Turning water into cash flow

Sustainable high yields from continuous double cropping with centre pivot irrigation

A report for

by Adam McVeigh

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Executive Summary

Many regions around the world practice double cropping. China has been successfully double cropping irrigated wheat and corn for 40-50 years, showing that it can be sustainable over long periods. Brazilian farmers are currently double cropping, with excellent yields but the tropical climate and cropping frequency are putting the system under constant threat from pests and disease. This highlights the need to manage the available genetic and chemical pest/disease control technology wisely to prevent the build-up of resistance.

This report investigates double cropping systems (two harvests in one year) which are irrigated by centre pivot, with consideration to long term sustainability. The aim is to provide information that will assist farmers with a low risk capacity to plan their cropping rotation in order to achieve sustainable high crop yields and high return per megalitre (ML) of applied water. Double cropping systems provide biannual income and typically have lower and more evenly spread input costs. The concept behind this double cropping system is to lower the financial risk associated with crop loss from natural disasters like flooding. With this in mind, the crop that presents the biggest gross margin may not necessarily be the best option for a business with a low risk capacity.

This report informs readers of some of the key considerations for designing centre pivot irrigation infrastructure, and also some practical farming techniques that aid in achieving maximum yield potential. It also outlines the importance of understanding risk capacity and the impact that this should have on crop rotation choices.

Careful planning that starts with the initial design of an irrigation development is crucial to achieve the highest yields and lowest input costs which ultimately lead to the highest financial return per hectare. Poorly designed systems will limit the cropping options and potential yields, and can also increase operating costs. Employing an experienced consultant to help identify potential design or management issues during the planning phase, will be significantly more cost effective than trying to rectify poor designs after installation.

Producing continuous high yields with double cropping can be sustainable providing the centre pivot irrigation system has been designed well. Farmers must consider their exposure to risk,

gross margins, residue management, nutrient management, integrated pest management, equipment and its proper operation.

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Foreword

In 2010 and 2012 my irrigated farm in the South Burnett was inundated with record breaking flood levels. To minimise the devastating financial impact of crop loss and farm damage from flooding in the future, I have been developing a resilient cropping program and irrigation system. My goal is to achieve a sustainable rotation that is not only 'financially safe' but that is also the most profitable. A Nuffield Scholarship has provided me with the ideal opportunity to further research and develop this system.

The cropping program to date has consisted of growing two grain crops annually under centre pivots, mostly Barley or Wheat during the winter and Corn during the summer. Part of this strategy is for risk management in the case of a natural disaster such as flooding destroying a crop. Double cropping provides income from the other crop grown in that twelve-month period and reduces the turnaround time after a flood event. This report looks at crop rotation considerations for centre pivot irrigated farmers with a low risk capacity.

I have been growing cotton and grain all my life, and irrigation is where my passion lies. Historically I have used flood furrow irrigation but in recent years have converted to overhead irrigation due to the appeal of water and labour savings and flexibility in paddock management. My farms are located near Dalby on the Darling Downs and Murgon in the South Burnett. All of the irrigation has been redeveloped from flood irrigation, travelling irrigator or side roll irrigator, and now consists of four centre pivots and one lateral move. The conversion was expensive and it is important to utilise the new infrastructure to achieve maximum value from the applied water in order to justify the change. My research looks at cropping techniques, considerations that farmers make when choosing rotational crops, as well as the design and operation of centre pivots.

The extraordinary opportunity presented by a Nuffield Scholarship has allowed me access to agricultural leaders, researchers, farmers, educators and other networks around the world. Experiencing the vast cultural differences has been incredibly enriching and the journey as a whole has provided huge personal and professional development. Throughout my travels abroad I visited England, France, Belgium, USA, Germany, Czech Republic, Poland, Kenya, South Africa, Brazil, Canada, China and Hong Kong. Not only have I researched cropping systems and overhead irrigation but I have also gained an excellent insight into the diversity of agriculture and the people involved in the industry right across the globe.

Acknowledgements

I would like to thank Nuffield Australia for awarding me with this amazing scholarship opportunity. The Scholarship has provided me with the sort of experience that money simply cannot buy! That being said there is a significant financial cost to travel abroad to meet so many incredible people, and I would like to thank GRDC for the investment that they have made in Nuffield and myself.

Between my Nuffield travels, work and a two-week family holiday, I spent more than six months away from home over a 13-month period. While I was away, my wife Edwina was taking care of our two young daughters Paige and Annie whom were four and two years old at the time, and I'd like to thank her for supporting me in this epic endeavour.

Throughout the journey so many people have generously contributed to the overall experience, and I will be forever grateful. I would like to particularly thank Sally Thompson (Brazil) and Professor Weili Liang (China) for their assistance in organising, translating and accompanying me in Brazil and China.

So much planning goes into each and every stage of a Nuffield scholarship and I would like to acknowledge and thank everyone working in the organisation and also all of the numerous investors.

Abbreviations

NCP	-	North China Plain
ML	-	Megalitre
$/ML	-	Dollars per Megalitre
N2O	-	Nitrous Oxide
CPLM	-	Centre Pivot and Lateral Move
CP	-	Centre Pivot
VRI	-	Variable Rate Irrigation
NCEA	-	National Centre for Engineering in Agriculture
EM 38	-	Electromagnetic-induction meter
N	-	Nitrogen

Objectives

The objectives of this project were to research management practices of farmers using overhead irrigation, in particular:

- To research overhead irrigation infrastructure in Brazil, South Africa, the United States of America and Australia.
- To investigate double cropping systems in Brazil, China, South Africa and Australia.
- To investigate the sustainability of continuous double cropping systems in China and Brazil.
- To provide information that will assist farmers with a low risk capacity to plan a high yielding double crop rotation for their centre pivot irrigation.

Chapter 1: Introduction

As human civilization evolved from a nomadic hunter-gatherer culture towards an agrarian society, it developed permanent residences, began to domesticate animals and cultivate plants. Since the first crops were grown, agriculture has continued to develop throughout the ages. One of the oldest and most significant of these developments has been the technology of irrigation. This allowed for the provision of water to crops by artificial methods when seasonal conditions did not meet the needs of plant growth.

The first successful efforts to control the flow of water for irrigation purposes were over 4,000 years ago in Mesopotamia and Egypt (Bazza, 2007; Dellapenna, 1996; Childe, 1950; Mays). This early irrigation relied on the flows of the river to bring water and nutrients to the alluvial areas adjacent to the river, which could then be planted with crops. Depending on the river, this method was unreliable and fraught with problems such as timing and crop destruction (Bazza, 2007; Dellapenna, 1996; Childe, 1950; Mays). Irrigation methods in agriculture have come a long way since then but the basic goals remain the same; to improve production by applying water to crops in addition to natural rainfall.

