FINAL REPORT

Summary Details

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Project Title: Feasibility of Cotton Production in the Burdekin

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Cotton CRC Program: The Farm

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Executive Summary

Situated in the Dry Tropics, the Burdekin is Australia's largest tropical irrigation area and is home to a vibrant range of agricultural industries. Cotton has a potentially excellent fit in the Burdekin sugarcane farming system as a summer fallow rotation crop in each field every 4-5 years (currently, an average of 15,000 ha is bare-fallowed annually within the region). In this system cotton offers the opportunity to use a tap-rooted, herbicide tolerant crop rotation option that allows targeting of problem weeds such as nutgrass. The incidence of nematodes and soil pathogens that prefer monocot hosts may also be reduced. Alternatively, cotton can be rotated with maize or grain legumes as part of a continuous double cropping program. This has the potential to be highly profitable although it requires a high degree of management skill as this system is intensive with short turnaround times at the end of each crop cycle.

New generation transgenic varieties enable the production of cotton in a tropical environment with fewer pesticides. Herbicide tolerant traits such as Roundup Ready Flex® allow weeds to be controlled post-planting with glyphosate, which is more environmentally benign than traditional weed management strategies that rely on soil applied residual herbicides and inter-row cultivation. Bollgard II® varieties have significantly reduced the need for insecticides on cotton and provide a foundation on which more sustainable Integrated Pest Management (IPM) practices can be applied.

Whilst cotton production would appear to be an intrinsically attractive cropping option, the Burdekin has a number of climate-related challenges that set it apart from all other Australian cotton production regions. Therefore this project focused on determining whether or not cotton could be successfully grown in the Burdekin climate and developed a set of unique production practices that better enable growers to manage and offset climate risks.

The key outcome from this project was a demonstration that high quality, high yielding cotton can be successfully grown in the Burdekin climate on course textured soils and that during wetter than average seasons (the key climatic impediment) acceptable yields can be grown provided that locally tailored agronomic tactics are used. Excellent fibre quality has been a consistent characteristic of cotton produced in the Burdekin since commercial trials commenced in 2008.

Cloudy weather in autumn (typically associated with later than normal monsoon weather systems) can limit yield potential. The frequency of these events is difficult to predict as reliable weather records only span a 60 year period, however the short term data suggest that these patterns occur in approximately 30% of seasons. Despite this climatic constraint the agronomic practices developed (varietal selection, optimal sowing window, sowing rates, canopy and nitrogen management strategies) can be used to produce acceptable yields of 7-8.5 bales/ha in these constrained seasons which is sufficient to recoup costs and generate modest returns for growers.

For drier than average autumns that occur more than 50% of the time, the research demonstrated that very high yields (>8.5bales/ha) of cotton can be grown with locally tailored agronomic practices that account for the earlier summer monsoon.

This project has shown the potential for cotton production in the region developed a range of tactics that can be deployed to minimise the impact of cloudy wet weather. These agronomic tactics have been published in a new book - **NORpak - Cotton production and management guidelines for the Burdekin and NQ coastal dry tropics.** This publication has been specifically targeted for local sugarcane producers who may stand to benefit by including cotton rotation crops into their current largely mono-culture production systems. This publication is available at http://www.cottoncrc.org.au/industry/Publications/Northern_Production.

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Acknowledgements

Before going any further with this report I thought that it was essential to acknowledge the contribution of a number of collaborators, co-operators and industry people. The delivery of this project and resultant development of a basic cotton production package which has been captured in the NORpak publication and this report was only possible due to the efforts of a range of people who made various contributions to the R&D program. I would like to personally thank:

Burdekin growers and consultants

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I would like to specifically acknowledge **Lyndsay Hall's** efforts and regional advocacy for cotton production and research in the Burdekin region since 2004. Without Lyndsay's enthusiasm and commitment it is unlikely that the impetus for the research on which this report and the NORpak publication is based would have occurred.

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NORCOM advocates

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Dr Greg Constable (Senior Principal Research Scientist, CSIRO) provided critical input into the design of the experimental program and varietal selections for the Burdekin region.

Tracey Leven (Program Manager, CRDC) has been a constant advocate for the research undertaken by the project team in the Burdekin and its potential implications for broader cotton industry issues.

Research project staff

Dr Stephen Yeates, who as well as being a collaborator, conspirator and general "partner in crime" throughout this project, has proven himself along the way as being amongst one of the best mentors I have had the fortune of working with since entering the Australian cotton industry research fray.

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Background

Deregulation of the Australian sugar industry and increasing global competitive pressures due to Brazil and Indias' emergence as major low cost sugar producers, recurring droughts in southern Australia, and the success of new transgenic varieties culminated in renewed interest in the possibility of producing cotton in the Burdekin region of north Queensland as both a rotation option for sugar cane and a cropping option in its own right. The Burdekin River Irrigation Area is Queensland's largest irrigation district. Supplied from the 1,860,000 ML Burdekin Falls Dam, the irrigation water is estimated to have an annual reliability of 95%, supported by the Burdekin river's annual mean discharge of 9,200,000 ML per annum.

The region is home to the largest hub of the Queensland sugar industry with approximately 80,000 ha under irrigated production supplying 8.5 MT of cane to four mills annually. In addition, approximately 8000 ha is occupied by a range of horticultural enterprises that produce vegetable and fruit crops cucurbits, sweet corn and mangoes. A further 8000 ha remains undeveloped and could be serviced by existing irrigation infrastructure whilst another 15,000 ha could be irrigated with the completion of works associated with the Elliot supply channel. These areas do not include the potential for additional irrigation land development through the Burdekin to Bowen corridor or the upper Burdekin region (e.g. Collinsville etc).

The Australian sugar price has fluctuated widely over the last 15 years; falling as low as $250/tonne in 2004 and rising above $600/tonne in 2010. An inability to forward market sugar until 2009 meant that many growers have been price takers, with returns having been below the cost of production for extended periods during the last two decades. The potential for good returns from cotton, the ability to forward sell, and the need for a viable broad-acre rotation crop to arrest yield decline in the Burdekin's mono-cultured sugarcane farming system was a significant driver of cane farmer interest during 2005-2009. Record prices for sugar since 2009 and a run of wetter than average seasons have caused this interest to abate in recent years. However, anecdotal evidence of increased sugarcane yields after a break crop of cotton, the inevitable return of sugar market prices to a more normal level, and the availability of a cotton production package developed from the last 5 years of research may see a future renewal of sugar grower interest in cotton production.

The recent drought in southern Australia and medium-term uncertainty associated with water entitlements on the Murray-Darling system also provided impetus for some existing cotton growers considering business risk diversification to include production regions like the Burdekin with its abundant water resources.

The arrival of genetically modified cotton varieties, which are less reliant on insecticides and (perhaps more importantly for the tropics) negate the need for soil-applied herbicides, has allowed major positive reforms in insect and weed management. These technologies allow the prospect of cotton production in regions such as the Burdekin where pests and weeds have historically been problematic and nearby environmentally sensitive receiving water bodies such as the regions extensive coastal wetlands and the Great Barrier Reef preclude the development of any industry that is reliant on production practices with high pesticide inputs.

Potentially cotton can be grown in the Burdekin as a rotation crop between sugarcane crops during the usual summer bare fallow period that occurs in each field every 4-5 years. In the sugarcane farming system, cotton offers the opportunity to use a tap-rooted broadleaf crop rotation option with transgenic herbicide tolerance, and thus target problematic weeds such as nutgrass and reduce the incidence of nematodes and soil pathogens that prefer monocot hosts.

Annually there is at least 15,000 ha of sugarcane land bare fallowed and therefore available for rotation cropping in the Burdekin during the wet season.

Cotton may have excellent potential as a rotation crop for sugarcane in the Burdekin

Alternatively cotton could be rotated with maize or grain legumes as part of a continuous double cropping program. The productivity of this system is potentially lucrative although it requires a high degree of management skill as crop turnaround times are short at the end of each crop cycle. The sustainability of such an intensive system would be dependent on having a well developed farming system that takes into account biotic factors such as weeds, pests, and diseases, as well as soil health and tillage considerations.

Whilst grower interest, land and water resources and transgenic varieties are critical drivers for a future Burdekin cotton industry, historical experiences from other centres throughout northern Australia have shown that new industries have a high likelihood of failure, particularly if they are not preceded by relevant R&D that seeks to understand local abiotic and biotic factors and production systems are not tailored accordingly. The collapse of the commercial cotton industry in the Ord River Irrigation Area in the 1970s stands as a testament against imposing a production system that, in hindsight failed to recognise the environmental and biological limitations of the region. These challenges were later overcome after a targeted research program identified that a dry season cropping approach that utilised transgenic varieties could provide a more sustainable platform for an integrated pest management program.

Unlike both the more northerly Ord River Irrigation region and the southern irrigation areas where cotton is currently grown, the Burdekin has a unique set of climatic constraints that require a tailored "third way" production system if cotton is to be a viable option.

This collaborative study by DAFF, CSIRO and a range of commercial partners had a very clear set of objectives that fitted within an overarching brief of assessing the feasibility of cotton production in the Burdekin region of North Queensland's Dry Tropics. Our objectives were:

1. To take a fundamental "bottom up" research approach, which sought to understand yield potential and cotton plant response to a climate that can have periodic, cloudy, humid and wet conditions associated with the tropical monsoon
2. Based on 1., identify and investigate a range of crop management tactics to better enable growers to mitigate wet season risks. These included sowing, canopy management, varietal response, row spacing, crop nutrition, tillage systems, insect management, and the minimisation of environmental impact due to water runoff.
3. Design and test farming system practices to enable the integration of cotton with the broader Burdekin sugarcane farming system.
4. Identify pest management issues for a future industry and develop solutions where necessary.
5. Build local human capacity for cotton production based on the above R&D.

This research has been delivered through two CRC/CRDC funded projects. The first project (1.04.14CRC) was conducted by DAFF, initially for 3 years, then extended for an additional 2 years. This project's brief was to focus on the interaction between cotton and the Burdekin climate, arising agronomic issues, locally relevant insect management issues, the potential impact that cotton production may have on runoff water quality, and delivery of a local extension program. The second project (1.04.17CRC1001) led by Dr Stephen Yeates CSIRO commenced in 2010 in an effort to bolster the RD&E effort in the Burdekin by further investigating agronomic issues such as cotton nutrition on sandy and clay soils as well as farming systems challenges.

This report will document the research conducted during the first project (spanning a 5 year period from 2007-2012). This project has demonstrated that high cotton yields with exceptional fibre quality can be grown in the Burdekin region. Critically, for this potential to be realised, a tailored agronomic package combined with a high degree of management skill is required.

Much of the knowledge gained over the last 5 years (from targeted R&D as well as the hard won experience of a significant number of pioneering growers) has been captured in a first edition of a NORpak for the NQ Coastal Dry Tropics publication. As research is still on-going, at the time of writing this report it is anticipated that the data arising from this project and continuing work by Dr Stephen Yeates will be combined and utilised to update aspects of the OZcot model which may allow more reliable projections to be made regarding yield potential for cotton in the Burdekin region.

Project Objectives

This project had a broad range of inter-related objectives. The objectives and the extent to which they have been achieved are

1. ***Identify potential climatic constraints in the Burdekin and develop and understanding of likely crop responses.*** This project has undertaken a 5 year study to determine the impact of the Burdekin climate on cotton physiology, morphology and yield potential. This body of research has developed a comprehensive data set that has informed our understanding of physiological responses of cotton to the Burdekin wet season and has provided a solid basis on which an agronomic package for cotton production in the region is being developed. This research has informed the likely yield potential for cotton in relation to probable climatic variation, defined an optimal sowing window, provided information of likely physiological growth responses, and demonstrated which varietal traits may be advantageous under Burdekin conditions. The information gained has also provided a foundation and framework for a range of agronomic crop management tactics to be developed and better targeted.

2. ***Identify and develop crop management tactics that assist in mitigating climatic risks.*** As the understanding of the likely impacts that climatic variables might have on cotton growth and development advanced, this objective aimed to utilise this knowledge to tailor crop production practices to maximise yield potential across the likely seasonal spectrum. This involved the validation and modification of existing standard practices as well as the development of new tools and techniques. This research has helped to define crop production tactics such as sowing rates and row spacing under conditions where solar radiation can be limiting for yield potential, as well as identify canopy management tactics that better balance yield potential in an unpredictable climate. This project has developed a new tool for assessing crop development and the appropriate use of growth regulants. It has also developed a new canopy management technique where purpose conducted tip pruning termed "trimming" is used to manipulate the timing and commencement of flowering. Combined with the outputs of project 1.04.17CRC1001 (*The development of sustainable cotton production in coastal North QLD*, which has had a major focus on nitrogen management), significant progress has been made on developing a package of management practices for cotton in the Burdekin. These practices are published in the **NORpak - Cotton production and management guidelines for the Burdekin and NQ coastal dry tropics.**

3. ***Cotton in the Burdekin farming system.*** Between this project and 1.04.17CRC1001 significant progress has been made on overcoming constraints associated with introducing cotton to the Burdekin farming system. The issues for integrating cotton within the sugarcane farming system have been well identified. Constraints for cotton following sugarcane have been identified and practical solutions developed. These feature prominently within the NORpak publication. Potential issues posed by utilising cotton as a summer rotation crop for sugarcane have been identified but not investigated by this project. However, this important knowledge gap is being addressed within a new GRDC and SRDC funded project of which cotton is a small partner which will identify the potential impacts and tradeoffs for rotation cropping in the sugarcane farming system.

4. ***Insect management and suitability of the Bollgard Resistance Management Plan (RMP) for the Burdekin.*** This project has fulfilled this objective by successfully identifying two pigeon pea cultivars that are suited to the Burdekin climate as a refuge option. Data has also been collected and used to make a successful submission to the AVPMA to have pigeon peas included as a refuge option for the Burdekin as of July 2012. This project also provided significant support for growers in managing an outbreak of the exotic mealybug *Solenopsis solani* which first appeared in the Burdekin

5. ***Determine the potential impacts and risks that cotton may present for tailwater runoff quality.*** A study was conducted over two years at multiple sites to sample the quality of run-off water from cotton fields in the Burdekin in terms of nitrogen and pesticide loading. This study identified the potential for high nitrogen losses to occur from cotton fields during the wet season and that for cotton to succeed the development of nitrogen management strategies to minimise these losses would be essential. This work also demonstrated that pesticides could be lost from cotton fields but the incidence of losses in runoff were minimal due to the effectiveness of transgenic varieties. The use of glyphosate-tolerant varieties has negated the need for soil-applied herbicide usage and therefore eliminated the potential for losses to occur. Soil-applied herbicides such as diuron that would otherwise be used in the absence of transgenic crops, have been identified as common contaminants in farm run-off within the Burdekin and are coming under increased scrutiny and regulatory restriction in Queensland's coastal farming systems. Bt transgenics were also found to substantially reduce the likelihood of insecticide contaminants entering water courses as insecticide use is generally delayed until later in the season when boll filling commences at which time the risk of rainfall causing losses diminishes significantly. Recent research by Dr Stephen Yeates within project 1.04.17CRC1001 has suggested that large upfront applications of nitrogen are detrimental from both agronomic and economic viewpoints and that a system of post-sowing nitrogen side dressing greatly reduces the amount of nitrogen required as well as minimises the potential for environmental losses. Work in this area is ongoing.

6. ***Conduct an effective extension program for Burdekin growers and engage with the local community on cotton production issues.*** A comprehensive extension program has been conducted in the Burdekin throughout this project. This project has conducted 16 field walks, 5 agronomy research half day workshops and 5 industry bus tours. This project has also sought to engage with the local community with a cotton display at the 2010 Ayr show, along with several school visits and a regular presence in local news media. Research discoveries that have had broader implications for other parts of the industry such as central Queensland which has suffered significant wet weather and flood damage over the last 4 seasons, have been extended with 5 field days conducted at Emerald as well as various publications in the Australian Cotton Grower magazine and CRDC's Spotlight magazine.

Methods, Results & Outcomes

The following section of the report will be presented as chapters that detail the various RD&E components that fulfilled the above stated project objectives.

1.0 Burdekin Climate Study 2007-2012.

Summary

A study was conducted over a five year period to determine the likely impact of Burdekin climatic conditions on cotton growth, development and yield potential. The primary focus of this research has been to determine physiological and morphological crop response to cloudy, wet monsoon conditions.

Data arising from this study demonstrated that yield potential can be high but is dependant on solar radiation levels throughout the flowering and boll filling period. Wet overcast conditions during the vegetative stages did not negatively impact later yield potential. A planting window that spans 20 Dec – 20 Jan was confirmed as the optimal period in which to sow cotton with the highest yield potentials being realised when cotton is planted during January. Extended cloudy (low solar radiation) weather was shown to have a number of impacts on crop growth and development. The shedding of squares and early bolls was a frequent response cloudy weather that extended beyond 3 consecutive days. However, biomass accumulation and yield data demonstrated that this response could be beneficial if cloudy weather occurs during early flowering and is followed by sunnier conditions. The loss of fruit in this instance during low radiation conditions reduces internal demand for assimilates that the plant can redirect to support additional vegetative expansion giving rise to new cohorts of fruiting sites that may better coincide with increasingly sunnier weather as Autumn progresses and the monsoon abates. In this regard indeterminate vigorous cultivars such as Siokra 24BRF and Sicot 74BRF were better adapted to overcome cloudy weather during the first weeks of flowering compared with more determinate varieties like Sicot 70BRF. The use of more vigorous indeterminate cultivars such as Siokra 24BRF when cotton is planted in the December part of the planting window forms an important part of a strategy for mitigating the likely risks of monsoon conditions coinciding with early flowering that for December sown crops commences in mid February. Although wet weather can occur at any stage between November and April, Monsoon conditions in the Burdekin generally peak between late January and mid-February in most seasons. Therefore early flowering of December planted crops will in most seasons coincide with periods of cloudy wet weather.

This study demonstrated that for drier than average and sunny seasons, that cotton production in the Burdekin is likely to be similar to regions such as Emerald in terms of fruiting dynamics with bolls produced in a more typical pattern throughout the crop canopy. During wetter than average seasons which occur approximately for 30% of years, lower fruiting branch positions are likely to be shed and/or reduced in size. The maximisation of yield potential in these seasons thereby becomes dependent on growing compensatory bolls on the upper canopy during autumn when the level of cloudiness generally declines during March and April. Compensatory growth can be encouraged by selection of more vigorous indeterminate varieties coupled with tailored agronomic management that ensures optimal nitrogen availability, judicious Mepiquat Chloride usage and timely irrigation management.

This study found that the proposed planting window can effectively mitigate the impact of monsoon conditions during the wettest months of January and February on yield potential for the majority of seasons. Crops were found to be generally resilient to wet overcast weather during the pre-flowering growth stages. Once flowering commences boll losses can be significant but provided that these losses were confined to the first 2-3 weeks of flowering and prior to mid March, significant potential exists to grow compensatory fruit during the mid-march to end of April period provided sunny weather returned. If flowering could be maintained, a period of 45 days of sunny weather was sufficient in several seasons to produce very high cotton yields (>10 bales/ha).

The primary climatic constraint for Burdekin cotton production identified and confirmed by this study is the duration and temporal incidence of cloudy conditions in relation to crop flowering. Low radiation and wet conditions for more than 3 weeks after the commencement of flowering pose significant challenges for crop management. To recoup associated shedding losses associated with extended cloudy weather requires continued vegetative expansion and production of new fruiting sites. This pattern of growth becomes increasingly difficult to maintain 3 weeks after first flower as the capacity to compensate declines due to the later constraint of cool night temperatures in June. After three weeks of shedding, crops also become more difficult to manage as plants continue to expend finite resources on production of new vegetative growth in lieu of fruit shedding losses from the lower branches that consequently become redundant.

Extended cloudy weather during March and April can be a significant impediment to cotton yield potential. Cloudy conditions at this time is particularly problematic as it will affect the peak flowering period for cotton (regardless of when crops are sown within the prescribed planting window) and can induce severe shedding losses or reduction in boll size. The potential to compensate these mid-season losses through the encouragement of continued canopy growth and fruiting site production, even if radiation levels subsequently improve, is eroded by cooler night temperature limitations and decreasing day length at the end of May.

The frequency of unfavourable low radiation conditions during March is difficult to predict due to limited weather records for the Burdekin. However conditions experienced during the 5 years of this study did span the historical range for March radiation (from the sunniest to the cloudiest) providing insights as to likely plant response and yield potential.

The 2011 and 2012 seasons where characterised by below average solar radiation levels for March. Despite this limitation acceptable yields of 7.5-8.5bales per hectare of quality lint were produced in 2011 but yields were more severely affected in 2012 particularly for the December sowing spanning a range from 5.5-7.5bales/ha. This contrasts 2008 and 2009 when March had higher than average radiation levels which enabled the production of 11-12.8 bales cotton per hectare.

This study developed an extensive data set on crop growth and biomass accumulation that will be used for further analysis to unravel relationships between climatic factors such as solar radiation and crop growth. It is anticipated that the data accrued during this study will be able to be combined with information from Dr Stepehen Yeates' project and used to update the CSIRO OZcot model thus contributing to a more effective decision support and climate risk assessment tool for the Burdekin region. The ultimate outcome from this work that growers and researchers will be able to use the knowledge to make better informed predictions of likely yield potential so as to make better informed in-season management and cotton marketing decisions.

1.1 Background

During the past decade cotton production has been the focus of research in northern regions of Australia with an extensively researched production system having been developed in the Ord River Irrigation Area (ORIA) of Western Australia (15.5°S). After earlier industry failures a more holistic research and development approach was taken to tailor production and pest management practices to better suit local tropical conditions and pest abundance (Strickland *et al* 1998 and Yeates *et al.* 2010). This approach culminated in a fundamental change to dry season (winter) cotton production to better avoid insect pests and tailoring of crop agronomy to suit the temperature and radiation limitations associated with tropical winter production. New transgenic varieties based on *Bacillus thurengiensis* (Bt) toxins were also utilised to reduce reliance on conventional insecticides (Yeates *et al.* 2010). These changes have resulted in an agronomic production package that enables the production of comparable yields to southern Australia (Yeates *et al.* 2007).

The Burdekin region is a well developed agricultural area situated in the dry tropics of Queensland (20.4°S) but is well south of the ORIA (15.5°S) and north of the nearest existing southern cotton production regions of the central Highlands (23.5°S) or Darling Downs (27.2°S). The irrigation area is situated within 30 km of the coastline and consequently has a unique climate. Figure 1.1 depicts the mean monthly temperature, radiation and rainfall records for the Burdekin region.

