled learning a Nuffield Scholarship brings.

I would like to thank all the people who hosted me throughout my travels. Time is a valuable commodity and people were extremely generous in sharing their time and knowledge with me.

I would like to thank my family for their unwavering support throughout the Nuffield Scholarship process. Without the support of my parents Tony and Sally, along with brothers George and Richie and the rest of the Quigley Farms team I would not have been able to spend the time away from the business necessary to complete a Nuffield Scholarship.

Finally, I would like to thank my wife Lauren for her support during this scholarship as I could not have done it without her.

Abbreviations

- CPLM: Centre Pivot and Lateral Move Irrigators
- RTK: Real Time Kinematic GPS
- GPS: Global Positioning System
- ha.: Hectares
- P: Phosphate
- Et: Evapotranspiration
- LAI: Leaf Area Index

Objectives

The objectives of this scholarship and report where to investigate how to grow high yielding and highly water efficient cotton crops under sprinkler irrigation. Specifically, these objectives were to:

- Visit successful farmers currently utilizing sprinkler irrigation to achieve high yielding and highly water efficient crops. This included California, West Texas, The Midwest of the United States, Mexico, Canada, Israel, Brazil, and Australia.
- Understand key elements these farmers employed to grow successful crops under sprinkler irrigation.
- Use these farmers experience to accelerate the learning of Australian cotton growers who have recently employed sprinkler irrigation to grow cotton.
- Report back to the Australian cotton industry and support growers who may choose to install sprinkler irrigation in the future.

Introduction

Cotton is a major summer crop grown in the Murray Darling Basin in Australia. In the last six years, planting areas have ranged from 600,000 ha to 200,000 ha, reflecting water availability in the Murray Darling Basin (Cotton Australia). Australian irrigated cotton growers' yields are three times the world average and in 2011/12 the Australian cotton crop produced 5.2 million bales at a value of close to $3 billion dollars (Cotton Australia, 2015).

Cotton has been grown in Australia since the late 1960's almost exclusively using furrow irrigation methods. This conventional furrow irrigated system is a full tillage farming system employing mouldboard tines to build a hill and furrow as shown in Figure 1. The cotton seed is planted into a fine seed bed on top of the hill and irrigation water is supplied by gravity through the furrow to irrigate the crop, as seen in Figure 2.

Figure 1. Cotton beds being constructed

Figure 2: Seedling cotton on top of the cotton bed

*Note the furrow either side of the hill to channel water and enable irrigation.

The onset of the Millennium Drought and severe water shortages in the Murray Darling Basin attracted political attention and urban voter's worry. This led to the Murray Darling Basin Plan being developed and announcement of Government incentives to modernise irrigation infrastructure to facilitate the return of water rights to government for the environment. Around 10% of cotton Farms (Ashton Oliver 2014) swapped water rights for the opportunity to upgrade part of their irrigation infrastructure to pressurised overhead sprinkler irrigation.

Sprinkler irrigation is seen to be water efficient because farmers have control over how much water is applied to a field rather than furrow irrigation which gives only completely dry or complete saturation choices. On the Trangie Nevertire irrigation scheme, 23 new Centre Pivot or Linear Move (CPLM) irrigators were installed on existing furrow irrigation land that had grown cotton previously, with promise of increased yields and lower water use. The promised benefits of the new capital-intensive and high energy input infrastructure did not eventuate, when farmers growing cotton under them for the first time used conventional cotton farming practices. Difficulties germinating cotton seeds, sand blasting of vulnerable germinating cotton, poor water infiltration and water run-off resulted, causing low yields and poor water-use efficiency.

Figures 3 and 4 both show water pooling and running off during and after a sprinkler irrigation event using traditional furrow irrigation land preparation techniques.

Figure 3: Water running off the hill and into the furrow of conventional cotton farming system under CPLM (Source: Author)

Figure 4: Water pooling in the furrows and running off in a conventional cotton farming system under CPLM (Source: author)

The traditional full tillage method of creating a bed made wetting the seed after planting difficult. In a typical irrigation pass a sprinkler irrigator can apply the equivalent of a 30-millimetre thunderstorm in under 10 minutes, an amount which far exceeds the soil infiltration rate of around 5mm/hour, resulting in run-off. In addition to this, cotton seed is planted just below the peak of the bed which is very difficult for water to infiltrate and wet the seed because the slope of the hill encourages water to run off.

This report seeks to share the perspectives and lessons learnt by farmers around the world who are already growing a range of high yielding, highly water efficient irrigated crops under sprinkler irrigation.

Chapter 1: The system key to growing cotton under sprinkler irrigation

From visiting highly skilled farmers utilising sprinkler irrigation around the world, and some of his own experiences, the author gained insights into elements required to successfully grow cotton under sprinkler irrigation. A particular farming system, which included ground cover, minimum till, precision ripping and fertiliser placement combined to give a successful recipe to grow high yielding, high water use efficient crop.

1.1 Ground cover and its integral part of growing cotton under sprinkler irrigation

The author found that traditional full tillage farming methods, designed to give a fine seed bed, turned the field into an open flat plain which enabled wind to pick up fine particles and cause sand blasting of young emerging cotton. Figure 5 shows seedling cotton in the foreground which has been protected by some dead grass cover, compared to the sandblasted cotton in the background. The protected cotton is far superior in growth to the cotton in the traditional conventional farming system.

Figure 5. Seedling cotton (Source: Author)

*The foreground seedlings have been protected from wind and sandblasting through dead grass weeds, while the background seedlings have suffered sandblasting.

With a reputation within the cotton industry for poor yield performance, could the key to success for growing cotton using CPLM irrigation be ground cover? Dryland farmers have widely adopted retained stubble farming systems to reduce the effect of wind, combat water runoff, and increase water infiltration. Around 19 million ha of the 25.1 million ha of crop land in Australia was sown with zero till farming practices in 2009-10 (ABS 13).

Scott et al., (2013) report that retaining stubble has the ability to reduce wind erosion and improve the water balance and increase soil water storage. Figure 6 shows the significant impact stubble has on wind speed near ground surface, which could potentially reduce or eliminate sandblasting of seedling cotton.

	NNW wind gusting to 35km/hr			**SW wind gusting to 27km/hr**		
Stubble Height	200cm wind reading	20cm wind reading	Wind speed ratio	200cm wind reading	20cm wind reading	Wind speed ratio
5cm	25.3	16.1	0.64	18.2	12.0	0.66
20cm	20.3	8.7	0.43	17.1	6.6	0.39
35cm	23.2	4.0	0.17	16.7	4.3	0.26

Figure 6: Average wind speed observations (km/hr) at 200 cm and 20 cm above ground height, and wind speed ratio at Port Germein, SA in wheat stubble (4.5 t/ha) at three heights in 30 cm rows aligned SW-NE (Mudge and Jeisman 2011)

Dryland farmers also recognise that stubble protects the soil surface from the impact of rainfall, maintaining soil structure and hence infiltration rates and holds water, preventing runoff. Hunt and Kirkegaard (2011) state that “residues slow the flow of water on the soil surface, allowing for more time for infiltration as well as slowing soil evaporation following rainfall events”.

Many farmers incorrectly believe that stubble cover eliminates evaporation. Hunt and Kirkegaard (2011) highlight that stubble cover will only slow evaporation, not prevent it. Therefore, stubble only contributes to stored soil water when rainfall events combine to push water past the evaporation zone of the soil. Scott et al (2013) summarise “Cumulative evaporation from the system with residue will catch up to that without residue if it is not followed by a second pulse” of rainfall. Stubble extends the time available for rain events to combine to push water past the evaporation zone.

The introduction of stubble into the cotton farming system under sprinkler irrigation and a move towards a “zero till” type system has the potential to overcome many of the problems associated with growing cotton under sprinkler irrigation, however stubble brings its own challenges

1.2 Zero-till cotton farming: is it possible?

Until recently Australian cotton farmers have been unable implement a full zero till system because of their Licensing Agreement with Monsanto. Australian cotton farmers are legally obliged to “Pupae bust” the soil post-harvest. “Pupae busting” refers to full disturbance of the soil to a depth of 10cm and is a non-chemical control of over-wintering pupae which carry resistance to the “Bt” genetically modified strain of Cotton. Farmers in Brazil and the United States do not have this requirement, and are growing cotton using zero till practices. However, farmers in Brazil reported that insects that where once controlled by the Bt gene found in genetically modified corn and cotton were developing resistance, and six to seven pesticide applications were required per season in cotton to control these pests. In the Texas High Plains of the United States, Farmer Ronnie Hopper was able to run a zero till type system because winter freezing killed off any soil borne pests, replacing the tillage pass of pupae busting.

