Tropical Cotton Production Systems

Issues relevant to cotton production in Northern Australia

A report for

By Luke McKay

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Executive Summary

Cotton is being assessed as a cropping option for Northern Australia, from the Gulf region of Northern Queensland, across the Northern Territory and to the Kimberley in Western Australia.

The objective of this report is to identify and discuss issues specific and relevant to cotton production in Northern Australia. In doing so the report discusses at length the in crop and area wide management of cotton.

While researching in Brazil, the most telling statement for this research was made:

> *"There is no recipe for tropical cotton, you must be in the crop, reading it and balancing its needs against the weather*" (Eduardo Kawakami).

The key metrics of the crop are identified as the relationship between canopy, roots and fruit retention, the role and influence the weather has on these and on the key tools available to managers, being nitrogen management, plant growth regulant and irrigation, and how to use them to manipulate production.

Management responsibility does not stop at the farm gate and all growers play a role in the area-wide management of pests and resistance in a Northern cotton industry. Case studies from Brazil and the United States are used to compare what effect areawide regulation and approaches can have on farms and industry as a whole. Lessons are drawn from each and examples demonstrate what effect inadequate area wide management could have for a North Australian cotton industry and how effective IPM (Integrated Pest Management) could be as a solution.

The report makes recommendations to industry and potential growers. These recommendations are aimed at building on the base of information provided by previous R&D, identifying risks and contingency plans for pests and diseases and working collaboratively with other agricultural industries and traditional owners to progress agriculture across the entire region.

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Foreword

Currently, I am employed by Kimberley Agricultural Investment (KAI) as farm manager, based north of Kununurra in Western Australia (WA).

In 2012, KAI were named as preferred proponent to develop and farm the area known as Stage Two in the Ord River Irrigation Area (ORIA). Since 2012, KAI has assembled approximately 27,000Ha in various land parcels with the aim of developing a fully integrated agricultural operation in the East Kimberley. KAI's initial focus had been on high value grains such as chia and quinoa as well as maize, chickpeas and sorghum, but with the rate of development and size of the eventual operation a crop that can be grown on an extensive scale has been sought.

Trials of Bollgard 3™cotton varieties in the ORIA from 2013-2016 and in larger trials 2016-2017 have shown promising results. However, while providing a potential option for extensive production, the introduction of cotton back to the region has raised plenty of questions. It was these questions that lead me to apply for and receive a Nuffield Scholarship.

During my travel I was fortunate to meet some exceptional people who were extremely generous with their time. My travels took me to The Netherlands, France, Singapore, The Philippines, Hong Kong, China, Germany, the United Kingdom, the United States of America (twice), Brazil and Zambia and across Australia.

I have had a working relationship with Dr Stephen Yeates of the CSIRO since KAI has moved towards cotton and he has always maintained that if you wanted to understand tropical cotton, get to Brazil. With his assistance I was put in touch with Eduardo Kawakami of TMG in Brazil. Eduardo hosted me for nearly two weeks, showing me cotton all over Brazil from Sapezal in North Western Mato Grosso to Barreiras in the State of Bahia and everything in between. Brazil by far had the most influence on my topic and owe a debt of gratitude to Eduardo.

My initial research focus was weighted towards setting up the farm to adapt to cotton, specifically double cropping, rotation crops, irrigation methods, staff requirements, machinery requirements, resource and environmental management. With a clean slate I wanted to be certain that we had sought out all the information we could to get our production system right at the start. While researching during 2018 KAI also planted the first commercial wet season cotton crop since the 1970's. The experience of managing this crop while conducting research around the world has slightly shifted my focus on what the key factors are for cotton production in the North and are detailed in this report.

Northern Australia currently lacks production scale, ginning, processing and logistics infrastructure. These factors are dependent on each other in the "horse and cart" scenario that has been constant in Northern development to date. Without infrastructure there is no production scale, without production there is no infrastructure and on it goes. This report aims to assist those seeking a cropping option in Northern Australia through understanding the production opportunities, risks, and how to manage them. From this it is hoped that investment decisions in production capacity and infrastructure can be made with more certainty and establish a viable cotton industry in Northern Australia.

Acknowledgments

I would like to acknowledge:

- Nuffield Australia for providing me with this opportunity. The global network is second to none in knowledge sharing and personal development.
- Cotton Australia and the Cotton Research and Development Corporation (CRDC) for their support of my scholarship and development of people and industry in the North of Australia.
- KAI for allowing me to take time away from the day-to-day part of my role and focus on the bigger challenges we have moving forward. I must especially thank Jim Engelke for his support in this process, as well as the outstanding farm team at KAI that took on extra workload in my absence.
- Dr Stephen Yeates of the CSIRO and Paul Grundy of QDAF for their abundant knowledge and direction in this topic and in the development of this report. They have been a great source of learning in this project, as is shown by the number of references to their work in this report.
- North Australian Crop Research Alliance (NACRA) for its ongoing research into tropical cotton production and access to results contained in this report.
- David Cross and David Menzel for their help and guidance in my early thoughts on this project and its eventual application.
- All the people and businesses that opened the doors to their homes and operations and took the time to help out. This report would not have been possible without the efforts made by people who genuinely want to help, and this is what makes agriculture such a great industry.
- I must especially thank Mick and Sarah Selby of Mkushi, Zambia for their hospitality. Getting such a close look at agriculture in Africa has always been an interest and would not have been possible without you.
- Mike and Yevette Green for opening their home to me and providing time, contacts, information and a cultural understanding of the South.
- Eduardo Kawakami. I could never have imagined I could learn so much in such a short period in Brazil. You went above and beyond with your hospitality and helping me

understand tropical cotton as well as Brazil more broadly along the way. I hope that one day I can return the favour.

- Most importantly my partner Kitty, who has been exceptionally supportive from the outset and through the more difficult parts of this journey. I am certain I could not have done it without you.

Abbreviations

BMP - Best Management Practice

Bt - Bacillus thuringiensis

CSD - Cotton Seed Distributors

CSIRO - Commonwealth Scientific and Industrial Research Organisation

GM - Genetically Modified

GPS - Global Positioning System

IPM - Integrated Pest Management

Mealybug - Solenopsis Mealybug

N - Nitrogen

NACRA - Northern Australia Crop Research Alliance

NAWF - Nodes Above White Flower

NSW - New South Wales

ORIA - Ord River Irrigation Area

PIX - Mepiquat Chloride

QLD - Queensland

RMP - Resistance Management Plan

TBWEF - Texas Boll Weevil Eradication Foundation

TIMS - Transgenic Insecticide Management Strategy Committee

WA - Western Australia

Objectives

The main objective of this report is to identify and discuss issues specific and relevant to cotton production in Northern Australia.

To do this the report will focus on the following areas:

- In-crop management, identifying the key factors influencing crop growth and yield.
- The case for area-wide management of cotton.

In addressing these issues, the report will recommend the key areas of focus for cotton production in Northern Australia, as well as areas where additional research and development is required, or procedures developed.

Chapter 1: Introduction

Northern Australia is broadly defined as all country North of the tropic of Capricorn, as shown in Figure 1. At present this area has no established cotton industry, although central Queensland may just be above the line. Because of the author's association with the ORIA, this report has a large number of examples and focus related to the East Kimberly but will show the key principles to successful production can be adapted to different areas.

Australia's cotton industry is largely based along the interior of Eastern Australia from Emerald in central Queensland extending to the Murray River in the south. Australian cotton production averages 1.5 million 227Kg bales annually, up from 9,000 bales at the start of the industry in the 1960s (Cotton Australia statistics).