Utilising regional weather records and the CSIRO Ozcot cotton growth simulation model, projections can be made as to the likely constraints associated with cotton production in the Burdekin climate and when cotton might potentially be grown. Modelling strongly suggested that cold winter night temperatures in the Burdekin during June to August (Fig 1A) would prevent the successful utilisation of a dry season cropping window similar to the ORIA (March-May sowing). This cool night temperature limitation was confirmed during two test plantings in 2004 and 2009 (unpublished data & section 6.0) where cold nights caused poor boll formation together with severe outbreaks of leaf blight caused by endemic *Alternaria* spp. - a disease that is exacerbated by cool conditions from flowering onwards. A mid-winter sowing window during June or July may provide a workable compromise for this problem by better coinciding flowering and boll formation with increasing solar radiation and temperatures during Sept – November. However, crop maturity would coincide with a rapidly increasing probability of rainfall in December with the onset of the monsoon (Fig 1B). A test planting in 2009 using a June sowing treatment confirmed the avoidance of cool night temperatures as flowering and boll development commenced in early September as night temperatures and solar radiation rapidly increases. However, crop maturity for the early June planting date did not occur until 20 December when the potential risk for wet weather harvest related losses become untenable (Section 6.0).

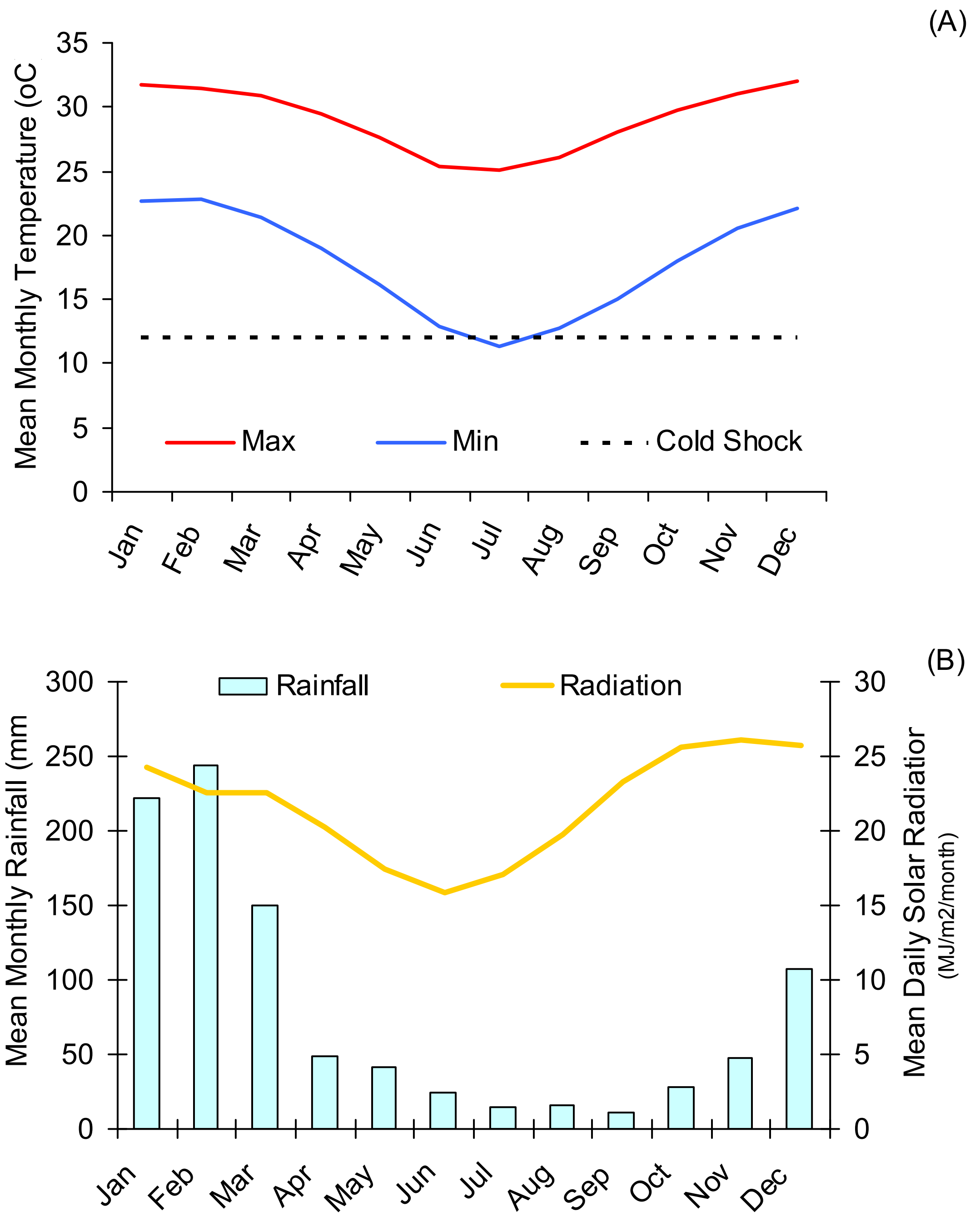


Fig. 1.1 The Burdekin climate: (A) mean monthly maximum and minimum temperatures and 12°C cold shock growth limitation shown as (--); (B) mean monthly rainfall (🟩) and mean daily radiation for each month (-).

A mid-spring sowing window similar to that traditionally used in all temperate southern cotton production regions would also be un-suitable for the Burdekin as boll formation and early boll opening would coincide with the wettest time of the year from December to March (Fig 1.1B) resulting in likely significant losses due to rain induced flower abortion (Burke 2002) and boll rot diseases.

Therefore the remaining production system proposed and tested with simulations using the OZcot model is one based on a narrow planting window that commences on December 20 and concludes on January 20. Figure 1.2 shows the climatic challenges of this sowing window for cotton compared to spring sown cotton in temperate latitudes such as Narrabri in NSW.

The proposed production system utilises a planting window timed to enable the sowing of cotton crops at the very start of the wet season so that many of the limitations of the wettest months occur primarily through the pre-flowering vegetative development phases. Subsequent flowering and fruit set would occur from mid-February to May, a period when the influence of the monsoon season is receding but temperatures remain warm allowing boll formation and maturation before cool winter nights begin to dominate in July (Fig 1.2B).

Despite the proposed planting window having the potential to avoid the worst of the wet weather during flowering and minimising exposure to cold winter nights for the later stages of boll filling, there still remain a number of inter-related climatic production challenges associated with the inherent variability of these factors that are either unknown or difficult to predict. This is compounded by the lack of long term meteorological data which only span 60 years or less.

The first challenge for the proposed 20 Dec to 20 Jan planting window may be the absence of planting opportunities in some seasons given that monsoonal influences can cause unstable weather conditions from early November onwards and records that indicate the incidence of rain days begin to increase at this time (Fig 1.2A). This risk may be partially or fully offset by ensuring fields are prepared well in advance of December, the use of reliable weather forecasting models that are readily available through the internet and ensuring the mechanical capacity to sow large acreages of cotton quickly once a decision to plant is made. This risk is greater for clay soil types that are inherently more difficult to traffic once the monsoon begins.

The remaining challenges relate to climatic factors that are likely to affect yield potential post sowing. The first is the duration and intensity of the monsoon season with its associated wet weather, high night temperatures, humidity and cloudiness which peaks in February (Fig1.2). The second is the onset of cool night temperatures that can occur earlier during May in some seasons prior to the onset of winter in June.

Climate records indicate that the intensity of the monsoon is highly variable for the proposed cropping period (December to June) most seasons being either much drier or wetter than the long term average (Fig 1.3A). Consequently solar radiation could be expected to be highly variable in some seasons particularly during the wetter than average years and the period between January and March. Day degree development models suggest that a late December sown cotton would flower during mid-February the wettest month (Fig 1.2B). The influence of overcast wet weather on early flowering cotton is not known although Burke (2002) demonstrated that rainfall on open flowers can cause the abortion of fruiting sites. The severity of shedding and its impact on yield are unknown but are likely to depend on the diurnal pattern of precipitation and the time of day that flowers open and then remain susceptible to rainfall. The impact of shedding may be offset by the capacity for plants to compensate by producing new fruiting sites later in the season when rainfall and cloudy weather is likely to diminish.

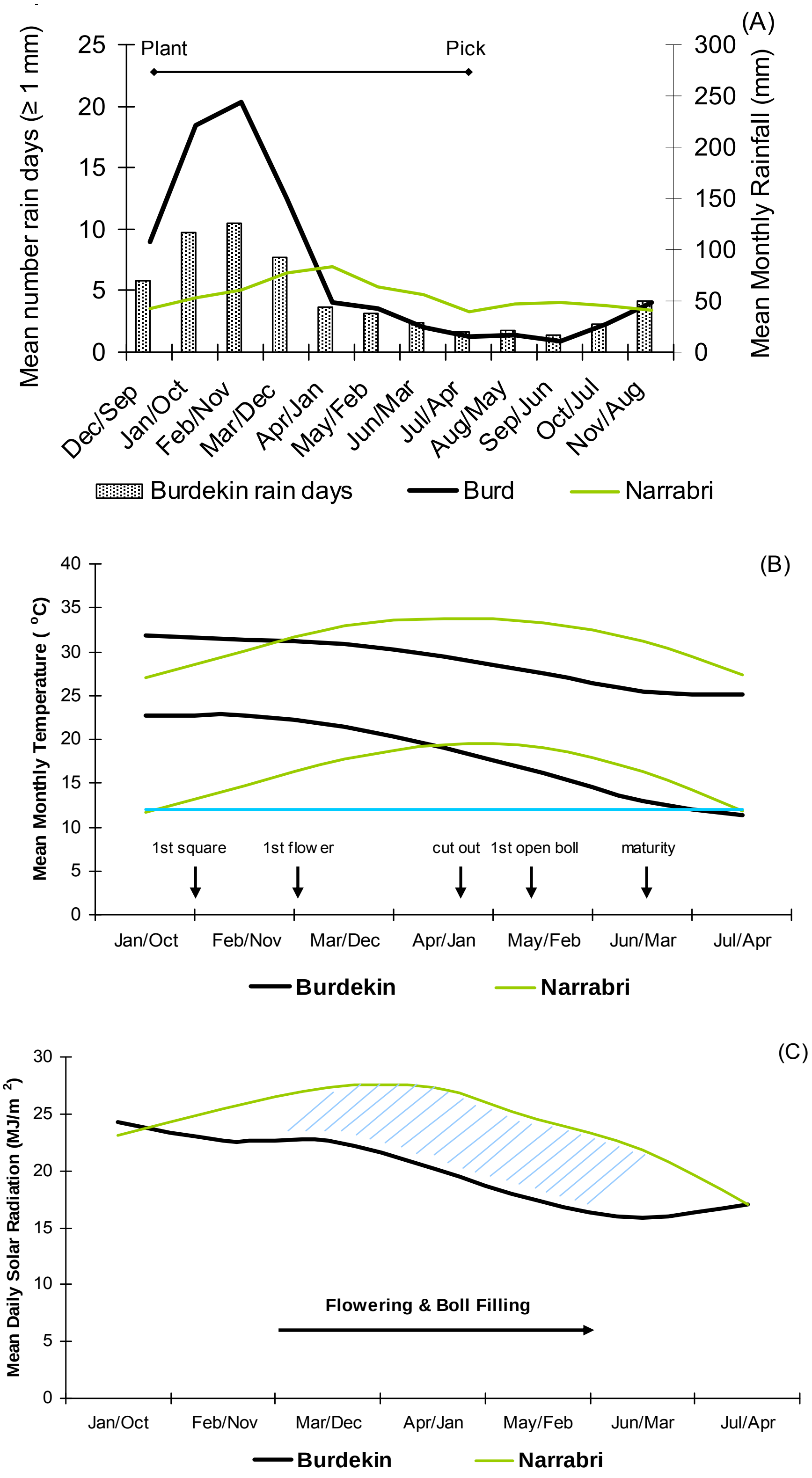


Fig. 1.2 Climatic comparison of the proposed cropping window in the Burdekin region (Dec to June) and the temperate summer growing season at Narrabri 30°S (October to April): (A) mean monthly number of Burdekin rain days ≥ 1mm (▨), mean monthly rainfall Burdekin (-) Narrabri (-); (B) average monthly temperatures with possibly development stages shown for Burdekin based on degree day sums (Constable and Shaw 1988); mean daily radiation for each month where (-) Narrabri and (-) Burdekin.

Day degree calculations suggest that a delay in sowing until early to mid January would post-pone the commencement of flowering until late February to early March and that as the long term rainfall records suggest a pattern of rapidly decreasing rainfall during March and to a greater extent April, a delay in planting until January to enable the commencement of flowering in early March maybe more favourable for flowering and boll development. However, despite March being statistically drier, records indicate that rainfall is quite variable (Fig 1.3a) and that whilst conditions are likely to be more favourable for early flowering compared with February some Autumn seasons (March & April) will have significant periods of rainfall and/or cloudy weather, the impact of which on yield potential is unknown. Predictions for solar radiation are stymied by meteorological records that only date back to 1990 which coincide with a period of generally lower than average seasonal rainfall since the early 1980s (Fig 1.3A). This is quite pronounced for the month of March (Fig 1.3B) during which crops would commence flowering and boll development with a January planting window.

Cloudy wet conditions post-planting could delay crop development or result in the abortion of fruiting sites (Burke 2002) reducing final fruit retention. If cloudy weather is prolonged particularly during the expected peak flowering and boll filling period of March and April, yield potential maybe further reduced through decreased boll size (Hearn 1994). In comparison to southern temperate cotton growing regions, daily radiation is about 75% of that received in Narrabri (30°S) during flowering and boll growth (Fig 1.2C). This may limit crop growth (Hearn 1994) although milder temperatures compared with Narrabri may provide a compensatory offset through potentially improved photosynthetic efficiency. Declining temperatures during May and June could reduce growth of later set bolls (Hearn 1994) and affect fibre quality (Gipson and Ray 1970) particularly if wet weather related shedding of positions in March results in cohorts of bolls being set late in the season. The effects of continual wet weather during January and February in some seasons on root development and water logging are also unknown (Thomson and Basinski 1962).

Predicting crop development and maturity is an important factor for assessing the likelihood of whether or not cotton can be grown with the spectre of wet weather related development delays and the season ending constraint of cool night temperatures from June onwards. Modern cotton cultivars are not sensitive to photoperiod and the time to first square, first flower as well as boll development are all proportional to temperature (Hearn and Constable 1984; Mauney 1986; Viator *et al.* 2005). The time to first square, first flower and crop maturity can be commonly predicted for spring sown crops (lat 24-36°S) using a degree day sum with a base temperature of 12°C (Constable 1976; Constable and Shaw 1988; Hearn 1994). However, weather related shedding could cause delayed or intermittent boll setting and crop maturity which cannot be predicted by such models. Yield loss due to weather related fruit shedding delays will depend on the length of season remaining after a shedding event before cool nights begin and whether or not plants can produce and mature compensatory replacement bolls in that period.

As the cotton plant is morphologically indeterminate, climatic conditions can determine the relative contribution that different cohorts of bolls might make to final crop yield. In temperate climates, solar radiation and temperature are typically most favourable early in flowering (Fig 1.2B) and hence at least 80% of yield is attributed to early flowers, that are on the first (P1) and second (P2) positions of the lower fruiting branches nearer to the base of the plant (Mauney 1986; Heitholt 1993). Hence (P1) fruit have the greatest probability of producing a harvestable boll (Kerby *et al.* 1987) with high crop yields in temperate Australia, California and Mississippi being associated with greater than 60% retention of P1 bolls (Jenkins 1990; Kerby and Hake

1996; Constable 1991). Hence monitoring of P1 fruit is common in Australia and in the USA for agronomic and pest management decision making.

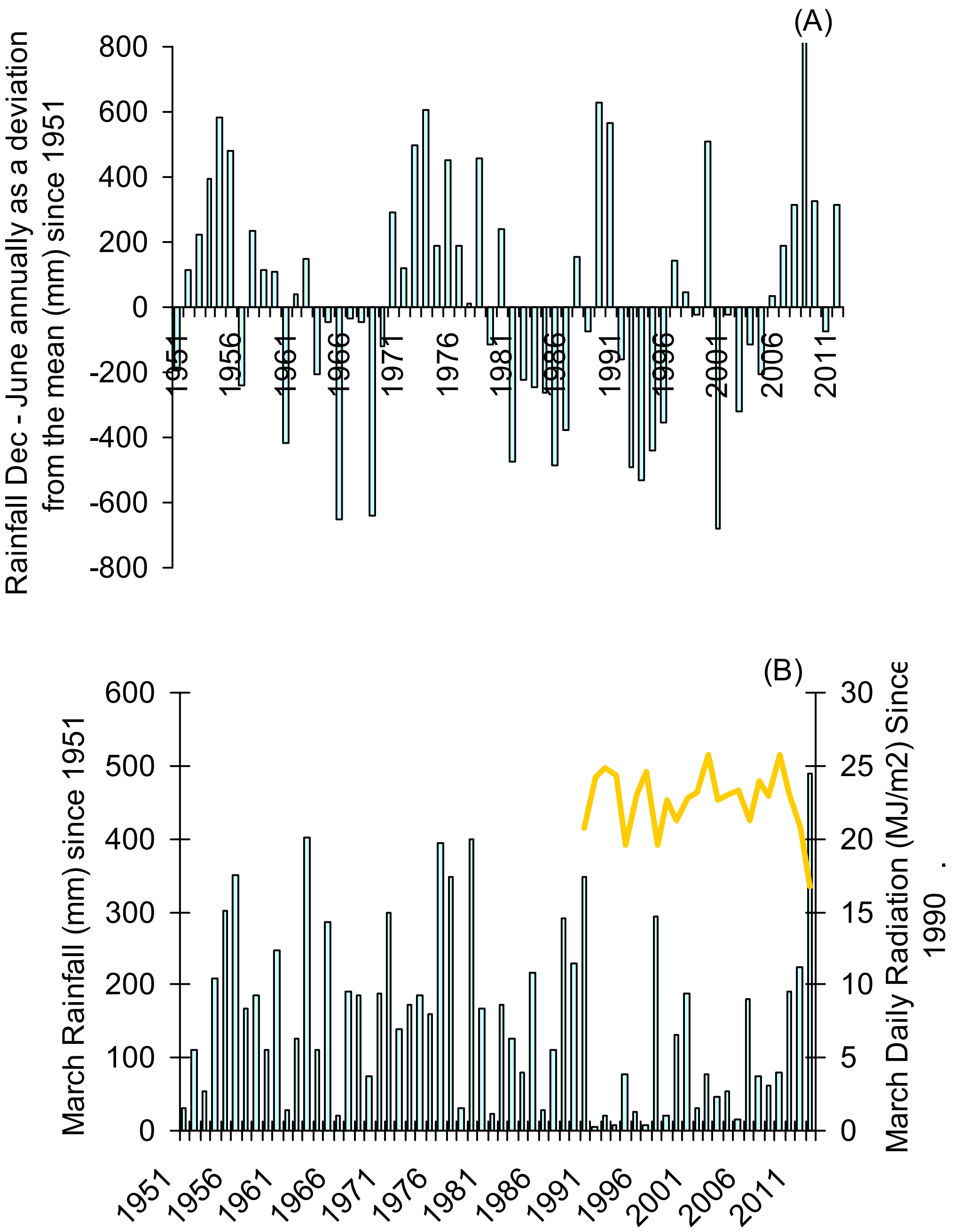


Figure 1.3 Rainfall records for the Burdekin measured at the Ayr Research Station (19.62°S; 147.38 °E) since 1951 expressed as (A) Rainfall received between Dec to June for each year subtracted from the mean for this period and (B) rainfall for March from 1951 to present together with mean daily solar radiation from 1990 to present.

However, it is not known how lower radiation and likelihood of flower abortion due to wet weather during late February and March will affect these accepted relationships between yield and plant architecture. It is likely that yield potential in some seasons will be more dependent on outer nodes on each fruiting branch due to earlier periods of wet weather and low radiation. A similar fruit setting pattern was recorded in cotton crops grown in the ORIA due to early season cool night temperatures that reduced the contribution of early set cohorts of P1 fruit (Yeates 2010a).

Photo 1.1 The impact of weather related fruit shedding on yield potential was unknown at the commencement of the study.

The proposed planting window avoids some of the climate constraints of the Burdekin region. However, with the variable effect of the monsoon particularly for wetter than average seasons it is important to be able to better understand the impact of such conditions on crop yield potential. **This research focused on the questions of what yield is possible and how do periods of wet weather and low radiation affect vegetative development together with fruiting site abortion, boll development and crop maturation to test if cotton can be reliably grown and picked in the Burdekin region**.

1.2 Methods

The primary purpose of this study was to define the yield potential of cotton using Bollgard II® and Roundup Ready Flex® stacked varieties in response to wet weather conditions that are associated with the monsoon season. As the monsoon influence is variable and at the commencement of the study the Burdekin had experienced a near 20 year succession of drier than average seasons (Fig 1.3A) an experiment was devised to increase the probability of wet weather crop exposure. As temperature variation is minimal during December to February the experiment utilised 3 spaced plantings of cotton to increase the probability of recording the impacts of wet weather on a range of crop growth stages - thus increasing the probability of enabling measurements to be made. For example it was anticipated that by planting cotton early in December that the normally wet month of February would provide data as to the impacts that may occur for a crop that would be developmentally well into flowering and boll maturation thus simulating the likely effect of a wet and overcast March period (for a January sown crop).

Photo 1.2 Replicated spaced planting dates in the climate study ensured that when wet weather occurred that crop response data could be collected from various growth stage scenarios

Photo 1.3 Weather conditions were extremely wet during 2009 providing an excellent test of monsoon conditions on cotton at a range of growth stages.

Experiments were conducted at the Ayr Research Station, 7km SW of Ayr Queensland Australia (19°62'S, Long. 147°38'E) in the Burdekin Irrigation Area during 2008, 2009, 2010, 2011 and 2012 seasons. The site had an alluvial silty soil to a depth of 600-700 mm under which was fine textured yellow sand.

The experiments used a split plot design, where main plots were the sowing date with four replications in randomised blocks. Subplots were different cotton cultivars. Three sowing dates separated by approximately 20 days were commenced early December for 2007, 2008 and 2009. The experiment was modified to incorporate a row spacing variation (this will be presented in the following section 3.0) and only two sowing dates were continued for the final two years commencing around Dec 20 for 2010 and 2011 (Table 1.1).

Table 1.1 Sowing dates for the 5 year study.

Season 1 (07/08)	Season 2 (08/09)	Season 3 (09/10)	Season 4 (10/11)	Season 5 (11/12)
3 Dec 2007	1 Dec 2008	1 Dec 2009	-	-
19 Dec 2007	18 Dec 2008	19 Dec 2009	18 Dec 2010	19 Dec 2011
7 Jan 2008	7 Jan 2009	7 Jan 2010	7 Jan 2011	7 Jan 2012

A buffer of 4 rows separated each sowing date to prevent drift of chemicals and to enable separate irrigation regimes. Five 'upland' *G hirsutum* L. cultivars were sown, during the study (Table 1.2). These cultivars were chosen as they represented a range of growth habit, leaf shape and maturity profiles when grown in temperate regions. Sicala 60BRF and Sicot 70BRF were medium height and maturity cultivars and normal leaf shape with Sicot 70 having smaller boll size. Siokra 24BRF is tall, mid to late maturing, has large bolls and possesses the okra leaf shape. Sicot 80 and Sicot 74BRF were more indeterminate late maturing cultivars with a conventional leaf. Sicot 80BRF and Sicala 60BRF were superseded by newer cultivars such as Sicot 74BRF and hence the use of Sicot 80BRF and Sicala 60BRF were discontinued in seasons 2 and 4 respectively and Sicot 74BRF included from season 2 onwards.