In Australia, irrigation for the purpose of growing crops was introduced by European settlers with the earliest reports dating back to the 1820s, with large scale irrigation schemes commencing in the 1880s (National Irrigators Council). Today, in Queensland, the gross value of irrigated production is about $3 billion and accounts for one third of the gross value of the state's agricultural production (DAF Qld, 2015). This is produced on approximately 500,000 ha by 7,600 irrigators, using about two million megalitres (DAF Qld, 2015).

The last two decades in particular have seen massive innovation and advancements in irrigation practices in Australia. This has been driven largely by reduced water availability, due to the effects of drought, increasing environmental demand and legislative changes. These pressures have driven farmers to explore methods of improving their production systems and management, with the aim of achieving maximum profitability per ML of water applied. The popularity of centre pivot and lateral move (CPLM) irrigation systems has increased significantly during the last decade. In 2013-2014, a massive 61,000 hectares of Queensland's irrigated land was under CPLM systems (DAF Qld, 2015). The two leading factors driving the adoption of CPLM systems have been labour savings and water savings (Smith *et al.*, 2014).

- The average water applied by CPLM systems in 2011-12 was 30% less than that applied using furrow irrigation, whilst maintaining similar yields (Smith *et al.*, 2014).
- The median labour requirement compared to furrow irrigation reported for CPs was 25% (Smith *et al.*, 2014).

Smith *et al.* (2014) stated that from 2001 to 2011, CPLMs continued to be favoured by cotton growers for their potential to save water and labour, to maximise rainfall capture and minimise waterlogging and to provide soil health advantages through stubble retention and minimum tillage. Across the world, CP irrigation has become increasingly popular. Of all the states in the USA, Nebraska has the most acres under irrigation and of that area approximately 80% is CP (Johnson, Thompson, G, Van NewKirk, 2011).

Farmers are business people and so they choose to grow the crop that gives them the best financial return on their water. When choosing which crop to grow, farmers will not only evaluate gross margins, but will assess a number of other factors including the risks that their business is exposed to throughout the production cycle. Table 1 lists examples of financial indicators of a business in relation to risk capacity.

Financial indicator	Example of lower risk capacity	Example of higher risk capacity
Debt level relative to asset base (equity)	High debt (low equity)	Low debt (high equity)
Financial reserves and off-farm assets	Small reserves and fewer off-farm assets	Large reserves and substantial off-farm assets
Off-farm income (or the potential for)	Low	High
Income	Volatile	Stable

Table 1: Examples of financial indicators of a business's risk capacity

Source: GRDC, Farm Business Management: Farm Business Risk Management' Factsheet

This report is particularly relevant to irrigators in Queensland and New South Wales where cotton is a popular option. About 1,250 farmers choose to grow the crop as it often provides the best return per unit of water (Cotton Australia, 2016). Cotton is an annual crop that is grown over the summer period and it has a high input cost requirement. In a back to back summer crop rotation, if a crop fails due to a natural disaster (or any reason), the time lag between income events becomes two years. Farmers with a low risk capacity as outlined in Table 1 may not necessarily be capable of relying on a single crop of cotton or similar for income. For these farmers, factors like cash flow may play a more important role when assessing cropping options rather than choosing crops which can potentially return the highest gross margin.

Double cropping (two harvests in a 12-month period) is a common practice in many parts of the world. One of the advantages is the spread of income and risk across the year. If one crop fails due to a natural disaster, there will still be income from the other crop, and the delay after crop destruction to planting the next crop is reduced. This brings the next harvest/income around faster which can be crucial in the recovery from devastating natural disasters.

To maximise the financial return from a CP irrigated, double cropping program, many considerations have to be made regarding system design and management, as well as crop choice and farming system. These are discussed in the following Chapter.

Chapter 2: Overhead irrigation

In Queensland, the agricultural area irrigated by the various systems is divided as follows: surface irrigation around 45%, sprinkler irrigation used on 44%, and micro-irrigation (surface and sub-surface drip, trickle and microspray) on 11% (DAF Qld, 2015). Different forms of irrigation require customised management to achieve the best results. In recent years, there has been a significant increase in the area irrigated with CPLM systems (DAF Qld, 2014). Some of this investment in improved irrigation technologies has been stimulated by on-farm irrigation infrastructure funding programs (Smith *et al.*, 2014).

The focus of this report is specifically on overhead irrigation in the form of CPs. A CP irrigation system consists of three major components:

1. Buried water delivery pipeline and three-phase power cable (or diesel generator).
2. Pump station.
3. Centre pivot.

In the case of a flood, the mainline and power cable, being buried, are to some extent protected, and pump stations can be designed to be flood-proof. The actual CP is the most vulnerable component and there are limited options to protect it but fortunately, they can be insured against flood damage.

Below is a table of some advantages and disadvantages of CPs:

Advantages	Disadvantages
• Insurable against flooding • No channels/earthworks to maintain • High uniformity of application • Easy and accurate method of fertiliser application in solution. • Ability to irrigate marginal/variable soils • Reduced crop waterlogging • Flexibility of irrigation amount applied • Easy to maintain and use • Very low physical labour required • Automation/telemetry compatible • Variable Rate Irrigation (VRI) capability • Ability to irrigate undulating country • Can improve soil structure • Ability to zero till (no need for raised beds) • Less ground preparation than flood irrigation (forming raised beds) • Maximise value from small rainfall events	• Circle in a square paddock leaves corners unirrigated • Pressurised system leads to higher pumping cost • Water needs to be filtered • Setup cost can be high • Bogging issues • Vulnerable to damage from extremely high winds • Not suitable for corrosive water (unless poly lined) • Limitation on maximum area under one circle

Table 2: Advantages and Disadvantages of Centre Pivot irrigation

Source: A.G. McVeigh 2016

Smith *et al.*, (2014) stated that from 2001 to 2011, CPLMs continued to be favoured by cotton growers for their potential to save water and labour, to maximise rainfall capture and minimise waterlogging and to provide soil health advantages through stubble retention and minimum tillage.

2.1 System capacity

The rate at which water can be supplied to the area under CP irrigation is referred to as the system capacity and is expressed in millimetres per day (mm/day). It is the main criterion that the pump, pipes and sprinkler design is based on and is typically between eight and 20 mm/day (Agriculture Victoria, 2007). Figure 1 below provides an example of the daily water use of cotton plants. CPs should be designed so that the system can keep up with the peak crop evapotranspiration rate.

