Improving Nitrogen use in Irrigated Cotton

A report for

by Nigel Corish
2014 Nuffield Scholar

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Executive Summary

The aim of the report was to improve nitrogen use in irrigated cotton. The aim of the research was to look at how farmers around the world are improving Nitrogen Use Efficiency (NUE), and to identify what management tools and practices farmers are implementing to improve NUE. To achieve this research was carried out in England, USA and Japan.

The research undertaken overseas highlighted that farmers have implemented rotations and cover crops to improve NUE. Rotations are being used to increase the amount of mineral nitrogen in the soil through planting legume crops that fix nitrogen in the soil. Cover crops are being used to provide ground cover for the soil surface, to improve water infiltration, improve water holding capacity, and reduce leaching and runoff.

Farmers overseas have introduced new irrigation techniques to improve Water Use Efficiency (WUE) and reduce waterlogging, which in turn improves NUE. Farmers have moved away from flood irrigation and have introduced overhead sprinkler irrigators, in which Australian cotton growers have been slow to adopt.

Research undertaken in USA and England showed that both dryland and irrigated farmers have introduced no till farming practices. While in Australia dryland farmers have adopted no till farming practices, irrigated cotton growers have not introduced these practices and still use excessive tillage as a farming practice. No till farms in the USA and England illustrate the benefits of no till outweigh the conventional tillage practices.

The adoption of Precision Agriculture (PA) has been much faster overseas compared with Australia. Famers are using a number of PA practices including imagery and real time soil testing to improve NUE through the introduction of Variable Rate Technology (VRT). Farmers are using NVDI imagery from satellites and drones to create management zones across the fields. Farmers are able to apply different rates of fertiliser through VRT, which has not been widely used by Australian cotton farmers.

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Foreword

I am a third generation farmer from Goondiwindi, Queensland. Irrigated cotton has been the predominant crop grown in the family since 1982. I have been involved with the family farms from a young age and took over management of one of the family properties, “Yambocully”, in 2007. Over the years I have seen floods and drought have an enormous effect on the production and profitability of the family business. In recent times I have seen profitability become more difficult to achieve as input costs have increased at the same time that commodity prices have remained constant.

At the start of my Nuffield Scholarship I considered myself a progressive and adaptable farmer; the Nuffield Scholarship has shown me the benefits of stepping away from the farm and local industry to travel and learn from other farmers around the world. To be asked why we do certain things on my farm was challenging, and at times it was difficult to provide a good

When I was considering applying for a Nuffield Scholarship I wanted to choose a project that firstly improved farming methods on my farm and also reduced input costs. At the time fertiliser, and in particular nitrogen (N), was by far the biggest input cost the farm had for irrigated cotton, around $700 per ha on fertiliser alone. The average irrigated cotton yields on the farm have been increasing over recent years from 10 lint bales per ha in 2008 to 13.8 bales per ha in 2013. This increase in yield has been partly due to the application of more nitrogen fertiliser.

At the time I was seeing the irrigated cotton crop yellowing at the bottom of the furrow irrigation fields and put this down to nitrogen movement or leaching down the field. The yield maps showed after harvest that there was a significant yield loss in these areas.

In 2013, I undertook a Back Paddock nutrition course, focusing on nitrogen. The two day course highlighted to me that I needed to improve nitrogen use on my farm, and look at a number of areas to improve nitrogen use efficiency. In the same year I conducted an on-farm nitrogen trial in irrigated cotton and the results showed that the NUE (Nitrogen USE Efficiency) was below industry standard, at 8kg of lint / kg of N, compared to a target benchmark of 13 to 18 kg of lint / kg of N.

A Nuffield Scholarship allowed me to undertake the Global Focus Program (GFP), where I travelled to the Philippines, China, Canada, USA, The Netherlands, France and Ireland with a group of 2014 Scholars. It was a great insight to global agriculture and highlighted the role food production will play as demand increases with population and economic growth. In China, our group saw the transition to large scale mechanical farms with Chinese built tractors, planters and harvesters. We also saw the wealth creation in the second and third tier cities where diets are changing to westernised fresh vegetables, fruit and meat. The group visited Hohot, the milk capital of China and it was unbelievable to see the growth of the milk industry under increased demand.

This Scholarship allowed me to travel for eight weeks to complete my study project which included England, USA and Japan. In the USA I visited North Carolina, the Mississippi delta, the Mid-west, South Dakota and California. On my travels I had meetings with researchers, consultants and farmers that were invaluable and insightful and taught me to look outside “the box” and explore the world of nitrogen and soil health. Undertaking this project I have learnt that nitrogen is a complex and challenging subject to research and that the whole system needs to be in balance to achieve high nitrogen use efficiency.

Acknowledgments

I am greatly indebted to my sponsors Cotton Australia and the Cotton Research and Development Corporation (CRDC) for investing in the scholarship and the future farmers of their industry. I would also like to thank Nuffield Australia and in particular Jim Geltch, the CEO of Nuffield, for providing the support required to complete the scholarship.

Thanks are due to my immediate family who allowed me to be away from the farm for extended periods of time while I traveled overseas to undertake my studies. Thank you to Alex Stevens who stepped up and managed “Yambocully” in my absence and showed me that the farm continued to operate efficiently while I was away.

Thanks also to my GFP group with whom I spent six and a half weeks together traveling around the world. It was insightful and enjoyable, and was a highlight of my Nuffield Scholarship. Thanks Tania, Nicky, Finola, Justine, Aubrey, Greg, Paul and Steve.

I am also grateful to the farmers, consultants and researchers who hosted me and met with me on my travels. You challenged me, questioned me and have changed the way I farm today. Thank you for your time and hospitality.

A special thanks to my wonderful wife Vanessa, who encouraged me to apply and to travel overseas for long periods of time, while looking after our two young children at home. Thank you.

Abbreviations

N:	Nitrogen
NUE:	Nitrogen use efficiency
iNUE:	Internal nitrogen use efficiency
GM:	Genetically modified
Bale:	227kg bale of lint cotton
Mt:	Metric tonne
CI:	Cotton Incorporated
VRT:	Variable rate technology
VAM:	Vascular arbuscular mycorrhizae
CO2-e:	Carbon dioxide equivalent
RMP:	Resistance Management Plan

Objectives

The objective of this project was to learn how to improve nitrogen use in irrigated cotton by researching different farming practices and to look at the practices that influence iNUE.

To improve nitrogen use it is important to look at the factors that influence. Nitrogen can be lost through denitrification, leaching and volatilisation. Research was undertaken to see what farming practices were being used overseas to reduce losses.

Objectives included:

- To look at what practices farmers are implementing to reduce the use of synthetic nitrogen, and what rotations and cover crops are farmers using to improve NUE?

- To identify what effect tillage is having on NUE and what benefits no till has on improving NUE.

- To research and investigate how farmers around the world are adopting and using precision agriculture (PA) to improve NUE.

Chapter 1: Introduction

Cotton has been grown in Australia since the First Fleet arrived and grown commercially since 1961 (Cotton Australia 2015). 2011 was the largest production year on record in Australia, with some 566,000 ha grown and 5.3 million lint bales produced (Cotton Australia 2015).

The cotton plant, (Gossypium hirsutum L), belongs to the Malvaceae family of plants that includes rosella and ornamental flowering hibiscus. It is a perennial shrub that can grow up to 3.5 metres in height; commercially it is grown as an annual plant that rarely exceeds 1.6m, and it is sown, harvested and removed each year (Williams, 2015). Cotton is a rare crop where protein (nitrogen) is not present in the main product produced by the plant, namely cotton lint. Rather it is present in the seed which is a secondary product for growers (Hake 2014).

A majority of Australian cotton is grown on vertisols (cracking clays), which are naturally fertile, alkaline and with high clay content. Some soil types are dense with sodic sub-surfaces which have poor permeability (the ability of water to move through the soil, and hence limit root growth) (King 2015).