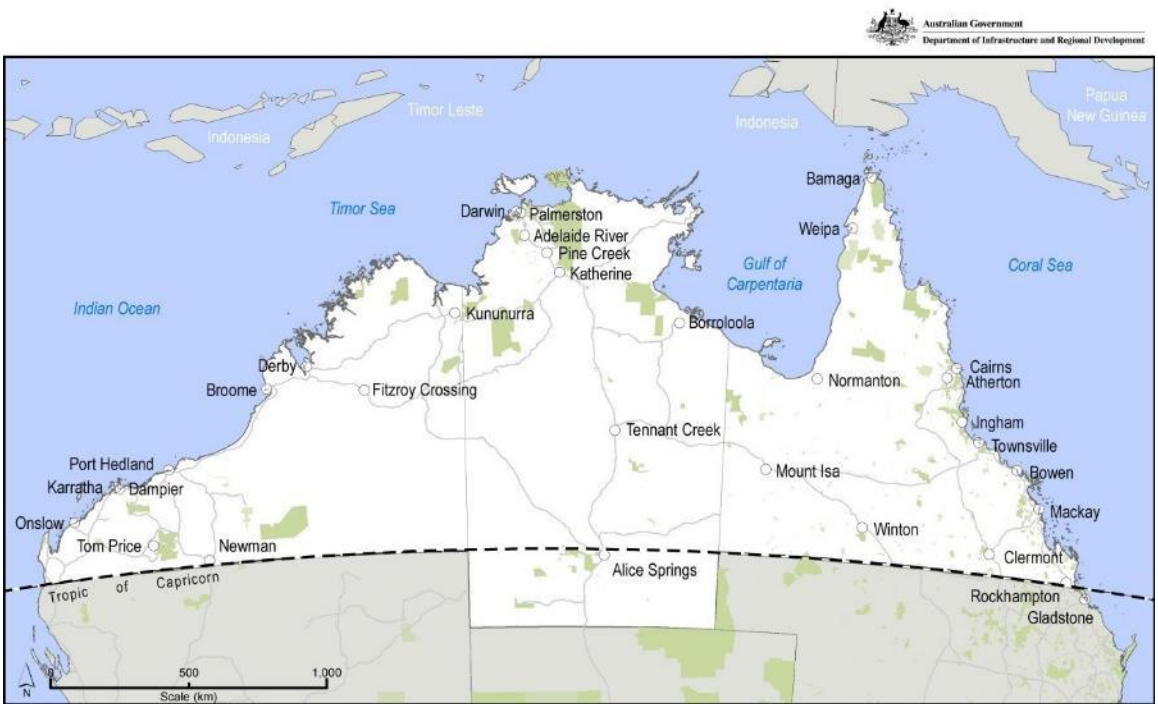

Figure 1 Map of Northern Australia (Source: White Paper for Developing Northern Australia)

Cotton has previously been grown in the ORIA, but the industry ceased in the 1970s because there was total reliance on broad spectrum insecticides for the control of major pests. In 1974, 40 sprays were applied with a total of 77 Kg/Ha of insecticide for the season (Strickland, 2017, DAFWA). Resistance to insecticides built up and resulted in uncontrollable pest populations.

Northern Australia differs from the traditional cotton growing areas because the crop is planted when temperatures and daylight hours are decreasing. Planting during April and May, at the beginning of the dry season, means the crop will be flowering and filling bolls during the shortest and coolest days of the year.

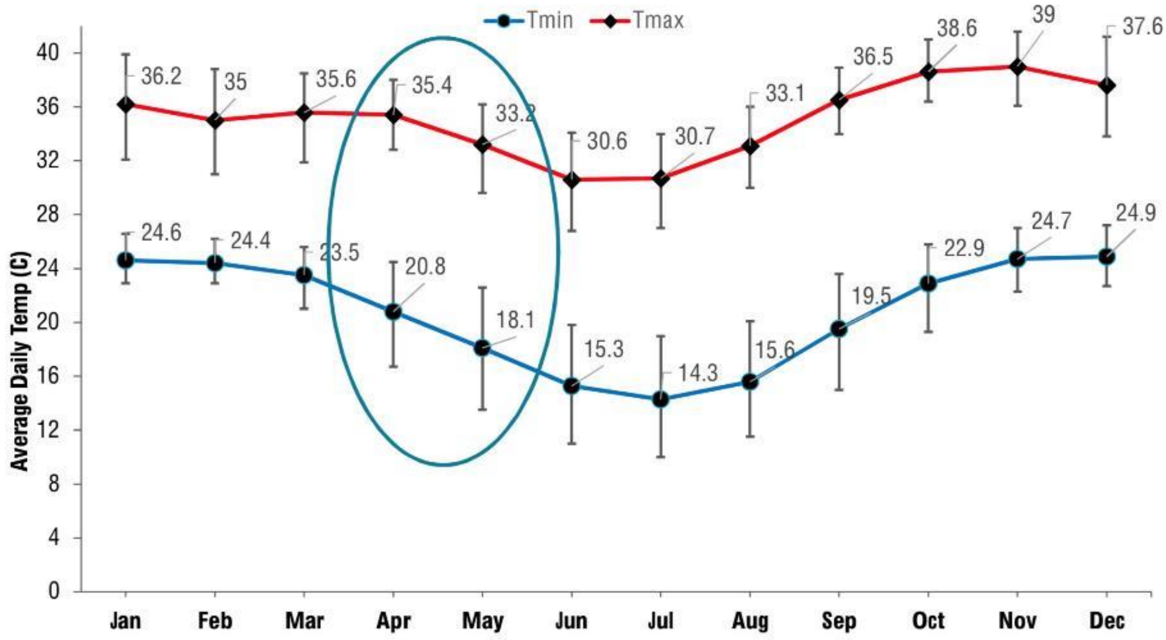

Figure 2: Average Minimum and Maximum temperatures – Kununurra (source: Yeates)

Figure 2 shows the average minimum and maximum temperatures for Kununurra as well as the possible range for the month. The blue circle shows the ideal conditions for flowering and boll fill. To take advantage of these conditions, crops need to be planted from mid-January through until the end of February. Planting during this period exposes the crop to the peak season for *Spodoptera litura* (Strickland, 2017).

The commercial introduction of Bollgard 3™ to the Australian cotton industry in the 2016/17 season provided Northern Australia with the opportunity to re-assess wet season cotton. The Bollgard genes in cotton express the protein Vip3A which is toxic to Spodoptera litura. Research into the toxicity of Bollgard 3™ on *Spodoptera litura* was conducted by NACRA in Kununurra during the 2018 season. The research confirmed this toxicity, showing good control during three stages of the growing season. With this confirmation, further investment and continuation of research into the development of cotton could be made.

After visiting farmers and researchers from around the world, as well as using some of his own experiences trialling cotton in the ORIA in 2018, the author gained insight into what the key factors are for producing cotton in the North. The factors are complex, and Eduardo Kawakami of TMG in Brazil summarised the approach.

"Everyone wants to know the cake mix for tropical cotton, there isn't one. You must be in the crop assessing what it is telling you, what the weather is going to do, then make a decision on what to do next" (Kawakami, 2018).

This statement was further confirmed by Dr Steve Yeates of the CSIRO during a presentation of NACRA's research results in November 2018 at Kununurra, WA. He stated that managing the transition from wet and dry weather is one of the most important management factors for wet season cotton. Decisions are complex and require the balancing of three key factors:

1. *What can the plant tell you?*
   In order to assess the health of the plant the following factors must be monitored: fruit retention, root development and canopy vigour.
2. *What is the weather going to do?*
   Temperature and rain forecasts must be weighted against historical averages.
3. *What is your capacity to respond?*
   How flexible are your management tactics on nutrition, irrigation and PGR?

Management of cotton in the tropics does not stop after picking or at the farm gate. There is sufficient temperature and in an irrigation system adequate moisture, for the crop to persist year-round. The issues this raises is in the extension of exposure to the Bt toxins as well as creating a "green bridge" for pests to survive the off-season and immediately move into a crop the following year.

Cotton plants containing the Bt toxins must be planted inside a prescribed window as part of a resistance management plan (RMP) set by the transgenic and insecticide management strategy committee (TIMS). The TIMS committee's role is the development, review and oversight of the Australian cotton industries insect, herbicide and Bt resistance management strategies. The aim of the RMP is to limit or reduce the risk of resistance and part of this is control of ratoon and volunteer cotton post-harvest. Doing this along with a refuge and trap crop to dilute any resistant numbers aims to maximise the longevity of the Bt toxins. Paul Grundy (DAF) stated, in a meeting in Kununurra in November 2018, that continuous 12-month cropping, whether cotton or a combination of other crops, is the fastest way to build up pest populations and select for resistance in Northern Australia.

This risk is not limited to pests controlled by the Bt toxins. Solenopsis mealybug (mealybug) provides a good example of why creating a fallow period free of hosts is important. Mealybug currently has limited chemical control options with the most effective control method being to encourage and preserve beneficial insect predators and enact strict on farm hygiene with a host free break of at least 3 months (Grundy, 2018). This challenge will extend to any cotton seed used as a feed source in Northern Australia and making sure it does not germinate and become a host for pests within the landscape over time.

Chapter 2: In-Crop Management

This chapter will discuss the key factors influencing crop production, and methods available to manage growth and yield. As outlined in the introduction, crop management decisions can be broken down by focusing on the three key questions raised previously:

- What can the plant tell you?
- What is the weather doing?
- What is your capacity to respond?

What can the plant tell you?

Cotton is a perennial plant manipulated to grow as an annual crop. Heat units rapidly accumulate in the tropics and when combined with unlimited moisture and potentially high N the cotton plant can enter periods of extremely fast growth. If a stress occurs the plant will shed fruit but because of the rapid growth, one week of cloudy weather could affect up to four nodes. As a reference point, the average southern crop has 16 fruiting branches, meaning the loss of four nodes affects 25% of the crop (Grundy, 2019).

The commencement of flowering signals the beginning of a complex period for cotton management in the tropics. The plant must balance concurrent growth as it continues to both develop a canopy whilst retaining bolls in a tropical environment where photosynthesis may be impacted by variable radiation, hot night temperatures and changes to nitrogen availability in the soil due to rainfall.