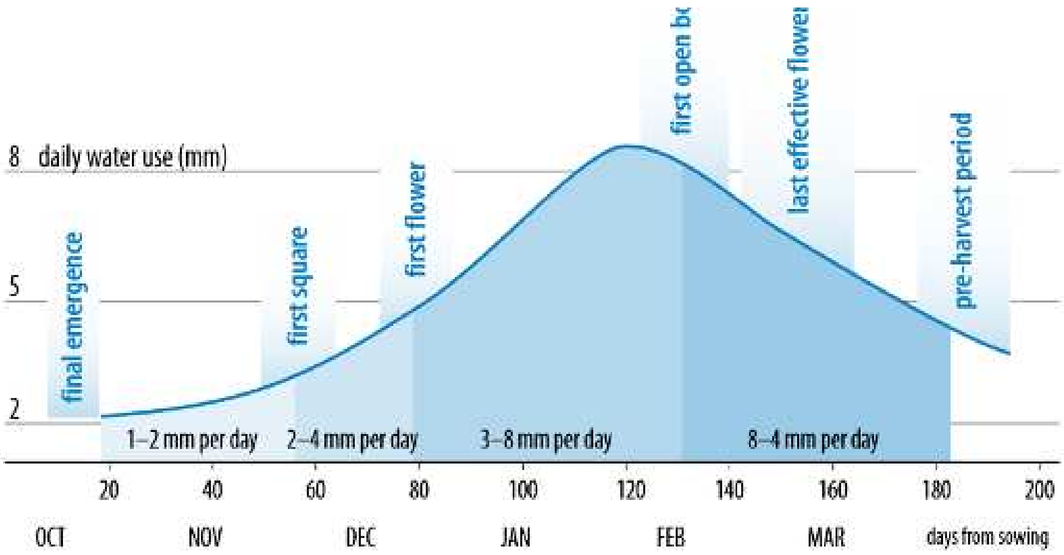

Figure 1: The daily water use of cotton plants

Source: WATERpak, CRDC, 2012

2.2 Infiltration rate

One of the limitations of overhead irrigation is the ability to get large volumes of water into the soil in a single irrigation event. Soil type and the length of the machine play a big role in this.

There are a number of methods of improving water infiltration into the soil:

1. Spreading the footprint of the sprinklers (Figure 2).
2. Retaining a good standing stubble cover is one of the most effective methods of limiting runoff and encouraging infiltration.
3. Instantaneous application rate - Limiting the length of a CP will keep the instantaneous application rate down. Instantaneous application rate is the relationship between

volume of water applied in a given amount of time (eg: 40mm/hr). This relationship increases from the centre point out as nozzle size and speed of machine increases. Smaller nozzles at the centre spend longer in one spot to apply a given amount of water compared to big nozzles on the outer spans that apply a given amount in a short time-frame.

4. Soil health - A good soil structure can be beneficial to water infiltration. For example, high sodium levels may increase soil dispersion and result in sealing of the soil surface.
5. Controlled traffic – Compaction increases the shedding of rainfall/irrigation so concentrating any wheel tracks to designated paths will help with the paddock's overall ability to soak up water.

Figure 2: Spreader bars fitted to increase the 'footprint' of sprinklers

Source: A.G. McVeigh 2016

2.3 Sprinkler selection

The main advantage of overhead irrigation is the ability to apply specific amounts of water per irrigation event as opposed to a flood irrigation system that typically has to fill the soil profile every time a field is irrigated. To achieve this effectively and uniformly, the correct nozzle package is crucial. Every nozzle of a CP takes a different amount of time to travel one full rotation relevant to its distance from the centre point. As a result, the volume of water dispensed needs to increase as the distance from the centre point increases. Installing a nozzle package that is not appropriate will affect the irrigation uniformity across the paddock and can cause bogging issues.

There are a multitude of options for equipping a CP with sprinklers and every situation will benefit from an individual assessment. The factors that will influence the nozzle selection are crop type, soil type, system type, and water and energy needs. The style of emitter can have a large impact on the instantaneous application rate, with a spinner for example covering a larger 'footprint' compared to a static plate which continuously concentrates streams of water onto small areas. Water loss between the nozzle and the ground from evaporation has been a concern for irrigators, but modern sprinkler packages have been demonstrated to have very low evaporative losses, with maximums in the order of 0.5% (CRDC, 2012).

A visit to Nelson Irrigation in Walla Walla, Washington USA, highlighted the high standard in engineering design and precision manufacturing that goes into the sprinkler components. Before the manufacturing stage, there is substantial research program and testing of products with the use of 3-D printers and field-testing of prototypes. Australian farmers need to thoroughly research the varied options in order to choose a nozzle package as this will be a major contributor to the results achieved from centre pivot irrigation.

While the major manufacturers will have solutions for most applications, it can sometimes be an option to customise a homemade solution to achieve the desired outcome (Figure3).

Figure 3: Oregon USA - drag hose with small holes to gently lay the water down

Source: A.G. McVeigh 2016

2.4 Energy Use

The increasing cost of electricity in Australia is having a large impact on the bottom line for irrigated farmers, particularly those that operate pressurised systems like CPs. It is important to consider this when designing CP irrigation. Some of the major considerations are:

- Mainline pipe diameter.
- Pivot span pipe diameter.
- Length of suction pipe to pump.
- Correctly paired pump and motor to flow and pressure requirements.
- Type of valves and bends used between pump and pivot point.
- Operating pressure of the system.
- Changes in elevation across the paddock.

On Australian irrigated cotton farms, pumping water accounts for roughly half to three-quarters of all on-farm direct energy consumption (Figure 4) (CRDC). With this in mind, any improvement in irrigation energy efficiency can significantly reduce the total farm energy bill.