The Australian cotton industry has increased cotton lint yields significantly over the last 40 years, on average one bale per ha every ten years (Constable 2014). The 2012-13 season saw the Australian cotton industry average 11.8 bales per ha for irrigated cotton (Roth 2013), with some growers achieving 16 bales per ha. The yield increase can be attributed to plant breeding producing higher yielding and disease resistant varieties, the introduction of GM (Bollgard and Roundup Ready cotton), better farm management including irrigation and fertiliser management.

With the increase in yields the industry has also seen an increase in nitrogen fertiliser applied to the crop, as shown in Table 1, with irrigated growers averaging 243 kg of N per ha in the 2013 season and 20% of the industry using over 300kg of N per ha (Roth 2013). Research conducted in Australia shows that the optimum iNUE is 12.5kg (+ or - 2 kg) of lint per kg of N. This research also showed that growers are over-applying N by 83 kg N/ha above the optimum (Rochester 2012) shown in Table 1. Continued and expected increases in cotton yield and hence nitrogen fertiliser use raises concerns over the future environmental impact irrigated cotton growers and their fertiliser use may have.

Over-application of N fertiliser can lead to nitrous oxide emissions contributing to greenhouse gas emissions. Oversupply of nitrogen in cotton will also encourage rank vegetative growth, encourage fruit shedding, delay maturity and hamper defoliation (Rochester 2001).

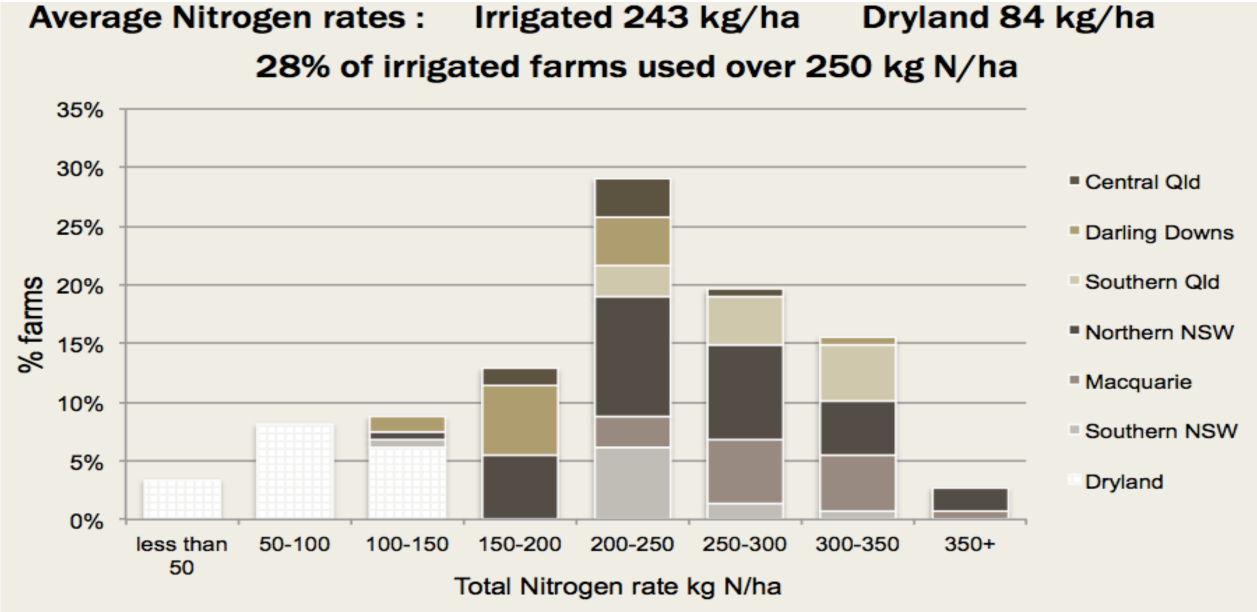

Table 1: Australian Cotton Grower Survey 2013

With a global focus on climate change, the Food and Agriculture Organisation of the United Nations published that nitrogen demand has driven agricultural emissions to increase globally, as shown in Figure 1 below (FAO 2015). In 2008, the Australian agricultural greenhouse gas emissions were 87.4 Mt $CO_2{}^{-e}$, which was 16% of Australia's total greenhouse gas emissions (Parliament of Australia, 2010).

Seventy six percent of nitrous oxide emissions in Australia come from Agriculture (Eckard 2010). Nitrous oxide is a powerful greenhouse gas with 298 times the warming potential of carbon dioxide over a 100-year time period (Parliament of Australia, 2010). Figure 1 below shows the world consumption of fertiliser and predicted outlook consumption into the future. How long will it be before a nitrogen application limit is put on Australian cotton growers by the government or consumers?

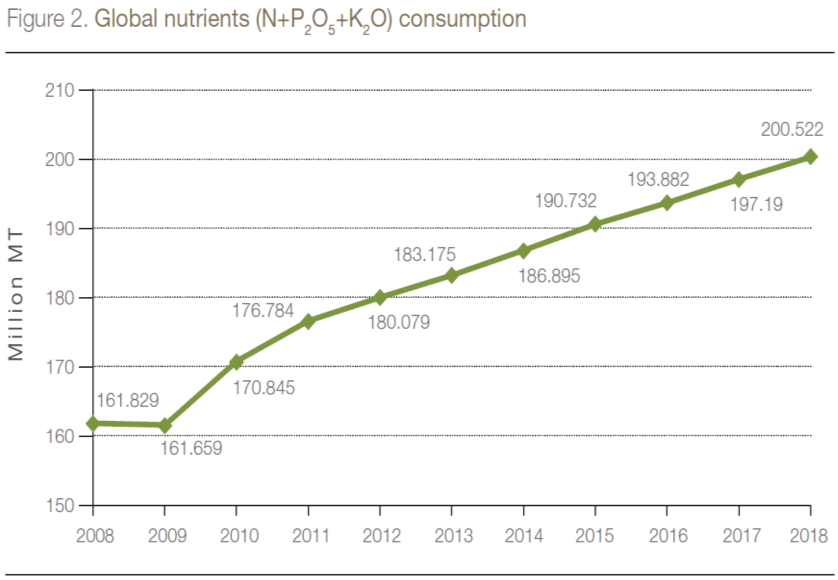

Figure 1: FAO, World Fertiliser trend and outlook to 2018

The cost of synthetic nitrogen fertilisers is increasing for growers as the amount of N applied is increased. If growers are applying 300 units of N per ha and if N costs $1.50 per unit growers are spending $450 per ha alone on nitrogen. Growers cannot afford to under-fertilise as N deficiency has a large impact on yield, and therefore profitability. Farmers need to find ways to meet the nitrogen demand of the cotton plant to achieve high yields using less synthetic nitrogen.

Cotton plants can source nitrogen from either organic or synthetic sources. Organic N includes mineralised N from legumes or organic matter decomposition. 95% of nitrogen in the soil is unavailable to the plant in organic form (Smith 2015). About 60% of applied nitrogen is removed at harvest in cotton seed, which can be as high as 171 kg N per ha with a yield of 14 bales per ha (Smith 2015).

Cotton prefers to uptake nitrogen in the form of nitrate N rather than ammonium N and does this during the period of vegetative growth. Nitrogen is transported to the leaves of cotton at a young age; most N is taken up in between 50 and 100 days after sowing (Rochester 2001).

Applied nitrogen fertiliser can be lost from the soil in a number of ways. These include denitrification, leaching, volatilisation, removal at harvest and removal of stubble. Farmers need to look at the “four Rs” to reduce losses when applying nitrogen: Right fertiliser, Right rate, Right time and Right place (Smith 2015). The six common causes of low NUE from the Back Paddock Company are shown in Table 2.