Cotton has been successfully grown in southern Australia since the 1970's and continual adoption of new technology like Genetically Modified (GM) varieties, a focus on input efficiencies and a breeding program that has selected for yield traits has placed Australian cotton growers at the for front of the worlds cotton growers. The continual pursuit of improvement through research and development has provided a production blueprint for how to best manage cotton crops in temperate Australia. Part of the author's initial focus on research for this topic was finding ways to develop a similar blueprint for Northern Australia, but a comment from Eduardo Kawakami in Brazil about there not being a "cake recipe" for tropical cotton meant the focus shifted to better understanding crop growth responses in the tropics and being prepared with appropriate agronomic management tactics when required.

Narrabri Crop @ First Flower

Burdekin Crop @ First Flower

Figure 3: Different growth patterns of cotton: Northern NSW and Northern QLD (Source: Yeates)

Figure 3 shows a cotton crop in Narrabri, NSW against a crop in the Burdekin region of North Queensland, both at first flower. Accepting that cotton grows differently to what most producers expect is the first step in preparing to manage the crop in the tropics. Both these crops had a similar yield of 12 bales/ha (Yeates).

Nutrition

While growth patterns can be vastly different for cotton grown at different locations the total nutrient uptake required to produce a bale of cotton remains largely the same across environments (Figure 4). Difficulties emerge in the tropics with managing availability of nutrients as rainfall can cause both nutrient loss and make application of artificial nutrients difficult.

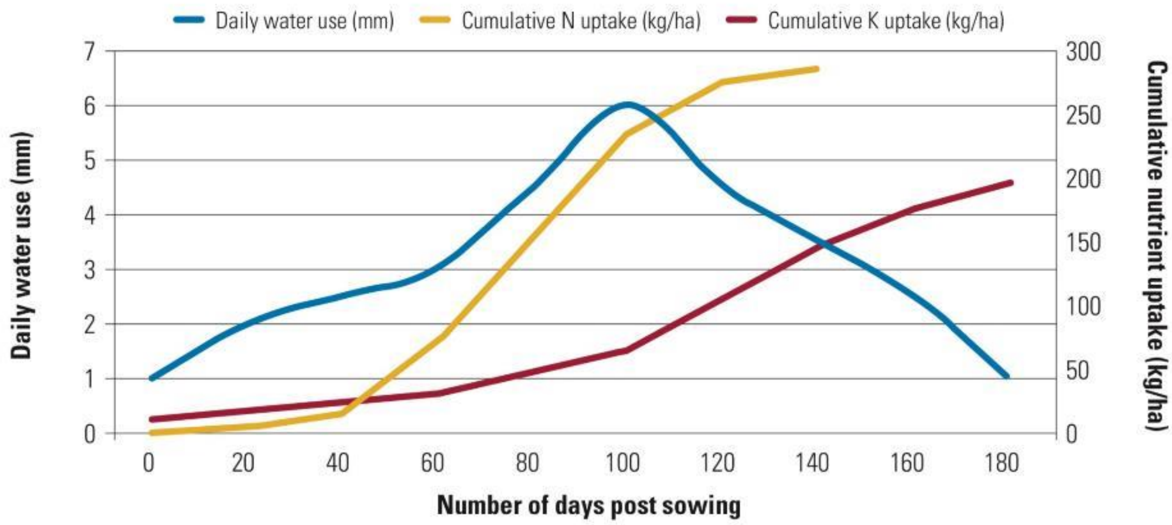

Figure 4: Nitrogen and potassium uptake of cotton and water use over time (Source: Cotton Seed Distributors)

Nitrogen management presents one of the more specific challenges for tropical cotton. Research by Dr Stephen Yeates has shown that nitrogen uptake can be as low as 13% on clay soils during the wet season, when applied before, or at planting, when using urea.

Timing of N fertiliser application	**Average % N Fertiliser uptake (range) For maximum yield**	
	Clay*	**Loam/sand#**
At or pre sowing	**27 (13 - 51)%**	**45 (26 - 61)%**
Most N applied after 30 days to first flowering	**45 (35-56)%**	**78 (70-89)%**

Table 1: Nitrogen uptake efficiencies, Burdekin 2010-2014 (Source: Yeates)

Table 1 shows the different uptake efficiencies of cotton in North Queensland during trials during 2010-2014 on both clay and sandy loams using different timings. Losses can be extensive during wet conditions on clay. Similar conditions can be experienced on clay soils of the ORIA during the wet season. While the plant may be showing signs of N deficiency, as seen in Figure 5, a flexible management strategy to limit losses and maximise uptake must be in place, because weather conditions may not allow timely applications. The management strategies around nitrogen management will be discussed later in this report.

Figure 5: NACRA Nitrogen trial ORIA 2018. Lighter-coloured crop on the right-hand side had zero applied N. (Source: Author)

Fruit Retention

A cotton plant can lose squares and bolls throughout squaring and flowering for different reasons such as moisture stress, cloudiness, and insect damage. Retention is the percentage of fruit retained compared with the total number of fruiting sites; as a guide, temperate environment crops are managed to maintain retention at or above 60% during squaring and peak flowering (Grundy, 2019). If fruit shedding is occurring, then the cause needs to be established and the best treatment strategy decided. Because of the warmer climate, crops in Northern Australia have more ability to compensate for early fruit losses, unlike the situation in southern Australia where the opportunity for compensation is more finite due to winter temperatures (Yeates). For the tropics, this does not mean that crop growth can be extended without consequence. Pushing maturity later into cooler weather may still have detrimental effects for yield potential, lint quality and increase crop exposure to pest insects. This risk is illustrated in Chapter 3 of this report.

Canopy

Canopy management is a key component for tropical cotton production. Leaf colour can indicate nutrient deficiencies, leaf size and petiole length the vigour at which the crop is growing. Row closure, that is the growth of leaves to cover the inter-row area, will also provide an indication of how and more importantly where the plant is likely to set fruit. The more expansive growth habit of tropical cotton compared to temperate crops enables row closure much earlier in the season (Figure 3). This in turn can reduce light penetration to the lower canopy and effect boll retention and growth. A more open canopy in early boll growth allows light to be intercepted by lower leaves and bolls are more likely to be larger and to be retained, which is desirable in shorter growing seasons (temperate growing areas). This growth may exacerbate fruit shedding and lead to later boll set, causing a “top crop”, and a delay in crop maturity (Yeates).Paul Grundy put it simply “*as each boll has a leaf associated with it, the leaf is essentially a solar panel for the boll and no light no power*”. Figures 6 and 7 show cotton plants from Sapezal in Mato Grosso (Figure 6) and Bahia (Figure 7) in Brazil. Both show the plants preference to set a top crop as opposed to bottom fruit traditionally seen in southern Australia.


Figure 6: (Left) Top Crop in Sapezal (Source: Author)

Figure 7(Right) Top Crop in Bahia (Source: Author)

In the photo from Bahia (Figure 7), the plant the author is holding was cut off around 70cm from the ground. There were four small bolls below that point, and the nine nodes above it held 24 bolls. This farm was owned by Grupo Horita and during the visit picking was 75% completed. Farm average yield for the season was 9.25 bales/ha, all rain fed. The agronomist for Grupo Horita allows the crop to grow to 1.3m tall to maximise node production and top crop potential. This was a similar strategy to Bom Futuro in Spaezal, where their agronomist said they are happy with 1.3m as a target but are not worried if the crop is up to 1.5m tall.

An effective tool in assessing the canopy of the crop is a chart developed by Grundy et. al. (2012) which graphs crop height and node number against a “preferred’ range that also takes into account crop vigour and lower canopy fruit retention. Initially developed for the Burdekin region, it requires validation for other regions, but is a good starting point to help make decisions about the canopy.

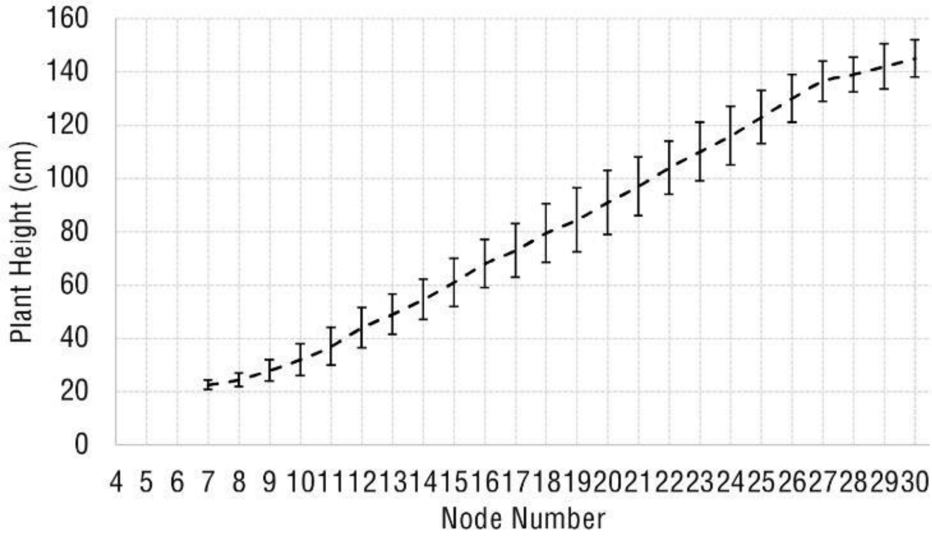

Figure 8: Height vs Node number ex Burdekin (Source: Yeates)

Figure 8 shows the "optimal" growth curve for cotton in the Burdekin region of Northern Queensland. While this is an excellent reference to show where the crop canopy is at, it must be weighted against all other crop growth characteristics, as well as the short-term weather forecast to make decisions. The use of this chart will be discussed in the management decisions section of this report.