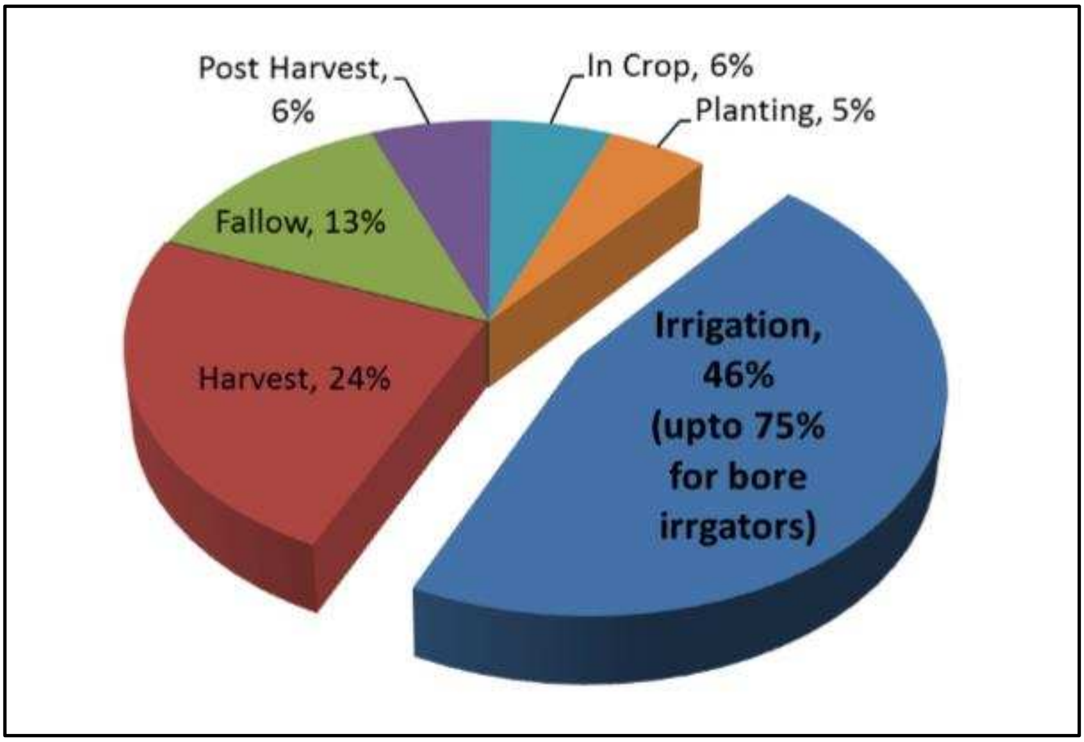

Figure 4: Typical direct on-farm energy use for a cotton grower

Source: Pumping Efficiency, CRDC

Peak oil and an exponentially expanding world population are maintaining strong upward pressure on the price of energy. This is an issue for farmers all around the world. In Brazil, farmers only irrigate for 20 hours / day due to the prohibitive cost of electricity during the four hours of highest energy demand by the large cities. At these times, the cost of electricity is so great that it becomes uneconomical to use for agriculture. (C. Busato, personal communication, July 16, 2016).

2.5 Management of wheel tracks

The management of CP wheel tracks is crucial to limit potential bogging of the irrigator. Any delay in irrigation could have an impact on a crop's yield potential. Typically, a well-designed machine will have a daily application rate that can keep up to a summer crop during peak water demand. Due to the cost of larger pipe and pump combinations and also limitations with infiltration rates it is rare to have a CP with a daily application rate that can provide more than the forecasted peak water demand. This means that if the CP has been stopped, and the moisture deficit of the crop exceeds the system capacity of the machine, it becomes impossible to meet the crops requirements without the help of rainfall.

In some lighter soil types, wheel tracks do not present challenges and the area around wheels is treated no differently from the rest of the paddock. Some soils however require careful management to prevent bogging (Figure 5). Prevention or minimization of wheel ruts is preferable and more cost-effective than dealing with them after they have developed.

Some options for managing wheel ruts are:

- Boombacks (similar to the spreader bars in figure 2 but positioned behind the wheels only, so that the water is placed behind the direction of travel).
- Smaller nozzles around wheels.
- Fitting half-throw sprinklers on solid drops adjacent to each tower.
- No irrigation around wheels.
- Ensuring there are no areas that pond water (Figure 5).
- Filling problem areas with crusher dust or similar.
- Larger wheels and tyres.
- Light irrigation applications.
- Renovating wheel tracks after harvest (Figure 6).
- In crop wheel track renovation.
- Build up and compact wheel tracks.

Figure 5: A bogged drive wheel in ponded water

Source: A.G. McVeigh 2014

Figure 6: Wheel track Renovator

Source: A.G. McVeigh 2016

2.6 To farm in a circle or across the wheel tracks

CP systems irrigate a circle, which covers 78% of a square (Agriculture Victoria, 2015). These circular paddocks present the issue of planting crops in a circular pattern or in straight lines and crossing the irrigator's wheel tracks. Generally, this choice comes down to the farmer's personal preference and often with a theory that works for their operation. Circular planting is done mainly to avoid field operations over wheel ruts formed by the CP irrigator. Reasons for planting in straight rows were for the practicality of field operations, especially harvest (Smith *et al.*, 2014).

Lateral move irrigators have been the preferred option for cotton growers who have converted flood-irrigated paddocks over the last decade or so (Smith *et al.*, 2014). The main reasons for this are the longer and uniform run lengths and no loss of hard to manage dryland areas between circles. While both configurations have advantages and disadvantages, this report focuses on CPs due to:

1. Lower maintenance required, particularly with regard to earthworks and spraying of open channels to control weeds. This is also a major benefit in the case of a flood where water is allowed to flow across the farm freely and repairs to earthworks is generally confined to levelling the paddock so that there is good drainage.
2. Lower labour requirement for monitoring.
3. Suitability for automation.
4. Ability to irrigate undulating paddocks.

2.7 Automation, telemetry and Variable Rate Irrigation

Basic CPs are very easy to automate because they are anchored in the centre and always irrigate the driest part of the paddock. The addition of telemetry means that operating parameters of the machine can be monitored and adjusted anywhere there is internet access. This is a major benefit of CPs with the level of labour required for monitoring only really rivalled by underground trickle tape which has less moving parts.

The use of automation and telemetry can reduce the labour cost involved with irrigating and many irrigators comment on the 'lifestyle enhancement' that comes with the ability to start, monitor, and stop pivots remotely. Additional comfort comes from knowing that if there is an issue with any of the operating parameters that the pump and pivot will stop automatically and there will be no water overflowing from ditches or return water. Automation is essential to take full advantage of the CP's 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 (CRDC, 2012).

VRI is at a point now that customised irrigation maps can be loaded onto the CP controller allowing for individual sprinklers to be turned on or off as required. The cost of additional equipment required for VRI capability including solenoids for each sprinkler can be very expensive and is far more complex to maintain.

2.8 Ability to irrigate undulating paddocks with minimal earthworks

CPs are fed from a pressurised mainline and the water is distributed by a moving piece of machinery, therefore they can irrigate significantly undulating land. In some cases, where the development of flood irrigation would require significant cut and fill, the cost per hectare of installing a CP can be lower than flood irrigation. Despite this, drainage is very important to ensure there is no ponding of water that could cause waterlogging or bogging of the CP. With modern GPS, paddocks can be easily surveyed and processed with programs like Optisurface® or Igrade®. These programs design field layouts with set parameters for minimum and or maximum grade and calculate the smallest possible amount of soil required to be moved.