1.	Supply of N greater than demand – oversupply
2.	Inefficient N uptake
3.	Applied but temporarily unavailable
4.	Applied or mineralised but lost from soil
5.	Available in soil but not taken up
6.	Taken up in biomass but not transferred to harvested produce

Table 2: Six Common Causes of low NUE (Dowling 2015)

Definition of Nitrogen

Nitrogen is a non-metallic element that makes up about 78% of the atmosphere by volume, occurring as a colourless, odourless gas. Its a component of all proteins, making it essential for life, and it is also found in various minerals (The American Heritage Science Dictionary 2014).

Synthetic nitrogen fertiliser was first created in 1909 when Fritz Haber first synthesised ammonia from the atmosphere. Carl Bosch was the engineer at BASF in Germany who commercialised the process known as the Haber-Bosch synthesis. Ammonia synthesis took off after World War II when the demand for ammonia in ammunition dropped. The amount of N produced has increased from 3.7 Mt in 1950 to over 133 Mt in 2010. It would not be possible to feed 45% of the world's population without nitrogen (Smith 2015).

To improve NUE all inputs need to be examined to determine what is the most limiting factor on improving NUE. Irrigated cotton farmers tend to overlook inputs like the weather, soil health and irrigation methods when determining nitrogen application rates (Dowling 2015). When determining N requirements growers need to look at the physical, biological, and chemical processes in the soil (Smith 2015). Most cotton growers use their experience from previous cotton crops when determining nitrogen rates (Nutripak 2015).

This report is divided into five sections that will investigate practical topics to identify and improve nitrogen use in irrigated cotton. The five topics that will be discussed include rotations, Irrigation, source of nitrogen, tillage and precision agricultural. In each section of the report case studies will demonstrate the approach of leading farming around the world to improve nitrogen use.

Chapter 2: Rotations and cover crops

Definition of a crop rotation

A crop rotation is the "*system of growing a sequence of different crops on the same ground so as to maintain or increase its fertility" (Collins English Dictionary 2012).*

The standard rotation for the Australian industry is to grow two cotton crops back-to-back followed by a cereal or legume rotation over winter; however in some cases cotton can be grown back-to-back for five to six years (Roth 2013), because of the high gross margin returns achieved with irrigated cotton. Table 3 below shows a gross margin of $2,589 per ha compared to lower gross margins for other summer crop options.

In drought years cotton fields can be fallow for a number of years without a crop. In these circumstances mycorrhiza numbers can decline, and cotton plants are dependent on this fungus for optimum growth. This lack of VAM (Vesicular arbuscular mycorrhizae is often referred to as) (Stewart et al., 2010) long-fallow syndrome and can lead to poor establishment and poor seedling growth as well as symptoms of nutrient deficiency. VAM form a symbiotic relationship with plant root hairs to form “a net” to catch water and nutrients (Zimmer 2014).

Commodity	**Cotton**	**Corn**	**Soybeans**	**Sunflowers**	**Sorghum**
Gross Margin/ha	$2,589	$1,559	$1,396	$974	$583
Gross Margin/ML	$357	$218	$233	$250	$153

Table 3: Gross margin comparison in irrigated summer crops (CSD 2014)

Definition of soil organic matter

Soil organic matter is very important in the role of NUE in cotton; the higher the amount of organic matter in the soil the more available N will be available to the plant.

Soil organic matter (OM) is the organic matter component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesised by soil organisms. OM exerts numerous positive effects on soil physical and chemical properties, as well as the soil’s capacity to provide regulatory ecosystem services

Particularly, the presence of OM is regarded as being critical for soil function and soil quality (Brady 1999).

Soil organic matter is a key source of the mineralised N during the cropping season. The mineralised N released by the OM can be calculated by the following equation (Smith 2015):

N mineralisation (kg/ha) = 0.15 x Organic C (%) x Growing season rainfall (mm)

The amount of Nitrogen mineralised in Australian cotton can be quite low as the natural organic matter in the soil can be low (below 1%), as a result of the low rainfall and warm temperatures in the cotton growing regions of Australia (Dowling 2015). In some cases zero nitrogen can be mineralised from season to season and in other cases and be as high as 100kg of N per ha. Cropping rotations play an important role in how much nitrogen is mineralised as shown in Table 4 below.

Species	No. of crops	Prop. crop N fixed (%)	N fixed (kg/ha)	Residual fixed N (kg/ha)
		mean	mean	mean
Summer				
soybean	6	83	371	194
peanut	2	80	273	168
(late sown)	3	40	84	33
(saline)	1	14	37	-20
adzuki bean	4	20	12	5
mung bean	5	51	47	12
pigeon pea	5	14	16	
cowpea	3	74	160	
lablab	9	73	140	
Winter				
faba bean	35	74	177	113
lupin	3	71	176	97
field pea	5	75	161	
lentil	1	61	169	
Winter forage				
clover	9	86	118	
medic	3	84	149	
vetch	4	89	171	

Table 4: Nitrogen mineralised from a CSIRO trial (Nutripack 2015)

Definition of a cover crop

“A crop planted between main crops to prevent leaching or soil erosion or to provide green manure” (Collins English Dictionary 2012).

Rotations and cover crops are not widely used in the Australian cotton industry. The benefits of cover crops was highlighted while undertaking the Nuffield Scholarship. Farmers visited on the scholarship are introducing cover crops into their rotations to improve a number of things including erosion, increase organic matter, increase infiltration and reduce leaching and runoff of nitrogen.

The following case studies from the UK and the USA were chosen to illustrate how researchers and farmers are using cover crops to improve nitrogen use by increasing organic matter, reducing run-off, increasing infiltration, and introducing legumes into cover crops.

Case studies –Cover crops in the UK

Cover crops in England have become an important management practice for farmers to manage NUE. England is part of the European Union and is part of the Common Agricultural Policy (CAP). Under the CAP farmers are restricted to the amount of total N that can be applied to a crop; farmers also need to control the runoff or leaching of N from the paddocks.

ADAS - England

ADAS is a research and consultancy business that was started sixty five years ago in England. ADAS consults for local growers and the UK government. Measured fertiliser nitrogen losses indicate that once applied to the crop, nitrogen gets locked up by biomass or organic matter in the soil, therefore growers are losing up to 60% of applied nitrogen as it is locked up or lost to the environment (Sylvester-Bradley 2014), as seen in Table 5 below.

Components of nitrogen efficiency		kg/ha N
Fertiliser: N applied to wheat grown for bread-making, including 33 kg/ha N applied late, to boost protein[1]		212
Ammonium nitrate N applied for yield[2]	42%	
Additional N applied late to boost protein to 13%[3]	25%	
Overall recovery of fertiliser N in harvested grain	39%	83
'Unused N' added to the environment: leached, volatilised as ammonia and emitted as N_2O.[4]	61%	129
Trading: grain grown for breadmaking, accepted.[5]	75%	
Milling: Grain N retained in flour.[6]	74%	
Overall net retention of applied N in bread.	22%	47

Sources and assumptions:

[1] British Survey of Fertiliser Practice, 2011.
[2] HGCA Project Report 438.
[3] HGCA Project Report 400.
[4] Assumes soil organic N and mineral N are unchanged by cropping.
[5] Defra and HGCA statistics indicate 25% rejections.
[6] Assumes 80% flour extraction and 1% protein difference between grain and flour.

Table5: NUE between fertiliser application and bread consumption in the UK

Microorganisms in biomass compete with the plant's roots for the nitrogen available. Research undertaken at ADAS shows that nitrogen use efficacy is linked to photosynthesis of the crop; the higher the photosynthesis the higher the higher nitrogen uptake. It is therefore not efficient to apply nitrogen once photosynthesis slows in the plant. A measure of soil health is how well a crop can grow in the soil. Biomass can be hard to manage and in some environments growers maybe better treating their system like hydroponics (Sylvester-Bradley 2014).