Figure 9: Small root development on cotton (Source: Grundy)

Roots

Root development reflects the location of moisture available to the plant. If continued wet weather is experienced, the plant has no need to extend roots down to find moisture (Figure 9). In extremely wet weather, roots have been observed developing sideways into a bed in an effort to get away from waterlogged furrows (Grundy). The roots give an indication of the soil water conditions that the plant has been exposed to, which the crop manager can use to predict how the crop might respond to irrigation or future weather conditions.

Nodes Above White Flower

Nodes Above White Flower (NAWF) is a measurement to show whether the crop is still actively growing during flowering. A crop that has a rapid reduction in NAWF may be experiencing a stress impact. Once the crop reaches 4-5 NAWF it “cuts out”, meaning the vegetative expansion and production of new fruiting sites has ceased and the crop will then mature the fruit that have been set. There is a risk when transitioning from wet to dry season conditions that the plant can cut out prematurely particularly when large plants have poorly developed root systems that rapidly become stranded in the drying upper soil profile. Measuring NAWF weekly can detect plant stress that is curtailing growth in time to make management adjustments for irrigation or nutrition.

Weather and climate influence

Cotton, having an indeterminate growth habit, will develop fruit while producing leaf and stem. Once the production of squares commences, the plant can favour vegetative or reproductive organ growth depending on conditions. While growers have no control over the climate it is important to understand what different conditions can do to the plant so that decisions can be made to minimise risk or to quickly react to changing conditions. It is easy to view Northern Australia as having ideal weather conditions for cotton production, but the intensity and variability of conditions has major impacts on crop growth, and on the partitioning of that growth into vegetative and reproductive components.

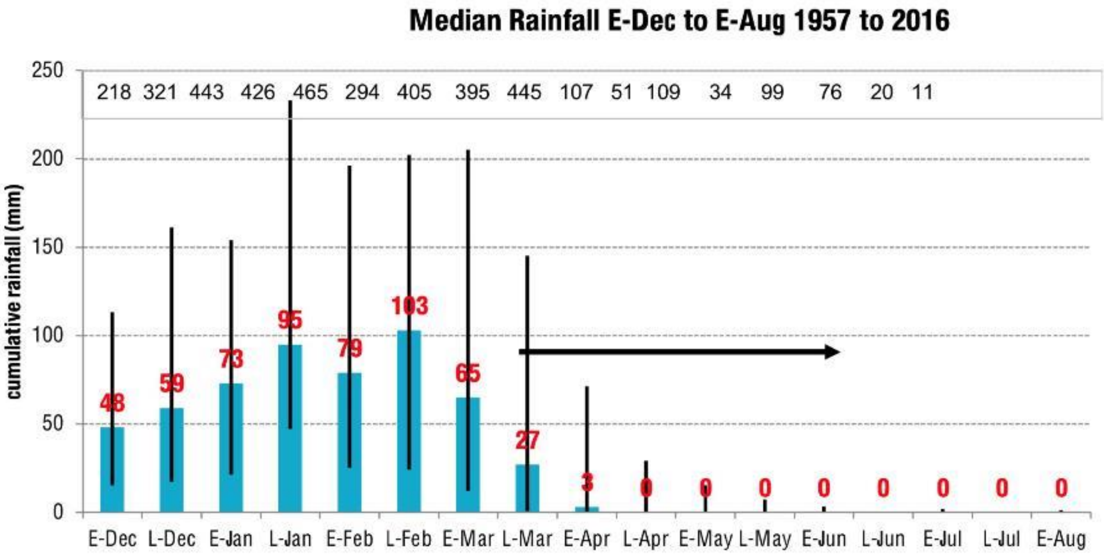

Figure 10: Median rainfall early Dec to Early August ORIA (Source: Yeates)

Figure 10 shows the average half-month rainfall for the ORIA, but most telling is the extreme variation from the average that can be experienced. Late March for example has an average of 27mm but a range from 0 – 150mm. This illustrates the difficulty in planning operations in the tropics and shows why plans must remain flexible to meet varying conditions.

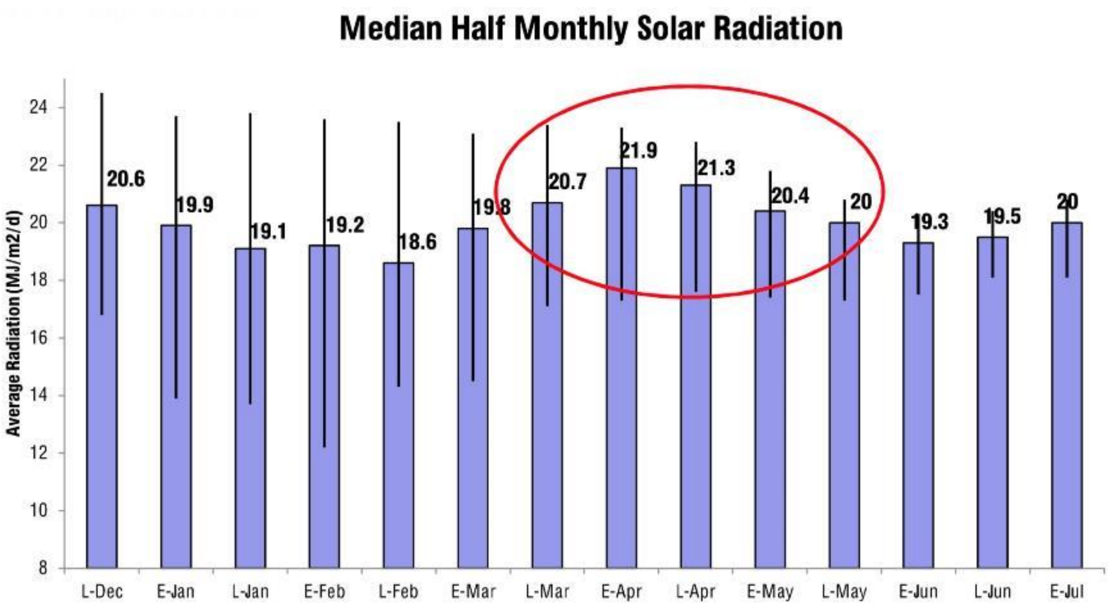

Figure 11: Median half monthly solar radiation ORIA (Source: Yeates)

When viewing the average half-month solar radiation (Figure 11) against half-month rainfall, it is clear that rainfall, or more importantly cloudy weather, coincides with a reduction in solar radiation. The red circle indicates the best conditions for filling and maturing bolls.

For an irrigated system the limiting factor on yield is solar radiation and decisions are made to best match flowering and boll filling with the best solar radiation conditions. In a dryland cropping system the limiting factor to yield is moisture availability, so decisions are based on utilising periods with the highest rainfall. While discussing irrigation systems, the influence of climatic conditions can be similar to dryland crops, but the management decisions may differ. The methods for planning and assessing climate influence are the same.

The rainfall and solar radiation available, matched with the plant growth stage, will dictate what type of plant will develop. Low rainfall and sunny conditions are likely to set more bottom fruit and in wet, cloudy weather a top crop will develop once solar radiation increases.

The plant condition reflects previous weather combined with actions already taken like planting date and fertiliser put on the field. Reading what the plant is telling you and holding it against the short-term forecast and historical averages will assist in suggesting what the crop will do or need next and what decisions are needed to meet that.

Management strategies – how do you plan and react?

There are too many different combinations of factors to outline a strategy for each scenario. This section will outline how to approach planning for the season, reacting to different conditions by reading the plant and balancing the short-term forecast and historical averages.

When planning to grow cotton in the tropics it is best to plan around historical climate averages in the first instance, as long-term forecasts are generally less accurate. Hypothetical situations are endless and individual managers will have different risk appetites for each but clearly establishing and understanding what you are prepared to sacrifice or lose going into the season is a key step and first in the decision-making process.