Table 1.2 Cultivars planted at each sowing date for the 5 year study.

Season 1	Season 2	Season 3	Season 4	Season 5
Sicala 60 BRF	Sicala 60 BRF	Sicala 60 BRF	-	-
Siokra 24BRF	Siokra 24BRF	Siokra 24BRF	Siokra 24BRF	Siokra 24BRF
Sicot 70BRF	Sicot 70BRF	Sicot 70BRF	Sicot 70BRF	Sicot 70BRF
Sicot 80 BRF	Sicot 74BRF	Sicot 74BRF	Sicot 74BRF	Sicot 74BRF

All cultivars were transgenic and expressed the *Bacillus thurengiensis* based toxins Cry1ac and Cry2ab (Bollgard II™ Monsanto) which provide excellent season long control of caterpillar pests e.g. *Helicoverpa* spp.. All cultivars were also genetically modified to allow season-long "over the top" applications of Glyphosate. This herbicide tolerant trait is marketed by Monsanto as Roundup ready Flex™.

The same field was utilised for each seasons experiment. For the first season the cotton crop followed a failed maize crop which was incorporated 3 months prior to cotton sowing. For the remaining seasons a cover crop of Siberian millet, *Setaria italicawas* L Beauv. was established in August and grown until October after which it was incorporated during bed preparation for re-sowing of cotton in the same field. The purpose of this cover crop was to even out residual cotton crop treatment effects, recycle nitrogen from the breakdown of cotton stubble residues and provide a monocot rotation that allowed the control of any cotton seedling volunteers.

A plant population of 5-7 plants per metre row were established on 750 mm spaced rows (6.5-9.3 plants/m^2). The experiments were established using a row configuration of 2 rows per bed separated by 75 cm with irrigation furrows between beds. Furrow irrigation was used for seasons 1 to 3 whilst drip tape irrigation was used for seasons 4 and 5 with the tape being buried 5cm deep in the middle of each bed leaving the between bed furrows to provide wet season runoff drainage. Plots were 12 rows wide by 10 m long in seasons 1, 2 and 3 and 12 rows wide by 15 m long for seasons 3 and 4. Insect pests were managed by scouting 2-3 times each week with insecticide decisions being made when pest densities reached levels at half of those used recommended for temperate regions (Cotton Pest Management Guidelines). This was done to ensure that pest activity had minimal impact on fruit abortion.

Fertiliser, 90 kg/ha N as urea, plus 20 kg/ha P and 85 kg/ha K placed in a band 10 cm deep and 15 cm within the crop row within a week of sowing. A further 90 kg/ha N and 108 kg/ha S was applied as a side-dressing within the same location 4-6 weeks after crop emergence. A foliar application of $ZnSO4.7H2O$ at 100 g element/ha at the 3rd true leaf stage. During seasons 4 and 5 an additional 13 kg/ha N and 44 kg/K as potassium nitrate was applied through the drip irrigation at 10 days after first flower.

The 18 December planting during season 2 was affected by a phenoxy herbicide contaminated (Fluroxypyr) spray application at the 12 node stage which caused distorted growth for 4-6 nodes across all cultivars. This treatment went on to set bolls after growing out of the damage but the extent to which this herbicide altered growth and fruiting dynamics in relation with the weather is difficult to ascertain.

Measurements

Date of first squaring was defined as when 50% of plants within a metre of row had one square with an unfurled subtending leaf. Dates of first flower and first open boll were defined as when one per meter of row per plot was present. Nodes above the uppermost first position white flower (NAWF) were counted on the same 5 plants in each plot at approximately weekly intervals from first flower. Cut-out or last effective flower was defined as when NAWF <4 (Bourland *et al.* 1992).

Plant height was defined as the distance from the soil surface to the unfurled leaf and was measured weekly from 5 plants in each plot commencing 2-4 weeks after sowing.

Photo 1.4 Field measurements such as heights and nodes were collected regardless of field conditions and the weather during the 5 year study.

Above ground biomass from 1 m of crop row from each plot was partitioned into stems, leaves, squares, flowers and bolls (green, open & unpickable) prior to drying at 60°C for 6-8 days in a fan forced oven. Biomass was partitioned at 6 nodes, 12 nodes, First Flower (FF), approximately

15 and 30 days after FF, First Open Boll and finally when 60-70% of bolls were open to derive a final reproductive biomass. The leaf area of each biomass sample was measured using a leaf area meter (Licor Industries 3000, Nebraska, USA).

Photo 1.5 An example of a biomass sub-sample that has been partitioned into stems, leaves, green bolls, unpickable bolls and open pickable bolls prior to oven drying.

The proportion of light intercepted by the treatment plots was measured at 7-10 day intervals from early squaring until maximum interception was reached (>95%). A 0.9m line sensor (Licor Industries, Nebraska, USA) was placed across the centre of one row in each plot. Readings were taken at ground level and above the crop at two locations in each plot within 30 minutes of solar noon.

Crop maturity was determined when 60% of the bolls were open and pickable. This was determined by counting and hand harvesting open bolls from 3 meters of row within each plot every 5-7 days from FOB till all bolls were open.

Photo 1.6 Collection of light interception data.

The contribution of different boll cohorts to overall yield was measured using a segmented picking technique just prior to machine picking. The fruiting branches of each plant within 2m of row was numbered from the base towards the top and grouped into subsets of 4 nodes resulting in fruiting branches (FB) 1-4, 5-8, 9-12, and all FB branches >13. For each of these FB groups on each plant the number of bolls were counted in the P1 and ≥P2 locations and seed cotton handpicked for weighing. In this way the number, size and contribution to overall yield could be calculated relative to each canopy section of the crop.

Seed cotton was machine harvested with a spindle picker from the entire length of 4 plot rows that had not been used for other destructive plot assessments. Larger plot end plants were manually removed prior to machine picking. Lint yield was calculated by ginning a 400 g subsample with a 10 saw gin. Ginning was conducted at the CSIRO Plant Industry laboratory at Narrabri in NSW except 2010 and 2012 when the seed cotton subsamples were ginned at Toowoomba DAFF. Because the turnout from a small 10 saw gin is higher than a commercial scale gin, the gin turnout was adjusted each season to be consistent with commercial values using data from concurrent commercial cotton plantings in the Burdekin that were processed in a commercial gin. Adjustments to gin turnout was made relative to commercial crop averages for one of the cultivars sown on the same date. Generally the turnouts from the 10 saw gin were 3-4% higher than the commercial scale gin. Ginned lint was assessed for Micronaire, Strength and Staple length.

Photo 1.7 The canopy sections of these plants have been marked (see pegs) to enable segmented picking of lint and counting of bolls from each canopy section.

Weather Recording

Field conditions were monitored with an automated weather station (Environdata Weather System 2000) which recorded temperatures, rainfall, humidity, solar radiation wind speed and wind direction. The cotton trials were also located within 20 m of the official Australian Bureau of Meteorology recording site for the Burdekin (Ayr DPI Research Stn {station 033002}) which provided an additional validation of site field conditions.

Photo 1.8 Downloading the field site weather recording station as cyclone Yasi moved closer to the Qld coast.

1.3 Results

Observed Climate

Each of the growing seasons recorded rainfall close to or significantly in excess of the long term Burdekin average for the months of January and February. During season 2 record rainfall totals were measured for the January – February period exceeding all prior records since 1951 (Fig 1.4A). During March seasons 1 and 2 were much drier and below the long term average compared to seasons 3 and 4 which were above average. Season 5 was characterised by an extremely wet March that also exceeded previous recorded totals since 1951. This wet period in season 5 was preceded by monthly totals of rainfall that were just below average during January and February (Figure 1.4A).

Photo 1.9 Conditions were so continually wet during 2009 that tadpoles were able to complete their development in the trial plot furrows.

Similarly solar radiation levels deviated considerably from the long term average during the five seasons. For Seasons 1 and 2 radiation levels were well below the monthly mean for January and February which coincided with wet weather. However March and April radiation was above average for the first two seasons. Radiation levels for season 3 were generally below the mean by 10-20% for the period spanning January to April whilst season 4 was characterised by a sunny conditions during January and February followed by below average radiation levels during March and April. Season 5 was unique with radiation levels close to the long term mean except for the month of March which was characterised by very cloudy wet weather resulting in the lowest monthly measurement of radiation (MJ/m^2) recorded during the January–May period during the 5 year study (Figure 1.4B).

Maximum temperatures were close to the long term mean for each of the seasons particularly for the period of March to June which coincided with the setting and filling of bolls. The exception was cooler than average conditions during January and February during season 2 which again coincided with high rainfall and cloudy weather. Minimum temperatures were similar to the long term mean for seasons 1 and 2 but significantly below the mean for seasons 3 and 4 during the period from April to June. The number of nights that recorded cold shock minima <12ºC were significantly higher during season 4 (32) compared with seasons S1 (10), S2 (12) S3 (15) and S5 (18).

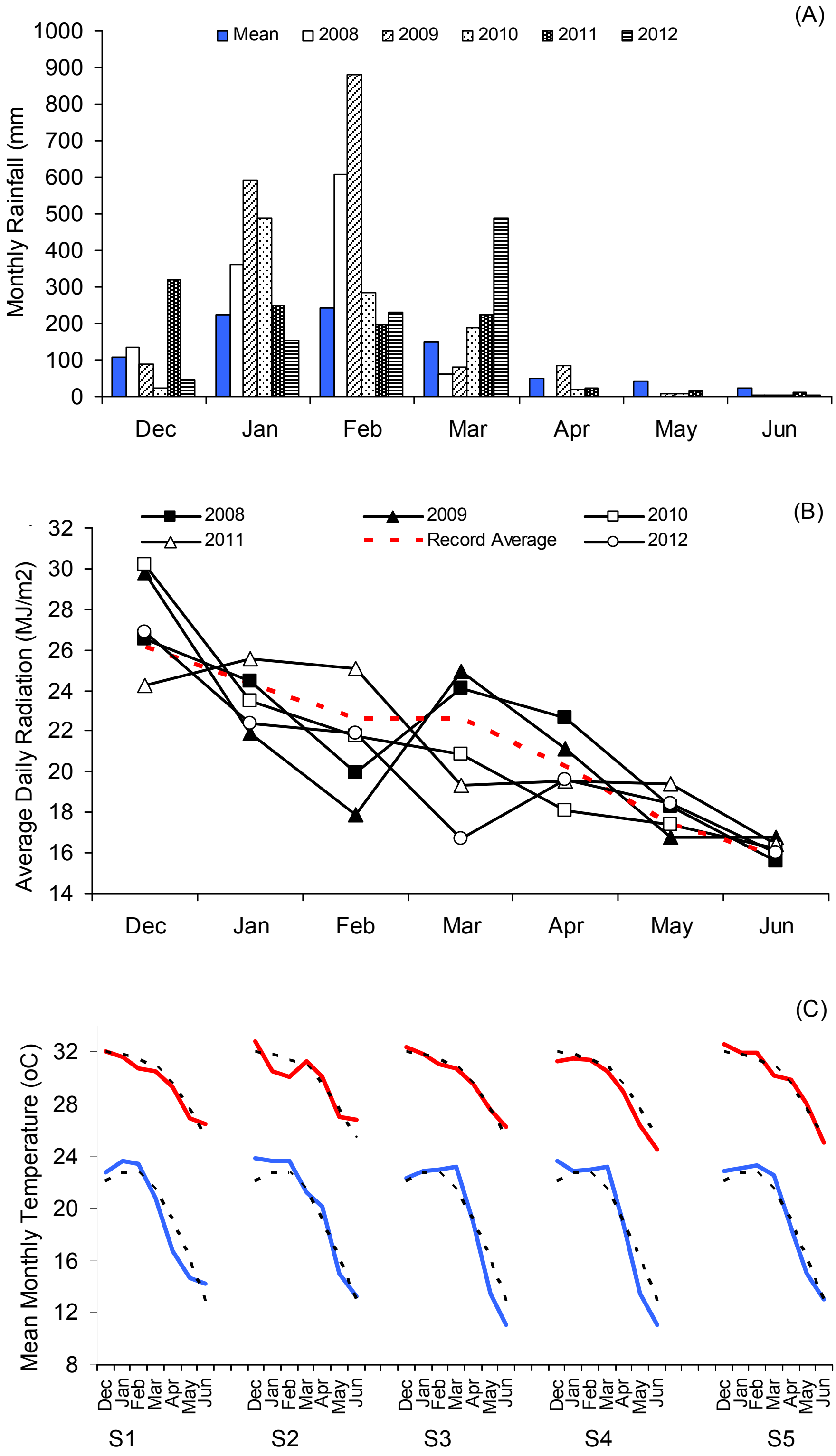


Fig 1.4 Climatic data for the five seasons (S1-5) of the experiments reported: (A) monthly rainfall; (B) average daily solar radiation and (C) average monthly maximum and minimum temperature for each month of crop growth. The long term mean is also given for each parameter.

Lint yields and within canopy yield partitioning

Lint yields ranged from 1179 kg/ha to 2900 kg/ha during the 5 seasons depending on cultivar and time of sowing. Sowing date had a significant effect on lint yield in seasons 1 and 2 and 5. Later sowing on 19 Dec and 7 January during season 1 and the 7 January sowing in seasons 2 and 5 resulted in significant increases to lint production (Fig 1.5). This contrasts with the affect of sowing date having no significant affect on lint production for seasons 3 and 4.

Cultivar main effects were limited in most seasons with significant differences ($P<0.05$) only observed in seasons 2 and 3 between Sicot 70BRF and Sicala 60 and the more indeterminate Siokra 24 and Sicot 74 both early December sowings and Sicot 70 and Siokra 24 and Sicot 74 for the January sowing in season 3. A significant difference was also recorded for the January sowing in 2012 with Sicot 74 yielding more lint than Sicot 70.

The discussion of the above treatment yields in relation to the sowing date is at best disingenuous as the primary factor affecting crop yield were preceding climatic conditions particularly radiation and rainfall. This will become apparent with the following results and discussion.

There was no consistent relationship between time of sowing date and gin turnout (Fig 1.6). The seasonal variability in turnout being potentially more indicative of season related climatic variables (when cloudy wet weather occurred) as opposed to any specific sowing date by turnout interactions However, cultivar differences were generally consistent over the 5 seasons with all cultivars having the same turnout except Sicot 74BRF which was significantly higher (+3.5-4%) than all other cultivars for each planting date in each season.

Yield Components

Within the season, weather conditions had a major influence on the pattern of fruit set both between and within fruiting branches. Where the commencement of flowering coincided with extended wet weather and cloudy conditions as was the case for early and late December sown cotton in seasons 1 and 2 and early December sown cotton in season 3 the contribution of the lower fruiting branches and/or first position fruit from the first 12 fruiting branches was reduced (Figs 1.7 1.8 & 1.9). This contrasted the January sown treatments in these seasons for which the onset of flowering largely coincided with sunnier conditions and a more regular boll partitioning throughout the entire canopy (Figs 1.7, 1.8 & 1.9).

During season 5, wet weather and low radiation in March resulted in the loss of fruit from the lower branches in the January sowing due to shedding. For the December sowing, this period of monsoon weather coincided with the latter half of flowering which resulted in reduced boll size in the lower canopy and shedding from the upper fruiting branches (Fig 1.11).

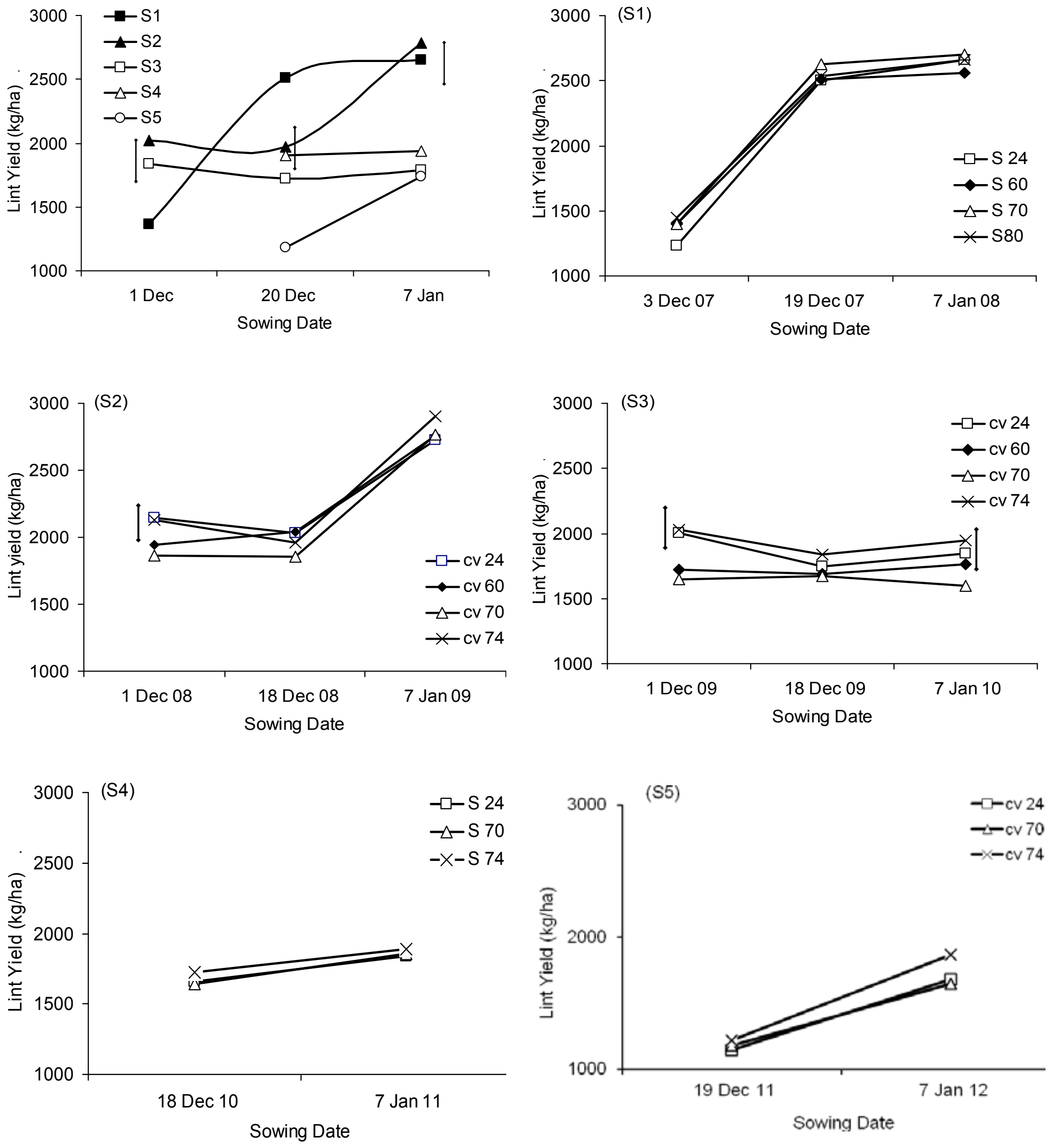


Fig. 1.5 The effect of sowing date on lint yield for seasons 1-5. The sowing date by cultivar interaction. Bars ↕ are LSD 0.05 where significant.

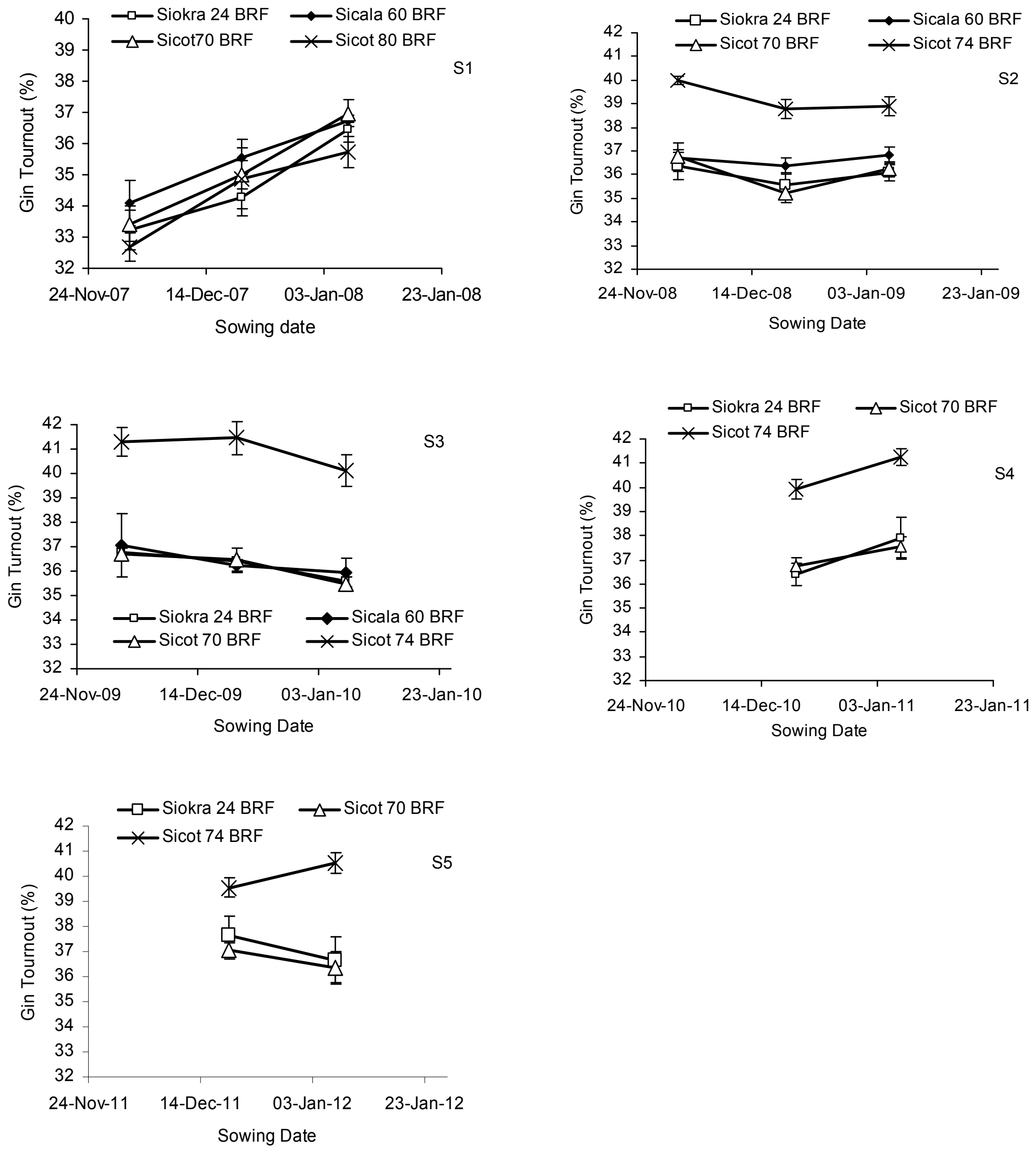


Fig. 1.6 Gin turnout for each cultivar and planting date for seasons 1-5.