NIAB - National Institute of Agricultural Botany

The National Institute of Agricultural Botany (NIAB) was formed in 1919 and is one of the UK's oldest research providers. NIAB has been looking at cover crops in wheat systems for the last ten years and has long-term projects to look at the advantages and disadvantages of cover cropping. The reason for trialing cover crops is to look at the erosion control benefits and the reduction in nitrogen leaching. Cambridge receives 1,500mm rainfall per year and erosion has been a problem in the past; research has shown that 30% ground cover can reduce erosion by 80% year (Stobart 2014).

The first cover crop trialed was a white clover, then went to a blend of 17 species and ended up with a mixture of four including white and red clover, fodder radish and trefoil. As part of the research, three nitrogen trials were undertaken using three rates; zero, standard and double.

There was no yield improvement between the three different nitrogen amounts. The cover crops increased rainfall infiltration dramatically from 0.5mm to 1.2mm per minute and bulk density was reduced from 1.5 to 1 g/mm^3 at 20cm depth. The gross margin between the trials showed that there was a $160 per ha reduction in the nitrogen cost, however this did not include the costs of establishment of the cover crop. It takes between five to ten years to get the advantages of cover cropping; growers also need to look at the other advantages of cover cropping, such as less herbicide use, less fungicide use, 25% reduction on black rust in crop, and less fuel use (Stobart 2014).

Case Studies - farmers visited in England

A number of Nuffield Scholars and farmers were visited in England. Farming practices that were observed included the extensive use of rotations and cover crops. The main focus was to increase organic matter to increase efficiencies including NUE. Farmers had increased the organic matter above 4% in their fields (Freestone 2014). Wheat yields above 10t / ha were being achieved; for instance Kings Lynn is in the top 5% top yielding wheat areas in England, with some farms achieving 12t / ha (Meirs 2014).

Extensive and multi-species rotations were used on farms, including winter wheat, spring barley, sugar beet, oil seed rape and beans (Walston 2014). Potatoes were another example of a rotation which was profitable, with gross incomes of up to $25,000 per ha (Meirs 2014). Potato crops were only grown once every six years, because of nematodes in the soil and the compaction after harvest.

One integrated business, Mercer Farming, located at Burton-on-Trent in England, combined an arable cropping business with free range chickens and pigs. The three businesses rotate and share the same land to make the land more productive and profitable. The free range pigs cultivated the soil and the chickens grazed over the land increasing organic matter.

Case Studies in the USA

Cotton Incorporated

Cotton Incorporated is based in Raleigh North Carolina; it was formed in the 1960's when cotton's share in the apparel market fell from 80% to 35%, with the introduction and growth of synthetic apparels. It was formed by cotton growers in Texas who decided that the cotton industry needed an organisation to promote cotton in the USA. Cotton Incorporated was part of the National Cotton council until three years ago. In 2014, Cotton Incorporated invested $100 million dollars in cotton research, investing in 480 projects that were undertaken by State universities and other research organisations (Hake 2014).

The researchers presented data that showed the average cotton yield is five bales per ha in the USA. Low yields are believed to be because of the shorter growing season, only receiving around 1,700 day-degrees in a season. The real requirement for nitrogen in the cotton plant is 200 kg N per ha. The researchers stated that some fields have been growing cotton back to back for 150 years. About 10 to 20 years ago, growers changed from growing cotton year in year out, to a rotation. Growers adopted a three step rotation of corn, soybeans and cotton. This rotation builds organic matter in the soil and fixes nitrogen into the soil through the soybeans (Nichols 2014).

Midwestern Bio Ag, Wisconsin

Gary Zimmer is an organic biological farmer from Blue Mounds, Wisconsin. Gary was also a founding partner of Mid-western Bio Ag in 1984. It is a biological fertiliser business and consulting firm. Gary was a teacher and bought his farm in 1979. It started out as a dairy then moved into organic farming. Gary is a biological farmer and believes in a balanced approach to farming.

Growing high yielding crops without the need for application of nitrogen is a great way of knowing that the soil is healthy (Zimmer 2014). If there is too much soluble nitrogen in the soil it will shut down the natural N-fixing systems, such as Rhizobia in legume plants that take gaseous N_2 from the atmosphere and convert it to ammonia in root nodules.

Roots are very sensitive to temperature change in soils, allowing for root and soil life growth. Bare soils are hot; growing cover crops is a good way to regulate soil temperature. Soil is made up of living organisms, and needs feeding every day. Different soil organisms feed on different plant species, so increasing diversity with plant species will promote better soil heath, suggesting that more rotations are needed (Zimmer 2014).There are different types of rhizobia that live on different legume species; for example a different strain is needed for beans, compared to clover (Zimmer 2014).

Conclusions

Cotton has only been grown commercially in Australia since the 1960's. The management practices to grow the crop were introduced from the USA. These practices are still widely and have not changed over time. Visiting the UK and the USA have highlighted that the Australian cotton industry has not changed its management practices and has become a monoculture where cotton is grown back to back for a number of years, up to five years in some cases.

There are a number of rotations that can be recommend to irrigated cotton growers in Australia, after harvest in April or May, a winter rotation crop of barely or faba beans can be planted in June; the barley will improve soil structure and help with compaction issues as it is a deep-rooted plant. Faba beans is a legume and will fix nitrogen back into the soil.

Summer rotation crops like sorghum and corn can be planted to increase stubble cover and organic matter in the soil. Growers need to budget and plant rotation crops into the farming system as it introduces plant diversity, which will improve soil health and in turn improve nitrogen use efficiency.

If rain occurs outside of a planting window, cover crops like French white millet, oats or barley can be planted. Cover crops provide the soil with living roots which will feed the microorganisms in the soil. Once the cover crop is sprayed out the roots will provide air pores in the soil to allow oxygen and water to enter the soil. The stubble on the soil surface provided by the cover crop will reduce evaporation and increase water infiltration.

One of the disadvantages of a cover crop is that it will use soil moisture to establish. To establish the cover crop it will only require a small amount of soil moisture. It is recommended that the cover crop be sprayed out in the vegetative stage of growth. This is when the roots of the plant are fully developed (Zimmer 2014).

The next chapter of the report investigates what affect flood furrow irrigation has on nitrogen use in irrigated cotton.

Chapter 3: Irrigation

Flood Furrow irrigation

A large percentage of Australian cotton is irrigated using the flood furrow method. Furrow irrigation can be characterised as a process whereby small parallel channels are created along the field length in the direction of predominant slope. Water is applied to the top end of each furrow and flows down the field under the influence of gravity. Water may be supplied using gated pipe, siphon and head ditch or bankless systems. The speed of water movement is determined by many factors such as slope, surface roughness and furrow shape but most importantly by the inflow rate and soil infiltration rate.

It is considered best management practice to split the application of nitrogen across the season to reduce losses (Smith 2015). Growers have the option to side-dress nitrogen and incorporate it using cultivation or irrigation. The second is to apply nitrogen during irrigation. It is not recommended to water-run anhydrous ammonia as it is distributed poorly down the field and volatilisation will occur from the water, with losses of about 25% per hour (Rochester 2001).

Definition of denitrification

"The loss or removal of nitrogen or nitrogen compounds; specifically: reduction of nitrates or nitrites commonly by bacteria (as in soil) that usually results in the escape of nitrogen into the air."

The soil becomes susceptible to nitrogen loss through denitrification once the soil is 60% saturated. Anything that affects water uptake will affect nitrogen uptake (Dowling 2014).

If pre-plant nitrogen is applied, a field can be irrigated three to four times before the plant is requiring nitrogen, at around 50 to 100 days post-plant (Back Paddock Company 2013). Denitrification is increased as losses will occur after each irrigation event. The current best practice in cotton for fertiliser application, is to pre-apply a percentage (up to 50%) of nitrogen to reduce losses in-season. This application should occur over the winter months (June to August) before cotton is planted in October (Back Paddock Company 2013).