With the introduction of Bollgard III for the 2016 season, cotton defoliated early in the season may be exempt from pupae busting. Monsanto Technical Development Manager Tony May reported in The Land (“Bollgard breakthrough” Ruth Caskey, 24 Feb 2015) that early harvested crops do not produce over-wintering Heliothis pupae, and therefore do not require the pupae-busting pass. With this in mind, zero till cotton in Australia may be possible in the near future.

1.3 Cotton on the flat

Cotton grown under sprinkler irrigation lends itself to be grown “on the flat”. “On the flat” refers to growing cotton on the natural surface of the soil, rather than traditional raised beds. Raised beds are necessary in furrow irrigated cotton because they create a furrow to run irrigation water down, and raise the plant roots which reduces water logging. Raised hills are not necessary under overhead CPLM irrigation systems for two reasons. As water is applied overhead from the CPLM machine, a furrow to run water in is not required. Secondly, because application rates of water can be controlled, the soil does not become saturated like furrow irrigated cotton, reducing the risk of waterlogging. As discussed above, using traditional raised hill systems in CPLM systems is a disadvantage because the hill creates slope for water to run off, reducing the surface area of the soil where moisture can infiltrate. Growing cotton on the flat gives the maximum surface area for moisture to infiltrate, and reduces water movement and runoff. West Texas growers Ronnie Hopper, Glen Schur, and Steve Olsen all championed growing crops on the flat including cotton under CPLM machines, and dryland cotton farmers on the Australian Darling Downs, have been growing cotton on the flat in dryland situations for more than two decades (Grant 2016). However growing cotton on the flat has its own challenges, particularly in terms of root cutting and ratoon cotton destruction. Solutions to these problems will be explored later in this report.

1.4 Evapotranspiration in a cotton crop, highlighting the importance of ground cover

Evapotranspiration refers to the water loss to the atmosphere both from surface evaporation and transpiration through plants. Schneider (2000) reported that fully wet bare soil surface will lose up to 10mm in the first 24 hours after application, and that the evaporation from the plant canopy was typically less than 5%. Figure 7 highlights the proportion of evapotranspiration which is lost as evaporation during the growing season of a crop. As ground cover increases through increased leaf area, as shown by the Leaf Area Index (LAI), soil evaporation decreases. Using Schneider's (2000) findings, growing ground cover prior to the cotton crop, either through previous cereal crops or designated cover crops, will help reduce evaporation, and increase plant available water, which could lead to greater yields and hence higher water use efficiency.

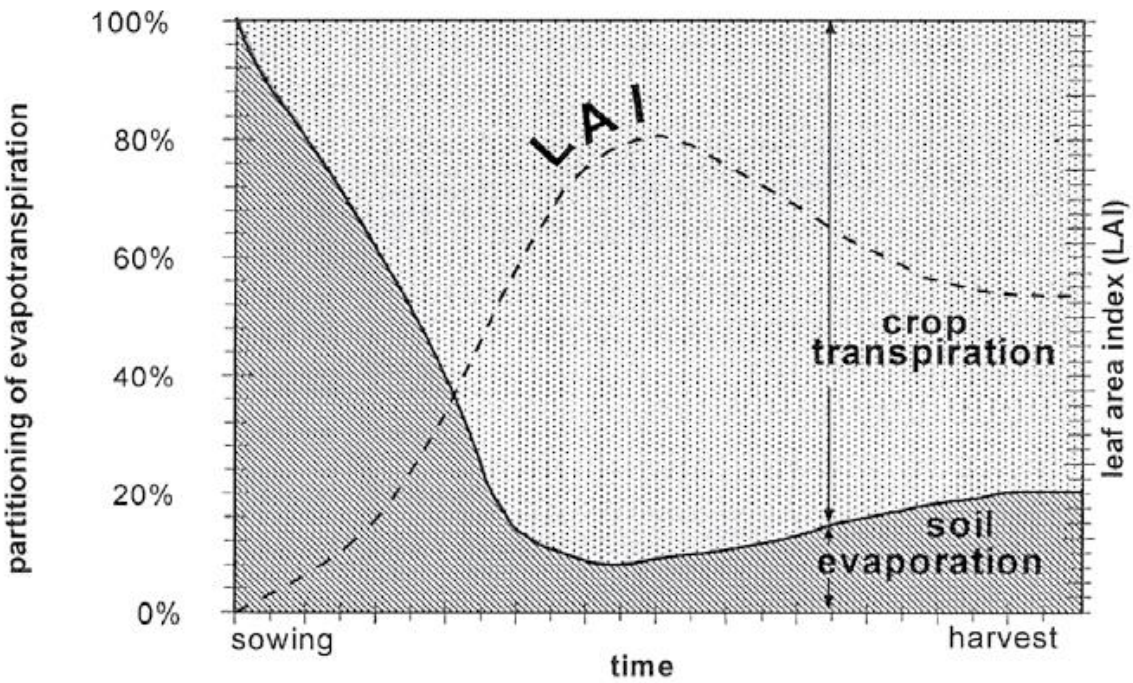

Figure 7: Diagram of partitioning of evapotranspiration (Source: Allen, R.G. et al (1998) Crop evapotranspiration: guidelines for computing crop water)

1.5 Using retained crop residue or growing specialist cover crops?

Farmers can employ two methods to produce ground cover to grow a cotton crop under sprinkler irrigation. They are, retaining previous cereal crop stubble, or growing specialised cover crops. Retaining stubble created by a previous year's cereal crop is the option most familiar to farmers, because many already utilise stubble as cover in zero till dryland farming systems. Retaining cereal stubble gives farmers an 11-month fallow period from November, when cereal crops are harvested, to the following October when cotton is planted, in which to accumulate soil moisture for the following cotton crop.

The other option is growing a cover crop. Cover cropping is when a farmer plants a crop of single or mixed species, with the sole purpose of protecting and improving the health of the soil. Cover cropping is a relatively new concept in Australia, however it has been used in the high rainfall zone in the U.S and Europe for some time. The principle is to sow a mix of species as quickly as possible behind the previous crop, with the aim of achieving maximum bulk before the next crop is sown. It is argued that the cover crop will utilise moisture that is in the evaporative zone of the soil profile, so it will not have a large impact on the water budget. A dense cover crop is desired so it will shade the soil, conserving moisture and prevent weeds from germinating. Dr. Dwayne Beck of the Dakota Lakes Research Farm uses cover crops to "take the E out of Et" (evapotranspiration). Dr Beck explains that if you can remove evaporation, the extra moisture can greatly increase yields. This is seen in Australian dryland farming systems, when stored moisture contributes to grain yield. The Dakota Lake Research Farm has also seen an increase in organic carbon levels in the soil, which Dr. Beck explains is the throttle of the soil, "Soil productivity is limited by organic carbon; find a way to increase organic carbon and you will increase the productivity of your soil".

2013 Nuffield Scholar Peter Kaylock reported in June 2014 that corn was useful as a cover crop because its strong roots could break up compaction layers and allow water infiltration. Kaylock visited David Brandt, who has been using cover crops since 1978 in southern Ohio. Brandt advised Kaylock "in our drier Australian conditions to grow our cover crops as early as possible, and sow into them" (Brandt 2014). Brandt disputed that dry conditions will limit cover crop success, saying that "fertility brings moisture, bulk of crop brings fertility" (Brandt, 2014). This is in agreement with Dr. Dwayne Beck, who found a rotation including 66% high residue corn crop would dramatically increase soil carbon, which in turn increased the productivity of the soil.

It is clear that cotton requires cover to be grown effectively under CPLM sprinkler irrigation systems; the way the cover is produced is not important. Certainly, in back to back situations, (growing cotton in a field consecutively two summers in a row) a winter cover crop would need to be grown between the two summer cotton crops, in order to generate enough ground cover to protect the second crop of cotton. However, in a fallow situation would stubble carried over from a previous cereal crop 11 months prior be sufficient? The cost of extra irrigation water to grow the cover crop would also have to be considered in assessing the benefits of cover cropping verses long fallow after a winter cereal. The author intends to better understand this with future on-farm experiments required to give a more detailed local understanding.

West Texas farmers have had decades of cotton growing experience under sprinkler irrigation. There are around 13,000 Centre Pivots surrounding the city of Lubbock, Texas, the home of the Texas High Plains cotton crop (Mahon 2015). A number of farmers interviewed around Lubbock utilised some sort of cover to protect their seedling cotton from sand blasting, increase water infiltration, and improve application efficiency of sprinkler irrigation.

Southern America Cotton Grower of the year in 2014, Ronnie Hopper and his son, RN, used simple wheat cover crops to stimulate biological activity, reduce evaporation during establishment of cotton, hold soil in place and capture rainfall in severe thunderstorms. They found wheat (and wheat stubble) was a good cover crop, and did not believe that the expense of multi-species cover crops could be justified.