Once decisions are made on row spacing, planting rate, variety and sowing date there are three tools available to manage the crop:

- Nitrogen
- Plant growth regulants (PGR or Pix)
- Irrigation

Nitrogen

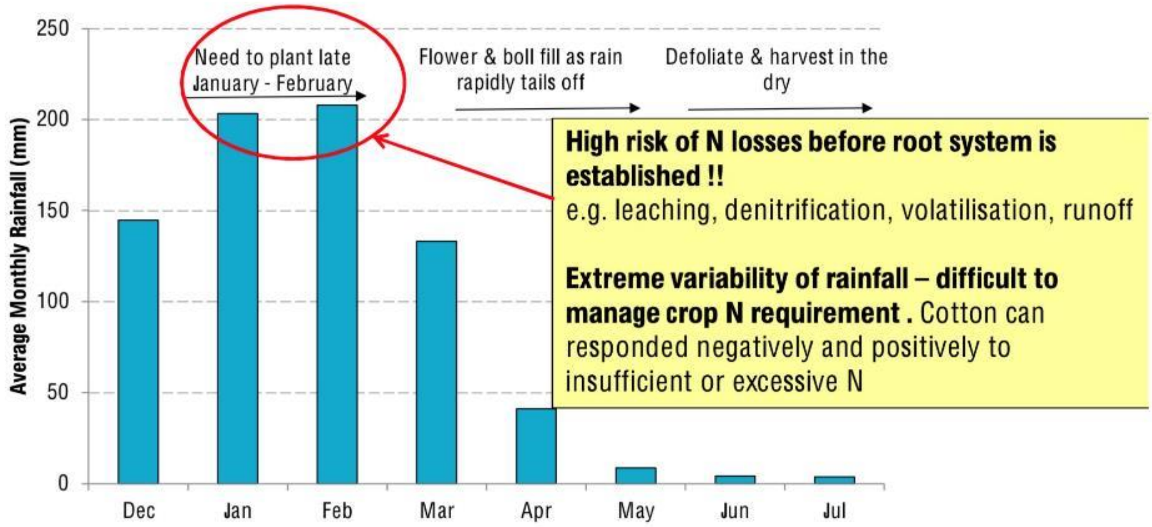

Figure 12: Nitrogen loss risk (Source: Yeates)

Figure 12 shows the risk period for N loss but also states that cotton can respond positively or negatively to N. Excessive N available to the crop early, combined with moist sunny conditions, can encourage the plant to perennate, because it has it "too good" and sees no need to reproduce until conditions change.

Crop N requirement starts ramping up around 30 days after planting (Figure 4) and need to be able to take up 3-4 Kg/ha/Day of N from day 30 through to 90 (Yeates). There are various agronomic options available to best achieve this.

In Brazil the author witnessed a trial using the legume crotalaria as a cover crop before cotton. Crotalaria does two things in Brazil. The first it can reduce nematodes and the second is to fix nitrogen. At the trial site in Sapezal, Eduardo Kawakami stated that crotalaria can fix up to 60 Kg of N and make it available to the following cotton crop.

The use of cover crops can be an effective way of storing some N for the coming crop, but the residue must be balanced with the ability to get on the field to plant and conduct other operations. In the free draining sandy loam of Brazil this is not a major concern, but on a heavy clay ground cover will hold soil moisture and limit access. The use of cover crops must also be weighed against the possibility of being a host for pests and creating a green bridge into the following cotton crop. Figure 13 shows young crotalaria already nodulating in Mkushi, Zambia.

Figure 13: Young crotalaria already nodulating, Mkushi, Zambia (Source: Author)

Another management tool available is delayed-release N products. There are two main types:

1. *Polymer-coated* which is urea covered by a coating to delay the breakdown of granules and release of N, and
2. *Ammonium stabilisers* (Entec) which act by suppressing the bacteria that convert ammonium to nitrate N. Both products were assessed in a large-scale nitrogen trial conducted by NACRA in the ORIA during the 2018 season.

Year	Urea	Polymer	ENTEC
2103	25	57	39
2014	24	53	38
2015	30	50	35
Average	**26**	**53**	**37**

Table 2: Percentage N uptake with different products applied pre-plant (Source: Yeates)

Over three years the delayed release products clearly show increased uptake efficiencies (Table 2). How these products are used by growers is dependent on their risk assessment for N losses or their ability to get N into the plant. Delayed-release products are more expensive, so a cost benefit needs to be completed.

An easy way to anticipate N requirements in crop is the use of a zero-treatment strip. This area should have no N applied to it before or during the season and will give managers an indication as to what the plant is getting from the soil unassisted and as it runs short of N will show up in advance of the rest of the field, giving managers time to plan and react as required. Figure 5 illustrates this clearly, where shorter light green crop is set against taller healthy-looking plants.

Growth regulator management

Mepiquat chloride (PIX) is a plant growth regulator used to control fruiting and vegetative growth in cotton. It can be used to address excessive vegetative growth and also to induce cut out. In presentations on the Burdekin research Paul Grundy states there are three key principles to using Pix successfully in the tropics:

1. Do not apply it to stressed plants or when an immediate stress is likely
2. Check what the goal is in applying Pix and ask is it the answer.
3. Think about the future – what is the weather like in the coming week, is my irrigation on schedule and what is my fruit load?.You can only impact tomorrow's growth; if you have a tall plant in front of you, you can't change that.

If crop assessment and weather conditions suggest the crop is about to grow vigorously then apply pix to check it slightly. The rates and uses are different in the tropics compared to temperate growing regions. Bom Futuro agronomists in Sapezal had used a total of 2L/ha of pix in the 2018 season over eight applications. One of these applications was 800ml/Ha for cut out and using as little as 150ml/Ha during earlier crop growth.

The index of crop height versus the number of nodes is the most effective indicator of whether or not a pix application will be required.

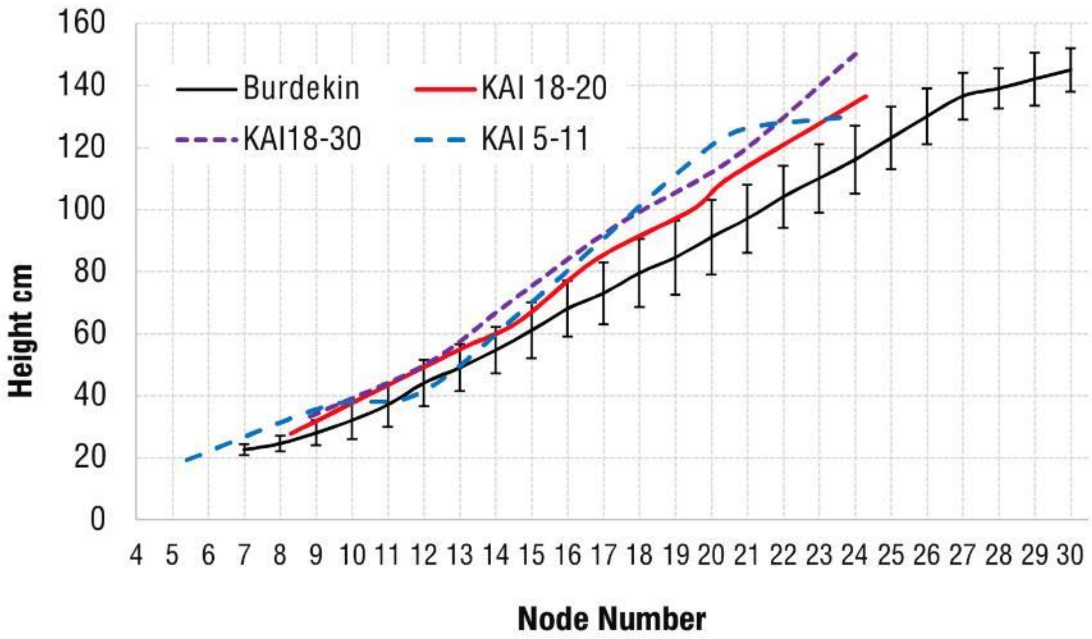

Figure 14: Height vs Nodes KAI 2018 (Source: NACRA / KAI)

Figure 14 shows the height plotted against the node number for crops grown by KAI in 2018 against the Burdekin optimal growth curve. It shows crops looking to push out of the optimal range around nodes 13-15 suggesting a pix application to check the height. This also illustrates the importance of balancing all decision tools. Due to lower than average rainfall, irrigation commenced in the crop around the same period, following side dressing application of the N required. Irrigation schedules were 7-10 days due to hot weather. Short irrigations following the N application were the cause of the jump, what was required was to induce a slight moisture stress on the plants, which would have brought the vegetative growth in check, not pix. The optimal curve requires continual validation as more data is gathered. Although outside the optimal range these fields yielded between 10.4 - 11.3 bales/ha.

Pix can also be a problem. The author visited a trial site near Campe Verde in Brazil which was trialling the use of pix to manage growth and asses its effects on the plant for that season. Figure 15 shows two plants. The left plant has received no pix, it has 23 nodes and 20 bolls. The right plant received heavy rates of pix to limit the height and did so, resulting in there only being 19 nodes and 13 bolls.