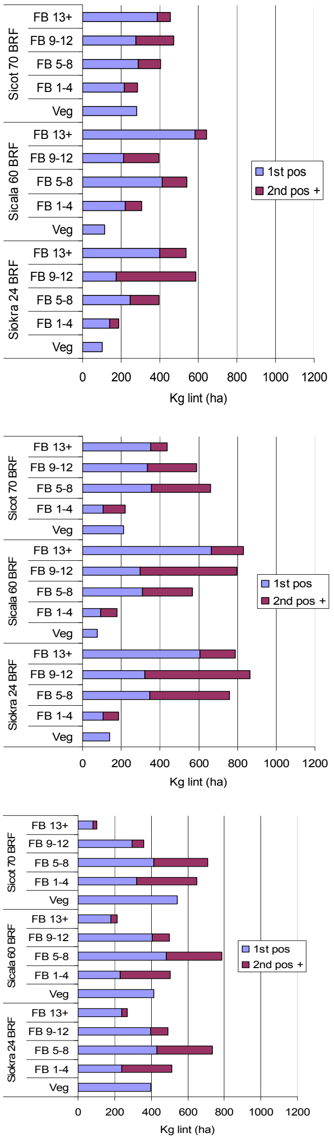


Fig 1.7 Segmented picking results for the varieties planted in season 1. The planting dates from the top figure to bottom were 3 & 19 December 2007 and 7 January 2008.

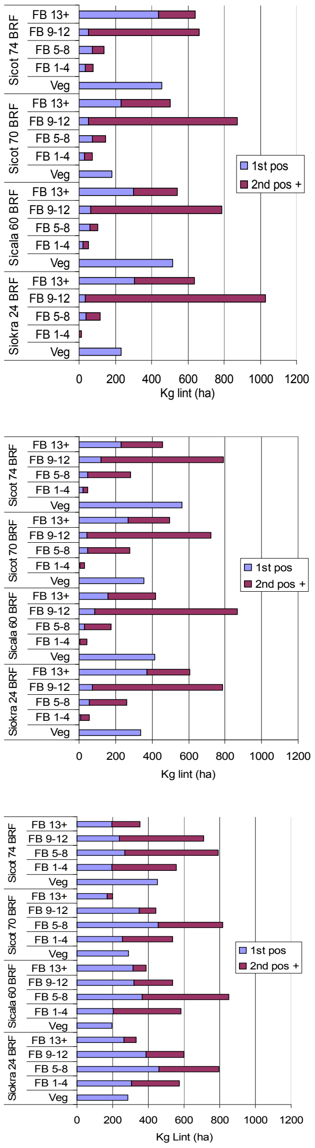


Fig 1.8 Segmented picking results for the varieties planted in season 2. The planting dates from the top figure to bottom were 1 & 18 December 2008 and 7 January 2009.

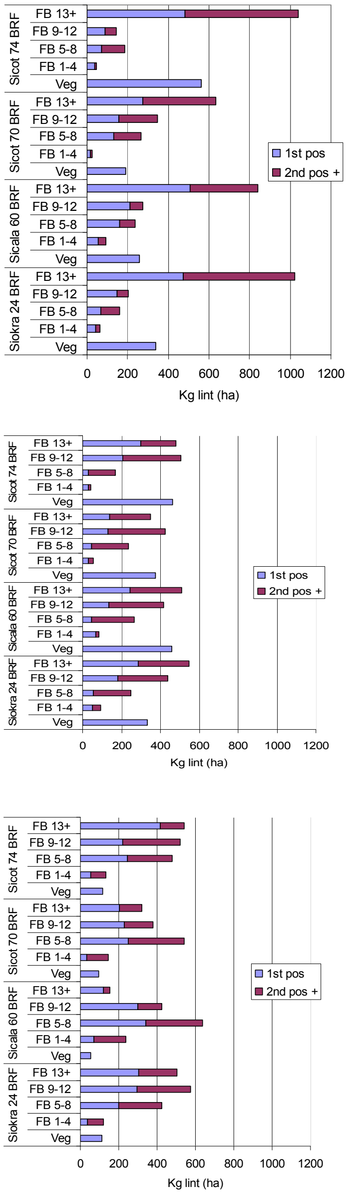
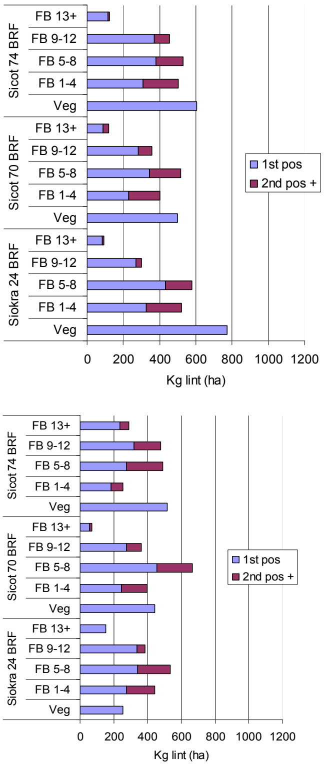


Fig 1.9 Segmented picking results for the varieties planted in season 3. The planting dates from the top figure to bottom were 1 & 19 December 2009 and 7 January 2010.



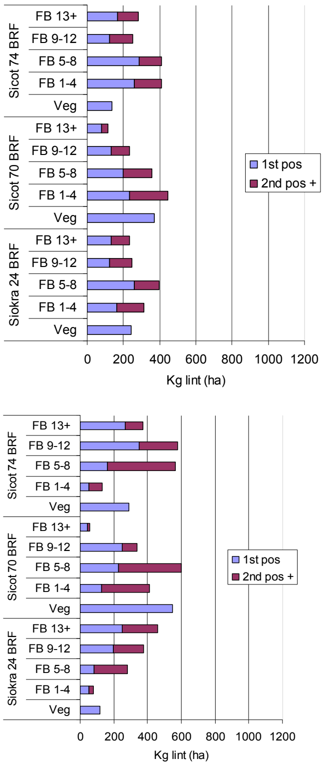


Fig 1.10 Segmented picking results for the varieties planted in season 4. The planting dates from the top figure to bottom were 18 December 2010 and 7 January 2011.

Fig 1.11 Segmented picking results for the varieties planted in season 4. The planting dates from the top figure to bottom were 19 December 2011 and 7 January 2012.

**Crop yield has been segmented into 4 main-stem fruiting branch sections (1-4, 5-8, 9-12 and 13 and above) as well as vegetative branches. The fruiting branches are also partitioned into first position fruit and second position or greater fruit branch have also been partitioned into first branch position bolls (1st Pos) and outer branch positions (2nd pos +).

To simplify the parallels that can be drawn between weather conditions and yield partitioning the data presented in Figure 1.12 shows the aggregate contribution of each fruiting branch and boll position cohort to overall lint yield for all cultivars for the early December sowing in season 2 together with the aggregate cultivar yield for subsequent January sowing. The December sowing (labelled as cloudy) received 5-6 weeks of cloudy wet weather from first flower (mid January) on compared to the January sowing (labelled sunny) that commenced flowering in early March and received mostly sunny conditions during flowering. (Fig 1.12 & 1.15). This figure shows the contrast in yield partitioning which relates to the pattern of radiation received during the respective flowering periods. The low contribution of the bottom branches is due primarily to the shedding of these fruiting sites during overcast weather in January and February or resultant boll rots. Without the yield contribution of the upper canopy and outer bolls for the early December sowing (marked cloudy), overall yield would have been poor. Figure 1.13 shows the mean weight of the bolls produced on the canopy sections of Siokra 24 and Sicot 70BRF from the early December season 2 planting. This data shows that the upper and outer canopy bolls that were set during the mid to late flowering period were larger in size compared with lower set bolls, producing more lint as the development of these bolls coincided with improving radiation conditions during March.

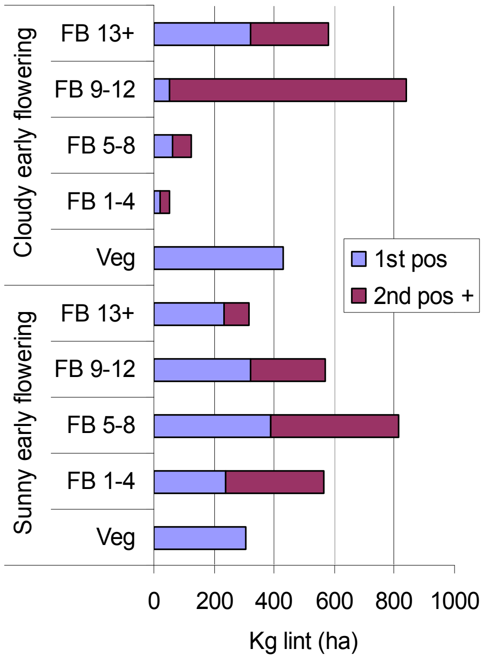


Fig 1.12 Mean yield from all cultivars from early December and January sown cotton for season 2. The top section shows the contribution of fruiting branches and boll positions whereby cloudy weather affected the first 5-6 weeks of flowering. The bottom section shows that January planted cotton that received predominantly sunny weather during flowering in March and April. The cloudy scenario cotton has lost most of the bottom bolls due to shedding and reduced boll size whilst the sunny scenario has set a good range of bolls over each canopy section.

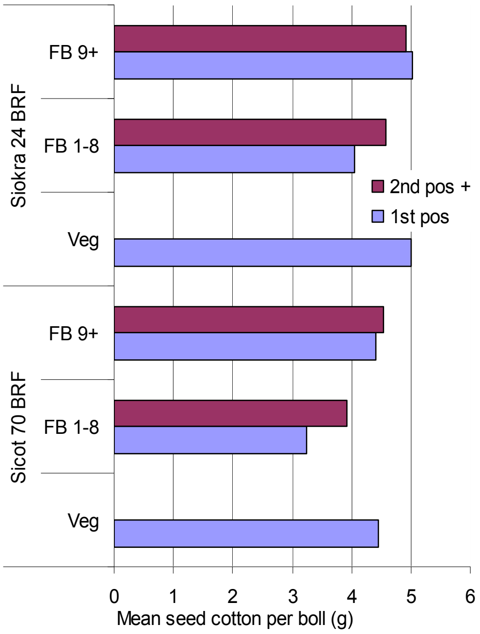


Fig 1.13 Segmented picking results showing mean boll size for each fruiting branch cohort and boll position for the early December sown cotton varieties Siokra 24BRF and Sicot 70BRF in season 2. Note that heavier bolls were produced on the upper canopy fruiting branches (FB9+) and the 2nd pos+ bolls on the lower branches compared to 1st pos bolls on the bottom 8 branches. These cohorts of bolls formed later from flowers set during late February to March when solar radiation increased (Fig 1.14) compared to the lower branch bolls that formed during cloudy wet conditions from mid January to February.

Where flowering commenced during continued sunny weather the contribution of lower fruiting branches and first position bolls was much greater (Fig 1.12) and more typical of the pattern of partitioning observed for temperate grown Australian crops where the lower canopy bolls are the primary contributor for yield (Constable 1991). The January sown cotton in the first two seasons when flowering commenced in early March when wet weather was tailing off demonstrates the greater contribution of the lower branches to crop yield. In seasons 3 and 4 cloudy weather was more intermittent and occurred for periods during March and April (Fig 1.15). This weather affected both December and January plantings by reducing overall boll size and retention (Figs 1.9 & 1.10). The variable conditions affected bolls within each of the cohorts of fruiting branches with the main affect being a reduction in the contribution of outer branch second position bolls. The segmented picking data demonstrate the plasticity of the plants in response to radiation variability and the ability to compensate particularly for the scenario of early season fruit losses characterised by the December plantings in seasons 1 & 2.

Compensation for extended periods of low radiation as occurred in S5 is problematic as cooler temps in May and June as well as decreasing day lengths reduce the time available to grow a larger "top crop" in the instance of the January sowing. For the December sowing compensation is limited by the internal competition for assimilates between existing lower bolls that had been retained during earlier sunny conditions which reduce the rate of new growth and fruiting sites. This scenario (monsoon conditions during mid to late flowering) is the most debilitating for yield potential as compensation is problematic.

Differences were also observed between cultivars particularly for the December sowings during seasons 1 and 2 when crops were subject to wet weather for the first weeks of flowering. A comparison between the indeterminate variety Siokra 24BRF and the determinate Sicot 70BRF shows that Siokra 24 BRF retained very limited numbers of bolls on the lower branches, undergoing extensive shedding and instead set a larger number of upper and outer canopy bolls whereas Sicot 70BRF retained more lower branch bolls during early flowering and produced less upper canopy bolls later in the season (Fig 1.14). This partitioning explains where the overall significant yield reductions for Sicot 70BRF in the season 2 early December sowing (Fig 1.5) occurred in the crop canopy which correlates with the low radiation recorded during early flowering for this treatment (Fig 1.4b & 1.15). The Siokra 24BRF retained fewer of these bolls due to shedding (Photo 1.10) during this period and consequently was able to set a larger quantity of bolls and lint on the later grown upper and outer canopy partitions (Photo 1.10 & 1.11). Photographs of the plots at harvest further illustrate this response with many of the lower set and retained bolls on the Sicot 70BRF plots having a visibly reduced size and high proportion of tight locking (Photo 1.13). Despite having a potentially poor potential for lint recovery during spindle picking these bolls will have competed for assimilates early on in the life of the crop which may be a causal factor for the reduced "top crop" and overall yield reduction from this cultivar (Photo 1.12 & 1.13)

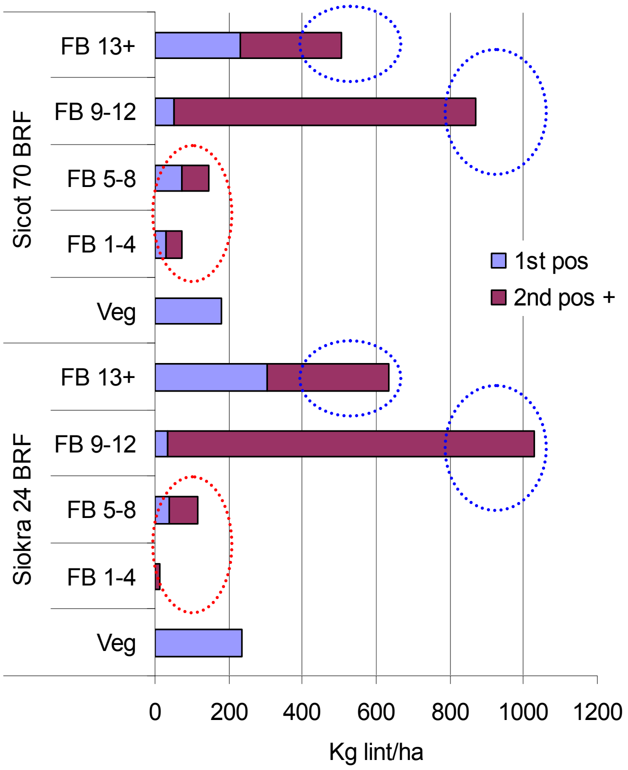


Fig 1.14 A comparison of the different canopy segments to overall lint yield for Siokra 24 BRF and Sicot 70 BRF for the early December sowing in season 2. This figure shows that the Siokra 24BRF retained very few bolls on the lower branches and instead compensated on the upper and branches and particularly on outer position fruit.

Photo 1.14 A Siokra 24BRF plant from the early December sown season 2 experiment showing the extensive shedding that has occurred from the bottom branches. The upper branches have started producing flowers which will become a top crop.

Photo 1.11 The same Siokra 24 BRF treatment at harvest showing the lack of bottom bolls and extensive top crop.

Photo 1.12 This is the same treatment but Sicot 70 BRF. This variety has retained many more lower bolls and has less bolls on the upper canopy.

Photo 1.13 Many of the lower bolls are poorly developed due to earlier cloudy conditions during the first 30 days of boll formation.

Lint Quality

The quality of lint picked each season fulfilled base grade fibre characteristics regardless of sowing date, season or variety sown (Table 1.3). Of interest is fibre length and strength which has been excellent for each variety grown in all seasons and planting dates. Staple length and fibre strength has generally been in premium range being both long and strong. Micronaire has been within the base grade range for all varieties and planting dates.

Table 1.3 Fibre Quality parameters measured from lint harvested from each, cultivar, planting date and season.

Planting Date	Fibre quality parameters											
	Length	Strength	Mic	Length	Strength	Mic	Length	Strength	Mic	Length	Strength	Mic
Season 1	**Siokra 24 BRF**			**Sicala 60 BRF**			**Sicot 70 BRF**			**Sicot 80 BRF**		
3/12/2007	1.23	32.5	3.9	1.19	35.1	3.4	1.23	33.4	3.7	1.21	33.4	3.7
19/12/2007	1.27	32.4	4.2	1.25	33.0	3.9	1.27	31.7	4.1	1.27	31.3	4.3
7/01/2008	1.23	31.6	3.9	1.22	31.7	3.7	1.24	31.5	3.7	1.25	31.2	3.9
Season 2	**Siokra 24 BRF**			**Sicala 60 BRF**			**Sicot 70 BRF**			**Sicot 74 BRF**		
1/12/2008	1.19	32.1	3.9	1.17	33.1	3.9	1.21	32.4	3.9	1.26	31.4	4.1
18/12/2008	1.23	31.8	4.2	1.18	31.8	4.2	1.21	31.5	4.3	1.27	32.5	4.0
7/01/2009	1.22	32.1	3.9	1.20	32.3	4.1	1.25	29.7	4.0	1.27	31.7	3.8
Season 3	**Siokra 24 BRF**			**Sicala 60 BRF**			**Sicot 70 BRF**			**Sicot 74 BRF**		
1/12/2009	1.25	28.9	4.5	1.18	30.0	4.1	1.23	30.7	4.5	1.23	29.3	4.5
19/12/2009	1.26	30.5	4.3	1.22	30.6	4.3	1.23	31.2	4.4	1.25	30.5	4.6
7/01/2010	1.27	30.0	4.1	1.21	31.3	4.2	1.35	29.8	4.2	1.25	30.0	4.6

Planting Date	Fibre quality parameters								
	Length	Strength	Mic	Length	Strength	Mic	Length	Strength	Mic
Season 4	**Siokra 24 BRF**			**Sicot 70 BRF**			**Sicot 74 BRF**		
18/12/2010	1.26	29.4	3.8	1.21	28.8	3.8	1.22	30.0	4.1
7/01/2011	1.26	29.6	3.8	1.22	30.0	4.0	1.26	28.7	3.7
Season 5	**Siokra 24 BRF**			**Sicot 70 BRF**			**Sicot 74 BRF**		
19/12/2011	1.26	32.2	3.8	1.20	30.3	4.0	1.24	32.0	4.0
7/01/2012	1.26	30.4	4.0	1.23	31.2	4.2	1.24	30.4	3.8

Shedding, Biomass accumulation and partitioning

Shedding is the abscission of squares (flower buds), flowers and young bolls from the plant. Generally bolls larger than thumbnail size cannot be shed and will be retained on the plant until boll maturity. The shedding referred to here and throughout this document does not refer to the loss of squares and early bolls that often occurs at or just after cut-out whereby a plant has reached a point where no further fruit can be held and surplus squares and young bolls are discarded. Instead the term shedding in this document describes the early to mid season abortion of squares, flowers and early formed bolls that can occur during the vegetative and early to mid flowering growth phases in response to climatic stimuli.

In the Burdekin, shedding was regularly observed in response to extended periods of cloudy, low radiation conditions whereby the plant aborts existing fruiting positions.

Shedding was generally manifested in two forms during the wet season, each associated with a particular sequence of climatic events:

1. **Very cloudy weather that extends beyond 3-5 days and may or may not be associated with heavy rainfall.** This was the most frequent observed cause of shedding that affected young bolls, flowers and advanced squares. Medium to large sized squares yellow and drop off or young bolls up to thumbnail size desiccate and may remain attached to the fruiting branch as a mummified small boll for several weeks. The shedding generally progresses from the most mature susceptible fruiting site positions to the least developed (e.g. first position fruit and squares will abscise before second positions on the same branch) (Photo 1.14 & 1.15).
2. **A sudden weather change from extended cloudy weather to sunny dry conditions.** The shedding induced by these conditions was generally restricted to very young squares, this shedding can affect all squares of a similar age and is independent of the location within the crop canopy (Photo 1.16).

Photo 1.14 This crop is shedding squares and day old bolls due to a week of cloudy weather in March 2011.

Photo 1.15 This plant has shed bolls that started to form after pollination. Note that desiccated early bolls are often retained.

Photo 1.16 Small squares often shed if the weather turns sunny and hot after extended periods of overcast wet weather.

The effect that planting date had on biomass accumulation was variable and the observed differences are readily attributed to the within season pattern of radiation in relation to crop flowering phenology. For seasons 1 and 2 the shedding of lower branch positions resulted in subsequent upper canopy expansion and production of additional fruiting sites. This is reflected by the general trend whereby the total biomass of the early December plantings in Seasons 1, 2, & 3 that were subject to overcast and wet conditions during the first 4-6 weeks of flowering generally exceeded the January sowing biomasses that received sunnier conditions from the commencement of flowering onwards. Essentially these crops grew larger as earlier canopy sections became redundant due to shedding of fruiting sites requiring continued growth and extended flowering to compensate for early season fruit shedding. This trend when a comparison is made of the proportion of total biomass partitioned into bolls at maturity generally showed an increasing relationship with delayed planting 1 Dec≥20Dec≥7 Jan during seasons 1 and 2. This is reflective of the increased retention of fruiting sites on later planted cotton across lower canopy sections due to the better alignment of flowering with improving radiation (less cloudy days) in March and April.

For season 4 the proportion of bolls was high (50-60%), however total biomass was lower than all previous seasons. This is reflective of the intermittent radiation where sunny conditions were regular enough to ensure retention of bolls and limited shedding (hence high boll proportion), but insufficient to allow continued vegetative expansion and production of a larger plant and extra fruiting sites thus curtailing final yield.

Table 1.4 Final Crop Biomass for each season, sowing date and variety.