Leading farmer in the Lubbock area Glen Schur preferred to manage last year's cotton residue rather than plant a designated cover crop. Glen explained water was too expensive to spend on a crop which would not make a cash return, and preferred to accumulate moisture during the fallow period to contribute to the following cotton crop.

Both Glen and Ronnie agreed that the most critical part of the cover was that it contained enough lignin and cellulose to provide ground cover until row closure in the cotton crop. Glen provided an example that cereal crops sprayed out in the tillering stage would breakdown before row closure, and therefore not provide ground cover for the length of time required to give the full benefit. The same cereal crop killed at head emergence however, would have had enough lignin and cellulose to provide ground cover until well after the cotton crop's row closure, maximising the benefit of ground cover.

The authors own on-farm experience supports the view that designated cereal cover crops desiccated at head emergence, and previous year's cereal stubble, have provided a thick layer of groundcover throughout the growing season. Scientifically replicated trial work needs to be done to give a clearer, more detailed understanding of the various options of designated cover crops or previous crop residue to determine the most effective path forward.

1.6 Nitrogen fertilizer application in a full cover min-till sprinkler irrigated cotton system

Nitrogen is water soluble and hence there are a greater range of options to applying this fertilizer than phosphate. Anhydrous ammonia is the most common form of nitrogen application in traditional full tillage cotton situations, with about 80% of Nitrogen fertilizer applied in this form (Cotton NUTRIpak). However, broadcasting urea is becoming more popular because of the ease and speed of application, especially in overhead sprinkler situations.

Anhydrous ammonia could be easily applied during the strip till process on the same shank ripping and delivering Phosphorus fertilizer using equipment cotton growers would already own. Applying Nitrogen pre-plant during the strip till process has the added advantage of putting nitrogen at depth as well as delaying further nitrogen applications to the crop until after winter crop harvest is complete.

Broadcasting urea is a quick and simple way to apply nitrogen fertilizer to cotton growing under sprinkler irrigation. This is because once the urea is spread, farmers can use the sprinkler irrigator to create a rain event to dissolve the urea prills, encouraging infiltration, a luxury traditional furrow irrigators do not have. Broadcasting nitrogen is more challenging logistically because correct application timing can clash with winter crop harvest in some cotton growing regions.

Fertigation refers to the practice of applying liquid fertilizer through an irrigation system. Centre Pivot sprinkler irrigation is well suited to fertigation as a fertilizer tank can be easily installed in the centre of the pivot to store and supply fertilizer to the machine. Ditch fed lateral move irrigators are more difficult because of the awkward modifications needed to attach the fertilizer tank to the cart and the physical weight of the fertilizer tank. Growers in the United States reported a number of benefits of fertigation in both cotton and corn crops, which included:

- Applying nitrogen while irrigating which reduced tractor passes and labour requirements.
- Using less nitrogen overall by splitting nitrogen applications over a number of irrigations instead of one bulk application.
- Ease of application.
- Increased yield.

More research is required into fertigation to give scientific evidence of increased fertilizer efficiency of fertigation in Australian cotton growing under sprinkler irrigation.

1.7 Herbicide resistance in zero till and minimum till cotton

With all minimum tillage agriculture, there is a heavy reliance on chemicals to control weeds. Herbicide resistant weeds are well documented and becoming more common in Agriculture. The introduction of Genetically Modified (GM) cotton which is tolerant to Glyphosate has encouraged large numbers of applications of the chemical. Repeated applications of Glyphosate will select naturally occurring resistant individuals in the population, which then reproduce and create a chemical resistant population.

Glyphosate resistant Palmer Amaranth in the cotton growing regions of the United States has been well documented, and is a stark warning to Australian cotton producers about the future of the industry here. Keith Burch a cotton farmer from Lazbuddie, West Texas had a large amount of glyphosate resistant Palmer Amaranth in his cotton fields. Keith reported that resistant Palmer Amaranth went from an easily controllable weed to “fields where you couldn’t see the cotton for the Palmer Amaranth” in two years.

Integrated weed management is required to ensure that resistant weeds do not become common-place in the Australian cotton industry. An integrated weed options for weeds in cotton under sprinkler irrigation includes the use of pre-emergent herbicides, strategic inter-row cultivation, and shielded spraying of chemicals which have different active ingredients to glyphosate before weeds become resistant. West Texas cotton growers were gaining control of Palmer Amaranth by applying Paraquat at 50% solution with water, using a weed wiper once the weed grew taller than the cotton.

Australian cotton growers need to use a wide range of chemical and non-chemical control measures to ensure herbicide resistance does not become a widespread problem in the Australian Cotton industry. Keith Burch explained that the weed wiper was superior for controlling glyphosate resistant weeds which grew taller than the crop. The weed wiper could be set above the height of the crop targeting those weeds and a significant amount of product could be applied to the plant through the wiping process.

Chapter 2: Sprinkler irrigator design

Growers that where visited and discussions with machine manufactures indicated that machine capacity and sprinkler type had large parts to play in terms of delivering adequate water to grow successful crops. Wheel tracking and machine maintenance where also nominated to be key elements once machines where installed and were operating.

2.1 Machine capacity

Perhaps the most important consideration of growing cotton under sprinkler irrigation is understanding the capacity of the CPLM machine to irrigate a crop of cotton. Matching the area and density of cotton grown under the machine is vital to growing a successful cotton crop, because a farmer cannot grow a successful crop if they cannot supply enough water to the crop in peak demand periods. A common criticism of CPLM irrigators is that they cannot supply enough water to the crop and cause water stress without supplementary rainfall, resulting in poor yielding crops. As shown in Figure 8, a cotton crop has a peak water demand of 12-14mm/day of evapotranspiration (Brodrick et al, 2013).

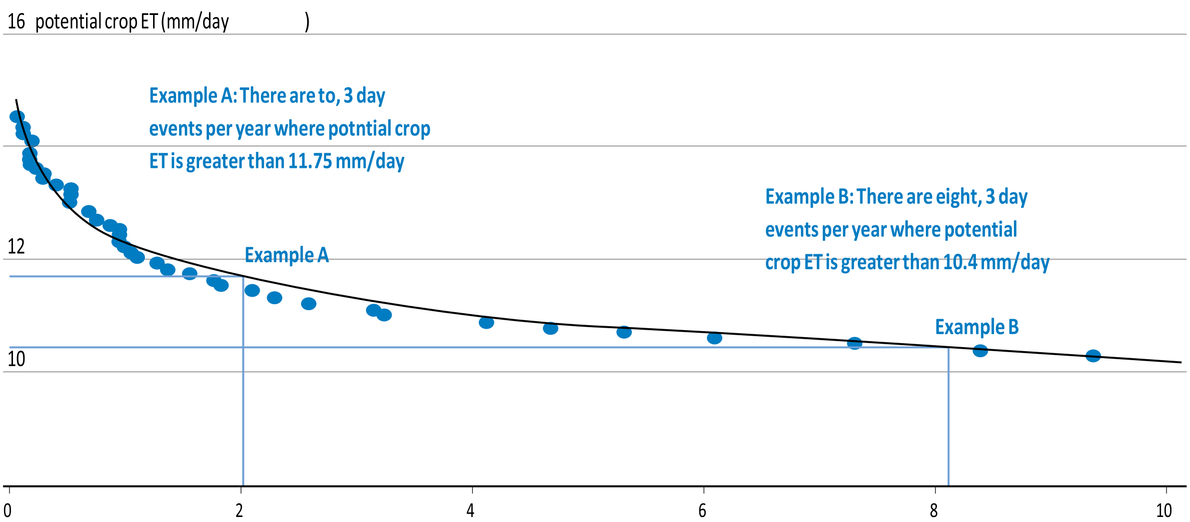

Figure 8: Crop evapotranspiration rates at St George, QLD (Brodrick Et al)

Machine capacity must be matched to deliver at least 12-14mm per ha per day to adequately supply both the transpiration demand from the crop and the evaporation losses from the soil in a solid plant configuration. By using different row configurations of single skip (66% of solid plant) and double skip (50% of solid plant), machines with lower capacity (8mm/ha/day and

6mm/ha/day respectively) can still be used to irrigate cotton and deliver an adequate amount of water to the plant. A consistent plant stand is important to growing cotton because the cotton picker cannot pick cotton very well from isolated plants. This is why row spacing is used to manipulate water requirement rather than plant population along the row.

Importantly, all growers interviewed using CPLM irrigators during the Nuffield program stressed the need of meticulous maintenance of machines. This is because, when a machine broke down and was unable to apply water, then the capacity to irrigate the crop fell to zero which could result in severe water stress and yield reduction. Machine maintenance will be explored further in the report. With adequate irrigation capacity, growers have a solid foundation to grow excellent irrigated cotton yields.