Figure 15: Plant comparison from Pix trial, Campe Verde, Brazil (Source: Author)

Irrigation

A tropical crop may be set up for irrigation, but high and continued rainfall may mean the first irrigation may not be until 60 days after planting for a mid-January planted crop. A crop in this situation is likely to have a small root system relative to the large canopy. Irrigation needs to be scheduled to give the plant time to adapt to the changing conditions. After receiving weeks of rain and a full soil profile it is easy to under-estimate the moisture requirements of the plant. Irrigations may need to be as soon as five days after the last rainfall event and scheduling should take into account the ability to irrigate the entire program soon after the last effective rainfall has occurred.

Alternatively, a low rainfall season may require earlier irrigation and combined with warm sunny days and high nutrition can send the plant into excessive vegetative growth. Irrigation needs to be used in the same manner as pix, to address the future requirements of the plant. Fruit counts to establish total fruit/m is the best indicator of the need for irrigation in this scenario. Placing moisture stress on the plant at this point could be beneficial to encourage it to produce more fruit. Once there is fruit on the plant, the moisture demand changes and irrigation is needed to hold and mature that fruit, or to develop more, to achieve the yield target.

Making effective decisions in-crop

These plant growth indicators allow the grower to assess the status of the plant and evaluate what influence the weather can have and what tools are available to influence production.

Defining a manager's appetite for risk is a key point in the decision-making process. The next key point is setting a yield target and knowing how many bolls per metre are needed to achieve this. The tools available to influence crop production are about the future of the crop and a yield target balances the cost of decisions against their return. It also outlines the parameters for the season. It is not suitable for the target to be "*as high as possible*". Decisions to push the plant above the initial target should be assessed against the impact on the whole cropping system. For example, how much longer will the crop have to grow to achieve the new target? How does that effect pest management or ground preparation for the next season?

Chapter 3: The Case for Area-Wide Management

As mentioned previously in this report, cotton is a perennial plant manipulated to grow as an annual. Because of favourable temperature and moisture conditions in an irrigated system, cotton has the ability to grow year-round in Northern Australia. As part of the Northern RMP (Northern Resistance Management Plan), all Bollgard 3 crops must be slashed or mulched and controlled to prevent regrowth within four weeks of harvesting.

This can be done through established methods currently used by producers in eastern states, but Northern Australia does not have the benefit of a cold winter and frosts to assist in killing survivors. The RMP is focused on a system that reduces the risk of resistance build up to Bt genes, but effective crop destruction and control of ratoon and volunteer cotton has benefits beyond the risk reduction for Bt.

During the NACRA 2018 cotton research update, Paul Grundy stated that sustainable pest management will depend on the following:

- Growing cotton in a way that limits crop duration in the field
- Managing pests with the softest possible insecticide option
- Ensuring a high level of stewardship of products to limit resistance risks
- Utilising crop rotations that minimise year-round pest transition
- Farm hygiene – achieving 100% effective crop destruction
- Biosecurity – keeping foreign pests out and crosschecking anything unusual

The following case studies discuss the Brazilian cotton production system and the US cotton industries' Boll Weevil eradication program, as witnessed by the author during his research. These provide examples of the potential problems of an unregulated system and the positive outcomes that can be achieved from a coordinated, unified industry-wide approach to a problem.

Case Study 1: Unregulated cotton production in Brazil

Cotton production in Brazil provides exceptional opportunities to learn how cotton behaves in similar climatic conditions to Northern Australia. Whilst many of these lessons are positive, one of the strongest messages taken out of there is that, without a plan or process for managing pests, disease and resistance on an area or industry-wide scale, the solutions that advancements in technology provide may be short-lived.

Grupo Bom Futuro is one of the largest agribusiness companies in Brazil, the largest soybean producer in the world and one of the largest cotton producers (Grupo Bom Futuro). In the 2018 season they planted 270,000 ha of soybean and 116,000 ha of cotton. By comparison, the area planted to cotton in Australia during the 2015-16 season was 473,000 ha (Cotton Australia).

During a meeting on one of their properties in Sapezal, Mato Grosso, Director of Agriculture for Bom Futuro, Enasau, spoke of the need for regulation in the industry and their desire to see it happen, but while there was no area-wide plan and other farmers could do what they like, Bom Futuro could not operate in isolation. The real problem in the system stems from the number of days cotton is growing during the year. Cotton planted in December/January in Brazil can take 210 days to harvest, compared to 170-180 days in the ORIA in 2018 and around 155 days in central NSW. The 210 days of production is not the only issue, with no regulation on planting dates, planting can be conducted over a three-month period on neighbouring fields in the same area. This means that there could potentially be cotton in the ground for 300 days of the year in one location. This provides an opportunity for pests to persist through to the following season, with a limited break to the next crop and potentially a soybean crop growing to narrow the gap further.

Bom Futuro's operation in Sapezal had applied ten fungicides during the 2018 season for control of grey mildew. Discussing this with Eduardo Kawakami, he commented that there is only one chemical registered for the suppression of grey mildew and limited varieties with resistance to the disease. There is no planned use or restrictions on the number of applications of this chemical.

During a visit to Fazenda Sao Francisco in Bahia, the farm manager noted that this year he had averaged USD $200/ha on boll weevil control, around 10% of total production costs. The farm averaged 18 sprays and as many as 30 in one problem area. When insect resistance shut the ORIA cotton industry down in the 1970's, farmers were conducting a similar number of applications for caterpillars.

Coupled with the cost of spraying is the fact that ongoing control of boll weevil requires the use of broad-spectrum insecticides, meaning a reduction of beneficial predators on sucking pests like whitefly, resulting in spikes in their population. This was witnessed by the author on several visits in Brazil, where honeydew from whitefly could be found on the lint across wide areas.

Case Study 2: US boll weevil eradication program

Boll weevil is a native of Mexico and Central America. It was first introduced to the US in Texas in 1892. By 1922 it had spread to all cotton growing regions of the US (Texas Boll Weevil Eradication Foundation, or TWBEF).

Figure 16: Boll Weevil on an unopened flower (Source: Alton, N)

Boll weevil causes damage to squares and bolls through feeding, egg laying and larval development. Eggs are laid inside bolls and when they hatch larvae burrow to the centre of the boll to feed. These bolls are often aborted and drop off the plant; bolls that remain will not open properly and can be subject to boll rot. Yield is impacted through the abortion of fruit and infested bolls remaining on the plant will produce poor quality lint (NSWDPI Prime Fact).

Females can lay 200 eggs in a 10-12-day period. High temperatures and humidity can speed it up, but under favourable conditions the life cycle can be completed in 2 ½ - 3 weeks. For a 180-day crop that would be 6-8 generations from first square to picking.

The National Boll Weevil Eradication Program was launched in the late 1970's along the Virginia and North Carolina border. Over time the program expanded to Arizona and southern California; ultimately the boll weevil was eradicated from the East and North West back to Mexico. Figure 17 below shows the status of eradication for the US in 2014. Boll Weevil is shown still persisting in the Rio Grande Valley area of southern Texas and was confirmed as still persisting during a visit to Texas by the author in 2018. Continual monitoring in other areas of Texas shows the pests occasionally moving out of this area.