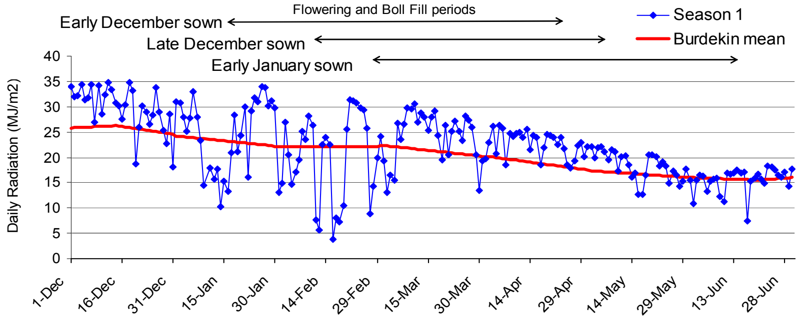
	Final Crop Biomass (g/m)			Boll Proportion (%)		
Time of sowing	**1 Dec**	**20 Dec**	**7 Jan**	**1 Dec**	**20 Dec**	**7 Jan**
Season 1						
Siokra 24 BRF	1385	1864	1699	37.2	56.1	62.4
Sicala 60 BRF	1300	1596	1528	41.5	59.0	63.5
Sicot 70 BRF	1465	1762	1381	43.7	54.3	65.9
Sicot 80 BRF	1530	1713	1581	34.6	52.4	62.6
Season 2						
Siokra 24 BRF	1749	1393	1877	35.6	48.3	61.4
Sicala 60 BRF	1453	1417	1773	32.4	49.9	60.5
Sicot 70 BRF	1914	1490	1631	31.1	47.1	61.2
Sicot 74 BRF	1399	1360	1715	30.7	49.0	61.8
Season 3						
Siokra 24 BRF	1366	1439	1239	39.7	41.6	47.2
Sicala 60 BRF	1232	1569	1202	47.5	46.6	49.3
Sicot 70 BRF	1483	1482	1291	44.7	46.5	46.2
Sicot 74 BRF	1271	1395	1232	36.1	45.0	53.7
Season 4						
Siokra 24 BRF	n/a	1400	1268	n/a	60.3	53.8
Sicot 70 BRF	n/a	1255	1198	n/a	60.9	57.0
Sicot 74 BRF	n/a	1278	1533	n/a	57.6	53.2
Season 5						
Siokra 24 BRF	n/a	1811	1623	n/a	40.7	51.0
Sicot 70 BRF	n/a	1750	1723	n/a	43.7	48.3
Sicot 74 BRF	n/a	1658	1603	n/a	43.0	51.3

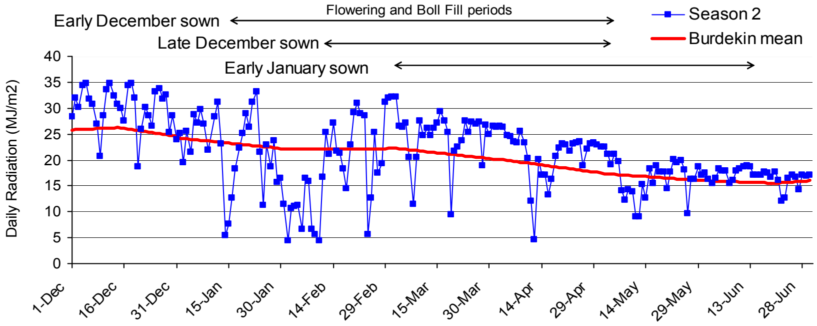
In terms of crop exposure to cloudy overcast conditions from first flower onwards figure 1.14 (seasons 1-5) show the daily radiation from 1 December until 30 June for each season together with the commencement of flowering and cessation of boll filling (when 60% of bolls were open) (boll filling and setting period) for each planting date. These figures show that for the first two seasons cloudy days were mostly confined to the January and February period and as such only directly overlapped the flowering and boll filling periods of the December planted sowings. The January sowings largely avoided exposure to cloudy days from early flowering onwards. Seasons

3-4 were characterised by cloudy days that overlapped flowering and boll setting for all planting dates particularly during March and April. This intermittently variable radiation reflects the reduced boll setting across all planting dates for these two seasons as shown by partitioned picking showing a cumulative reduction across all boll cohorts. This contrasts seasons 1&2 where only the early cohorts of bolls were negatively affected.

Season 5 contrasted all other seasons in that January and February were predominantly sunny with a 2-3 week cloudy and very wet period in March followed by predominantly sunny conditions thereafter. The result was a major loss of bolls from the December sowing due to shedding of the upper branch positions and boll rot damage in the lower canopy sections. The January sowing shed a significant proportion of lower bolls but grew compensatory bolls on the upper canopy with a fruit set patter similar to Dec plantings in previous seasons whereby flowering was affected by wet weather. These shedding losses ultimately reduced the yield potential for this season and resulted in the January cotton being picked several weeks later than all previous experiments. This was a function of the later set cohort of compensatory bolls which developed more slowly due to lower temperatures in May and June.

Early season crop development in the Burdekin is characterised by the rapid development of the crop canopy and resultant leaf area index. Generally peak LAI was achieved within 60 DAS well before vegetative expansion ceased particularly for the December sowings (Figs 1.15–1.18).





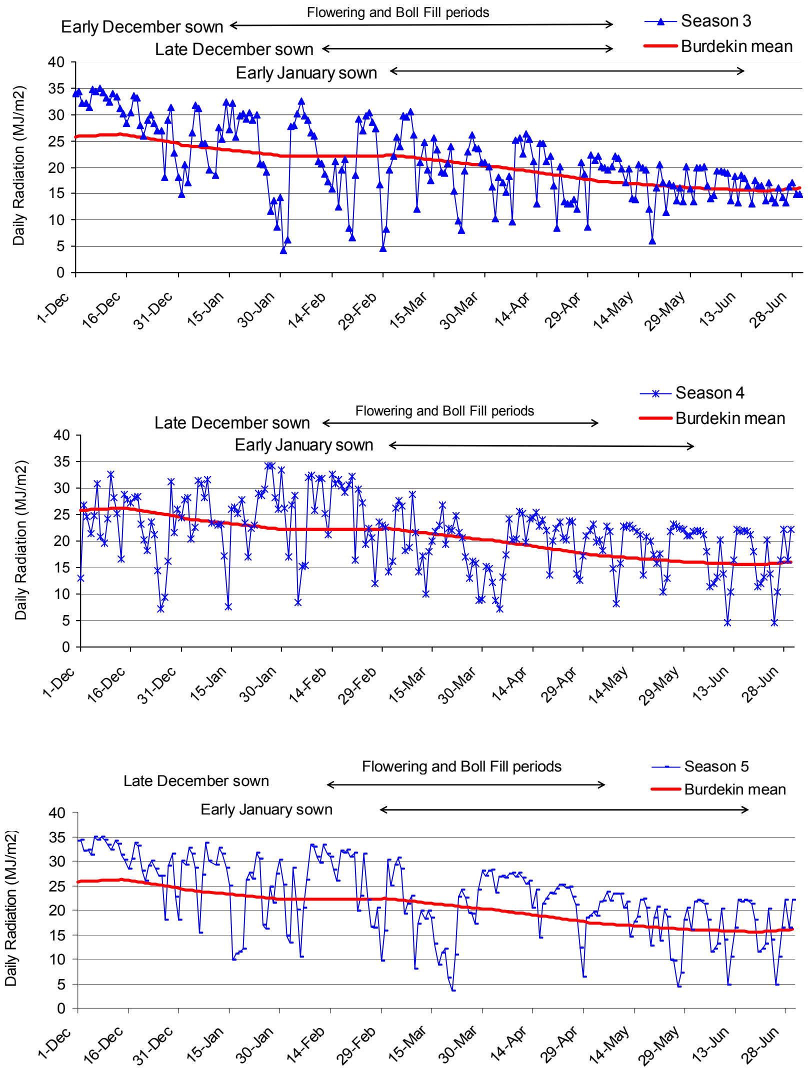


Figure 1.15 Daily Radiation (MJ/m^2) recorded during seasons 1-5 compared with the long term Burdekin mean. Shown on the figures are the flowering and boll filling periods for each planting dates during each (indicated by arrows). This period commences at first flower and ceases at 60% open bolls.

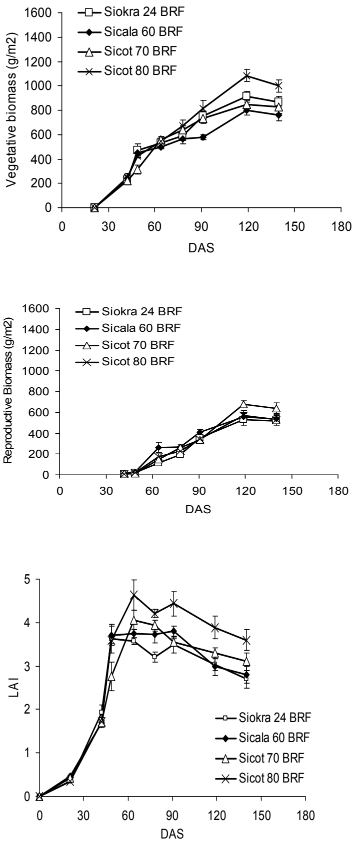


Fig 1.16a Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 3 December 2007 (Season 1).

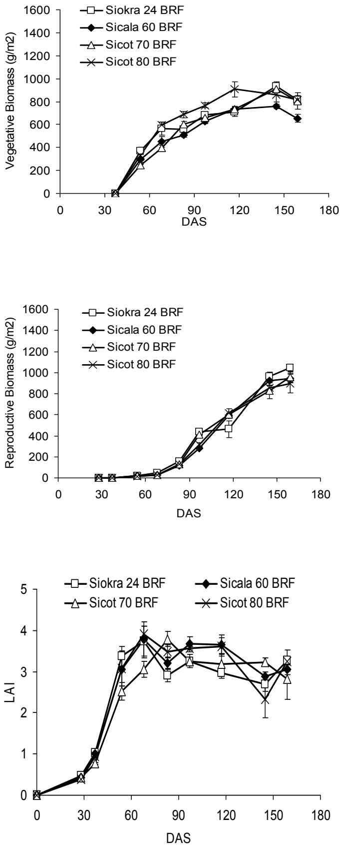


Fig 1.16b Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 19 December 2007 (Season 1).

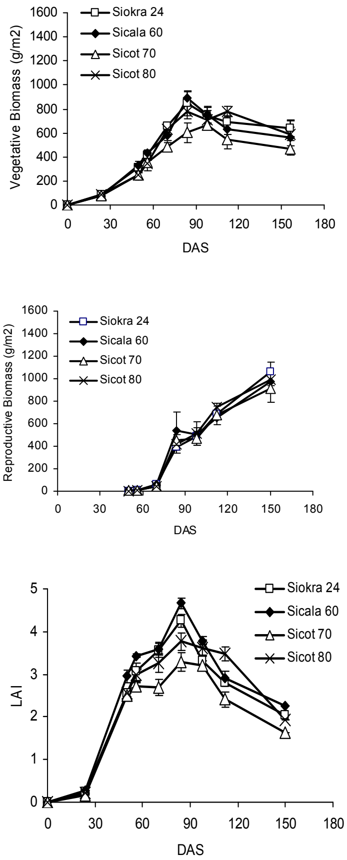


Fig 1.16c Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2008 (Season 1).

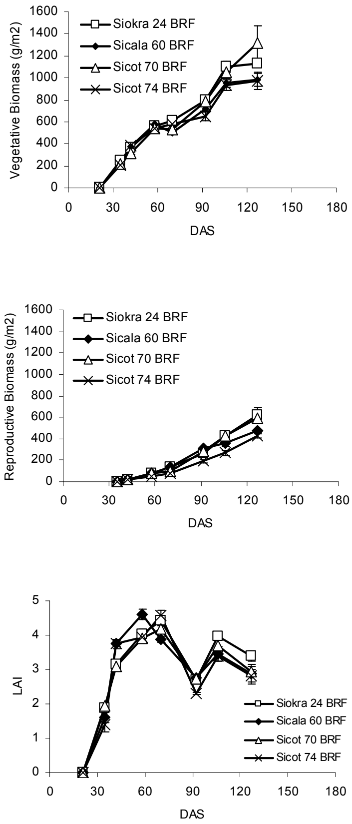


Fig 1.17a Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 1 December 2008 (Season 2).

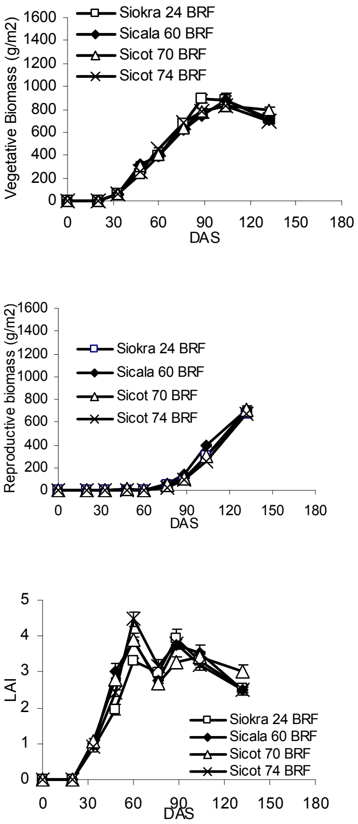


Fig 1.17b Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 18 December 2008 (Season 2).

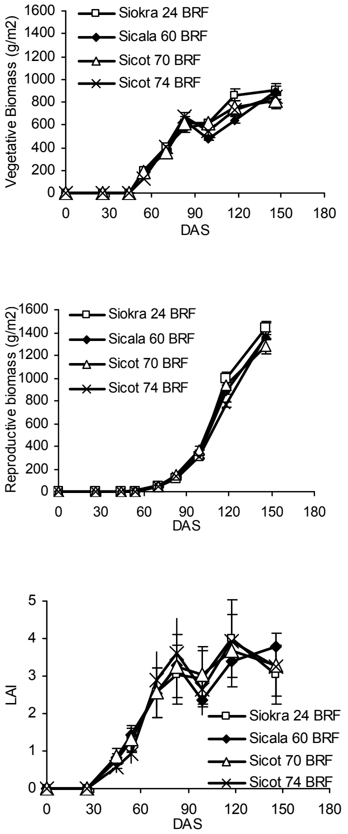


Fig 1.17c Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2009 (Season 2).

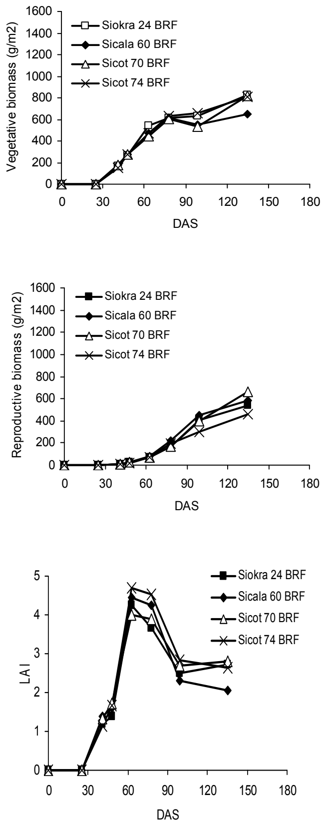


Fig 1.18a Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 1 December 2009 (Season 3).

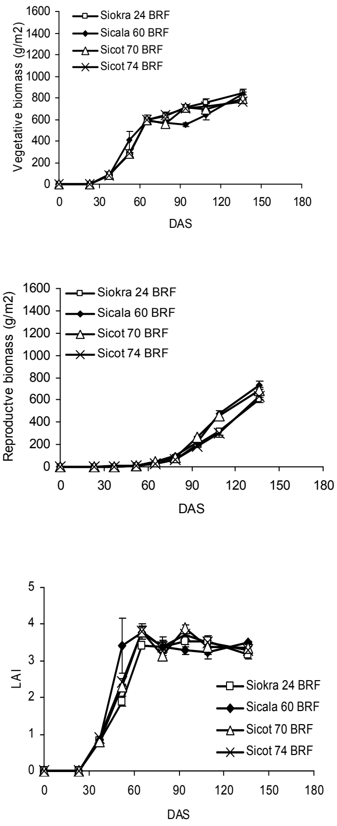


Fig 1.18b Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 19 December 2009 (Season 3).

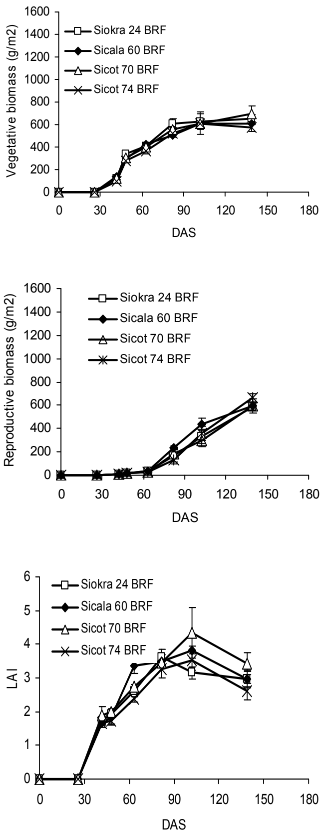


Fig 1.18c Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2010 (Season 3).

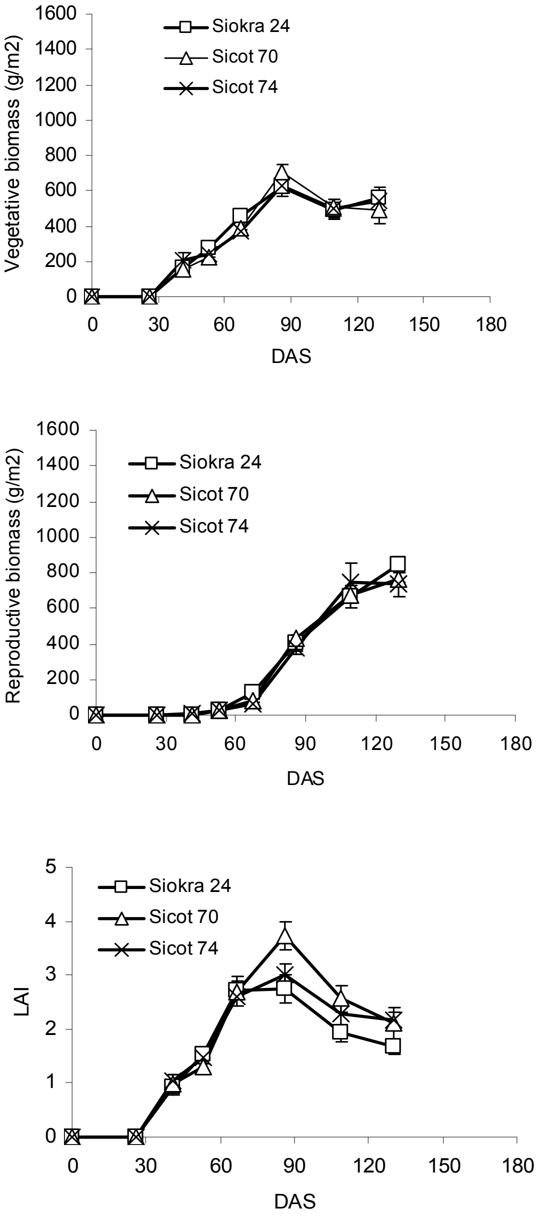


Fig 1.19a Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 18 December 2010 (Season 4).

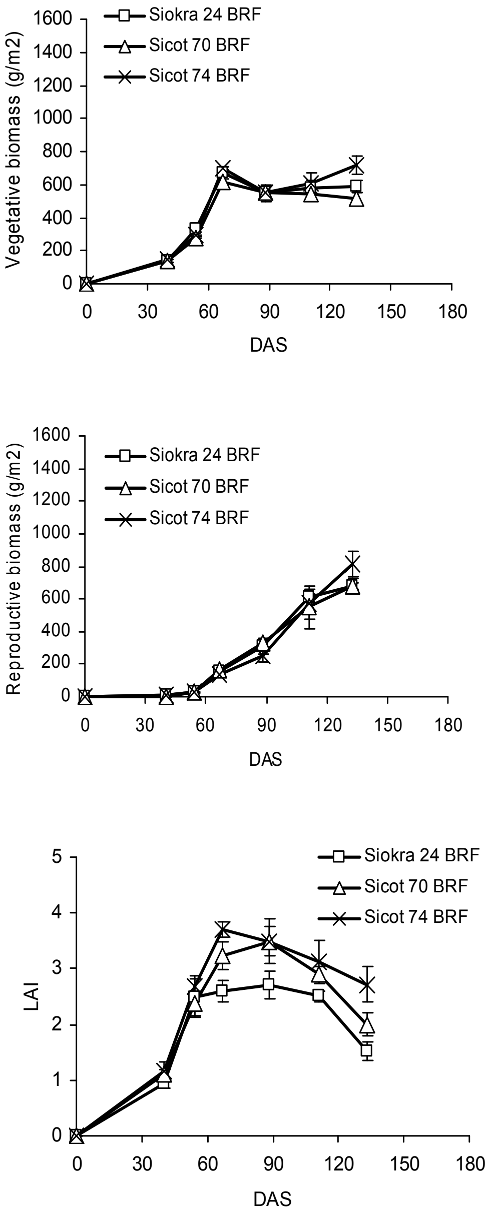


Fig 1.19b Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2011 (Season 4).

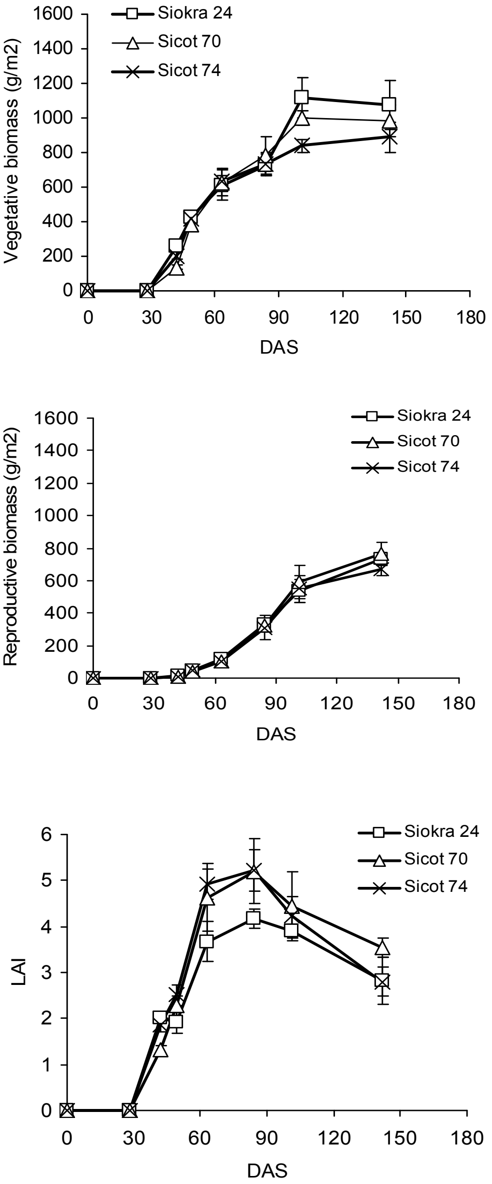


Fig 1.20a Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 19 December 2011 (Season 5). **Note** that the reproductive biomass for this sowing includes un-pickable bolls.