2.2 Sprinkler type

Emitter types and sprinklers have a significant importance for cotton growers using CPLM machines. Sprinklers are responsible for 70% of the machine’s performance, even though they only account for around 7% of the capital cost (Foley Et al 2013). There are a number of sprinkler types available to cotton growers using CPLM machines, which include:

Static plate sprinklers refer to the fixed spray pattern of the sprinkler. As shown in Figure 9, this system is simple, however they deliver the water to the soil in streamlets. This can cause high instantaneous application rates in the immediate area where streamlets land, which can lead to runoff. They generally have the smallest footprint of any sprinkler type (Foley Et al 2013).

Figure 9: A Static Plate Sprinkler (Source: Author)

Moving plate sprinklers refer to a sprinkler where the water jet causes the sprinkler plate to move. Moving plate sprinklers have a lower instantaneous application rate than the same number of static plate sprinklers because they create a bigger footprint, as well as a more uniform drop size (Foley et al 2013). Figure 10 demonstrates how moving plate sprinkler systems break up the streamlets into smaller droplet size reducing impact energy by droplets, leaving soil in better condition for future infiltration.

Figure 10: A Moving Plate Sprinkler (Source: Waterpac 2013)

Low Energy Precision Applicator (LEPA) applies water directly to the ground through a flexible hose once the water has gone through the regulator. Its advantage is that it is highly efficient in applying water because the water does not travel through the atmosphere, however it does deliver very high instantaneous application rates which could cause run off.

Figure 11: A LEPA sprinkler (Source Waterpac 2013)

Low Energy Spray Applicator (LESA) like the name suggests creates a low energy spray travelling directly to the soil surface. Its advantage is that it creates a concentrated stream of water travelling a short distance to the soil so has very high efficiency, but can also create very high instantaneous application rates which could cause run off.

Figure 12 An LESA system (Source: Author)

A Bubbler is a static plate that does not have any groves to direct water, so the water bubbles out of the sprinkler and falls to the ground. Like LESA it creates a concentrated stream of water travelling a short distance to the soil, so has very high efficiency, but can also create very high instantaneous application rates which could cause run off.

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Figure 13: A bubbler (Source: Author)

Pivot dragging drip tape. Glen Schur from Plainview, Texas was experimenting with water being applied to the soil through drip tape which was dragged along the soil surface be the sprinkler irrigator. Glen's Hypothesis was that he could reduce losses between the emitter and the soil surface by piping the water to the soil surface, rather than water traveling through the atmosphere.

Figure 14: Glen Schur and his pivot dragging drip tape

2.3 Application efficiency from different sprinkler types

West Texas farm consultant, Bob Glodt carries out research on farms around Plainview, Texas. He found that spray nozzles fitted at head height were 40-50% efficient in getting water to the root zone, while spray nozzles fitted in the crop canopy were 60-70% efficient once canopy closure occurred. During our visit, Bob explained sprinklers wet the entire soil surface evenly, and hence more moisture was situated in the evaporation zone of the soil. Bob championed the use of Low Energy Spray Applicator (LESA), which applied water to precise narrow strips of the field, pushing moisture deeper within the applied strip and out of the evaporation zone of the soil, increasing moisture utilized for the plant. Farmer Glen Schur also at Plainview Texas had seen around a $370/ha benefit from using LESA over spray irrigation in his cotton crops and stated “LESA gives you bigger droplets, which means more water to the ground”. This is demonstrated in the four Figures below which demonstrate how the soil moisture changes under different irrigation application techniques.

Figure 15 and Figure 16 demonstrate the change in soil moisture under sprinkler and LEPA application methods of irrigation. The blue colour indicates increases in soil moisture whilst light pink indicates a decrease in soil moisture.

Figure 15 shows the wetting pattern of a sprinkler irrigated system, where the entire surface is wetted evenly. This is seen clearly in the left-hand image, where the entire surface is wet uniformly, and exposes more water to the evaporation zone of the soil.

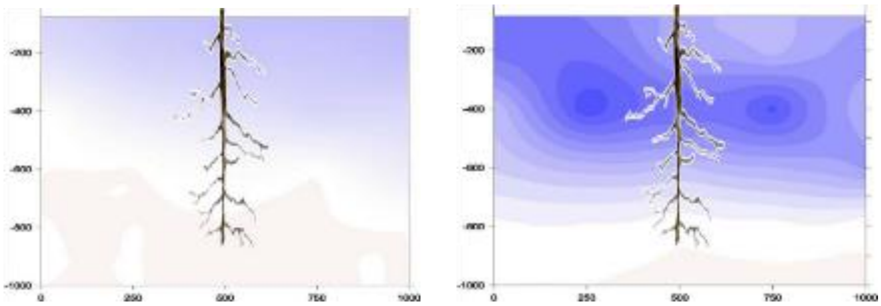

Figure 15: The change in soil wetness from sprinkler emitter on black cracking clay soil, and red hard-setting soil (Source: Waterpac)

LEFT	**RIGHT**
Black cracking clay Sprinkler 90 mm soil deficit 26 mm application Water infiltrates to a depth of 500 to 600 mm	Red hard setting soil Sprinkler 50 mm soil deficit 24 mm application Water infiltrates to a depth of around 600 mm, preferentially filling some drier areas that existed at around 400 mm

Figure 15 is contrasted to Figure 16, which shows the wetting pattern of an LEPA application system. Unlike the sprinkler irrigator which will apply water to the soil surface evenly, an LEPA applicator will wet up strips of the soil, and force water lower into the profile and out of the evaporation zone of the soil. This is especially evident in second image where the soil water deficit is smaller, the LEPA system concentrates water into a strip to the left of the plant line, reducing the amount of water in the evaporation zone of the soil.

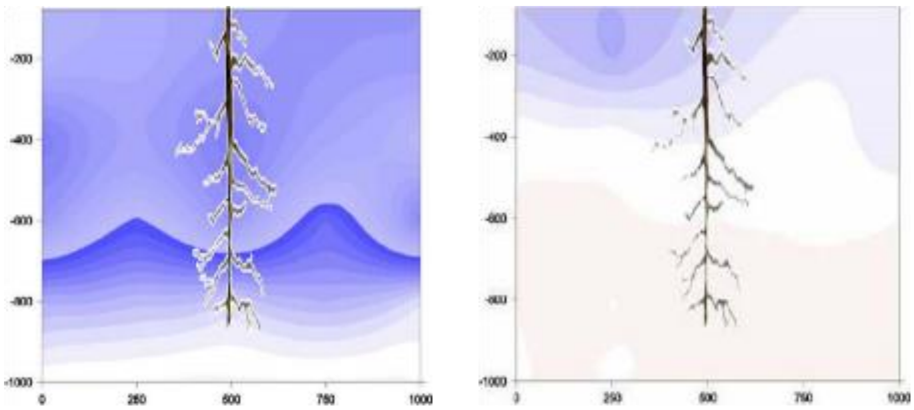

Figure 16: The Change in soil wetness from a LEPA emitter on black cracking clay soil, and red hard-setting soil (Source: Waterpac)

LEFT	**RIGHT**
Black cracking clay	Black cracking clay
LEPA Bubbler	LEPA Bubbler
80 mm soil deficit	30 mm soil deficit
50 mm application	30 mm application
Irrigation water rapidly infiltrates the soil to depth, indicating flow through cracks. Soil in the non-watered furrow is also rapidly filled demonstrating the rapid redistribution of water throughout the profile.	This irrigation was applied 24 hours after that in the previous image. Irrigation stays near the soil surface as the deficit was now much lower and the cracks were closed. Water still moves through the plant line to the non-watered furrow. Some extraction of water at depth.

An Australian report “More Profit Per Drop” (Harris et al, 2013) found that low pressure static plate systems where achieving 80-90% application efficiency, moving plate systems up to 95% efficiency and bubbler type systems where getting up to 98% efficiency when runoff was controlled.

Although finding different levels of efficiency from sprinkler applicators both Harris and Glodt found that application efficiency increased when a more concentrated stream of water was applied closer to the ground, provided run-off was controlled.