Cotton fields under flood furrow irrigation in Australia can have water running from head ditch to tail drain for up to six to twelve hours. The soil can stay saturated for 24 to 48 hours after irrigation. Some fields can be irrigated up to 10 to 12 times per season depending on rainfall.

Research conducted by Arthur Hodgson in 1982 at Narrabri Australia shows that cotton lint yield will be reduced by 48kg of lint / ha per day if soil is waterlogged, or equivalent to 0.2 of a bale yield loss every day of water logging (WaterPack 2012).

The type of irrigation will also affect root development of the cotton plant, which will also affect the ability of the plant to source nutrients in the soil. Over-irrigation will cause poor root growth and will result in less nitrogen uptake. The advantage of overhead (sprinkler) irrigation is that nitrogen can be applied during an irrigation event directly to the plant roots, making it more available.

CSIRO researcher, Dr Ben Macdonald, has been researching Nitrogen loss from flood furrow irrigation. The research looked at the movement of nitrate, ammonium, dissolved organic nitrogen (DON) and urea in irrigation supply channels and tail water systems (Jensen 2015). Initial research has shown that DON is the biggest loss pathway; this component of the N pool is typically overlooked in N management (Jensen 2015). The loss occurred mainly during the first irrigations, while urea losses occurred during the growing season. The biggest loss was primarily during the first irrigation (Jensen 2015).

The Intergovernmental Panel on Climate Change suggests between 0.5 to 25g nitrous oxide is produced for every kilogram of nitrate lost. Potentially, up to 1.5kg of nitrous oxide could be produced from the tail water surface alone, when DON is included in the calculation (Jenson 2015).

The following case studies from California highlight what farmers are implementing to prevent water logging and increase the efficiency of nitrogen use in irrigated cotton.

Case studies: Irrigation in Corcoran and Los Banos California

Irrigated cotton growers in California are seeing salinity issues in the soil. The lack of rainfall in the current drought has meant that the salts are not being flushed down through the soil and the high number of irrigations is drawing salt to the surface.

Using safflower as a rotation crop gives some control of salt issues. A rotation of cotton, tomatoes and safflower is being used in California to draw down salt levels. After a tomato crop the water table can only be three feet down, therefore cotton cannot be grown after tomatoes (Spellman 2014).

One way to recover losses from flood irrigation is the installation of tile drainage. Tile drainage was popular in California to recover water that drains below the root zone in irrigation fields. Cannon Michael, a farmer visited in California, has installed sixty km of tile drainage 2.4 m under the soil surface. Cannon said that the drainage cost $1,400 per ha to install (Michael 2014). Pipes are laid out under the soil surface to collect water that drains through the soil, past the plants' roots, after an irrigation or rainfall event. Cannon has also converted sixty percent of the farm to sub-surface drip irrigation, increasing this area every year, costing $3,700 per ha to install.

Conclusions

Overhead irrigation and drip irrigation has not been adopted in Australia because of the high cost of instillation and because in the past the irrigation method has not been able to supply the cotton plant with the peak daily water requirement (14mm of water per day). New technology has increased the water output of the machines, which are now able to meet the daily water demand. This will allow for farmers to change to alternative irrigation methods and improve nitrogen use in irrigated cotton. By moving away from flood furrow irrigation growers will reduce waterlogging.

It is important for farmers to reduce the chances of waterlogging as it will reduce yield. Farmers need to develop the fields correctly and make sure that the drainage is adequate. If there is no oxygen in the soil from water logging there is no nitrogen available to the plant.

The next chapter investigates the different sources of nitrogen fertiliser growers can apply to meet the nitrogen demand of the plant.

Chapter 4: Nitrogen source

The introduction of GMO's and the increased use of herbicides, as well as the increased use of synthetic fertiliser, and heavy tillage can cause an imbalance in the soil. Heavy tillage or excessive tillage introduces high amount of oxygen into the soil, creating an imbalance of microbes resulting in nitrogen being used up quickly. Growers are over-applying fertiliser by 25% as an insurance against lower yields. It is unprofitable for growers to under-fertilise (Zimmer 2014).

Anhydrous ammonia (NH_3 at 82% N) is the main source of nitrogen used in the cotton industry in Australia, followed by urea (42% N) and liquid UAN32 (32% N). The main reasons for choosing the source of nitrogen are price per unit, availability, efficiency, and ease of application to the growers. The atmosphere is made up of 79% nitrogen; it is the only nutrient that is freely available, and the only nutrient growers can capture from the atmosphere.

Farmers need to look at the input of nitrogen fertiliser as units utilised per ha and not units applied per ha. Farmers normally choose the most concentrated form of nitrogen fertilizer, like anhydrous ammonia and urea; this is a mistake as they are not the most efficient and utilised form of nitrogen per ha. An example of this is UAN or sulphate of ammonia (SOA at 21%N), where the nitrogen content is low, but because it is in an ammonia it is much more efficient and less units per ha can be applied.

Most farms visited in the USA used anhydrous ammonia and liquid nitrogen as the source of nitrogen. This was largely due to variable rate technology (VRT) that the farmers were using to apply the product. Farmers found that these two sources were able to be applied more easily using VRT than urea (Martin 2014).

The highest corn yield Gary Zimmer has seen is 18 tonne per ha, using a program of biological carbon based fertilisers including molasses, and side - dressing liquid nitrogen. Growers need to look at alternative nitrogen sources and also need to look at the energy costs of making anhydrous ammonia. Gary's dairy background provides him with a good understanding of microbiology; a cow's digestive system relies on micro-organisms like the soil, where imbalances in the system make the organisms react in different ways. An example of this is synthetic nitrogen breaking down too quickly in the soil (Zimmer 2014).

Australian cotton growers in the past have had little choice of synthetic fertilisers available. The Australia fertiliser market is small compared to worldwide consumption so products are more expensive and products are not available. Farmers need to do their own research into sourcing fertilisers as the import market of raw base fertilisers as they become more economical to source yourself. Examples of alternative synthetic nitrogen fertilisers include sulphate of ammonia and ammonium nitrate.

Conclusions

The type of nitrogen fertiliser and the timing and placement of fertiliser is an important management decisions growers need to make. A recommendation to growers is to move to liquid nitrogen fertilisers as they can be applied directly to the plants root zone at planting or during the growing season.

There are a number of benefits for providing liquid fertiliser at planting (Hockey 2015).

- It will maximise the first 14 days of plant development (yield potential).
- Increase early root development.
- Increase root to shoot ratio.
- Increase root surface area.

It is recommend that growers move away from urea as losses can be high, and sometimes above 50% (Rochester 2012). It is recommend UAN nitrogen fertiliser is used as it is better utilised by the plant, the disadvantage is that it is twice the cost per unit, but better utilisation means that less needs to be applied to meet plant demand.

The next chapter of this report will discuss what affect tillage has on nitrogen use efficacy in irrigated cotton. It will discuss the negatives tillage has on soil structure and the benefits of zero till.

Chapter 5: Tillage

The purpose of tillage is to allow air and water into the soil by breaking up compaction. Tillage is also used as a management tool to remove weeds and prevent insecticide and herbicide resistance. Tillage can also control soil borne diseases in the soil, an example of this in cotton is tillage is used to control fusarium and verticulum wilt. The reason for zero till is to protect the rhizosphere and the plants roots, avoid moisture loss and to avoid compaction (Zimmer 2014). One of the main arguments against zero till is that by leaving large amounts of stubble residue on the soil surface it will oxidise carbon out of the stubble and be lost to the soil (Beck 2014). Aggressive tillage will speed up the breakdown of organic matter as it introduces oxygen to the soil.

Compaction will lead to poor nitrogen uptake as root growth is restricted in the soil. Compaction in a zero till program can be controlled using a number of cover crops including barley or radishs (Beck 2014).