Flooding can move large amounts of topsoil and for some irrigation systems like flood irrigation where the water is required to run from one end to the other, this can be a major issue to rectify. The major challenge is that immediately after a flood, the soil is completely saturated and extremely difficult to level. An advantage of CP irrigation is that the levelling of paddocks simply requires good drainage in any direction and this can be achieved by moving as little soil as possible. This means the paddock is quickly returned to productivity and cash flow is generated sooner.

2.9 Importance of irrigation scheduling

Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximise crop productivity. Correct scheduling improves water-use efficiency (WUE), reduces waterlogging, controls crop canopy development, quantifies the effectiveness of rain and allows better management of soil structure problems.

Farm managers of CPs continually comment that irrigation scheduling is extremely crucial because if crops are under-watered it is very difficult to 'catch up' to an acceptable level due to the limited daily application rate of the system design. To achieve the best results careful planning and application is necessary, starting with a knowledge of available water supply, potential crop water use and limitations of the irrigation system.

There are many tools available to help irrigators plan their irrigations, the most commonly used method in Australia is a deficit approach (CRDC, 2015). This method utilises soil moisture probes so growers can understand how much water their soil holds and how much is available for crops. Farmers also use:

- push probes to physically measure soil moisture depth.
- weather forecasts.
- visual monitoring of crops.
- EM 38 (Electromagnetic induction-based soil sensing).

Recent advances in sensing and satellite imagery to assess crop stress and spatial variability, are providing new tools to assist in the optimisation of irrigation applications. Plant-based scheduling techniques, such as canopy temperature sensors, can minimize the agronomic (yield and quality losses) and economic (cost of excess water application) risk of irrigation decisions (CRDC, 2015).

Smith *et al.*, (2014), reported that the superior ability of CPLM systems to capture rainfall and the ability to germinate crops with minimal water application were viewed as key features contributing to water savings over furrow systems. The 2011-12 findings indicated that the water savings of CPLM systems were around 30% compared to furrow irrigation systems (Smith *et al.*, 2014). Figure 5 illustrates the pattern of common and improved CPLM irrigation scheduling, compared to flood furrow irrigation (measured using the deficit approach). Note that the CPLM with improved scheduling never reaches the point of field saturation, thus allowing room in the soil profile to capture rainfall at all times.

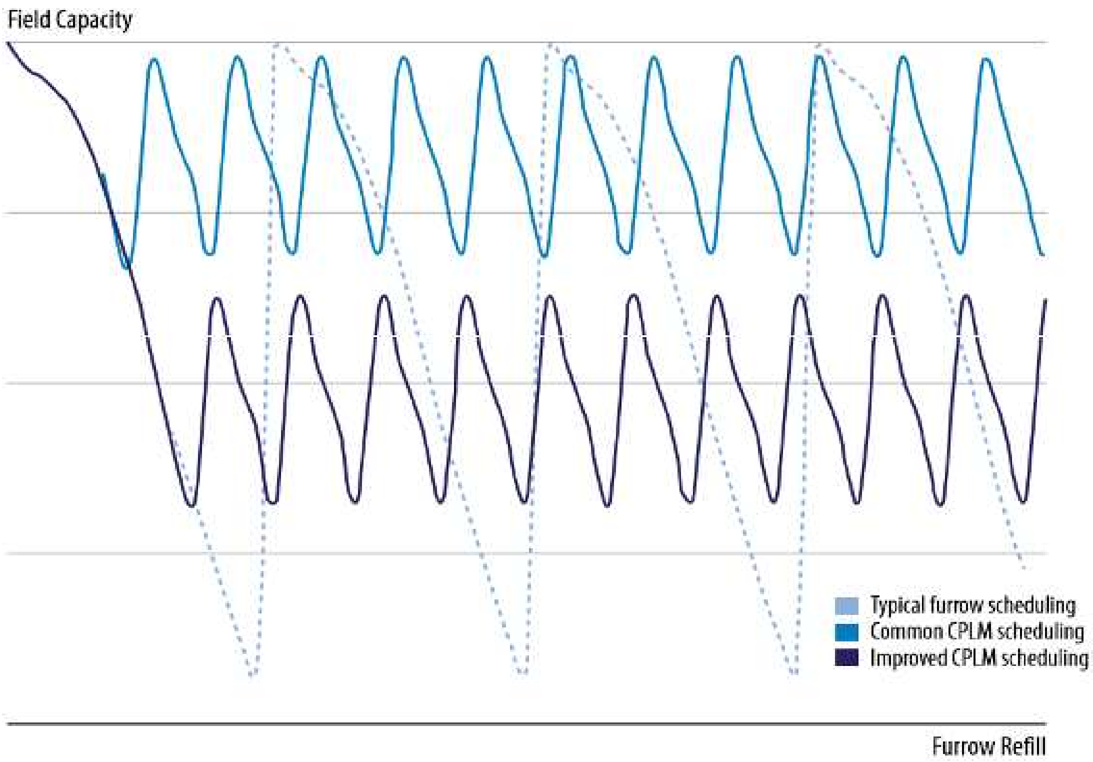

Figure 7: Difference in moisture deficit under furrow irrigation and alternative CPLM irrigation scheduling strategies

Source: WATERpak, CRDC, 2012

Ideally, the last irrigation will provide sufficient water to optimise final yield and quality, and a soil profile that is dry enough to enable harvest without causing soil compaction.

Chapter 3: Crop rotation – double cropping

Rotations can improve soil health by improving and increasing nutrient uptake, sequestering soil organic carbon, improving water infiltration and soil moisture holding capacity, breaking pest and disease cycles, and stimulating microbial activity (CRDC, 2016). A healthier soil requires less synthetic fertiliser and tillage, and forms the basis for providing optimal crop nutrition (CRDC, 2016).

When planning a rotation some of the main cropping practices that should be considered are residue management, nutrient management, integrated pest management, equipment and its proper operation, and many more. Aside from the cropping practice considerations, farmers need to ensure that the combinations of crops they grow are profitable and suit their risk capacity. Effective risk management is vital to maintaining farm sustainability and profitability for growers in the face of climate risk and rising production costs (GRDC, 2013).

3.1 Risk Management

Risk management plays an integral role in running a successful business of any kind. Across the globe, farmers are particularly vulnerable to variations in weather patterns and natural disasters. Dorothea Mackellar described Australia as *'the land of droughts and flooding rains*'. This could not be more accurate for Queensland in recent history, with much of the state being drought declared by the state government, while also suffering two widespread record flooding events during the same period.