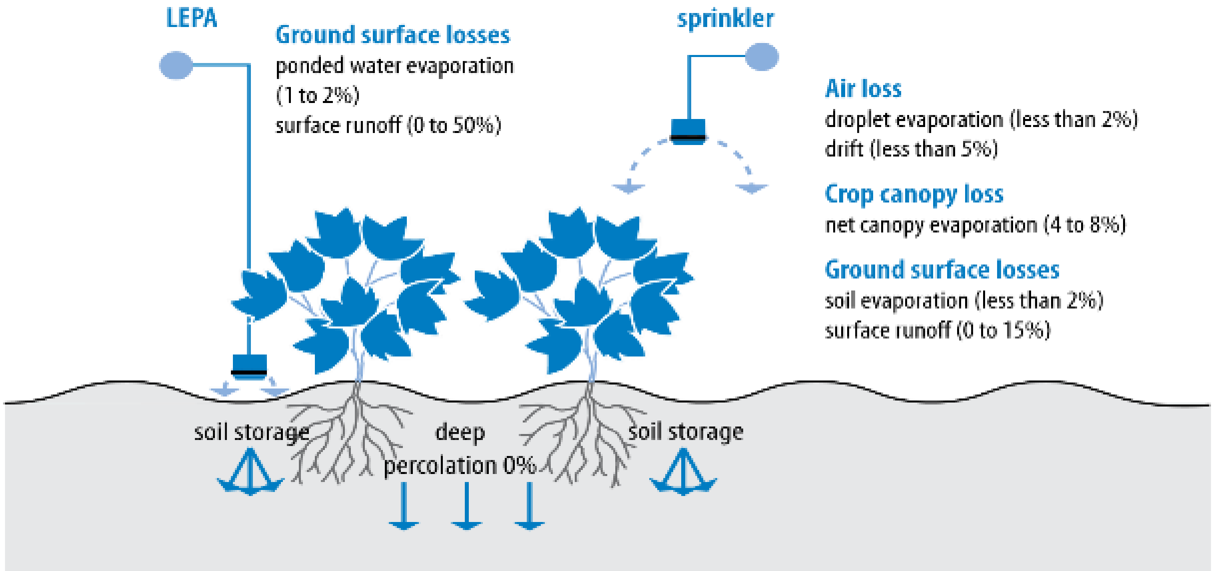

Figure 17: Pathways for water losses (Source: Schneider 1999)

There is a compelling argument for using bubbler and LEPA type emitters rather than fixed plate sprinklers, because of the increased efficiency in getting water into the ground provided surface runoff was avoided. In a typical cotton season in the Macquarie Valley around 800mm of irrigation water will be applied per ha. The information above shows that using LEPA emitters over static plate sprinklers will deliver at least an 10% increase in water reaching the soil profile, a volume of 80mm/ha of extra water. At a conservative water use efficiency of one bale of cotton per 100mm applied, this would lead to an increase in yield of 0.8b/ha and an increase in profit of around $400 per ha after accounting for extra ginning costs. This concurs with farmer Glen Schur's findings of around a $370/ha benefit.

2.4 Wheel tracking

Wheel tracking is a serious issue in cotton crops grown under sprinkler irrigation, with 64% participants of a survey run by Smith et al (2005) experiencing wheel rutting and bogging. Wheel tracking refers to the creation of large wheel tracks and ruts from the machine running on wet soil while it is irrigating. Foley (2000) found that three times the amount of water was applied around the wheels because of the intersection of the water spray with the tower structure.

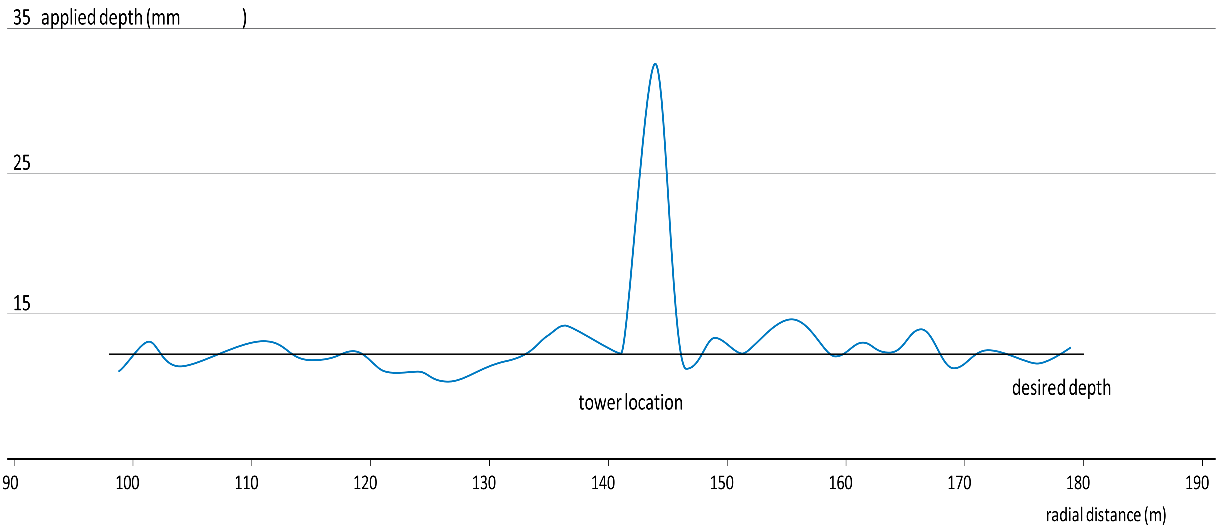

Figure 18: Application rates of water around towers (Source: Foley 2000)

Wheel ruts lead to water accumulation and bogging, and effect the steering of lateral move irrigators. These factors lead to machine shut down in minor cases and structural damage and lengthy breakdowns in severe cases. Machine shut downs lead to increased labour requirements and reduce the capacity of the machine because of reduced running time impacting on yields and profitability. Experienced operators of CPLM systems that we visited overseas and in Australia believed that prevention of wheel tracks was better than cure, with the main catch cry of "keep the wheel tracks dry". This is easy in principle but difficult in practice.

Wheel track strategies vary between Centre Pivots and Lateral Move Machines, and these are outlined below.

Centre pivots have some simple techniques to help keep wheel tracks dry. These include:

- The machine walks in a circle, the driest part of the field is immediately in front of it. This is represented in Figure 19, where moisture levels are indicated by the colour blue. The darker the blue the wetter the soil is as the machine travels in an anti-clockwise direction.

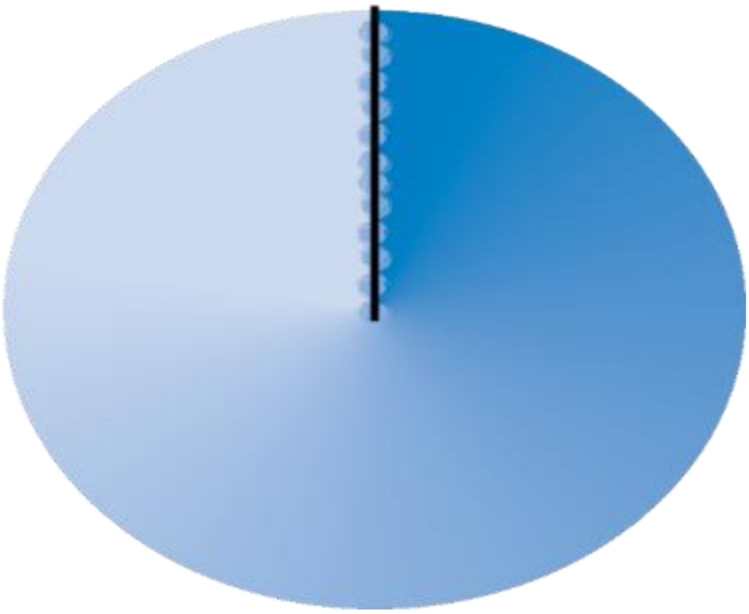

Figure 19: The wetting front of a centre pivot. The darker blue indicates wetter soil

- Ability to use “Boom Backs” which position the sprinklers around the tower 2-3m behind the wheel. This allows the wheels of the centre pivot to remain on dry soil and the while water is being applied behind them.
- Pivots are anchored at the centre end. This means the ability to build small mounds marginally higher than field height to let water run off away from the wheels.
- The use of “half-moon” sprinklers which only spray water away from the wheel track, helping keep it dry.
- Shutting off sprinklers around the wheel track to increase the distance from where water is applied to the wheel tracks.

Lateral Moves. Lateral moves have much more difficulty keeping wheel tracks dry. Many of the tools available to centre pivots is not available to lateral moves. This is because:

- Lateral moves move up and down the field. The means that the wettest part of the field is immediately in front of the machine and the driest part of the field is at the opposite end. This means the lateral move is forced to irrigate through the wettest part of the field to get through to the dryer end. The machine driving through wet soil creates wheel tracks.

- As lateral moves are moving up and down the field, once you change direction the wettest part of the field is immediately in front of you, rendering the use of boom backs useless.
- Farmers are unable to build a mound because the machine will “fall off it”. Lateral moves are not anchored to the ground because they do not have any fixed point. This means that if mounds were built for the machine to run on, the machine would fall off them, leading to continual shutdowns because of steering.
- Tools available for lateral moves include:
    - “half moon” sprinklers that direct water away from the wheel tracks.
    - Shutting off sprinklers around wheel tracks to increase the distance from where water is applied to the wheel tracks.
    - Laser levelling land to let water run off rather than accumulate and pool.