Almost 100% of Australia's cotton crop is grown with transgenic varieties (GMO). Biotech cotton area has increased to over 60% of the world cotton area in 2010 (Cotton Australia website), as part of the resistant management plan (RMP), the license agreement with Monsanto, it is a requirement that one hundred percent of the field needs to be cultivated or pupae busted at a depth of 10cm after harvest (Monsanto 2014).

It is best practice in the Australian cotton industry for the destruction of plants and the incorporation of crop residues by root cut and mulch operation, followed by tillage. Crop residues should be managed to minimise carryover of pathogens into subsequent crops and stop volunteer and ratoon cotton from growing. If back to back cotton crops are grown it is recommended that the crop residue is incorporated to prepare the seed bed for the following crop (Roughly 2015).

Growers use tillage to control compaction problems; growers can cultivate down to 30cm to do this. Compaction can significantly reduce yields by restricting root growth which reduces water and nutrient uptake. Compaction is caused by irrigation and machinery moving across the field at inappropriate moisture levels, such as the new John Deere 7760 round bale picker that weights 32 T (Bennett 2015). The most common form of tillage in cotton production in Australia is inverted tillage using tines and sweeps to reform beds with the same pass.

Shallow incorporation and vertical tillage

Shallow incorporation and vertical tillage are options to growers instead of inverted tillage. The approach is not to disturb the middle zone of the soil where the roots are active, examples of shallow incorporation is a rotary hoe or an offset plough; if it is only done when there is green leaf material on the surface organic matter will be incorporated into the soil. The vertical till approach is to use a deep tine at a 1.5m spacing to allow oxygen into the profile to reduce compaction (Zimmer 2014).

One of the main arguments against tillage is that it turns the soil over or inverts it, exposing micro-organisms to oxygen, resulting in a large increase in microbial activity. Organisms live on carbon from organic matter as their food source; as they digest it, organisms respire releasing carbon off into the air, where it is lost. Less carbon in the soil means that there will be less humus available. Over time organic matter is lost which leads to compaction, lower water holding capacity and poor soil health (Zimmer 2014).

Cotton farmers in the eastern states of the USA have adapted zero till for a number of years. The eastern states receive up to 1250mm of rainfall per year, resulting in erosion being a major problem. Zero till and the introduction herbicide-tolerant Roundup Ready crops have resulted in resistant weeds becoming a major problem. It now costs the growers $100 to $250 per ha to control pigweed. The main driver for herbicide resistance is that growers are choosing all GM herbicide tolerant crops in their rotation, for example cotton, corn and soybeans.

The following case study from the USA was chosen to illustrate the long term benefits of zero till after 30 years. Farmers need to look at the long term benefits of zero till as improvements won't be able to be measured in the short term. The case study highlights the benefits of a true no till system.

Case Study: Dwayne Beck - USA

Dwayne Beck manages the Dakota Lakes research farm. The farm started in 1990 to research zero till farming practices in the area. The farm is located on the edge of an ancient glacier melt: it has 1m of topsoil on a gravel bed, and it is a low rainfall environment, only receiving 300mm per year. A tour of the research farm showed that zero till has worked very well since it was introduced, improving soil heath, soil structure and lowering weed pressure. Worms and night crawlers in the soil have air aerated the soil through macro pores to a depth of one metre. The weed pressure was very low and the only herbicide used over summer was 2kg per ha of atrazine in the corn. This is because of the high residue ground cover. The planter is offset 10cm to plant the new crop. One of the rotations is corn, corn, soybeans and wheat, using a cover crop between beans and wheat. The biggest limiting factor in the soil is carbon. The research is using high carbon cover crops, including forage sorghum millet and oats, to increase carbon levels and reduce compaction (Beck 2014).

Cover crops control run-off and allow for better infiltration. The lateral move irrigator is able to apply 50mm of water in nine minutes with no run-off from the soil (Beck 2014). There was a trial where a number of legume and high carbon species had been inter- sown together so the legumes feed the corn through their rhyzobia. The farm has not used insecticides in 13 years because the diversification of plant species has increased predator numbers. Beck stated that *"a two crop rotation is still a monoculture and does not lead to improved plant diversity"* (Beck 2014).

Dow Agricultural Science conducted a drought tolerance trial testing two varieties of corn. The irrigation was turned off, and it was found that the crop kept growing and yielded 12 t/ha, 50% better than under a conventional tillage system (Beck 2014). Using flax (or linseed) in rotation, which has a good relationship with mycorrhizia, and dries the soil out, and controls compaction problems; wheat has responded well after a linseed crop (Beck 2014).

A quote from Dwayne is that, *“Farmers need to take the E out of ET”* (Dwayne Beck 2014).

E is short for evaporation and ET is short for evapotranspiration. Evaporation can be high from the soil if there is no ground cover and bare earth is present, a result from tillage that exposes the soil surface so there is no residue or stubble left.

There is too much water lost through evaporation. Potential production is lost when moisture is lost through evaporation. The farm has been using a zero till planter since 1990’s, and only puts on small amounts of phosphorus to reduce leaching into the river. Olsen tests are usually less than five parts per million of P. Beck only applies fertiliser early; once roots establish, the roots should form a relationship with mycorrhizae in the soil to source nutrients. For good nitrogen use efficiency plants need available nutrient, water, oxygen and roots at the same location (Beck 2014).

One of the problems with tillage is that it collapses the soil aggregates in the soil (Beck 2014). Under a no till farming system roots are left in the ground, which keep air pores open, which allows oxygen to leave the soil stopping it from becoming de oxygenated. The problem with tillage is that it seals the soil surface off, not allowing oxygen to enter or leave the soil.

The following case study from the UK was chosen as it is similar research that has been undertaken in Australia, and researches three different types of tillage deep, shallow and managed practices over a long period of time.

Case Study: NIAB TAG - England

This project is one of the biggest trials undertaken at NIAB TAG (National Institute of Agricultural Botany) in England and has been going since 2006. The main aim of the project is to look at wheat yields and gross margins under different tillage options, such as annual mouldboard ploughing, deep non-inversion, shallow inversion and managed approach. The managed approach was determined by the conditions at the time used a number of tillage options including offsetting and deep tines. Over 36m x 36m trial plots, the trial also compared cover crop versus no cover crop. The deep non-inversion plough produced the highest yield while the shallow non inversion produced the highest gross margin minus machinery costs. The yield across the compaction trial was 15% less than yields under controlled traffic regimes, as shown in Table 6. The data showed that a rotation of wheat and oil seed rape over a five year period resulted in a yield loss of 12% on the oil seed rape (Morris 2014), compared to a continuous wheat rotation, Table 6 below shows the results from the trial.

STAR - Long term trends in yield and margin data

Years 2006-2013

	Relative yield return (relative to ploughed approach)					Cumulative gross margin minus machinery cost (£/ha)				
	Winter	Spring	Cont	Alt Fallow	**Average**	Winter	Spring	Cont	Alt Fallow	***Average***
Plough	100	100	100	100	100	4593	2880	2668	2333	3119
Managed	96	104	109	92	100	4559	3268	3288	2062	3294
Shallow	94	91	100	97	95	3935	2895	2843	2350	3006
Deep	99	99	97	98	98	4872	3095	2600	2382	3237
Average	-	-	-	-		4490	3035	2850	2282	

Table 6: Star Project, NIAB TAG, Morley Research Farm, Norfolk, England

The following case studies were chosen to illustrate the tillage practices farmers are undertaking in the USA to improve NUE. The case study of Richard Kelly illustrates the negatives of zero till if not managed correctly.

Case study - University of Tennessee USA

A trial at the University of Tennessee compared a no till and tilled system with a vetch cover crop and no cover crop, from 2002 to 2011. Different rates of nitrogen were applied, from zero kg per ha to 90kg per ha. The highest yield achieved was with the tilled vetch trial with 30kg of N applied with 1,300kg per ha (5.7 bales/ha). Followed by the no till vetch trial with 30kg of applied N with 1,280 kg per ha (5.65 bales/ha). The results showed that there was little difference between the no till and tilled system over a ten year period. Taking into account the energy costs of a tilled system, the no till system is more profitable.