A fundamental part of running a successful farm business is managing risk, rather than just analysing and evaluating risk (GRDC, 2013). There are three main indicators to consider when assessing a business's risk capacity; the first two, financial risk (Table 1) and operational risk (Table 3) apply to the business as a whole, and the third takes into account personal risk indicators, namely health and personal resilience. Table 3 outlines some examples of operational indicators that can be used to describe a business's risk capacity.

Operational indicator	Example of lower risk capacity	Example of higher risk capacity
The stage of your farm in the business cycle	Starting out	Well established
Availability of labour	Inadequate or underutilised	Efficient and timely
Farm diversity	One enterprise	Two or more enterprises
Number of financial dependents	Many	Few

Table 3: Examples of operational indicators of a business's risk capacity

Source: GRDC, Farm Business Management: Farm Business Risk Management' Factsheet

Double cropping spreads income and risk across winter and summer. If one crop fails due to a natural disaster, there is still have income from the other crop.

3.2 Gross Margin

Gross margins are just one component of a whole range of factors, which go into planning a crop sequence for paddocks. Gross margins also usually only contain 30-40% of costs (Hutchings, 2016). The cost of maintaining and financing infrastructure and additional labour, interest, living costs and tax also need to be considered. Gross margins are therefore a poor indicator of wealth accumulation, as reflected in the bank account, or net worth.

The challenge for farmers is to devise a cropping program that is not only a 'safe' option but also the most profitable. To achieve this, a holistic view of the whole farming enterprise needs to be taken into account, starting with planning and budgeting.

The concept behind this double cropping system is to lower the risk associated with crop loss from natural disasters. With this in mind, the crop that presents the biggest gross margin may not necessarily be the best option for a business with a low risk capacity. In South East Queensland (SEQLD) spring planted Mungbeans are a good example of this, where recent high prices make the crop an attractive option on paper, but in reality, there is a high risk of a poor crop yield and quality due to wet weather at harvest. For a property that is flood prone, crops need to be considered on how well they can withstand a flood.

3.3 Considerations for choosing crop type

There is a multitude of options when it comes to selecting crops for a rotation. A good place to start is with the crops that are currently grown in the region, and firstly look at the planting and harvest windows to see what will line up. Timing is one of the most crucial components of selecting compatible crops.

A two-year wheat/cotton rotation is very common in the Australian cotton industry. Typically, wheat will be planted as soon as possible after the cotton crop, but after the wheat harvest, the paddock is left fallow for roughly 11 months. The big limitation to returning straight back to cotton is usually water supply, but also the harvest/planting window overlaps. This means that any delay with harvest (particularly wet weather) can set the cotton planting date outside the optimal window and influence final crop yield and quality negatively. With this scenario, low cotton yield coupled with lint quality dockages can quickly equate to a negative gross margin. In a dry season, however, when cropping operations and management decisions are not affected by the weather, this can be a highly profitable rotation for an irrigated farmer with good water supply.

In South Africa, double cropped corn (white and yellow varieties) were being planted on 500mm spacing into standing wheat stubble because it worked well with their other crops. They had not been able to show a yield difference with 1000mm spacing at the time of the visit. The crops total Nitrogen (N) requirement was being applied through the CP with the irrigation water.

A diverse selection of crops will help to increase soil biological activity and diversity. It will also allow for alternating herbicide chemistry to be used and hence slow the onset of herbicide resistance. The addition of a legume, which fixes N, will complement the following crop by reducing the fertiliser input requirement.

3.4 Zero tillage, controlled traffic and row spacing

Zero tillage and controlled traffic go hand in hand, and Australia is a world leader in the adoption of both. Controlled traffic in combination with zero tillage improves infiltration, which results in less runoff and more even moisture storage across the paddock. Good soil structure can also reduce waterlogging and its effect on crop yield and N loss. (Fritsch & Wylie, 2015).

In Brazil and the USA, zero tillage was noted as being the cornerstone of their crop production technology and the key to maintaining and even increasing the value and productivity of their land assets. University of Nebraska-Lincoln field trials have shown that using CP irrigation and no-till practices instead of furrow irrigation and conventional tillage can reduce irrigation need by up to half (University of Nebraska-Lincoln, 2009). Seasonal crop water use is a combination of evaporation from the soil surface and water transpired through the crop. With a centre pivot, soil is constantly wetted at the surface, causing additional evaporation. Leaving crop residue on the soil surface can reduce evaporation significantly (University of Nebraska-Lincoln, 2009).

Research conducted by the National Centre for Engineering in Agriculture (NCEA) showed that adoption of a minimum tillage system could reduce energy costs (and greenhouse emissions) by 12% and developing a 'near zero till' system could potentially reduce this to 24% (Baillie, 2013). Converting irrigated, conventional-till systems to no-till production systems can potentially reduce soil erosion, fossil fuel consumption, and greenhouse gas emissions (Halvorson & Reule, 2007).

With a zero-till double cropping system trash management is very important and farmers repeatedly comment that the importance of good residue distribution at harvest cannot be underestimated. Liang *et al.,* (2011) found that the wheat-maize double cropping system on the North China Plain (NCP) is highly productive and such an intensive system leaves approximately 17 tonnes per hectare of crop residue in the field. This large amount of residue can cause problems in land preparation, seeding and seedling establishment that could possibly result in yield losses.

Another important component of these systems is the chosen row configuration. Planting between the rows of the previous crop can assist with trash flow. For example, common row spacing for summer crop is 750cm and then winter at 37.5cm. If the sole focus was on winter cereals, a narrower row spacing may achieve a higher yield. No customised irrigation implements are required to farm under CP irrigation, whether water is available or not, the exact same equipment and management techniques as used for dryland zero-till farming can be used and the cropping frequency can just be ramped up or down.

In contrast to Australian controlled traffic, it is common practise in both Brazil and the USA to plant the second crop at 15 degrees to the first crops row direction.

Zero tillage has been implemented with overwhelming success in Australian dryland farming systems. However, the uptake in irrigated cropping has often been limited. One of the major reasons for this is the need for bed forming in flood furrow systems in order to direct the flow of irrigation water and also the challenges of dealing with heavy stubble loads impacting the flow and pumping of water. This is overcome with overhead irrigation and is one of the reasons continuous double cropping becomes an achievable option.

In an irrigated controlled traffic/zero till system it can sometimes be necessary and or beneficial to do some strategic tillage. Strategic tillage can be used for multiple purposes:

- To fill in tractor and pivot wheel tracks.
- To destroy hard to kill weeds.
- To incorporate excessive surface stubble and cycle nutrients to depth.
- To speed up stubble breakdown.
- To incorporate soil ameliorants, such as gypsum or feedlot manure.