2.5 Machine maintenance and life preservation

Machine breakdowns can lead to severe yield penalties if they occur at critical points in the season. Engineers at the Valmont Industries manufacturing plant supported grower experience and found that any preventable maintenance done preseason could prevent many in-crop problems. Pre-season maintenance will vary between machines, but the most common preventative maintenance Valmont Industries suggested included;

- Checking tyre pressures pre-season. Many growers reported having to roll out replacement tyres on wet ground to the middle of the field to change tyres.
- Checking for water in gear boxes and change gear box oil at recommended intervals.
- Fill in old wheel tracks from previous seasons.
- If using fertigation, ensure the machine is sufficiently flushed with fresh water to reduce pipe rust.

Chapter 3: Irrigation

Although the water requirements of a fully irrigated cotton crop will not change regardless of irrigation method, irrigation scheduling is very different. Fortunately, the tools growers already use and are available are also suitable for sprinkler irrigation.

3.1 Irrigation scheduling. What tools are available to help growers?

Cotton growers already use a range to tools to schedule irrigations of their cotton crop. The use of capacitance probes and neutron meters have been the most common form of irrigation scheduling in the Australian cotton industry (Onoriode & Brodrick 2015). Capacitance probes are permanent probes which measure the ability for the soil to store a charge (or its dielectric capacitance) to determine water content of the soil throughout the season (Foley 2015). Through online portals, the probes give growers a visual representation of how the soil moisture is changing in the field during the growing season. Growers have continued to use this technology to help schedule irrigations in sprinkler irrigated cotton, however newer technology is becoming available.

As the name suggests canopy temperature sensors are cameras which measure the temperature of the canopy of a small number of plants within a field. They were developed by Dr James Mahon, a plant stress pathologist with the USDA based in Lubbock Texas. Research by Dr Mahon indicates that cotton becomes moisture stressed once the canopy temperature exceeds 28 degrees Celsius. Dr Mahon told us during our visit that “well-watered cotton will keep its canopy temperature below 28 degrees Celsius, and will happily cool its canopy 10 degrees below ambient temperature”. Canopy temperature sensors only take measurements from an area about one square metre, just 0.0002% of a 50ha field per sensor. Therefore, like capacitance probes, extreme care must be taken to place canopy sensors in representative parts of the field to give better representation.

A trial in 2015 conducted by Onoriode Coast and Rose Brodrick of CSIRO Narrabri (which included a crop the author was growing), found that “there was a significant linear decrease in yield the longer the canopy temperature exceeded the optimum”. This is linear relationship is highlighted in Figure 19 of a chart created by Onoriode (2015). “Increasing the average daily time a crop canopy exceeded the optimum temperature required for crop development, growth and yield seemed to incur a yield penalty” (Onoriode Brodrick 2015)

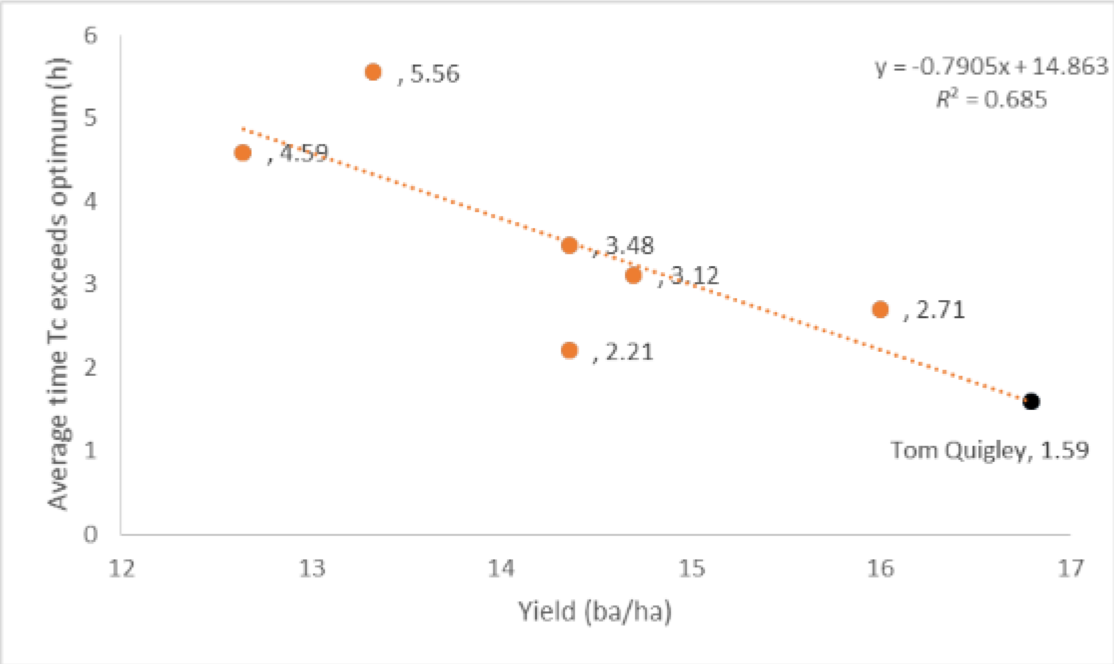

Figure 20: Relationship between Cotton yield and average time the canopy is above optimum temperature (Source: Onoriode, 2015)

There is a significant future for remote sensing of canopy temperature and tailored variable rate. A private company, Smartfield, located in Lubbock Texas, was at the time of the authors visit testing a stationary canopy temperature sensor capable of taking field size images from a centre pole instillation. Chief Operating Officer Joel Hohnberger outlined that by taking a field sized image, a more detailed and accurate picture is created than obtained by using the original smaller cameras. More detailed data allows for better management decisions by growers, which leads to greater yields and better water efficiency. Field size was a limitation of the system, with ranges from the centre being only 150m and cost was prohibitive, however the technology is advancing quickly.

The future of this technology ideally would be based on a self-docking autonomous drone which would take images of the entire field throughout the day. This would give growers access to a platform to create variable rate irrigation maps. Variable rate systems are already available for sprinkler irrigation systems. They function through a combination of ground speed and individual sprinkler valves to give an infinite number of water application rates. Prescription applications of water to a field could reduce overall water use without effecting yields, leading to greater water use efficiency and increasing profitability.

3.2 Irrigation scheduling – what does sprinkler irrigation look like, compared to traditional furrow irrigated systems?

Sprinkler irrigated cotton has a different irrigation pattern to traditional tillage furrow irrigated cotton when observed on a capacitance probe graph. Furrow irrigated cotton requires a much higher application rate than sprinkler irrigation, with furrow irrigation usually applying anywhere between 80 to 120 mm of moisture. At an evapotranspiration rate of 10-12mm per day this is enough water for the crop to survive eight to ten days before the next irrigation is required. The amount of water that can be applied using sprinkler irrigation applications is generally limited by the infiltration rate of the soil. This means that water application must be matched to soil infiltration rates to avoid runoff and increase water use efficiency. The application rate will change between soil types, but generally growers like to apply 15-30mm in any one application. Therefore, a cotton crop under a sprinkler irrigation system is likely to be irrigated three times while the conventional furrow irrigated crop would only need one irrigation during the same period. These quicker irrigation cycles are contrasted to furrow irrigation in Figure 21 below, with the broken line indicating the furrow irrigated crop and the two solid lines showing a sprinkler irrigated crop under common and improved irrigation scheduling.