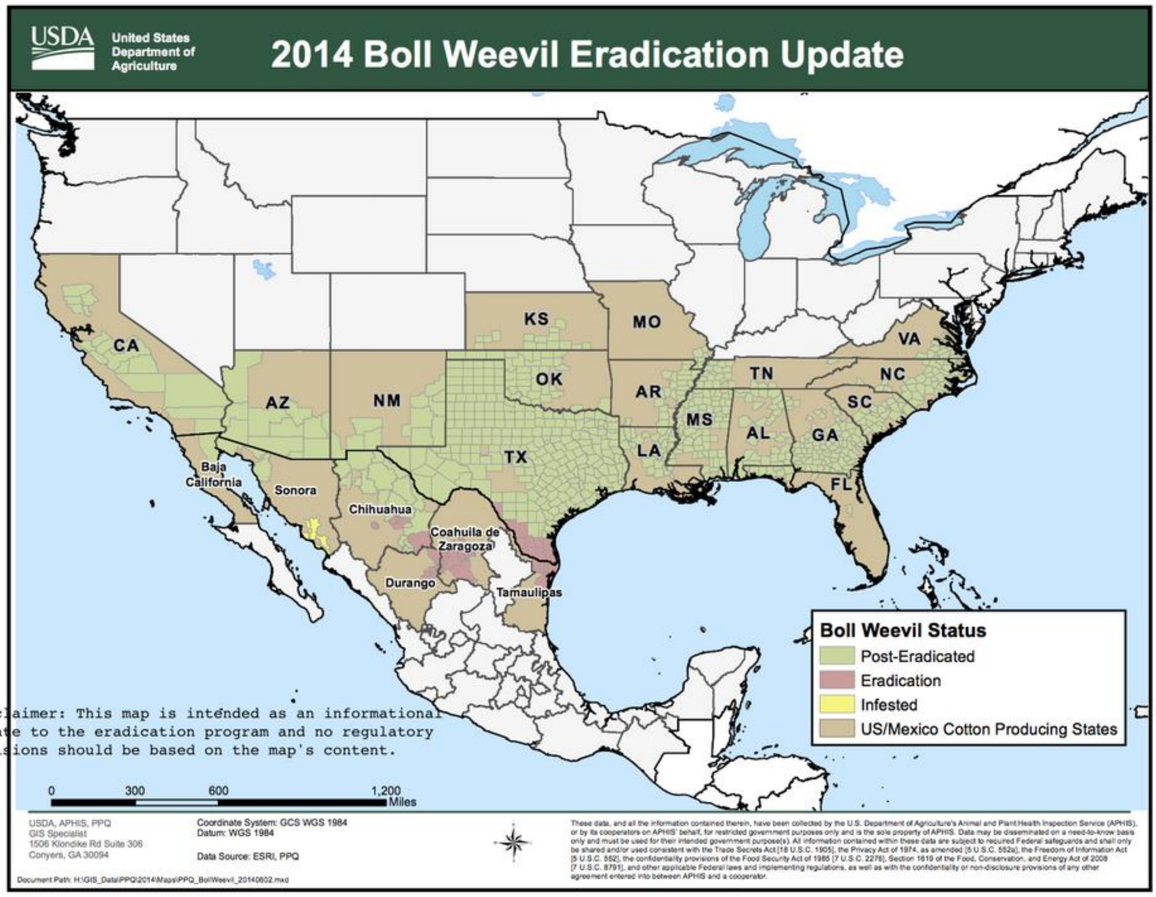

Figure 17: Boll Weevil Eradication Update 2014 (Source USDA)

The Texas Boll Weevil Eradication Foundation (TBWEF) was established in 1993 to eliminate Boll Weevil from cotton fields in Texas. The Foundation is majority funded by cotton producers with state and federal governments making up the difference. The program operates with three key components: mapping, trapping and treatment.

All cotton fields are mapped and coordinates are logged with GPS to provide accurate information to field technicians and spray applicators. Once mapped, traps are placed around the perimeter of fields, initially at a frequency of one trap every 160 m. Traps have a pheromone attractant that is a man-made copy of the sex attractant used by the male to lure females. The traps also contain an insecticide strip and act as a control method as well.

Control is accomplished through good farm hygiene and destruction of plant material post-harvest to remove it as a host and insecticide applications are also used. Spraying starts at squaring and finishes at picking that season. Program spraying continues until no boll weevil are found in traps. Figure 18 shows a Boll Weevil trap alongside a harvested cotton field in southern Georgia. Cotton on the ground in the background is the result of Hurricane Michael.

Figure 18: Boll Weevil trap - Georgia (Source: Author)

Traps are inspected once per week. Each trap has a barcode and inspectors input data about what was found as well as crop stage. Data from each trap is then associated with a computerised map location to monitor trends and hotspots. To maintain the integrity of the program some traps are "spiked" before a weekly check. Inspection supervisors can then monitor data to make sure field staff are correctly monitoring and reporting.

Once the eradication is successful in an area, the density of the traps is reduced. Currently in west Texas there is one trap per square mile. The East Texas monitoring zone was free of boll weevil for three years in a row before traps showed their presence again in 2015 and 2016. Trap density was increased back to 1/10th of a mile. In 2016 15,714 boll weevils were caught in traps. Treatment was initiated on all fields around a trap that that had boll weevil present. In 2017 that number had reduced to 1,292 (TBWEF).

Steve Verret, Executive Vice President of the Plains Cotton Growers Incorporation, the representative body for cotton growers on the high plains of west Texas based in Lubbock, said during a meeting in 2018 that once they started the eradication growers started to see the "top crop" set fruit and contribute yield. No one thought that cotton could grow like that on the plains, such was the influence of the boll weevil. He also noted that the program would not have worked as an ad hoc approach. The program's success is in the involvement of every cotton grower. Everyone needed to be in it together and that is the message going out for the program's continuation.

Boll weevil still persists in the Rio Grande Valley of southern Texas along the US/Mexico border. Despite the success and continued efforts of the TBWEF control program, the area is too close to uncontrolled cotton in Mexico and re-infestation occurs. The added challenge further south is warmer year-round temperatures. Figure 19 shows the average temperature ranges for the Rio Grande Valley. For reference the average maximum in January of is 21.11^{o}C, and average minimum is 10.56^{o}C. Agronomist Justin Roberts said that in some years in the Corpus Christi area to the North, volunteer and ratoon cotton will persist year-round, meaning boll weevil can access a host plant 12 months of the year.

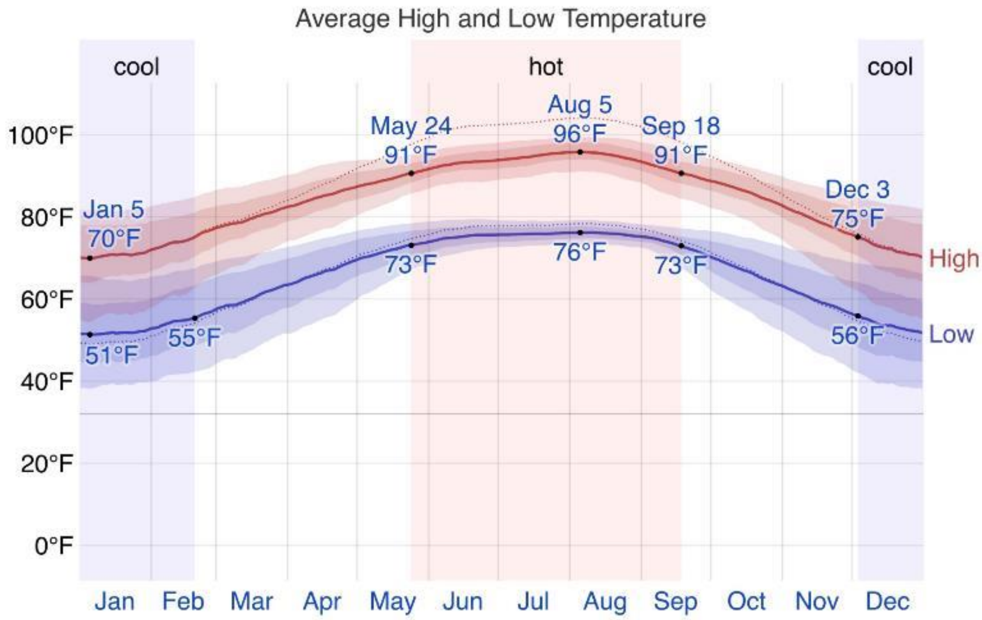

Figure 19: Average max and min temperatures, Rio Grande Airport (Source: Rio Grande Airport)

Plains cotton farmer Bill Heinrich, during a meeting in Lubbock 2018, commented that the Texan cotton growers would happily go down and assist financially and provide methods for Mexico to get boll weevil under control, but because of the drug cartels it was too dangerous to send staff.

The author visited the Corpus Christi area in November 2018 and met with advisors, ginners and growers. The area had received up to 500mm of rain at the beginning and duration of picking. This meant that destruction of the crop and control of ratoon and volunteers had been delayed. An extended deadline for crop destruction had been given to growers, but some faced an unexpected challenge.

Some varieties in the US contain more than one herbicide tolerance gene, for example to both Glyphosate and 2,4-D. Corpus Christi farmers would control ratoon cotton after harvest by slashing the stalk, allowing it to reshoot, then spraying with 2,4-D to kill it completely. One farmer visited would follow this up by driving his paddocks and spot-spraying any survivors. For this reason, Corpus Christi growers selected not to grow 2,4-D tolerant varieties. A contamination issue from a seed company has meant that 2,4-D resistant plants were grown across the area. A farmer visited said that it has been a frustrating mistake and there has been little support for growers now unable to control their ratoon and volunteer cotton with previous management techniques. Agronomist Justin Roberts believes it was probably only a matter of time before contamination started showing up but there was still no plan for it. During the visit both agronomists agreed the Corpus Christi area was not sure how this was going to affect the boll weevil eradication program going forward.

Lessons for Northern Australia

How does the situation in Brazil and the eradication program in the US relate to cotton production in Northern Australia?

During a meeting about cotton in 2011 in Kununurra, ORIA farmer David Menzel commented "*the Ord is the right place for the unusual*". The statement reflects the ORIA's history of crop failures and false starts due to pests and diseases. Not long after this meeting, rice blast, a fungal disease of rice not previously found in Australia, was identified. It was in the same area sugar cane smut was identified several years earlier. The focus on Brazil's issues and the US eradication program is not because we currently have or are going to get boll weevil, but because history suggests Northern Australia needs to be prepared for the unusual.

Moving forward without acknowledging and planning for the risks puts us on a similar path as Brazil. The example that the US cotton industry sets is that, regardless of the enormity of the challenge, a coordinated, unified and ongoing approach can work.