Case Study: Richard Kelly – Mississippi Delta, USA

Richard Kelly farms at Covernton, Tennessee, North West of Memphis, with his two son in-laws. A first generation farmer, he has grown his farming business himself, owning 3,600 ha and renting another 3,600 ha. The Kelly family in August 2014 were growing 4,800 ha of cotton, 800 ha of corn and 2,000 ha of soybeans. The introduction of zero till and GMO crops has led to a big Palmer Amaranth pigweed problem, costing an extra $120 per ha to control. It showed the disadvantage of a no till system if herbicides and GMO technology are not used correctly.

The pigweed was first discovered on the farm five years ago It has rapidly spread and now takes a lot of management to control and the family has had to scale back their farmed acres to manage it more effectively. Local farmers have moved out of cotton and soybeans to corn because it is easier to manage. The farm has seen the winter wheat followed by soybeans become a very profitable rotation, achieving 6t / ha of wheat and 4t / ha of soybeans.

The weed resistance problem has moved the Kelly family away from a back to back cotton rotation and has introduced wheat, corn and soybeans into the rotation. This has led to less nitrogen being applied as the soybeans are fixing nitrogen into the soil. The Kelly's have reduced the nitrogen input from 120 kg/ha back to 80 kg/ha (Kelly 2014).

These cases studies have highlighted that the Australian cotton industry is using excessive tillage which results in a number of disadvantages including water infiltration, increased evaporation, and lower organic matter, all leading to lower NUE. The case study from the Mississippi delta highlights that farmers need to remain flexible in a zero till system as weed resistance can be a real problem.

Conclusions

Farmers need to weigh the positives and negatives of tillage before the operation; many farmers do not think of the negatives of tillage before it is too late. The questions farmers need to ask before ploughing is:

- Will it reduce carbon levels of the soil?
- Will it decrease the microbial activity of the soil?
- Will it seal the soil surface and stop infiltration?
- Will it decrease the moisture content of the soil?

It is recommended that farmers move to zero till farming practices, as it will improve soil structure and increase carbon levels in the soil (particularly soils that are high in sodium and magnesium), in turn improving nitrogen use efficiency (SoilPack 1998). The disadvantage of a no-till system is that weeds become harder to control. Cover crops can reduce the weed pressure and the use of residue herbicides will help control problem weeds.

If compaction of the soil is a problem after harvest it is recommend that barley, the strong root system will break down the compaction if the soil is allowed to dry down.

The next chapter of this report investigates how the introduction of technology can improve nitrogen use in irrigated cotton. As technology gets cheaper more tools are available to farmers to use including satellite imagery, yield mapping, computer programming and real time soil sampling.

Chapter 6: Precision Technology

The adoption of precision agriculture in Australia has grown with the introduction of GPS steering. However, the adoption of VRT (variable rate technology) has been slower in Australia, with only around 3% of grain growers in Australia using VRT. VRT adoption has been slow due the expense of the required technological equipment, and the unknown profits that will be returned from this investment (Robertson et.al. 2007).

In comparison, growers in the USA have been much better at adopting precision agriculture into their farming business. Growers are using a wide range of technology such as the Veris machine and satellite and drone imagery. They are also using yield mapping data to apply fertiliser and chemicals at variable rates across fields. Growers are soil testing on a grid or zone sample across fields, averaging one soil test per hectare, which only costs growers about $10 per sample (Hake 2014).

The following case studies from the USA highlight how advanced precision agriculture has become in the USA and highlights how farmers can make better management decisions with the information produced through precision agriculture.

Case Study: Cannon Michael – California

Cannon Michael in California uses satellite technology significantly, using 14m pixels, it costs twenty cents per hectare to get one NVDI image every two weeks and costs $6 per hectare for aerial imagery that is 1m pixels. Figure 2 shows one of the satellite NVDI images from Cannon's farm. Through the imagery, Cannon has found 160 ha of non-productive land on the farm, at a land value of $37,000 per ha. Cannon has changed management practices for these areas. In the past he was applying high amounts of composts, gypsum and lime, however the soil was not absorbing them. The farm yield average for cotton is 1,600 kg/ha. Yield maps and satellite imagery are used to produce management zones, and he only soil samples the weak areas of the field. The Veris machine has been used in the past, however has Cannon found the satellite imagery was identifying the same weak areas. Cannon's theory is that he needs to find out what is causing the lower yield in the field. Is it lack of fertiliser, water logging, soil structure, compaction or drought stress affecting yield?

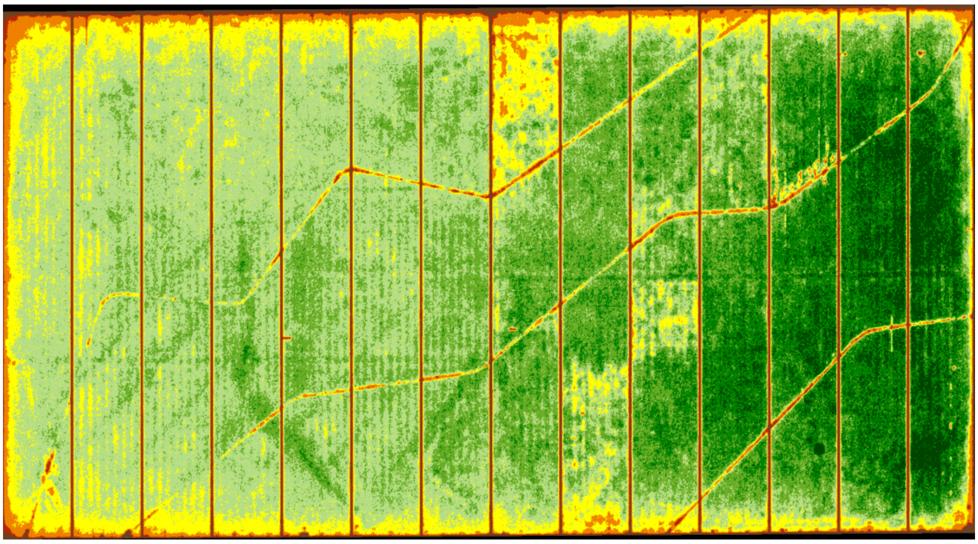

Figure 2: Satellite image by Cannon Michael, September 2014, Los Banos, CA, USA

Case Study: Larkin Martin – Mississippi

Larkin uses a computer program that overlays all farming inputs with soil and yield data information. Management zones are created across the fields to apply all farm inputs. Soil tests are completed across the management zones every year, sampling every hectare. VRT is used to apply lime, synthetic fertilisers with custom blends and manures. UN 32 nitrogen is used as it is easier to use with VRT, however the price is extremely variable. Drones or planes have been used in the past to get NVDI imagery, however cloudy days were causing problems.

Case Study: Visit to Farm Progress Show

The Farm Progress show is held in Iowa and attracts 120,000 people over three days, with hundreds of exhibitors in the one place. These exhibitors cover everything from seed, fertiliser machinery, to bio technology, research and precision agriculture. Farming is becoming quite advanced in the mid-west corn states in the USA due to the adoption of precision agriculture. Farmers are using precision planters to plant variable seed rates, plant two hybrid corn varieties at the same time, and apply variable hydraulic down force to the planter depending on soil type.

A wide range of nitrogen application machines to apply anhydrous ammonia and liquid nitrogen was exhibited at the farm progress show. All machines had VRT and section control across the machine. Anhydrous ammonia is very popular in corn because corn is very responsive to it. The

High Boy applicators were side dressing nitrogen in growing corn crops, and farmers were also using the High Boys to under sow cover crops underneath corn plants.