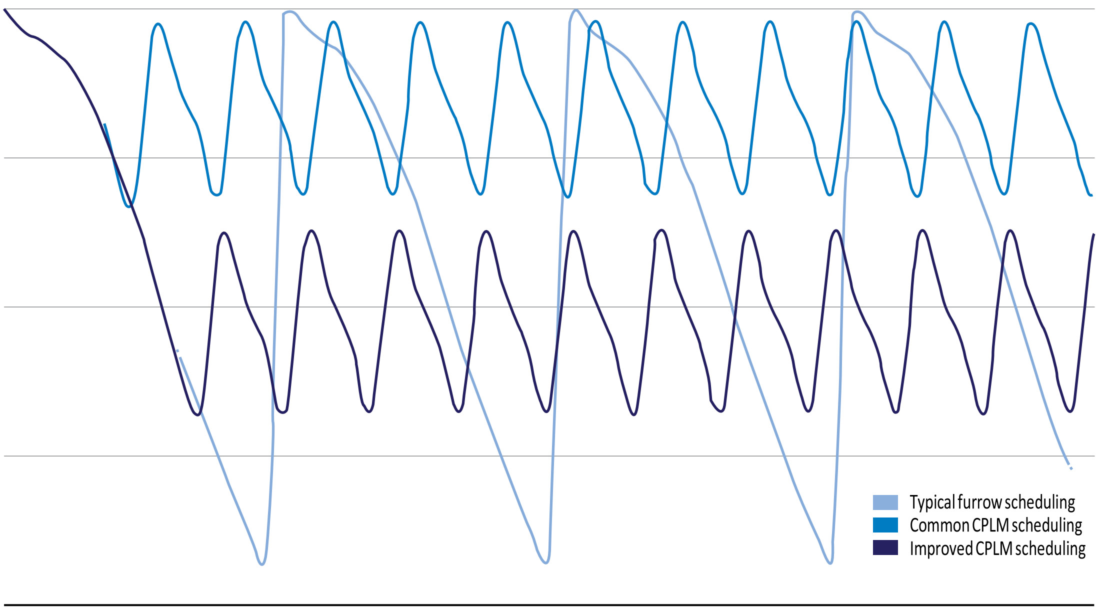

Figure 21: Contrast between traditional furrow irrigated crops compared to sprinkler irrigation (Source Foley et al, WaterPac 2013)

Chapter 4: Tools required for growing cotton under sprinkler irrigation

Specialised tools are not compulsory, but do help in the success in growing cotton under sprinkler irrigation. Strip tilling, precision planter aftermarket modifications, auto steer and dual drive root cutters all compliment the farming system and help to result in a successful crop.

4.1 Strip tilling

Growing minimum till cotton on the flat, with heavy stubble retention is a completely different approach to full tillage' conventional cotton farming systems. Zero till farming systems works quite well in dryland winter cropping programs, however it imposes many challenges in a cotton farming system. Preparing a fine seed bed, applying fertilizer, trash in the plant line and cooler soil temperatures at planting impose challenges on a minimum till, retained stubble, cotton farming system.

Strip Till Farming refers to the practice of cultivating a concentrated strip of soil on the intended plant line. In conventional one metre cotton row spacing, the 25cm plant line is cultivated, while the remaining 75 cm inter-row area is untouched, and remains zero till. As shown is Figure 22, a strip till machine comprises of a leading coulter disk, two angled trash whippers, a shank, two wavey coulters, and a rolling basket.

Figure 22: An Othman "1tRIPr" strip till machine (Source Orthman)

Strip-tilling combined with RTK GPS technology has a strong fit in minimum till, residue retaining cotton systems and has the ability to overcome many of the challenges presented. A strip-tiller performs four tasks in one pass, with each stage of the machine having individual importance. The stages are:

1. **Front coulter disc and trash whippers**. The front coulter disc cuts through thick residue loads and trash whippers move trash from the plant line. This is important for two reasons. The first is that it eliminates hair pinning at planting time, giving improved plant stands. The second reason is that it creates a bare strip of soil, which warms more quickly than stubble covered soil. Warmer soil temperatures at cotton planting mean quicker emergence, and higher seedling viability.
2. **The Shank**. The shank on a strip till performs two important tasks. The first is a precision ripping pass directly below the plant line with the ability to penetrate up to 30cm. The second is applying fertilizer at any depth up to 30cm.
3. **Wavey coulters**. The wavy coulters run on a very fine angle which throw loose soil onto the top of the plant line creating a "berm" (a small raised bed) and a fine seed bed.
4. **The Rolling basket**. The Rolling basket firms the seed bed and breaks down any large clods, leaving a smooth base for precision planter units to run, giving better seed placement and better germination (Kimberly 2015)

The combination of removing the trash from the plant line, ripping and adding fertilizer below the plant line, building and firming a fine seed bed. This means quick and efficient ground preparation using a strip-till compared to traditional furrow tillage situations which would require listing, fertiliser application, clod busting and rolling passes to achieve the same job. It also means that ground can be quickly prepared if irrigation water suddenly becomes available late in winter. Figure 23 shows cotton ground preparation occurring in a winter cereal crop because irrigation water became available late in the season. The cereal crop was sprayed out and provided excellent cover for the emerging cotton.

Figure 23: Preparing a fine seed bed in the plant line in a cereal cover crop using an Orthman Strip Tiller (Source: Author)

4.2 Advantages of strip tilling over zero till systems

1. **A superior seed bed**. A very fine seed bed is of the highest importance when growing cotton. This is because planting seed size has decreased as new higher yielding cotton varieties have been bred. Cotton varieties of the 1980's contained 9,000 seeds per kilogram, while modern varieties have around 12,500 seeds per kilogram, a 40% reduction in seed size. Seedling vigour has also decreased because of the decrease in seed size, as there is less energy contained in a smaller seed relative to a larger one. Soil preparation has increased in importance to achieving a viable plant stand because

of the smaller seed and this makes direct drilling cotton into thick stubble challenging. This is because trash can be pushed into the seed trench, resulting in poor seed-soil contact and poor germination, gaps in plant stands and ultimately poor yields. Strip-tilling gives the best of both worlds, retaining cover, but also preparing a fine seed bed for good seed-soil contact and better germination than a zero till situation.

2. **Precision ripping and deep placement of phosphate fertilizer**. Surface phosphate fertiliser (P) banding beneath or beside the seed is usually considered the most effective way of applying P fertilizer in the Australian cotton industry (Wang 2009). Zero till systems use a disc to apply seed and fertilizer, but are limited in application depth to the top 10cm of soil. Surface-applied phosphate fertilizer has regularly shown a low responsiveness on soils which have low phosphate levels (Bronson et al. 2001). This has been attributed to decreased availability of phosphate in rapidly drying soils (Nye and Tinker 1977), conditions which a cotton crop experiences regularly. Regular drying in the topsoil encourages deeper root growth, with root density being greatest in the 10-20cm soil zone, and least in the surface layers (Brouder and Cassman 1990). Research conducted in 2005 suggested that seed cotton yields increased by 17-67% when P fertilizer was applied at depths of 10-15cm and 25-30cm compared to when it was applied at the regular depth of 7-10cm (Singh et al. 2005). Wang et al (2005) summarised "Deep P placement is effective in increasing cotton yield under field conditions possibly because of an enhanced contact between root and fertilizer during the later stages of growth, and also a sustained P availability under periodic surface drought conditions". He went onto say that "tap-rooted crops such as cotton with a relatively higher proportion of roots in the subsoil were superior in accessing immobile nutrients like P from the deeper soil layers and at a later growth stage". Soil P pools beyond the fertilizer band showed a significant contribution (more than 90%) to the total P uptake by cotton (Dorahy et al. 2008). Utilising the shank on the strip till machine, phosphorus fertilizer could be applied at greater depths of up to 30cm, which could increase the contact of roots with phosphorus. The research indicated this would increase the effectiveness of the phosphate fertilizer.
3. **Quick and efficient ground preparation**. Strip tilling rolls four traditional field passes into one pass. This delivers greater efficiency through reduced tractor requirements and associated diesel, labour and maintenance costs. One pass ground preparation

also means growers are more flexible and able to capitalize on opportunities more easily than traditional furrow irrigated cotton.

4. **Bare seed beds**. The strip-tiller clears trash from the plant line prior to planting, allowing the soil strip that cotton seed is going to be planted into to warm up, unlike zero till type system. This means being able to plant earlier in the sowing window, which results in increased seedling vigour.

4.2 Planter set up in strip-tilled cotton

Cotton is planted with precision vacuum planters, to ensure uniform seed placement down the row which is very important for growing high yields of cotton. Existing cotton planters used to plant cotton on traditional beds are suitable to plant cotton onto min till, strip till cotton situations with some minor modifications. In a presentation to the 2015 United States National Strip Till Conference, Kevin Kimberly, a farm tillage consultant, outlined the most important planter modifications for population dependent crops like corn and cotton. The modifications included:

- **Down pressure**. Full tillage cotton beds are usually very soft and the weight of the planter unit is enough to keep the depth wheels in contact with the surface of the bed. Excess down force usually results in the planter unit "bulldozing" apart the soft bed. In min-till strip till situations where the ground is much more consolidated, down pressure is required to ensure that the planter unit is in contact with the soil surface to resulting in more accurate and even seed depth, giving better germination.
- **Walking depth beam**. Precision planters use two depth wheels that run on the soil surface and determine planting depth. Some brands of planters with a rigid depth bar take the depth from the highest gauge wheel, while others use a "walking beam" and take the depth as an average of the two depth wheels. The units with the rigid depth bar cause uneven seed depth, because when one depth wheel rides over a bump, it lifts the whole unit, planting shallow seeds which dry out faster and struggle to germinate. The walking beam planting unit allows the planter to more accurately follow the soil surface, which in turn gives a more accurate seed depth relative to soil surface leading to better germination.