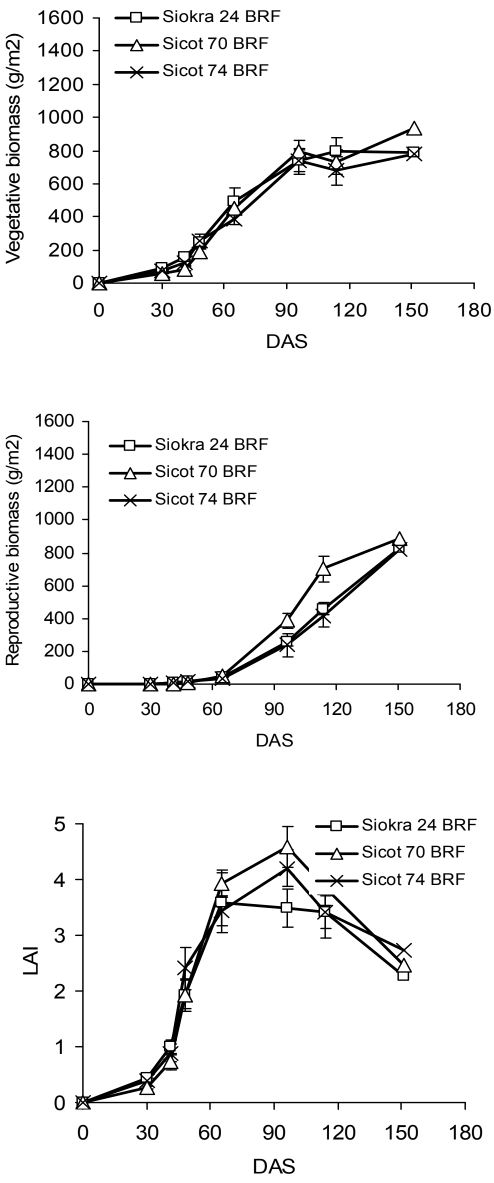


Fig 1.20b Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2012 (Season 5).

Fruit Retention

As demonstrated by the segmented picking, yield and biomass accumulation data the production of fruiting sites and pattern of retention was directly influenced by weather conditions particularly during the flowering period for each sowing date. The total production of fruiting sites tended to be higher for the earlier plantings that were subject to more cloudy weather during flowering for seasons 1-3. This was due to the loss of many earlier positions due to shedding which is indicative of the low rates of retention which allowed the crops to continue vegetative expansion and thus create additional new fruiting sites. The first December planting in season 1 did not follow this trend, however agronomic management practices deployed at the time to reduce crop height (more restrictive irrigation and MC usage) in part explain this response.

The January plantings in seasons 1 and 2 produced a proportionally lower number of fruiting sites but had higher levels of retention and thus final boll numbers which reflects the lower rates of physiological shedding in these treatments. The January plantings in seasons 3 and 4 also produced a lower mean number of fruiting sites although differences were not as large compared to the earlier plantings.

Final boll number and retention was lowest for the December planting in season 5. This reflects the monsoon conditions in March which caused extensive upper canopy shedding of bolls, loss of lower bolls and a failure to grow many new sites to compensate. This shows that the impact of monsoon conditions in March can be particularly severe for December sown cotton particularly if preceding conditions are sunny.

Table 1.5 Fruiting factors (Total fruiting sites, final boll number and % retention) for each seasons planting date and cultivar per metre row.

Fruiting Factors	**Total Site Production**			**Final Boll Number**			**Final Retention (%)**		
Approximate Time of Sowing	**1 Dec**	**20 Dec**	**7 Jan**	**1 Dec**	**20 Dec**	**7 Jan**	**1 Dec**	**20 Dec**	**7 Jan**
Season 1									
Siokra 24 BRF	381.9	501	545.7	82.3	174.6	211.1	21.6	34.9	38.7
Sicala 60 BRF	329.9	441.1	405.2	87.1	151.2	208.5	26.4	34.3	51.5
Sicot 70 BRF	396.3	452.3	357.5	90.4	161.1	213.8	22.8	35.6	59.8
Sicot 80 BRF	423.8	492.9	369.7	94.4	192.7	212.5	22.3	39.1	57.5
Mean	**383.0**	**471.8**	**419.5**	**88.6**	**169.9**	**211.5**	**23.2**	**35.9**	**51.8**
Season 2									
Siokra 24 BRF	600.2	604	558.2	128.6	116.5	192.7	21.4	19.3	34.5
Sicala 60 BRF	569.4	482.1	482.4	127.8	119.1	131.2	22.4	24.7	27.2
Sicot 70 BRF	522	526	510.8	132.2	128.5	192.1	25.3	24.4	37.6
Sicot 74 BRF	590.7	559	489.1	118.8	121.3	166.4	20.1	21.7	34.0
Mean	**570.6**	**542.8**	**510.1**	**126.9**	**121.4**	**170.6**	**22.3**	**22.5**	**33.3**
Season 3									
Siokra 24 BRF	552.6	502.6	475	114.5	105.3	121.1	20.7	21.0	25.5
Sicala 60 BRF	493.4	397.4	332.9	102.6	127.0	113.2	20.8	32.0	34.0
Sicot 70 BRF	494.7	394.7	389.5	103.9	118.4	106.6	21.0	30.0	27.4
Sicot 74 BRF	561.8	423.7	434.2	103.9	105.3	122.4	18.5	24.9	28.2
Mean	**525.6**	**429.6**	**407.9**	**106.2**	**114.0**	**115.8**	**20.2**	**26.9**	**28.7**
Season 4									
Siokra 24 BRF	n/a	467	422	n/a	138	113	n/a	29.6	26.8
Sicot 70 BRF	n/a	384	397	n/a	131	118	n/a	34.1	29.7
Sicot 74 BRF	n/a	430	405	n/a	135	124	n/a	31.7	29.0
Mean		**427.0**	**408.0**		**134.7**	**118.3**		**31.8**	**28.5**
Season 5									
Siokra 24 BRF	n/a	471	381	n/a	75.7	102.4	n/a	16.1	28.8
Sicot 70 BRF	n/a	425	333	n/a	74.6	112.3	n/a	17.5	33.7
Sicot 74 BRF	n/a	402	461	n/a	82.8	119.3	n/a	20.5	25.8
Mean		**432.6**	**395.0**		**77.7**	**111.3**		**17.9**	**28.1**

Crop Height and Node Production

As a general trend the earlier December plantings produced more nodes than the later January sowings which is indicative of the higher incidence of shedding in these treatments and consequent continued vegetative expansion. Likewise the height of these treatments also tended to be greater than the January sowings in seasons 1 and 2 that had sunnier conditions (Table 1.6). This pattern for height and node data is consistent with the data on retention and yield partitioning. Essentially where compensatory bolls were produced, plants grew additional nodes and consequently taller.

Table 1.6 Final crop number of nodes and total height (cm) for each planting date and cultivar.

	Total Nodes			Final Crop Height (cm)		
Time of Sowing	**1 Dec**	**20 Dec**	**7 Jan**	**1 Dec**	**20 Dec**	**7 Jan**
Season 1						
Siokra 24 BRF	27.5	28.6	25.4	140.3	148.1	126.4
Sicala 60 BRF	25.4	26.4	24.4	113.2	125.3	109.3
Sicot 70 BRF	25.0	26.2	22.3	123.5	129.4	106.3
Sicot 80 BRF	28.9	27.7	24.9	132.3	143.6	129.5
Mean	**26.7**	**27.2**	**24.3**	**127.3**	**136.6**	**117.9**
Season 2						
Siokra 24 BRF	29.8	28.5	24.2	158.8	148.1	131.3
Sicala 60 BRF	26.3	26.2	23	143.7	121.0	111.2
Sicot 70 BRF	27.2	24.9	22.9	138.3	126.1	116.2
Sicot 74 BRF	27.1	27.8	23.9	146.8	130.1	118.5
Mean	**27.6**	**26.9**	**23.5**	**146.9**	**131.3**	**119.3**
Season 3						
Siokra 24 BRF	29.1	27.3	27	129.1	136.9	130.7
Sicala 60 BRF	26.3	24.2	24.4	107.0	110.6	108.5
Sicot 70 BRF	23.8	22.9	24.3	102.0	111.4	112.2
Sicot 74 BRF	28.3	26.6	26.1	120.1	114.6	119.5
Mean	**26.9**	**25.3**	**25.5**	**114.6**	**118.4**	**117.7**
Season 4						
Siokra 24 BRF	n/a	25.7	22.7	n/a	97.6	109.2
Sicot 70 BRF	n/a	23.6	19.9	n/a	86.3	84.9
Sicot 74 BRF	n/a	24.2	21.8	n/a	98.1	96.2
Mean		**24.5**	**21.5**		**94.0**	**96.8**
Season 5						
Siokra 24 BRF	n/a	24.6	22.9	n/a	130.2	122.8
Sicot 70 BRF	n/a	21.4	20.7	n/a	105.1	96.8
Sicot 74 BRF	n/a	22.6	20.9	n/a	117.6	103.2
Mean		**22.8**	**21.5**		**117.6**	**107.6**

Crop Flowering Period and Time to Maturity

Similarly to the production of nodes and crop height, the period of flowering was also generally extended for the December plantings compared to January. Again this is reflective of the earlier sowings being exposed to cloudy conditions for longer during flowering, with resultant shedding allowing the continued production of new fruiting sites and flowering (Table 1.7).

Time to maturity generally occurred within a 140-155 day time frame for most treatments and seasons. Time to maturity was extended for the early December sowing in season 2 which reflects the longer flowering period whereas both sowing in season 4 had rapid crop maturity of 118 and 136 days which reflected the curtailed flowering period for this season due to on-going intermittent cloudy weather and resultant solar radiation limitations (Fig 1.15 and table 1.7). Monsoon conditions in March during season 5 and the resultant shedding that occurred in the

January sowing resulted in the lengthiest time to maturity of 157-164 days due to the slower development of later set bolls in the upper canopy.

Table 1.7 The flowering period (from FF to cutout) and time until final maturity or each planting date and cultivar for the 5 seasons.

	Flowering Period (FF to 3 NAWF) Days			Crop Maturity - 60% Bolls Open (DAS)		
Time of Sowing	**1 Dec**	**20 Dec**	**7 Jan**	**1 Dec**	**20 Dec**	**7 Jan**
Season 1						
Siokra 24 BRF	27	52	45	144	150	150
Sicala 60 BRF	27	49	45	137	144	150
Sicot 70 BRF	27	49	45	137	144	150
Sicot 80 BRF	27	52	45	144	150	158
Mean	**27.0**	**50.5**	**45.0**	**140.5**	**147.0**	**152.0**
Season 2						
Siokra 24 BRF	68	55	49	163	145	149
Sicala 60 BRF	68	49	49	163	143	149
Sicot 70 BRF	68	49	49	163	145	156
Sicot 74 BRF	75	55	55	163	152	156
Mean	**69.8**	**52.0**	**50.5**	**163.0**	**146.5**	**152.3**
Season 3						
Siokra 24 BRF	50	50	40	150	139	138
Sicala 60 BRF	50	50	40	142	134	128
Sicot 70 BRF	50	44	40	142	134	138
Sicot 74 BRF	55	55	46	163	146	151
Mean	**51.3**	**49.7**	**41.5**	**149.3**	**138.3**	**138.8**
Season 4						
Siokra 24 BRF	n/a	40	35	n/a	118	136
Sicot 70 BRF	n/a	40	35	n/a	118	136
Sicot 74 BRF	n/a	45	40	n/a	125	142
Mean		**41.6**	**36.6**		**120.1**	**138.0**
Season 5						
Siokra 24 BRF	n/a	50	53	n/a	129	157
Sicot 70 BRF	n/a	45	48	n/a	129	157
Sicot 74 BRF	n/a	50	58	n/a	136	164
Mean		**48.3**	**53.0**		**131.3**	**152.6**

1.4 Discussion

Being situated within the dry tropics of coastal north Queensland, the Burdekin is considered to have excellent levels of solar radiation with an annual average of more than 300 sunny days (higher than most other north Queensland cropping regions). However, solar radiation is most variable during January to March a period that overlaps first flower to peak flowering for cotton crops planted in the proposed planting window.

This study has demonstrated that the key climatic challenge to growing cotton in the Burdekin is the variability of cloudy weather during boll growth (from first flower to 60% of bolls being open). Solar radiation (sunniness) and rainfall were the primary abiotic environmental factors that are likely to have an overarching negative effect upon all other environmental factors that influence cotton growth and development in the Burdekin for the proposed 20 Dec to 20 Jan sowing window. The success or otherwise of agronomic management and use of crop inputs is largely determined by radiation during flowering. The wetter than average conditions that have occurred during the study period allowed the collection of a comprehensive data set that measured the impacts of monsoon conditions on cotton growth, development, and yield potential.

The data from the January sowings in 2008 and 2009 demonstrate that in drier years when conditions could be expected to be mostly sunny during flowering and boll filling that cotton growth and development is likely to be similar to other Australian production regions with the possibility of very high yields and excellent fibre quality being produced. These test sowings despite being subject to extremely wet and overcast conditions prior to flowering exhibited similar vegetative and reproductive biomass partitioning (Table 1.4 & Figs 1.22 & 1.23) to temperate grown Australian crops where the lower and mid canopy contribute over 60% of total yield (Mauney 1986; Heitholt 1993; Constable 1991). These sowings received largely sunny weather from the onset of flowering and produced lint yields in the range of 2600-2900kg/ha or 11.5-12.7 bales/ha (Fig 1.5). The bolls for these yields were set within a relatively compressed flowering period of 45-50 days during March through to mid-April (Fig 1.15 and Table 1.7).

For the plantings that received periods of overcast and rainy weather from first flower onwards, yield potential was much more variable and was lower compared to plantings that received mostly sunny conditions during the boll filling period. Yields for these plantings varied significantly from 1179-2625 kg/ha. The lowest aggregate yields recorded during the study was from the early December planting in season 1 and the late December sowing season 5 which had a mean yield (across all cultivars) of 1233 lint kg/ha or 5.4 b/ha and 1179 lint kg/ha or 5.2 b/ha respectively. Data collected during the first experiment in season 1 suggested that modifications to crop management in terms of reduced MC usage, and increased irrigation frequency after last effective rainfall maybe beneficial for encouraging continued vegetative expansion which may offset wet season related shedding losses through the production of new fruiting sites. Better deployment of crop husbandry practices to encourage vegetative expansion at the end of wet weather in subsequent seasons resulted in significantly higher yields from the early December plantings in seasons 2 & 3 that also received extended periods of overcast weather after first flower. This approach could not mitigate the effects of monsoon conditions in March for the December sowings as the crops had already retained a significant number of bolls which impeded the production of compensatory fruit.

Sustaining crop vigour during the wet season and importantly maintaining growth during the first weeks of sunny weather when conditions can rapidly change from cloudy to sunny is fundamentally important for maximising yield potential post-monsoon. Essentially the available period for flowering is truncated by cool weather in June, which means that last effective flowers should be set to ensure boll maturity by the end of April. Therefore the effective period during which bolls can be reliable set depend on the extent to which sunny conditions occur prior to the end of April after which setting additional bolls is problematic. Segmented picking demonstrated upper and outer fruiting branch bolls can make a significant contribution to overall yield potential particularly if conditions were cloudy during early flowering (Figs 1.7, 1.8 & 1.12). Without these later cohorts of bolls after extended periods of wet weather and associated shedding losses yield can be significantly reduced.

In this regard cultivars with more vigorous and indeterminate growth habits such as Siokra 24 and Sicot 74BRF may be advantageous and be able to grow more additional sites after wet weather ceases. This was evidenced by the additional nodes produced by these varieties as well as the greater contribution from outer position fruit (Table 1.6 Figs 1.8-1.12). A characteristic of Siokra 24BRF is the prodigious shedding of lower branch positions during extended wet weather which then allows for very rapid growth, canopy expansion and fruiting site production when sunny weather returns. The growth habit of Sicot 74BRF diverges in retaining a greater number of lower branch fruit during overcast weather which slows the rate of vegetative expansion when sunny weather returns. Sicot 74BRF generally yielded the same as Siokra 24BRF but generally had a delayed crop maturity of 7-14 days (Table 1.7). Sicot 70BRF and Sicala 60BRF were more determinate varieties and tended to retain more bolls during overcast wet conditions in February (Figs 1.7 & 1.8, 1.11). The more determinate growth habit and higher retention of lower fruit during cloudy weather disadvantaged these two varieties when sunny conditions return with regard to producing new fruiting sites. The higher retention of bottom fruit by these varieties compete for internal assimilates and reduce the rate of new vegetative growth and production of fruiting sites. These later sites often produce better bolls due to improved solar radiation conditions (Fig 1.13). Segmented picking for these varieties demonstrates that whilst more bottom bolls were retained, boll size was reduced due to cloudy conditions during the first weeks of their formation compared to cohorts of upper canopy bolls. These poorer quality bolls in effect substitute for later fruiting sites that may have been produced and serviced by an expanded canopy (Figs 1.11–1.13).

Overcoming early season shedding due to low radiation conditions was clearly dependent on growing additional compensatory fruiting sites. However, the potential yield of these fruiting sites is dependent on weather conditions during March and April. During the 2008 and 2009, the wet season was very intense with weeks of prolonged wet weather and very few sunny days. For late December sown crops, flowering commenced in mid-February at a time when the monsoon was very active. Shedding from these sowings was extensive with very few lower branch positions being retained during wet weather. However, both of these seasons were characterised by a rapid improvement of conditions in early March with sunny weather that allowed rapid canopy expansion and production of new larger bolls (Fig 1.12 & 1.13). The first two seasons demonstrated that the impact of the monsoon season could be overcome through compensatory growth provided that sunny conditions return in early autumn and that crops are managed for vegetative expansion and new fruiting site production. The rate of vegetative expansion being dependent on the minimisation of stress by ensuring responsive irrigation and ensuring sufficient soil available nitrate and avoidance of excessive Mepiquat Chloride application.

Seasons 3 and 4 had very different climatic conditions compared with the first two seasons. These seasons represented the type of conditions that could be expected to be more problematic for cotton production in the Burdekin. Season 3 was characterised by rainfall totals for January and February well in excess of the long term mean and cloudy weather resulting in below average radiation (Fig 1.15). This was an improvement on conditions recorded during seasons 1 and 2 except that March and April were afflicted by significant periods of cloudy weather with 33 days of below average solar radiation. Season 4 had improved conditions for January and February particularly after tropical Cyclone Yasi passed through north Queensland on 6 February after which sunny conditions occurred for nearly 4 weeks. However despite high radiation levels during most of February and resultant high retention of bolls particularly for the December planting the onset of cloudy conditions in March and April (Fig 1.15) led to a significantly reduced quantity of lint being produced. This is evident in figure 1.19a which shows a decrease in the rate of accumulating boll biomass between cutout at 105 DAS and 60% maturity at 130 DAS. In previous seasons this period was characterised by increasing reproductive biomass after cut-out (Figs 1.17 & 1.18).

Weather conditions in season 5 were potentially indicative of a worst case scenario for yield potential in the Burdekin based on the findings of the previous 4 seasons. This is primarily due to the cloudy wet weather occurring during mid to late March and at a time when the crop would be flowering and have lower bolls retained. Crops at this stage are most susceptible to an extended period of wet weather as the remaining season length to allow compensation is reducing and flowering is already well underway. For the December planted cotton the impact of this weather was severe and resulted in the lowest yields picked during the five year study. The wet weather for this sowing coincided with the latter half of flowering which constrained yield in several ways. Firstly many upper and outer bolls were shed in response to cloudiness and wet conditions. The lower bolls which had been retained during sunny weather during early March and late February provide competition for assimilates which limits new growth and production of squares. When sunny conditions resume the competition from existing fruit reduce the ability of the plants to rapidly compensate and produce new fruiting sites resulting in reduced boll numbers and yield (Figs 1.5 & 1.11). The size of lower first position bolls and contribution to overall yield that were retained was also reduced.

The influence of the monsoon in March during season 5 also affected later January sown cotton. For this planting the wet weather coincided with mid flowering which resulted in extensive shedding. The reduction of yield subsequently occurred as the time available for the production of new fruiting sites that could be matured by June is limited. This influence is demonstrated by the picking for this treatment being 2 weeks later than all previous January sowings together with the lowest yield.

Seasons 3-5 demonstrate the importance of weather conditions particularly during March - traditionally a transitional month between the wet and dry seasons. Seasons 1-5 spanned the likely historical variation that might be expected for this period with Seasons 1 and 2 being above average and seasons 3 and 4 being below and season 5 having the lowest levels recorded.

Solar radiation during March and April is critically important for yield potential because losses during this period become increasingly difficult to compensate for due to cooling night temperatures in May. This contrasts the scenario that was observed in seasons 1 & 2 whereby shedding losses incurred during February were offset by compensatory boll setting during March and April.

A comparison of planting dates is instructive when considering risks for Burdekin cotton production. The January sowing treatment provided significant yield advantages in seasons 1, 2 & 5 and no disadvantage in seasons 3 & 4. This was generally due to January sown crops commencing flowering very late February or early March (depending on lower branch shedding) which better coincides with the decline of monsoon conditions. This planting date was generally less dependent on compensatory growth and had higher proportions of biomass being directed towards reproductive growth (Table 1.4).

From a crop husbandry perspective, crops that commence flowering as the monsoon recedes are easier to manage compared to a crop that has endured extensive shedding losses, has a disproportionate amount of biomass accumulated vegetatively (due to shedding losses) and must then continue vegetative expansion to enable the production of new compensatory fruiting sites. For this scenario a crop manager has to work with an already large plant and grow it even bigger to produce additional fruiting sites to recoup early season losses. In doing this the proportion of biomass that has already been accumulated in the lower canopy structures of low retention fruiting branches will have consumed a proportion of available resources (time and soil elements) and thus the available resource pool from which additional canopy growth and boll production can occur is reduced.

The 20 Dec to 20 Jan Burdekin planting window limits the period for which flowering and setting bolls can occur in February when radiation is most variable and night temperatures are the highest. For December planted crops, flowering and boll filling will commence from mid-February onwards which has an associated risk of increased wet weather induced shedding and chance of decreased in yield potential. Sunny weather in March and April combined with effective crop management and selection of indeterminate varieties can potentially mitigate these losses (as demonstrated in seasons 1 & 2) although the extent which compensation is achieved is dependent on a range of inter-related factors during this period. For January sown crops, flowering during February is avoided and on balance is more likely to produce higher yields more reliably over the likely spread of wet weather scenarios. A mean of the five seasons yields for each planting date largely tells the story for the study period in the Burdekin that has been characterised by wetter than average conditions (Fig 1.20).