A strategic approach to cultivation in long term zero tillage systems has proven a profitable option for controlling herbicide-resistant weeds in Central Queensland. Farmers have noted that tillage has increased the overall productivity and profitability of their summer and winter crops: sorghum, maize, chickpeas and wheat. These gains are thought to stem largely from the reduced in-crop weed competition for water and nutrients (GRDC, 2016).

3.5 Nutrition

Increased cropping intensity can result in the progressive depletion of soil nutrients – requiring more fertiliser to replace these nutrients (CottonInfo). Forward planning a fertiliser program is critical with double cropping as a crop that lacks nutrition at key stages of growth will never reach its full potential. Knowing the soil nutrient status pre-plant is important information and regular nutrient testing should occur so a pattern of crop nutrient use can be established. In Australia and other countries visited by the author, soil testing is the most common form of nutrient monitoring. Other methods like petiole and leaf sampling are useful tools to monitor critical levels throughout the growing season too. Then there are emerging technologies that use spectral reflectance or transmission as a diagnostic tool. Once visual nutrient deficiency symptoms appear it is likely that a reduction in yield will occur despite remedial fertiliser application (CottonInfo).

Placement of fertilizer is very important as root burn can occur if some fertilizers are placed too close to the root system. For row crops like cotton, Incitec recommend that N be applied 10cm to the side of the plant line. Phosphorus and potassium can be placed under the row but far enough away not to cause root burn (Cotton Seed Distributors).

Correct crop nutrition is essential for maximising crop yields. Balancing the timing and volume of N applications is particularly important, as too little will reduce the potential crop yield and too much can cause excessive vegetative growth in the crop, leading to insect, disease and harvest problems. It is important to note that over-fertilising can affect profitability through increased costs. Winter cereals are particularly vulnerable to lodging and this can be managed with careful irrigation and N management. For high N soils, Sykes (2012) indicates that N fertiliser requirements for wheat crops, are more safely applied at stem elongation (growth stage 31). CPs offer the ability to apply precise amounts of fertiliser with the irrigation water (fertigation) at the appropriate time. This achieves complete and uniform coverage across the paddock. Fertigation with CP's provides great flexibility with N management and is easily achieved with small water applications. To protect and maintain the equipment, it is good practice to flush the machine after fertigation to prevent corrosion.

Getting crop nutrition right will not only help to maximise yield and prevent unnecessary over spending on input costs, but it can also help limit the impact of agriculture on the environment. Agriculture is responsible for an estimated 85% of Australia's emissions of nitrous oxide (N_2O), a greenhouse gas with almost 300 times the potency of carbon dioxide (GRDC, 2016). GRDC (2016) reports that, in clay soils typical of the Australian northern grains region, low soil carbon generally meant N_2O emissions were also low. However, double cropping on these heavy soils can lead to high labile carbon content in both soils and stubble, which, when combined with waterlogging and high N fertiliser rates, can result in large gaseous N losses, particularly early in the growing season (GRDC, 2016). When studying the effect of N, tillage and crop rotation effects on N_2O emissions from irrigated cropping systems, Halvorson and Reule (2007) found that '*crop rotation and N rate had more effect than tillage system on N_2O emissions*'.

Due to the high stubble loads produced from irrigated double cropping, large volumes of N can be tied up in the mineralisation process. This can initially require higher amounts of N to speed up the process and assure adequate N is available to crops. Importantly the additional N will eventually become available as mineralisation continues.

The use of organic soil amendments is common-place in many regions around the world. Numerous studies have shown that manures can improve not only the nutrient status but also the physical properties and the organic carbon levels of soils (Australian Grain, 2016).

Products presently being used include bio-solids, raw manures derived from cattle, chicken and piggery operations, compost of raw manures and composted cotton gin trash, and other composted material from green waste. Availability, price and proximity to supply are the main drivers of product use.

Sykes (2012) reported that when planting irrigated wheat into 'low soil-N, post-cotton paddocks, starter fertiliser containing phosphorus will improve establishment'.

Chapter 4: North China Plain Case Study

Double cropping wheat and corn began on the North Chins Plain (NCP) no later than the 1970s, and became popular in the 1980s with the adoption of shorter season cultivars and as advances in mechanisation and fertilisers improved (W. Liang, personal communication, August 24, 2016). The basic rotation is wheat planted with full soil disturbance and then corn zero-tilled directly into standing stubble after the wheat harvest. The corn is commonly harvested by the cob at high moisture and stored in very small mesh silos to dry down. After the corn harvest farmers cultivate the paddock to incorporate synthetic and in some cases organic fertilisers in the form of animal manures (of any kind available). Taking the crop off at high moisture achieves an earlier harvest and allows time for the ground preparation to be carried out before the next wheat crop is planted.

Research conducted on the NCP by Liang, *et al.*, (2011) suggests that there is potential to increase the aggregate production for the farmer grown wheat-maize double crops. In the 2004-2005 season, farmers averaged only 72% of the average production recorded from on-farm trials conducted, and 60% of the simulated average production potential for the region that season (Liang, 2011).

There are a number of factors that contribute to the disparity in yield between farmers crops and on farm trials, with some of the major limitations being:

- Access to reliable water supply and irrigation infrastructure.
- Uptake of modern management techniques including irrigation scheduling and growth regulator application.
- Quality of work carried out; for example, spraying with some blocked nozzles.

Farmers on the NCP have been double cropping corn and wheat for approximately 40-50 years now and it appears to be sustainable and not limited by the repetitive intensity of the rotation.

Figure 8: Hebei, China. Inspecting Wheat with Professor Li. NB incorporated corn stubble

Source: A.G. McVeigh 2016, China

Chapter 5: Brazilian Case Study

The summer crop growing season is much longer in Brazil than in South-east Queensland (SEQLD), so in regions like Bahia they are generally producing two summer crops, as opposed to a winter and summer crop rotation. The principles for the double cropping in Brazil can still be applied to the Australian farming system. The large Brazilian farming enterprises believe that double cropping allows them to increase the profitability of their land, diversify the production and commercial risk and enhance operational efficiencies. These include better utilisation of machinery, freight, labour and other resources, resulting in a dilution of their fixed costs. One of the keys to the success of a lot of the large farming business is the geographic spread of farmland across different regions, which allows them to minimise risk exposure to weather-related losses.

It is important to note that different double cropping systems are implemented and adapted for the different productive regions in South America, with the most frequent being wheat/soybean, wheat/corn, sunflower/soybean, corn/soybean, sunflower/corn and soybean/cotton.