- **Narrow gauge wheels**. After-market, narrow gauge wheels will also improve seed depth accuracy because the narrow wheels will more accurately follow the soil surface close to the plant line rather than the standard wide gauge wheels which can ride up over bumps not adjacent to the plant line.
- **Trash whippers**. In heavy stubble loads without a strip-tilled clear path hair pinning can occur. Hair pinning refers to straw being folded into the seed trench rather than being cut. Hair pinning causes poor seed soil contact which reduces germination and results in poor plant stands and reduced yields. Trash whippers are two discs with fingers that move straw away from the plant line, eliminating hair pinning. After market trash whippers are readily available and easily bolted onto existing cotton planters and easy to use.

4.3 RTK Auto Steer

Real Time Kinematic (RTK) Auto steer with 2cm accuracy and repeatability is an absolute prerequisite for strip till farming cotton under sprinkler irrigation. Using the strip tilled method of field preparation, precision strips are laid out where the rows of cotton will be planted. The accuracy of RTK Auto steer is required to ensure that the cotton planter units will run exactly on top of those strips during planting to get the full benefit of the prepared seed bed and fertilizer buried below the plant line.

4.4 Crop destruction, root cutting, and preventing ratoon cotton

Cotton is a perennial plant grown commercially in an annual fashion. This means that any cotton plants not destroyed after cotton picking will grow back the following spring. Cotton crops are shredded using a flail mulcher in Australia after cotton picking. The mulcher chops the bush up into small pieces and leaves a 10-15cm stalk protruding from the soil surface. This stalk will regrow when temperatures rise unless the root is cut from the stalk below the growing point. Root cutting is performed by a tool with two rotating disks coming together and intersecting, with the root being cut at the point of intersection, as shown in Figure 24.

Figure 24: A Cotton Root Cutter (Source TTQ Agricultural Equipment)

Root cutting is a standard operation on in traditional cotton growing systems, because the plant is on a raised bed. This means that the root cutting discs only engage the soil close to where the root is situated, close to intersection of the discs. On raised beds the discs have plenty of clearance for soil and trash flow to fall into the furrow, meaning the discs are clear and run without blocking.

Figure 25: Cotton plants after root cutting

Root cutting is more difficult for cotton on the flat. This is because the discs have to penetrate through much a larger amount of dirt to cut the root. Darling Downs farmers Daniel Hayllor, David Walton and 2015 Nuffield Scholar Matt McVeigh were interviewed after cotton picking in April 2016. They commented that using dual hydraulically driven root cutters with high trash clearance will successfully cut cotton stalk on the flat. They also advised that root cutting alone would not control ratoon cotton, and advised an additional tillage pass, with a shank or knife was needed to disturb the tap root and sever individual roots to ensure the plant did not grow back in the spring.

Australian Cotton Grower of the Year Jamie Grant from Dalby, and 2011 Nuffield Scholar Rob Blatchford from Gurley, both grow dryland cotton in a strict minimum till, controlled traffic farming system on the flat. Both leading growers have abandoned root cutting in their farming systems and instead rely on a horizontal shank to physically sever the taproot, and lateral roots, to prevent ratoon cotton. Both farmers think it’s a simple system and are happy with its results. They commented that they would continue this tillage pass to control ratoon cotton even though the tillage pass was not required for pupae control in Bollgard III cotton crops.

Figure 26: Jamie Grant's "knife system" to cut and dislodge cotton root systems (Source: author)

Figure 27: Rob Blatchford's slasher and shank system to dislodge cotton root systems (Source: author)

Jamie Grant has also trialled spraying a narrow band of herbicide over the plant line at mulching, however after three seasons has abandoned that line of ratoon cotton control. Jamie stressed tillage was still required to remove or destroy the main root to ensure re-growth does not occur.

Conclusion

Cotton can be grown successfully under CPLM machines and deliver improved water use efficiency and higher yields than conventionally grown cotton, however farming systems will have to be altered to achieve these results.

Introducing ground cover into cotton growing systems requires a new farming system to traditional full tillage raised bed farming systems. Minimum Till Cotton grown on the flat has a fit in CPLM sprinkler irrigation systems, when combined with precision strip-tilling. Strip tilling is a four in one tool which to create a fine seed bed, remove stubble cover from the plant line, reducing hair pinning and increasing soil warmth, precision rips and applies fertilizer at up to 30cm depth, all while leaving ground cover between rows untouched.

Ground cover in the form of plant material must be introduced into the farming system to help emergence, protect seedling cotton, and increase water infiltration and delay evaporation. Ground cover can be carried over from previous cereal crops or specific cover crops can be grown to provide cover. Further research is required to fully understand the economics of both options.

Sprinkler selection will determine the performance of a CPLM machine, with LESA and LEPA type sprinkler packages delivering the most efficient transfer of water from the emitter to the ground provided run off was controlled.

Machine maintenance is of the upmost importance with their being zero capacity to irrigate the cotton crop when the machine is broken down. Pre-season maintenance, regular servicing and carrying of spares is recommended to make sure that the machine is operational when required.

Zero till cotton is now possible with Bollgard III technology, however post-harvest tillage may still be required to eliminate ratoon cotton the following spring. As yet, a 100% kill from chemical options over the plant line has not been found. Root cutting on the flat is difficult, with modern dual drive hydraulic root cutter required in on the flat cotton growing situations, but it does help control ratoon cotton.

Wheel track prevention is key to a hassle and stress free irrigation season. Growers need to avoid wheel tracks at all costs because they encourage water accumulation, leading to bogging and potentially structural damage. There are a range of tools available to growers using both lateral move, and centre pivot irrigation systems.

Recommendations

- Further trial work needs to be completed to demonstrate the economic implications of retaining ground cover in the form of stubble from previous crops or growing designated cover crops in irrigated situations. Specifically, this research should be designed to answer the question “will *the moisture used to grow a designated cover crop be economical with the irrigation water used to replace this moisture costing $300 per mega litre.”*
- Canopy temperature sensing on commercial field size needs to be developed, and coupled with variable rate irrigation ability on CPLM machines to further drive water use efficiency.
- Sprinkler Irrigator groups need to be developed within the Australian cotton industry. The Macquarie valley have started a group for growers to share ideas and help each other, this could be expanded to the whole industry.
- Development of better delivery systems of water from the sprinkler to the soil surface. More specifically trialling the dragging of drip tape delivering water to the soil surface from under a sprinkler irrigator.
- Development of improved herbicide options for the control of ratoon cotton after crop destruction in the following spring.
- Cotton varieties with increased yields and water use efficiency need to be continuously developed.
- Herbicide resistance is a serious issue that could threaten the Australian Cotton industry. Herbicide rotation is key to the sustainable use of Glyphosate in cotton growing system. The industry should consider cultivation and layby residual herbicide use in conjunction with Glyphosate to prevent herbicide resistance developing.

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Plain English Compendium Summary

Project Title:	**Growing Cotton Under Sprinkler Irrigation**
Nuffield Australia Project No:	1502
Scholar:	Tom Quigley
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Objectives	• Visit successful farmers currently utilizing sprinkler irrigation to achieve high yielding and highly water efficient crops. This included California, West Texas, and the Midwest of the United States, Mexico, Canada, Israel, Brazil, and Australia. • Understand key elements these farmers employed to grow successful crops under sprinkler irrigation. • Use these farmers experience to accelerate the learning of Australian cotton growers who have recently employed sprinkler irrigation to grow cotton. • Report back to the Australian cotton industry and support growers who may choose to install sprinkler irrigation in the future
Background	Furrow Irrigation has almost been exclusively used to irrigate cotton in Australia since the industry was born. The Murray Darling Basin Plan provided incentives for farmers to swap irrigation water rights for water saving infrastructure. Farmers in the Macquarie Valley, including my own family, invested heavily in water-saving infrastructure, primarily as overhead sprinkler irrigation systems in the form of Centre Pivots and Lateral Moves (CPLM). These new, capital and energy intensive forms of irrigation did not deliver the promised results of increased yields and reduced water input using existing full tillage furrow irrigated farming methods. It was obvious that farmers would have to change techniques in order to achieve better yields and water-use efficiency in the future.
Research	Investigate farming systems that compliment growing crops under sprinkler irrigation. Research was conducted by visiting farmers and researchers already successfully growing efficient high yielding crops utilising sprinkler irrigation in America, Mexico, Brazil, Canada, Israel, New Zealand and Australia.
Outcomes	Cotton can be successfully grown under sprinkler irrigation however a radically different farming system greatly aids this success. Adopting groundcover, minimum till, strip tilling, and correct sprinkler packages has greatly aided in increasing yields and water use efficiency.
Implications	This report forms a guide as the farming system successful farmers have grown high yielding and highly water efficient crops. It also provides a base level of understanding to growers considering installing sprinkler irrigation.