Solenopsis mealybug

Mealybug presents a case of a pest previously not present in an area and the problems it can cause. Mealybug was first identified in the ORIA in 2004 and then identified in QLD cotton crops in 2009. This species originated in North America, but subsequently spread to India and Pakistan, but how it got to Australia is unknown (Grundy, 2018). There are currently only limited chemical controls available for mealybug, meaning Integrated Pest Management (IPM) is the most effective method available.

Mealybug can affect plant growth at all stages and in severe infestations plant death can occur. Heavy infestations, of greater than 500 Mealybug in the top eight nodes at cut out, have been found to result in around 80% reduction in harvestable bolls. Honeydew excreted onto the leaves is high in melezitose sugar, which is very sticky and can promote the development of sooty mould as well as contaminate ginning equipment (Cotton pest management guide 2018-19).

There are currently insecticides available on permit that offer control of mealybug but these can disrupt or damage beneficial predators. Targeting other pests during the season, like mirids, with harsh chemistry, may assist mealybug build-up and establishment through reduced predator numbers. Table 3 outlines the risk factors for Mealybug on cotton farms.

HIGH	- Previous history of mealybug - Weedy fallow of field margins (including ratoon and volunteer cotton) - Ineffective or poor crop destruction - Early season insecticide use - Low beneficial predator activity - Wetter than average fallow season
MEDIUM	- Late weed control - Late harvest of previous crop - Seed dressings
LOW	- Clean fallow - High beneficial activity (Particularly Lacewing, cryptolamus and other ladybeetle species) - Good weed control in and around field margins year-round

Table 3: Risk Factors for Mealybug (QDAF)

Northern NSW cotton grower, Andrew Watson, runs a successful IPM system on his property and has not sprayed an insecticide on cotton for 12 years. He encourages managers to trust industry advice and guidelines and his key points to a successful IPM system are:

- Consider your first spray very carefully
- Do not spray below thresholds; give beneficials a chance to build up
- Cotton can compensate for early damage; understand what researchers are saying about how much damage can be sustained without yield penalties
- Appreciate the role of native vegetation as a source of beneficials
- Look at averages across fields, not patches

Rob Weinthal, consultant to Andrew Watson and also a cotton farmer, follows the same principles and adds that there are too many upsides not to practice IPM. He tracks beneficial numbers as well as pests and believes the strength of the system is the diversity of the insects in it which build resilience. He believes this has never been clearer than in recent seasons with the march south of mealybug and is relying solely on beneficial predators to control them. (CRDC Spotlight on Cotton R&D).

The key pillar in IPM for mealybug in Northern Australia will be to maximise host-free periods between crops. Research has shown that mealybug can survive for up to 50 days without a food source (Grundy, pers comm, 2018). During a discussion in 2018 about a mealybug infestation on a cotton crop in the ORIA, Paul Grundy commented that in just about every case of mealybug outbreak encountered in commercial cotton fields, there has been a ratoon or volunteer plant nearby.

Figure 20: Ratoon cotton ORIA 2018 and mealybug found on the plants (Author)

Figure 20 shows ratoon cotton growing in a field after crop destruction in the ORIA. Despite the last irrigation being over three months earlier and very limited rain there was enough moisture for these plants to persist. Figure 21 shows a similar situation but on a much larger scale in the ORIA. This field was twice offset ploughed post-harvest, but ratoon cotton is seen here persisting in a strip along the head ditch in January 2019, four months after harvest. This has come about through an operator not ploughing a headland properly. These plants were sprayed ten days earlier with 2L/ha of Fluroxypyr (Starane) and showed no signs of completely dying. Ultimately multiple passes with Paraquat+Diaquat killed the plants but this was only possible because the plants were reachable from a trafficable area. When this photo was taken the rest of the paddock was too wet to access with machinery.

Figure 21: Ratoon cotton ORIA January 2019 (Author)

If this survival rate was widespread the only effective solution would be tillage, difficult during the wet season in the ORIA. Figure 22 shows mealybug on dying volunteer cotton in January 2019.

Figure 22: Mealybug on dying volunteer cotton, ORIA January 2019 (Author)

These photos show the importance of control of volunteer and ratoon cotton to limit its use as a host during fallow and how easy it can be for a pest to be carried from one season to the next. Northern Australia presents ideal growing conditions for cotton over the fallow season if moisture is available, so it is imperative that all growers are aware of their role in reducing the risk of pest infestations.

While worlds apart, and with unique situations, there are some clear lessons for Northern Australia from Brazil, the US and early experiences in the ORIA. Given the climatic similarities between Brazil and much of Northern Australia, it is a cautionary example of what could go wrong if risks are not acknowledged. The US boll weevil eradication program shows that if a problem is managed in a unified manner by all stakeholders, exceptional results can be achieved.

Conclusion

Cotton can be grown successfully in Northern Australia, however differences between tropical and temperate environments and the implications for the crop, pests and diseases need to be considered.

Cotton in Northern Australia has specific management considerations, but through a well-defined understanding of what the major crop indicators are, the climatic influences and the tools available for growers to manage evolving scenarios underpin successful cotton production. The speed at which the crop develops and at which conditions change mean that managers need to be constantly assessing the crop and tweaking their management to suit the conditions. As discovered in Brazil, there is no recipe for tropical cotton production. Most farmers and pastoralists in Northern Australia will tell you no two wet seasons are the same, so it makes sense that a production plan will differ year to year to match this variability.

The North is isolated, short on infrastructure, resources and support. It requires integrated industries to manage the downturns from production issues, marketing slumps and external influences beyond management control. This report shows that understanding the production risks and a manager’s role and ability to mitigate them are the foundations for the development of a cotton industry in Northern Australia.

Northern Australia presents unique opportunity and challenges. Those opportunities will be realised, and challenges mitigated, if all stakeholders acknowledge the risks, develop and adhere to best management practice and manage the variables within their control for the betterment of the entire industry.

Recommendations

- Continued research should focus on providing growers with information to help them understand and mitigate commercial risk.
- Australian cotton industries 'Best Management Practices' guidelines should be reviewed to reflect the climate and production systems in Northern Australia.
- Integrating guidelines for best practice into Bollgard 3 accreditation, with a focus on the importance of crop destruction and providing as wide a gap as possible without cotton crops growing and harbouring pests. Stewardship of cotton in Northern Australia extends beyond the recommended practices for Bt and Glyphosate resistance management.
- As the industry develops, engage existing growers and consultants to present their experiences, challenges and lessons to prospective growers. Informal chats in the paddock can have far more impact than slide shows.
- Develop programs to outline the risks to new and existing growers and the industry-wide benefit in minimising them. Participation from all stakeholders is required, from technology developers and providers, to seed companies, grower groups, gins, marketers and producers. This can only be achieved if everyone is aware of the role they play in reducing risk.
- Identify and rate pest and disease risk for Northern Australia, their causes and potential impacts. Plans should be developed to be quickly implemented in the case of new pest or disease outbreaks, so industry is on the front foot of containment and management, not reliant on direction from state departments.
- Northern agricultural industries should work together to identify the roadblocks common to them all, where each can complement or provide service to the other and present a unified case for investment and development. Northern Australia should be viewed and managed as one area, and not three separate states.

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Plain English Compendium Summary

Project Title:	TROPICAL COTTON PRODUTION SYSTEMS. Issues relevant to cotton production in Northern Australia
Nuffield Australia Project No.:	1815
Scholar:	Luke McKay
Organisation:	Northern Ag Management 107 Kestrel Place, Kununurra, Western Australia, 6743
Phone:	0488733358
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Objectives	- Identify and discuss issues specific and relevant to cotton production in Northern Australia - Overview in-crop management and factors influencing growth and yield - Present a case for area-wide management - Recommend key areas of focus for cotton production in Northern Australia
Background	Cotton has been grown in Northern Australia previously, but ran into issues around insect resistance which ultimately led to its demise. Advancements in GM varieties have allowed cotton to overcome some of these pest pressures and recent research has achieved positive results. With new technology and practices available, cotton is again been looked at by farmers as a broad scale cropping option for Northern Australia. While the varieties and technology have advanced, the overall production system has yet to be optimised.
Research	To investigate what growers in similar climatic areas around the world are doing to manage cotton and what are the risks, limitations and opportunities for cotton production in Northern Australia. Research was conducted by visiting farms and businesses in The Netherlands, France, Singapore, The Philippines, Hong Kong, China, Germany, The UK, The US, Brazil, Zambia and Australia.
Outcomes	Cotton can be successfully grown in Northern Australia. While there are no specific production guidelines that can be followed, identification of the factors driving growth, climatic influences and the methods available to growers to manipulate the crop, allow for plans and decisions to be made to suit the crop and season. Management of the crop extends beyond the farm gate. Decisions on each farm can have an impact on a wider area for pest management resistance management.
Implications	This report provides information to those seeking information on growing cotton in Northern Australia, the on-farm management and area wide implications to consider.
Publications	Nuffield National Conference, Brisbane, September 2019