Climate Corp had a big presence at the trade show. Monsanto is a business that is creating a complete cropping program for growers. Using weather forecasts, soil data, field history and VRT, Climate Corp is using computer modelling that produces prescriptions for farmers from planting to harvest. The computer models create different scenarios, where different planting rates or fertiliser rates are applied to the field, showing what gross margin will be produced if rates are changed (Climate Corp 2014).

The adoption of precision agriculture has been slow in Australia; farmers have introduced GPS auto steering systems and control traffic into the farms, but have not adopted its full potential. This is because of the high cost of PA and the true profit potential from it has not been known. Farmers in the USA have highlighted the benefits of PA if fully adopted and utilised through higher NUE and lower input costs.

The next case study was chosen because it illustrates the future of precision agriculture will be the ability to make real time decisions with the information produced. The researchers at the Tokyo University of Agriculture and Technology has made this a reality by commercialising a real time soil sensor.

Real Time Soil Sensor - Japan

Professors Sakae Shibusawa and Masakazu Kodaira from the Tokyo University of Agriculture and Technology have developed a commercial real time soil sensor. Professor Shibusawa has been working on this technology for the last twenty years. The machine has been commercialised by the Shibuya Company in Matsuyama. The machine uses visible and near-infrared (Vis-NIR: 305-1700nm) soil reflectance spectra to predict and map, at a high spatial resolution, soil properties for soil management and precision agriculture (Kodaira 2012).

Twelve soil properties are mapped in real time by the machine including moisture content (MC), soil organic matter (SOM), pH, electrical conductivity (EC), cation exchange capacity (CEC), total carbon (C-t), ammonium nitrogen (N-a), hot water extractable nitrogen (N-h), nitrate nitrogen (N-n), total nitrogen (N-t), available phosphorus (P-p), and phosphorus absorptive coefficient (PAC) (Kodaira 2012).

There have been two machines built by the Shibuya Company. One is staying in Matsuyama to be used by “Aguri” farming that is owned by the IKEE group and produces organic rice. The second machine has been brought by the Nippon Paper Company in Japan, who is going to use it in forest plantations in Brazil. Commercially the machine will cost US $200,000 (Shibusawa 2015).

Soil moisture needs to be high to accurately read soil properties as dust can cause interference with the sensors and reduces the soils reflectance (Shibusawa 2015). The sampler can only read at a set depth. The RTSS needs to be calibrated to the soil properties before the machine can be used. The machine has only been calibrated to two soil types so far in Japan. (Shibusawa 2015).

There are a number of restrictions for the use of the RTSS in Australia. Australia’s dry conditions would cause interference with the sensors; however an irrigated system would overcome this problem. The RTSS would also need to be calibrated to a number of soil types across the cotton growing regions of Australia. The ability to measure twelve soil properties in real time has great benefits for farmers and hopefully the technology is available to farmers in the near future.

The following case study was chosen as it illustrates how the RTSS can be applied to a commercial farm and the benefits to the farm owner.

Case Study – Aguri Farms Japan

Aguri farming grows organic rice on 50 ha in the Matsuyama region. Its annual rainfall is 1,300mm and the farming land consists of 400 individual cultivated parcels averaging five ha in size. The land is valued between $18,000 USD to $24,000 USD per ha.

Aguri sees the benefit of using the machine to map soil properties from year to year. In Japan food security is very important so the company sees the machine as a marketing advantage to show consumers and general public the soil improvements the company is making year to year.

Conclusions

The future of precision agriculture is going to be strong as the technology becomes cheaper. It will allow farmers to recognise poor preforming areas of the field and the ability to improve them and apply more inputs to gain higher yields. Precision agriculture will allow farmers to make better management decisions in real time. Computer modelling will allow farmers to compare gross margins that can be achieved if nitrogen amounts and timing are changed, allowing for better outcomes for the farmer.

Recommendations

Australian irrigated cotton growers are using synthetic nitrogen fertilisers to grow high yielding cotton crops on vertisol clay soils (cracking clays) that are limited in soil structure and organic matter. Growers may be over-fertilising when other factors may be leading to a reduction in NUE, including compaction, low organic matter or sodicity. Before growers start looking at a nitrogen plan or budget, they firstly need to look at the three properties of the soil, including physical, chemical and biological influences, which will affect NUE. A number of limiting factors and imbalances will cause lower NUE, such as compaction and sodicity. Growers can manage this by adopting precision agriculture and using satellite imagery to create management zones and use VRT to apply soil amendments like gypsum.

Australian irrigated cotton growers need to look at implementing rotations and cover crops to improve organic matter and microbiology activity. A rotation has to be identified as more than two crops, as it forms a monoculture environment, irrigated growers need to be planting a range of crops to increase soil carbon leading to higher organic matter.

Australian irrigated cotton growers need to look at the application method of irrigation and efficiency of their irrigation systems. A large percentage of the industry uses the flood furrow irrigation method that can lead to nitrogen loss through denitrification as a result of waterlogging. Farmers need to look at alternative irrigation methods like overhead sprinkler and sub surface drip irrigation to reduce water logging.

Australian irrigated cotton growers need to look at the amount of tillage that is occurring across the industry. Excessive tillage reduces the organic matter and carbon levels in the soil by introducing oxygen (encouraging oxidation), reducing infiltration from rain events, and increasing evaporation from the soil, all leading to a decrease in the internal crop N use efficiency.

Australian irrigated cotton growers need to develop smaller management zones across their farms. Farmers are relying on a small number of soil samples across large areas or relying on field history to determine their nitrogen requirements, whereas farmers in other countries are sampling fields on a one ha grid to determine variability across a field and create management zones.

Nitrogen use efficiency in irrigated cotton will continue to be hard to manage, with cotton lint yield still being the most important component growers are trying to achieve in order to gain the highest gross margin possible. Growers will continue to over fertilise as an insurance to achieve high yields.

When determining a nitrogen budget for the upcoming or preceding crop, growers need to look at the climate and weather forecasts for the next six months or growing season. This will determine the potential real yield the plant will be able to produce from the season. Every growing season will be different and growers need to adjust to this accordingly.

Growers need to consider all available sources of nitrogen before applying it to the crop. Growers need to reduce their reliance on synthetic fertilisers and weigh up the benefits and negatives it will have, particularly on soil health. Nitrogen is one of the only fertilisers that nature can produce. Growers need to remember this when preparing a nitrogen budget, and think outside the box before applying nitrogen

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Plain English Compendium Summary

Project Title:	Improving Nitrogen Use in Irrigated Cotton
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Objectives	To improve Nitrogen use efficiency (NUE) in irrigated cotton through changing farming practices like rotations, cover crops, and improved tillage and irrigation practices. What are other factors in the soil that lead to poor NUE including physical, chemical and biological properties? How can introducing Precision Agricultural Technologies improve NUE in cotton?
Background	Nitrogen use has increased in irrigated cotton in Australia over recent times with the increase in yield. The average amount of nitrogen applied is around 300kg of nitrogen per ha to target yield of 13 bales per ha. The industry target iNUE is 13 - 18 kg of lint per kg of nitrogen, most growers are well below this target of NUE. Could growers achieve the same yields if the amount of nitrogen applied to the crop was restricted by government regulation?
Research	Travel was undertaken to England, USA, and Japan to complete this study project. Research included visiting farms in these countries and interviewing the farm owners and managers. A number of universities were visited to look at different trial and research work being undertaken to improve NUE.
Outcomes	Irrigated cotton growers in Australia need to implement a good cropping rotation and not grow back to back cotton for consecutive years. Growers need to look at the amount of tillage that is occurring after harvest, excess tillage will lead to reduced carbon levels in the soil, therefore reduce NUE. Growers need to look at the type of irrigation used particularly flood furrow irrigation as waterlogging will lead to denitrification. Grower can improve NUE through implementing variable rate technology.
Implications	Irrigated cotton is the highest gross margin returning crop for most irrigated farmers. It is difficult for farmers to grow other rotation and cover crops as profitability can be affected.