Double cropping in Brazil is common practice and needs to be carefully managed to prevent the spread of pests and diseases. In 2014, many farmers planted soybeans followed by soybeans due the high returns at that time. This was classified as a phytosanitary failure but an economic success, as rust and pests proliferated but farmers earned more from double soybeans than they did from corn. Double-cropped soybeans are an unsustainable practice that threatens the Brazilian soybean industry as a whole.

The Brazilian government enforce various 60-90 day phytosanitary periods according to the laws of each state, which bans farmers from planting crops like soybeans and cotton during that period (Baumgratz, 2015). The main goal is to prevent the spread of the Asian Rust after some Embrapa (Brazillian Department of Agriculture) studies were released revealing that the lack of rotation was the reason for an outbreak. Among the benefits of the fallowing is a decrease of the disease and/or target pests, which reduces the need for other control methods and, therefore, turns out to save production costs. The period of absence of host plants can also help decrease the population of other pests such as whitefly and *Helicoverpa armigera* caterpillar (Baumgratz, 2015).

Brazilian farmers appear to have a great understanding of their soils nutrition and which inputs are required to maintain productivity. The big challenges facing the sustainability of double cropping practices in Brazil are the control of pest and disease pressure. Managing available genetic and chemical pest/disease control technology to prevent the build-up of resistance will be the key to this in the future. The cotton crop in Figure 9 had been sprayed 35 times (including fungicides, insecticides and herbicides), raising a big question mark over the sustainability of this cropping system.

Figure 9: Brazilian cotton being grown in very sandy soils

Source: A.G. McVeigh 2015, Brazil

Chapter 6: High Moisture Corn

Much of the corn grown around the world is harvested at a high moisture content of around 30%. In recent years. there has been limited use of high moisture corn for cattle feed in Queensland, with feedlots noting that supply is the major limitation to further use of the product.

Aiming for 30% moisture means that spring planted corn can be harvested at least three weeks earlier than the industry standard 14% moisture crop would be. For late planted crops that are drying down in autumn this could literally have the crop harvested months earlier.

A three-week shorter corn growing season opens up the potential for another summer crop to be direct drilled and watered up. A potential rotation that resembles the Brazilian rotation is high moisture corn followed by mungbeans. The two-crop rotation would grow from September to May with three months fallow over the winter.

Figure 10: Nebraska, USA. Processed high moisture corn stored in a silage pit

Source: A.G. McVeigh 2015, USA

Conclusion

Effective management of risk and profitability is the key to success in farming. For irrigators who are farming in regions that are vulnerable to crop destruction from natural disasters like flooding, achieving high yields from double cropping with CP irrigation can be a sustainable long term cropping option.

This report has shown that the keys to achieving this are:

- A well designed and maintained overhead irrigation system.
- Precise irrigation scheduling.
- Prevention or minimization of wheel ruts.
- Zero-tillage and controlled traffic.
- Managing available genetic and chemical pest/disease control technology to prevent the build-up of resistance.
- Flexibility in crop selection.
- Closely monitored soil/crop nutrition.

The importance of forward planning cannot be underestimated, but a plan that allows for some flexibility to account for seasonal variation and commodity market fluctuation can be valuable. Choosing a diverse selection of crops will help to increase soil biological activity and diversity. It will also allow for alternating chemistry to be used, and hence slowing the onset of resistance.

Every farmer and their farm business is different and so a *'one size fits all'* approach to rotation and irrigation planning will not work. Australia is a world leader in research and adoption of new farming technology. With good planning and management practices, there is certainly potential for sustainability in long term irrigated double cropping systems.

Recommendations

- Design the irrigation system around the proposed cropping plan. Devising a cropping plan around limitations of an existing irrigation system could cause sub-optimal results.
- Do not develop more land for irrigation than can be irrigated with average water availability, for example a paddock that is fallowed for 12 months between irrigated crops is an expensive dryland fallow when you include the development cost.
- Assess the physical farming capacity – Does the business have the ability to carry out every operation on time?
- Take advantage of government funding opportunities to help fund infrastructure upgrades. Consider employing a consultant to help.
- Prevention or minimization of wheel ruts is preferable and cheaper than dealing with them after they have developed.
- Be realistic about yield and commodity price potential. With double cropping, high yield is the key to competing with a 'one crop' option like cotton with a high gross margin.
- Avoid a rotation with narrow planting windows: the risk of missing the ideal window due to weather limitations is high.
- Choose the appropriate row configuration for your crop selection and be mindful that it may not necessarily be the spacing that has the highest yield potential, but one that compliments the rotation crop.
- Manage available genetic and chemical pest/disease control technology to prevent the build-up of resistance.
- Encourage further development of the High Moisture Corn market.
- Encourage investment into alternative energy research.
- Influence policy around irrigation electricity use.

Farming needs to be viewed with long term goals and it is important to ensure consistent, stable and viable returns.

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Plain English Compendium Summary

Project Title:	**Sustainable High Yields from Double Cropping with Centre Pivot Irrigation** - Turning water into cash flow
Nuffield Australia Project No.:	1511
Scholar:	Adam McVeigh
Organisation:	A.G. McVeigh Trading Pty Ltd
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Objectives	• To research overhead irrigation infrastructure in Brazil, South Africa, the United States of America and Australia. • To investigate double cropping systems in Brazil, China, South Africa and Australia. • To investigate the sustainability of continuous double cropping systems in China and Brazil. • To research management practices of farmers using overhead irrigation. • To provide information that will assist farmers with a low risk capacity to plan a high yielding double crop rotation for their centre pivot irrigation.
Background	Droughts and floods are part of life in Queensland and the appeal of farming on the fertile floodplain soils means that flooding will be a constant threat. Those farming operations need to be smart and practical in their approach to planning ahead of these events, in order to ensure they can recover quickly and effectively each time an event occurs.
Research	High yield double cropping systems and centre pivot irrigation system design and management. Research was conducted in South Africa, USA, Canada, Brazil, China and Australia using a combination of interviews, farm visits, conferences and personal study.
Outcomes	Producing continuous high yields with double cropping can be sustainable providing the centre pivot irrigation system has been designed well. Farmers must consider their exposure to risk, gross margins, residue management, nutrient management, integrated pest management, equipment and its proper operation.
Implications	This report informs readers of some of the key considerations for designing centre pivot irrigation infrastructure, and also some practical farming techniques that aid in achieving maximum yield potential. It also outlines the importance of understanding risk capacity and the impact that this should have on crop rotation choices.