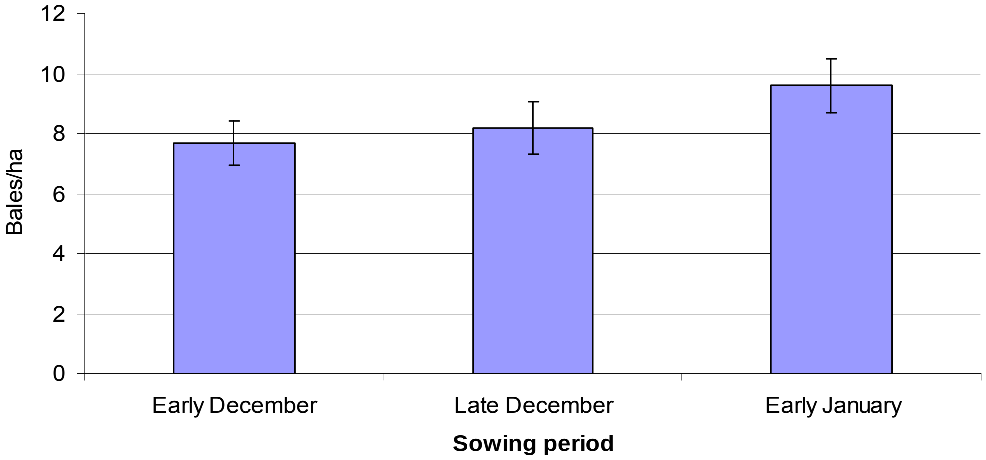


Figure 1.20 The mean yield from all cultivars and five seasons for each planting date (early December was only conducted for seasons 1-3).

It is possible during drier than average seasons that this trend may be reversed or cease to occur.

Although Burdekin cotton crops will receive on average 20% less radiation during flowering and boll fill compared to summer crops in temperate climates such as Narrabri or Dalby (Fig1.2), this may be partially compensated for by the likely range of autumn temperatures which are optimal for photosynthetic efficiency and consequently boll development. Burdekin cotton plants further compensate by growing larger, thinner leaves to intercept more sunlight as evidenced by the peaks in LAI that were often achieved by 60DAS well before peak vegetative biomass accumulation (Figs 1.16-1.19). The yields grown in the January plantings in seasons 1 & 2 demonstrate that very high yields can be grown despite the overall lower levels of available radiation compared to temperate Australian cotton production regions.

The significant decrease in radiation (due to decreasing day lenth) and temperatures by the end of May is a key limitation of the Burdekin climate. Achieving high yielding crops requires rapid setting of bolls during March and April with cut-out by 25 April. Flowers set by April 25 have a minimal risk of being exposed to cool night temperatures during the boll development period. In comparison, measurements taken from bolls arising from flowers pollinated in May on commercial cotton crops in the Burdekin in 2009 and 2010 were found to be reduced in size and cause significant crop maturity delays due to the onset of cooler weather (unpublished data).

Cloudy weather that occurs intermittently in periods of three or more days throughout autumn can be a problematic, as conditions are sunny enough to allow boll retention and minimal shedding but boll size is consequently reduced. Prolonged cloudy weather in March and April can result in significant shedding after which the opportunity to compensate with the initiation of new fruiting sites is limited due to cooling conditions in May to June. Essentially there are limited options for managing cloudy weather in March and April apart from ensuring that crop vigour is maintained prior to expected cut-out so that shed positions have the chance of being compensated for by adjacent branch outer squares (P2 and P3 sites) on existing fruiting branches.

Cloudy weather and yield potential

The frequency of cloudy weather is difficult to predict as official meteorological records for BRIA radiation during this period have only been kept since 1990, and March has been drier than average for a high proportion of these years (Fig 1.21). Rainfall and cloudiness are not necessarily correlated as March in particular can often have sunny days with evening rainfall.

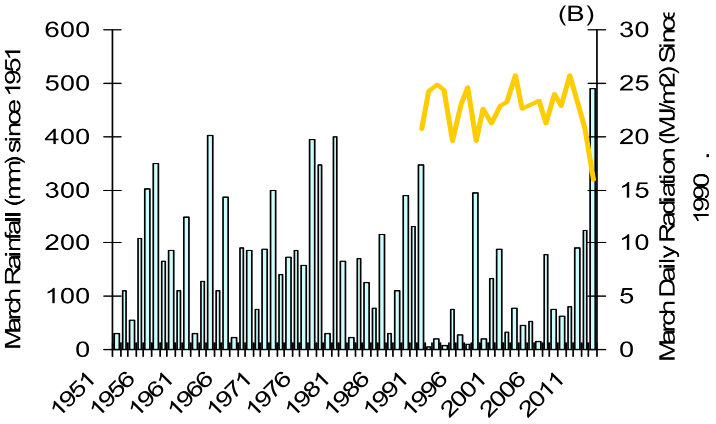


Fig 1.21 Rainfall records for March from 1951 to 2012 and mean daily solar radiation from 1990 to 2012.

The data presented here and commercial crop yield data (Fig 1.22) suggest that that 70-8.5 bales per hectare is attainable for seasons with cloudy weather in March and April. In these seasons, the high yields recorded during 2008 and 2009 are not possible due to radiation limitations that cannot be overcome with typical crop husbandry practices.

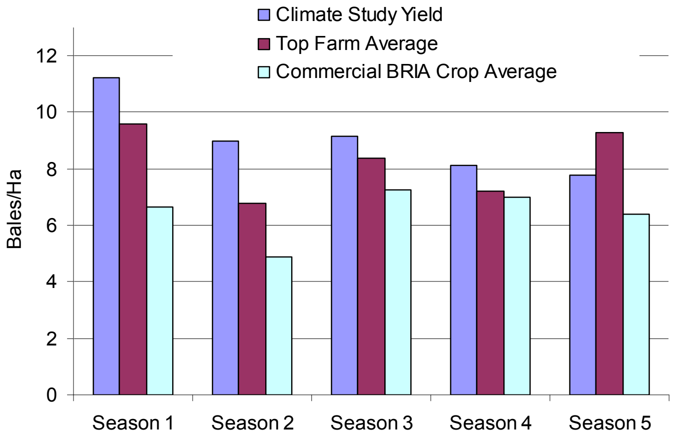


Figure 1.22 Yields from the climate experiment, top commercial farm average and Burdekin valley average (all farms) for 2008-2012. The yield presented from the climate study is the aggregate yield across cultivars for the planting date that represents the window in which the majority of the commercial crop were sown e.g. All commercial crops in 2008 and 2009 were sown between December 20 and 30 hence the yield from the December 20 plantings in seasons 1 & 2 are used for comparison. The yield from the January sowings is used for seasons 3-5 as this is representative of commercial plantings. The valley average is an estimate at the time of writing based on module weights pre-ginning.

Tropical cyclones and low pressure systems

The potential for crop damage or destruction from tropical cyclones and depressions is a climatic risk for cotton production in the Burdekin that has not been discussed. Whilst these events are part of the north Queensland climate, the frequency, severity and impact of these events is impossible to predict.

Historical records suggest that direct coastal crossings of tropical cyclones into the BRIA region (between Gumlu and Giru) have been relatively infrequent during the last 100 years, averaging once every 9-10 years. However, prior to 1970 only the timing and geographic location of coastal crossings are recorded, and limited records exist regarding cyclone size and wind severity, both of which are very important determinants for likely crop impact.

The incidence of crossings over the Burdekin region (between Cape Upstart and Townsville) is random. For example, cyclones appeared three years in a row between 1988 and 1990. Two of these (Charlie and Aivu) occurred in the March/April period and caused significant crop and infrastructure damage. Aivu was particularly damaging as the eye of the cyclone tracked directly up the Burdekin river past Clare taking 8-9 hours to pass.

Following Aivu, more than 20 years lapsed before severe tropical cyclone Yasi in February 2011. Although crossing at Mission Beach, Yasi was of sufficient size and intensity to cause significant tree and powerline damage in the Burdekin, however cotton crops were unaffected as they were only small at the time.

Therefore, while the region is impacted by tropical cyclones, actual damage potential for cotton will vary markedly depending on the stage of the crop and the individual characteristics of the weather system. Forward marketing should take into account the low risk of crop destruction. While the wet season and tropical cyclones may appear daunting, when compared to other regions the BRIA has a very low probability of hailstorms, riverine flooding or drought (Table 1.8), and should crop loss occur, the opportunity exists to take advantage of tropical temperatures and replant with sugarcane, maize or mungbeans to quickly re-establish cash flow.

The Burdekin has both significant climatic advantages and key limitations compared with other regions. The table below lists climatic events that maybe detrimental to a cotton crop and their relative likelihood for three different regions.

Table 1.8 Relative risks of the Burdekin climate verses central Queensland or northern NSW

Climatic Factor	Burdekin	Central Qld	Northern NSW
Widespread riverine flooding	☒	√	√
Hail storms	☒	√	√
Drought	☒	√	√√
Tropical depressions	√√	√	☒
Cyclones	√	☒	☒
Rainfall and cloudy weather at boll setting	√√	√	☒
Heat waves during boll filling	☒	√√	√
Cold shocks	☒	√	√√
Rainfall at harvest	☒	√	☒

☒ unlikely √ likely √√ highly likely

2.0 Within Row Plant Density in a Radiation Limited Environment

Summary

A preliminary within row density experiment was conducted during the 2009 season followed by a more comprehensive experiment in 2010 to investigate the impact of within row plant spacing on yield potential, fruit partitioning and crop height in a radiation limited environment. Whilst within row plant spacing has been extensively studied elsewhere and generally found to have minimal impacts on yield potential, the impact of density was investigated here as it was unknown whether increased plant competition due to higher stand density may impact yield potential, partitioning and crop height during the monsoon.

Increased sowing density was found to increase crop height via inter-node elongation. Boll partitioning within the canopy was significantly influenced by plant density with densities of greater than 9 plants per metre resulting in plants that predominantly set bolls in the P1 position with few if any bolls in P2 positions or vegetative branches. The potential implications of this for wet season risk management are discussed. The key recommendation from this research is that growers should aim to plant 6-7 seeds per linear metre.

2.1 Methods

2009

A preliminary experiment was established on 20 January 2009 at the Ayr Research Station to examine the impact of within row plant density on crop yield, partitioning and crop height.

Sicala 60 BRF was bulk sown at the ARS at 22 seeds/m row on a 75 cm row spacing. The field was then divided into small plot areas measuring 6 rows wide by 10 metres long each separated by 2 rows of cotton and 2 metres of bare earth on the ends. The plots were arranged in randomised blocks that allowed for 4 replicates of 5 density treatments. Density treatments of 3, 6, 9, 12 & 18 plants per metre row were randomly assigned to each block and were implemented by carefully hand thinning the number of seedlings from the planted 22/m row down to the respective treatment densities. This was completed within a week of seedling emergence.

The trial area was then maintained using the same agronomic practices, fertiliser rates and insect management techniques as per the methods outlined in the climate experiment for season 2.

Measurements of plant height, number of nodes and nodes above white flower were made at weekly intervals and upon defoliation segmented picking was conducted to determine within canopy yield partitioning before the middle two rows of each plot was machine harvested with a spindle picker.

2010

Two further experiments were planted to assess the impact of plant density on crop yield, partitioning and crop height. To increase the probability of different climatic conditions affecting the density treatments, two planting dates were used with the first experiment planted on 1 December 2009 whilst the second experiment was sown on the 10 January 2010.

Split plots were used for each experiment to allow a further comparison between the indeterminate cultivar Siokra 24 BRF and the shorter season more determinate Sicala 60 BRF.

The experiments were established by bulk planting the trial area with the two cultivars at each planting date with a seeding density of 22 seeds/m row.

The field section for each experiment was then divided into plot areas measuring, 12 rows wide by 10 metres long each separated by 2 rows of cotton and 2 metres of bare earth on the ends. Each plot was a split with 6 rows of Sicala 60 and 6 rows of Siokra 24 BRF. The plots were arranged in randomised blocks that allowed for 4 replicates of 5 treatment plots. Density treatments of 3, 6, 9, 12 & 18 plants per metre row were randomly assigned to each block and were implemented by carefully hand thinning the number of seedlings from the planted 22/m row down to the respective treatment densities within a week of seedling emergence.

The trial area was then maintained using the same agronomic practices, fertiliser rates and insect management techniques as per the methods outlined in the climate experiment season 3.

Measurements of plant height, number of nodes and nodes above white flower were made at weekly intervals. Crop maturity was assessed using the same methods as described in the climate experiment methods. Segmented picking was conducted to determine within canopy yield partitioning before the middle two rows of each plot was harvested with a spindle picker.

2.2 Results

2009

No significant differences in lint yields were recorded between the density treatment plots (*P*>0.05) (Fig 2.1). However, segmented picking demonstrated significant differences in the partitioning of yield within the canopy between treatments with the lowest densities attaining a large proportion of crop yield from vegetative branches whilst yield was generally confined to the first position bolls of the first 8 fruiting branches for the highest sowing densities (Fig 2.2). Due the late sowing of this experiment on 20 January, the experiment did not get exposed to cloudy weather during the flowering period which commenced on 8 March 2009. There was no boll shedding observed during this experiment.

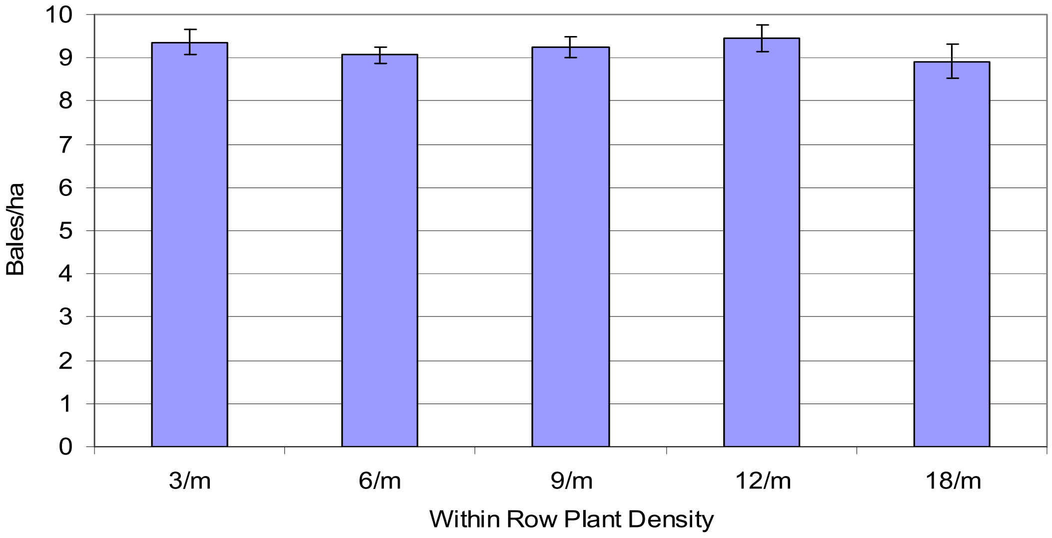


Fig 2.1 Treatment yields from the 2009 within row plant density experiment. Bars represent s.e.

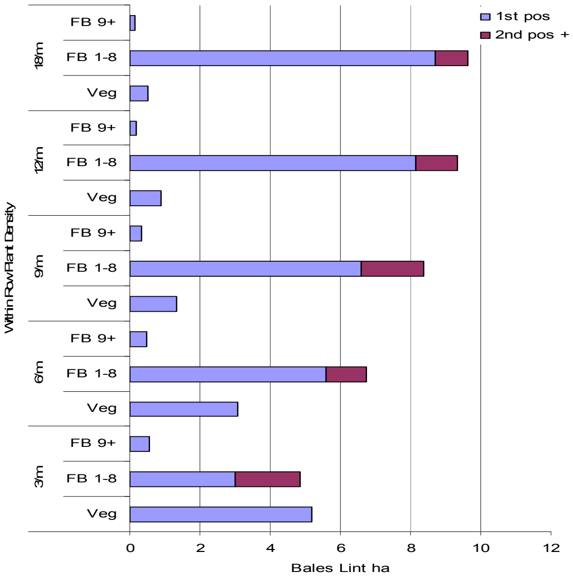


Fig 2.2 Segmented picking results for the 2009 density experiment showing the contribution of different canopy sections to crop yield. Canopy sections were grouped into fruiting branches 1-8 and 9 and above for first position (P1) and outer branch position fruit (P2+) as well as vegetative branch bolls.

2010

An ANOVA for treatment yields suggested that the only significant difference ($P<0.05$) observed within the 2010 (season 3) density experiments was for the highest density of 18 plants per metre for both cultivars for the first experiment planted on 1 December 2009 (Fig 2.3). This treatment yielded significantly less lint than all other density treatments for both cultivars. No other yield differences for lint yield were significant for the remaining treatments in this experiment (Fig 2.3) or any of the density treatments in the second experiment (Fig 2.4).

The observed trend of decreasing yield with increased planting density for Sicala 60BRF which resulted in significant yield loss for the 18 plants per metre treatment maybe explained when considering the segmented picking together with the height and node data. The total number of nodes had a negative linear response with increasing plant density for both the December and January sown experiments (Fig 2.7 & 2.8). Segmented picking data also suggest that the majority of yield was set as a top crop in the December planting and therefore a reduction in node number may have reduced fruiting site production due to a reduced number of fruiting branches (Fig 2.5).

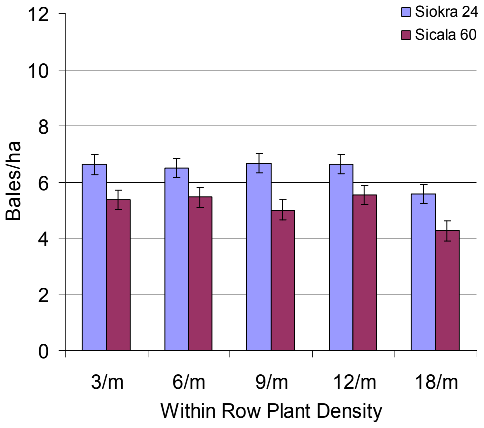


Fig 2.3 Treatment yields from the early December planted density experiments. Error bars denote LSD *P*=0.05 for each cultivar.

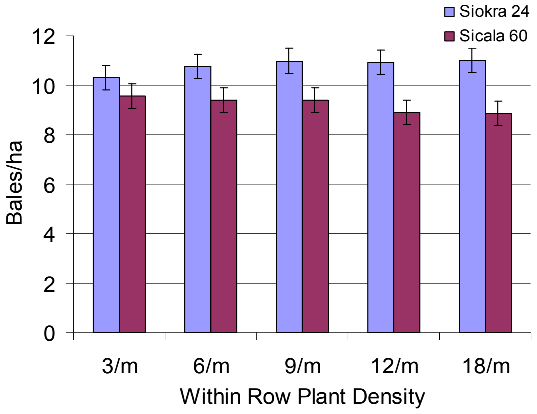


Fig 2.4 Treatment yields from the 10 January planted density experiments. Error bars denote LSD *P*=0.05 for each cultivar.

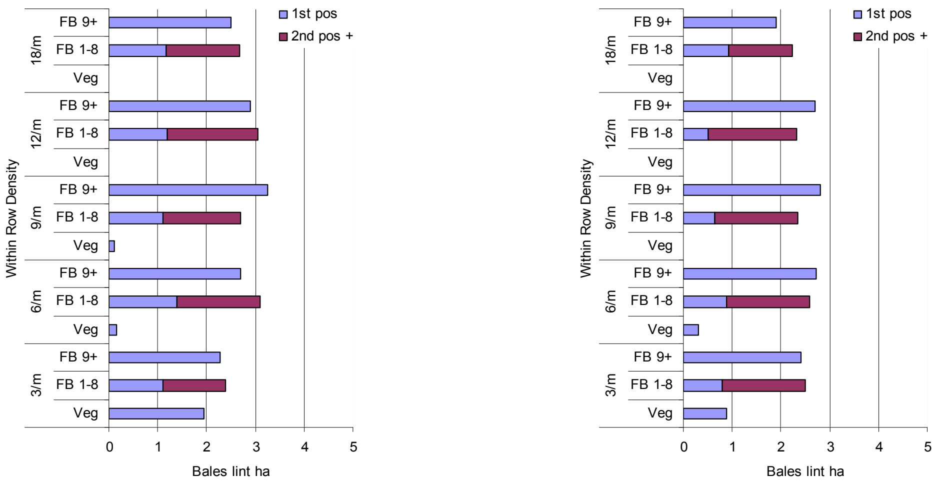


Fig 2.5 Segmented picking results for Siokra 24BRF (left) and Sicala 60BRF (right) 1 December sown density experiment. Canopy sections were grouped into fruiting branches 1-8 for first position fruit (P1) and outer fruiting branch positions (P2) and all position bolls 9 branches and above as well as vegetative branch bolls.

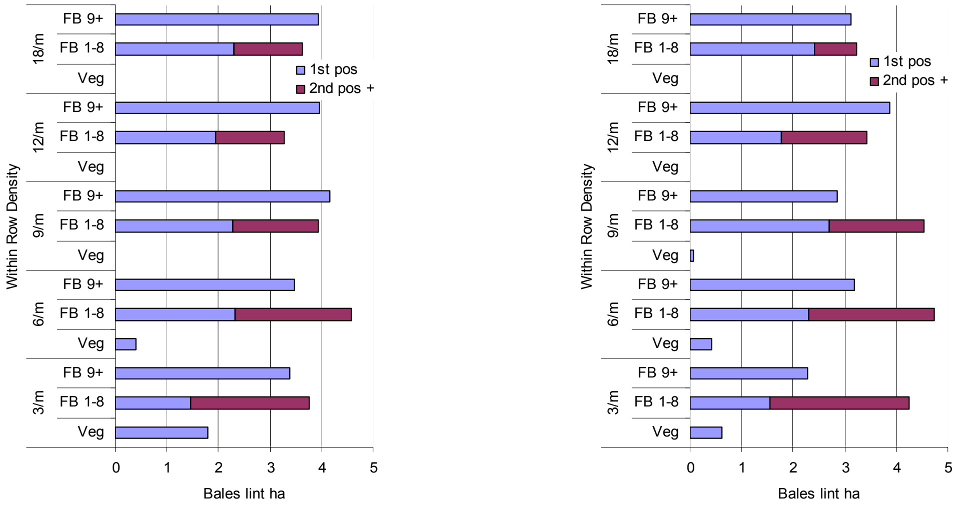


Fig 2.6 Segmented picking results for Siokra 24BRF (left) and Sicala 60BRF (right) 10 January sown density experiment. Canopy sections were grouped into fruiting branches 1-8 for first position fruit (P1) and outer fruiting branch positions (P2) and all position bolls 9 branches and above as well as vegetative branch bolls.

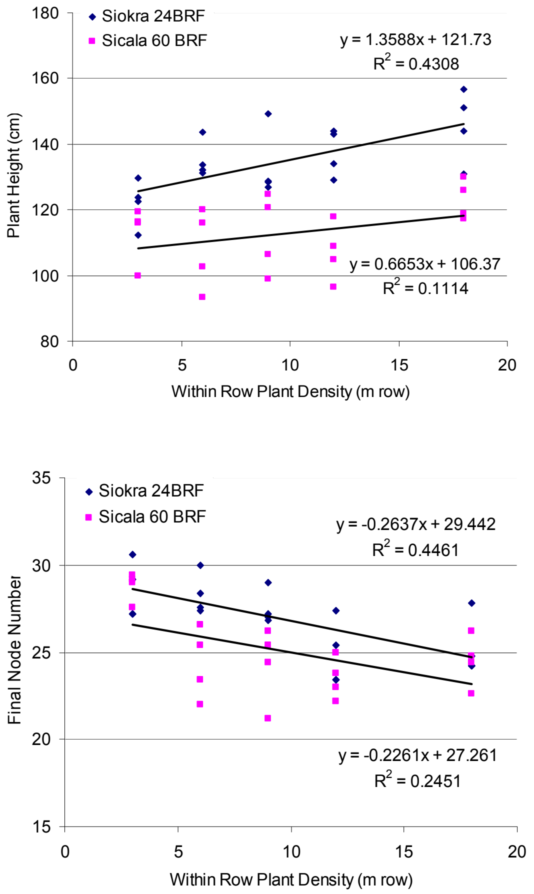


Fig 2.7 Final Crop height (top) and number of nodes (bottom) for the density treatments plots of Siokra 24 and Sicala 60BRF planted 1 December 2009.

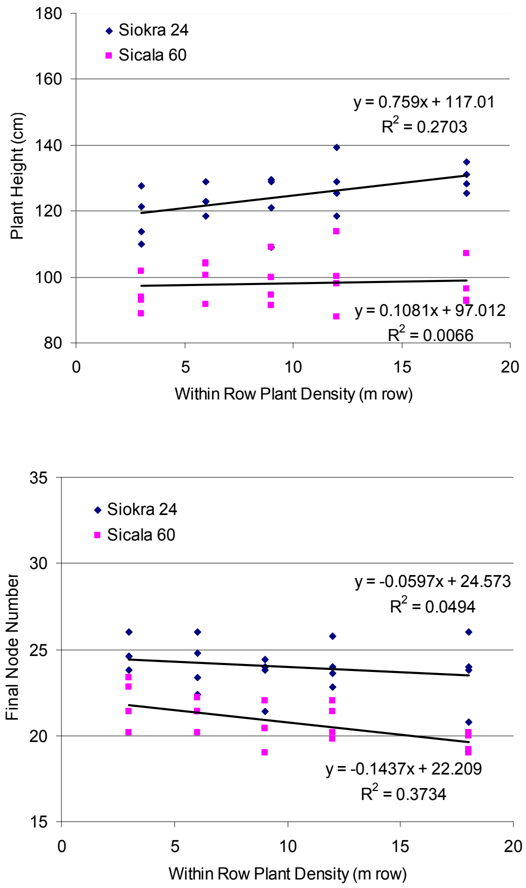


Fig 2.8 Final Crop height (top) and number of nodes (bottom) for the density treatments plots of Siokra 24 and Sicala 60BRF planted 10 January 2010.

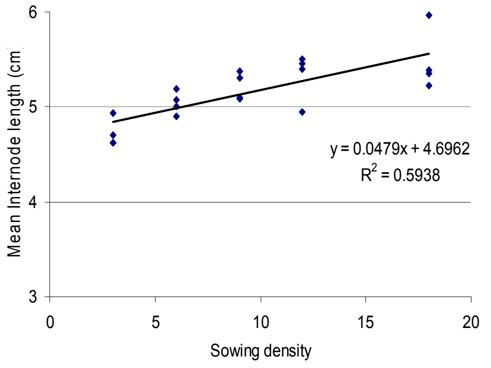


Fig 2.9 Mean internode length for Siokra 24BRF in response to planting density.

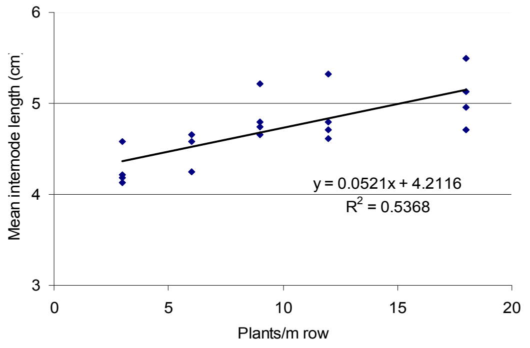


Fig 2.10 Mean internode length for Sicala 60BRF in response to planting density.

Final crop height had a positive linear response with increasing plant density for Siokra 24 BRF at both planting dates whilst the total number of nodes decreased with increased densities of both cultivars (Fig 2.7 & 2.8). The net result was that the increase in height recorded was due to the expansion of inter-node lengths as opposed to additional nodes which is unlikely to be beneficial from a crop management perspective.

Time to crop maturity was unaffected by plant density for either cultivar or planting date.

2.3 Discussion

Planting density was found to have a mostly limited affect on crop yield which is consistent with a range of other studies conducted in Australia (Kelly & Quinn 2010).

The only significant reduction in yield potential was recorded for the highest density of 18 plants per metre and only for the early December planting in 2010 which was subject to cloudy wet conditions during the first month of flowering. In the case of the December plantings, the cloudy wet conditions reduced the number of first position bolls that could be retained. Later compensation was then curtailed by limited canopy expansion due to a reduction in total nodes and no vegetative branch growth that would ordinarily contribute to the development of a proportion of bolls.

Although the experiments conducted here are limited in scope and lack replication to better determine the influence of seasonal variation, the data does suggest some basic trends that can be considered for determining a sowing density for the Burdekin.

The higher planting densities in these experiments failed to provide any significant agronomic advantages. Higher density plant stands were associated increased height but decreased node number. The additional height due to internode expansion as opposed to increased nodes is unhelpful in a climate whereby growth can become excessive during wet season conditions.

Second position bolls and the growth of vegetative branches was also limited with densities of 9 plants per metre or higher. Whilst the bolls produced on the laterals within the 3 and 6 plant per metre row treatments substituted for first position bolls produced on more dense plant stands, the spread of bolls between a range of cohorts within more widely spaced plants may offer advantages in seasons that have variable levels of radiation. Plants that have a more broadly partitioned canopy may be better able to compensate temporary periods of wet weather compared to high density sowings whereby bolls are largely confined to the main stem first branch positions.

The density treatments of 3-6 plants per metre produced plants that yielded the same or better than the higher densities and produced lint from well spread cohorts of bolls throughout the canopy including vegetative branches. These treatments generally had the smallest internode lengths compared to higher planting densities.

For the Burdekin climate and proposed planting window the sowing of seeds at a rate of 5-7 seeds per metre is recommended. Seedling establishment is generally high with a virtual absence of seedling diseases due to high soil temperatures. The sowing of 5-7 seeds per metre should be sufficient to ensure an even stand whilst allowing for some seedling losses. The architecture of plants grown on this spacing may have advantages in the local climate having reduced inter-node lengths as well as setting bolls across a broader range of canopy positions which may be advantageous by spreading the risk of intermittent cloudy weather. The sowing of 5-7 seeds per metre row also provides a cost saving for growers compared to the more typical rates of 9-12 seeds per metre used in the southern industry.

3.0 Row Spacing in a Radiation Limited Environment

Summary

No disadvantage was found with the production of cotton on 76 cm row spacing (30 inch) verse the traditional 102 cm (40 inch) row spacing. Yield data suggest that 76 cm spaced cotton may be advantageous in some seasons for both increased yield and decreased time to crop maturity. Given that the Burdekin farming systems is dominated by 1.5-1.6 m centred bed systems for sugarcane production growers should simply grow cotton on the spacing that fits the sugarcane farming system.

3.1 Introduction

In the Burdekin's climate whereby a third of seasons may be wetter than average, sowing density and row spacing were identified as two variables that may influence cotton growth and development.

Sowing density experiments suggested that yield maybe reduced at high plant densities but perhaps more importantly inter-node elongation was exacerbated at higher planting rates, which is generally unhelpful in a climate that can cause excessive growth during the monsoon season.

Row spacing was investigated in seasons 4 and 5 for a number of farming systems and climatic reasons. The majority of Burdekin sugarcane producers utilise a 1.5-1.6 m bed spacing whilst the majority of cotton producers in temperate Australia utilise 1.0 m spaced hills. During the first years of attempted commercial cotton production in the Burdekin growers either used the common local spacing of 1.5-1.6m centred beds upon which 2 rows of cotton were sown (resulting in a 76-81 cm row spacing) or the traditional 102 cm row spacing. For most sugar producers a 1.5 m bed spacing is the most convenient as this allows for the integration of cotton with sugarcane utilising the same tractors, tillage, fertilising, and spraying equipment without modification. As this is the dominant system in the Burdekin the climate study was conducted on 76 cm row spacings. For other growers that purchased farms in the area, a traditional cotton row spacing of 102 cm rows were used as these fitted the machinery that was often transported between the Burdekin and southern farming operations without modification.

Observations made between commercial fields using the two different row spacings suggested that the narrower rows may provide advantages of earlier crop maturity and reduced crop height. However, these observations were purely anecdotal as they were derived from different fields and soil types.

Published research suggests only a limited number of studies have been conducted to compare 76 cm and 102 cm spaced rows. These studies either concluded no differences in yield (Williford *et al.* 1986), or yield advantages of 7-9% in Mississippi (Williford, 1992), and 14% in Texas (Heilman *et al.* 1989) and 7% in California (Kerby *et al.* 1990) with the narrower 76cm spacings compared with 102cm (slight difference reflecting imperial measurement systems in the USA). Another study by Kerby *et al.* (1990a&b) suggested that narrower row spacing offered no advantage in experiments with Acala cultivars when grown on productive soils whereas an 11% increase was accorded for the same comparisons on poorer soils. A central hypothesis to emerge from some of these studies was that a genotype by row spacing interaction may explain the lack of consistency in yield responses whereby short season, compact varieties maybe advantaged by 76 cm rows compared to 102 cm spacings. It was hypothesised that more compact varieties intercepted sunlight more efficiently when grown on narrower rows (Kerby *et al.* 1990b).

A three year study conducted by Heitholt *et al.* (1996) further examined the relationship between 76 and 102 cm row spacing and cotton genotypes. This study found that cotton grown on 76 cm row spacings intercepted significantly more sunlight than the 102 cm spacing up until 80 DAS.

However, the 76 cm rows only out yielded the 102 cm spaced row treatments in one of the three seasons by 15% with no significant differences being recorded for the other two seasons experiments. This study could not identify a significant genotype by row spacing interaction (Heitholt *et al.* 1996). However, measurement of fruiting dynamics did suggest that the 76 cm rows increased the number of flowers by 21% compared to 102 cm spacing although final retention of these positions varied and were often subsequently lower (Heitholt, 1995). However, the interaction between increased fruiting site production and final retention is likely to be influenced by a range of abiotic and biotic field factors and offers a plausible explanation for why narrower rows out-yield 102cm rows in some seasons.

The collective accounts from these studies suggest that narrower row spacing either provided no significant advantages compared with a traditional 102 cm or significant yield increases. None of these studies documented a yield disadvantage for 76 cm spaced rows compared to 102 cm. Yield increases when recorded were generally attributed to increased light interception earlier in the life of a the crop and the production of more fruiting sites.

Within the Burdekin farming system a 76cm row spacing offers significant synergy with the local sugarcane production system. However, in a potentially radiation limited environment that can induce fruit shedding, a narrower 76 cm spacing may also offer advantages in some seasons by improving maximising interception sooner, whilst the production of additional flowers reported by other researchers may provide a buffer against fruit shedding losses.

3.2 Materials and Methods

The primary purpose of this study was to define the response of 3 cultivars to 76 and 102 cm row spacings utilising 2 planting dates to measure the potential influence of wet weather conditions on cotton growth, development and yield.

The experiments was conducted as part of the treatment structure used in the final two years of the climate experiment conducted at the Ayr Research Station, 7km SW of Ayr Queensland Australia (19°62'S, Long. 147°38'E) in the Burdekin Irrigation Area during the 2011 and 2012 seasons.

The experiment was a randomised complete block design with split plots, where main plots were the sowing date with four replications sown to either 76 or 102 cm row spacing in randomised blocks. Subplots were different cultivars. The two sowing dates and three cultivars grown were the same as the climate experiment in seasons 4 & 5 (Table 1.1 & 1.2). The field layout and preparation were the same as specified in the Climate study materials and methods (section 1).

The same within row density of plants was established for each row spacing treatment being the equivalent of 6 plants per linear metre row. For the 76 cm rows this equated to (8 plants/m2). This approach was used so that the within row interaction between plants was the same with the actual row spacing being the primary variant. The experiments were established using a row configuration of 2 rows per bed separated by either 76 cm or 102 cm with furrows between beds. Drip tape irrigation was used to irrigate the plots and allowed for the controlled application of water that enabled irrigation events to be calibrated so that the same volume of irrigation water could be applied per unit of field area. The tape being buried 5 cm deep in the middle of each bed leaving the between bed furrows to provide wet season runoff drainage. Plots were 12 rows wide by 15 m long for the 76 cm rows and 10 rows wide by 15 m long for the 102 cm row treatments.

Fertiliser, 90 kg/ha N half as urea, plus 20 kg/ha P and 85 kg/ha K placed in a band 10 cm deep and 15cm within the crop row within a week of sowing. A further 90 kg/ha N and 108 kg/ha S was applied as a side-dressing within the same location 4-6 weeks after crop emergence. A foliar application of ZnSO4.7H2O at 100 g element/ha at the 3rd true leaf stage. During seasons 4 and 5 an additional 13 kg/ha N and 44 kg/K as potassium nitrate was applied through the drip irrigation a 10 days after first flower. Fertiliser applications were calibrated to standardise the rate of fertiliser being applied per unit area in each row spacing treatment.

The same measurements of crop growth, development and yield as well as climatic variables that were conducted in the climate study were conducted for experiment.

3.3 Results

Lint yields and crop maturity

Lints yields ranged from 1035 kg/ha to 1954 kg/ha depending on cultivar, time of sowing and season. An ANOVA of row spacing for each planting date only showed a significant affect (*P*<0.05) on lint yield when comparing cultivars for Sicot 74 in the December sowing and Siokra 24 for the January sowing (Figs 3.1 & 3.2) in season 4. Despite the lack of significant differences for the remaining cultivars in each instance the trend was towards a higher yield being picked from the 76 cm row spacing cotton compared to the 102 cm spacing.

For season 5 an ANOVA for row spacing for each planting date showed a significant decrease (*P*<0.05) in lint produced from 102 cm spaced rows compared to 76 cm rows for Sicot 70BRF plots at each sowing date (Figs 3.3 & 3.4).

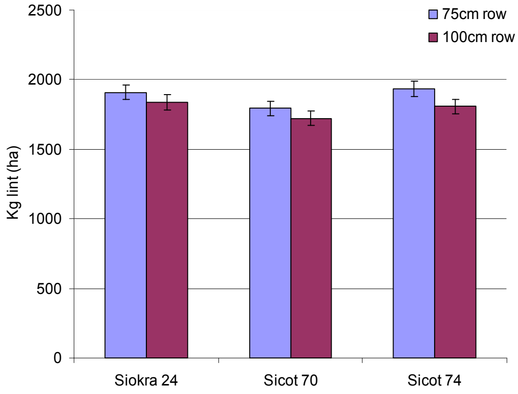


Fig 3.1. Lint yield for three cultivars of 18 December 2010 planted cotton on 76 and 102cm row spacing. Bars represent LSD at P = 0.05%

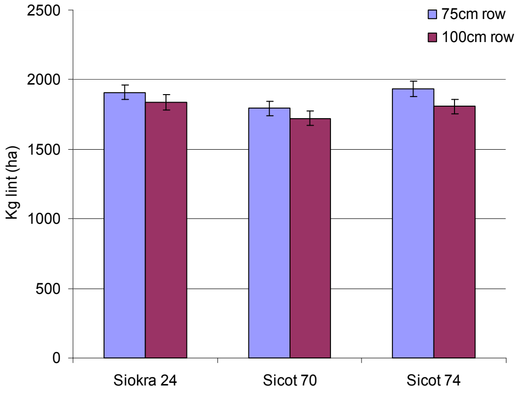


Fig 3.2. Lint yield for three cultivars of 7 January 2011 planted cotton on 76 and 102cm row spacing. Bars represent LSD at P = 0.05%

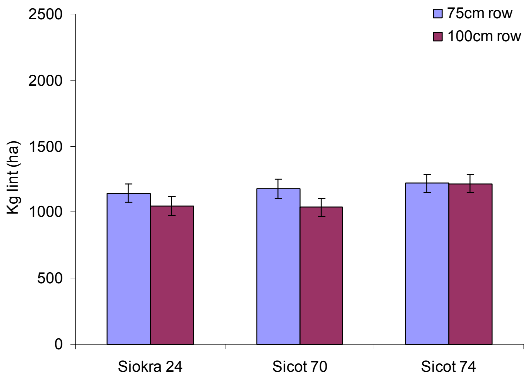


Fig 3.3. Lint yield for three cultivars of 19 December 2011 planted cotton on 76 and 102cm row spacing. Bars represent LSD at P = 0.05%

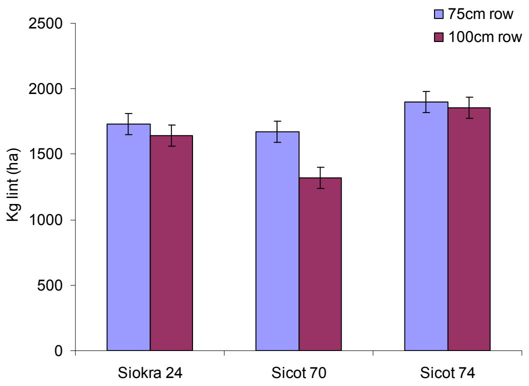


Fig 3.4. Lint yield for three cultivars of 7 January 2012 planted cotton on 76 and 102cm row spacing. Bars represent LSD at P = 0.05%

Lint quality was un-affected by row spacing, with all lint picked fulfilling base grade characteristics.

During season 4 crop maturity was significantly affected by row spacing for the December planting with 76cm rows reaching 60% boll opening approximately 26 days earlier than the 102cm row spaced cotton (Fig 3.5). Major differences were not observed for the second January sowing with a difference of only a few days between row spacing treatments (Fig 3.6).

No significant differences were observed for crop maturity between either row spacings or sowing treatments during season 5 (Fig 3.7 & 3.8).

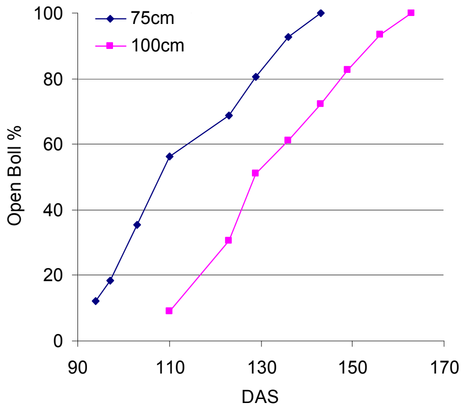


Fig 3.5. The rate of boll opening (cultivars pooled) for the December planted row spacing treatments 2011.

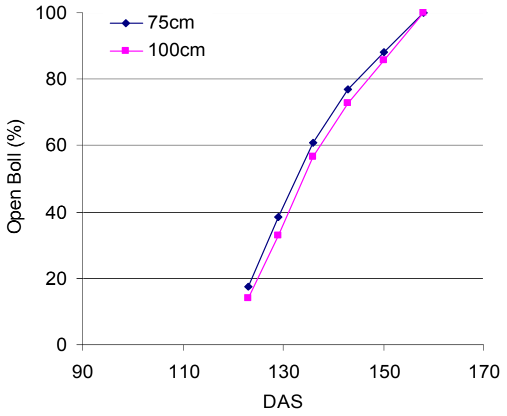


Fig 3.6. The rate of boll opening (cultivars pooled) for the January planted row spacing treatments 2011.

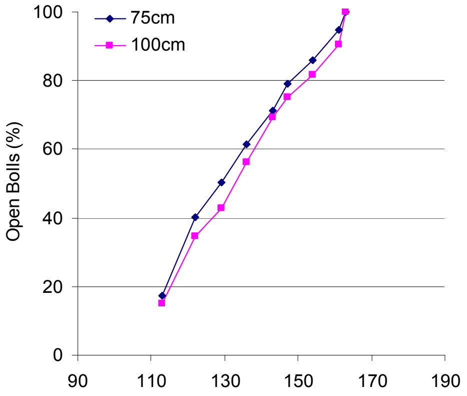


Fig 3.7. The rate of boll opening (cultivars pooled) for the December planted row spacing treatments 2012.

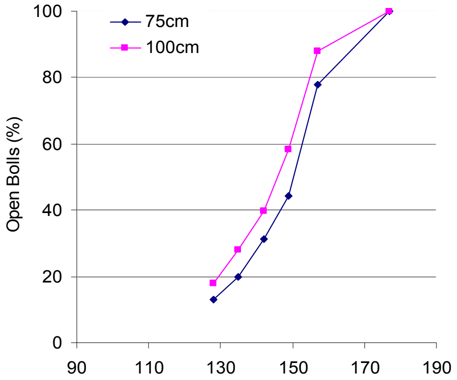
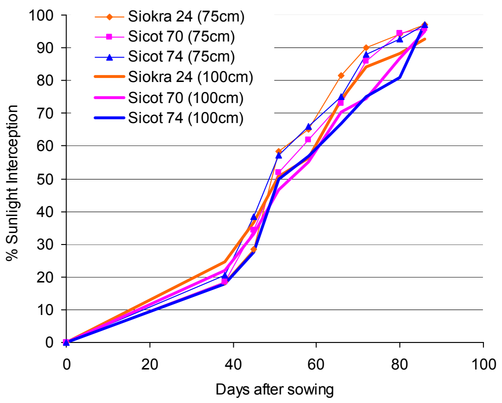


Fig 3.8. The rate of boll opening (cultivars pooled) for the January planted row spacing treatments 2012.

Biomass Accumulation and Crop Development

The 76 cm row spacing treatments generally intercepted proportionally more sunlight from around first flower (45DAS) until 80DAS for the December planted treatments after which the 102 cm spaced cotton soon closed the rows resulting in complete interception at 86DAS (Fig 3.9 & 3.11). The January sown treatments reached 95% interception more rapidly than the December sown cotton at 60-70DAS compared to 80DAS (Fig 3.10 & 3.12). The 76 cm spaced cotton intercepted proportionally more sunlight than the 102 cm spaced period for a shorter period than the December sowings from around first flower at 45 DAS until 60 DAS.



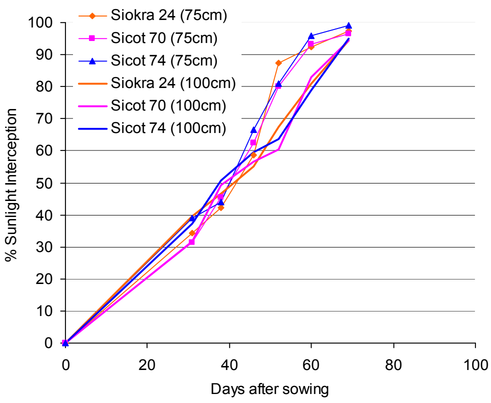
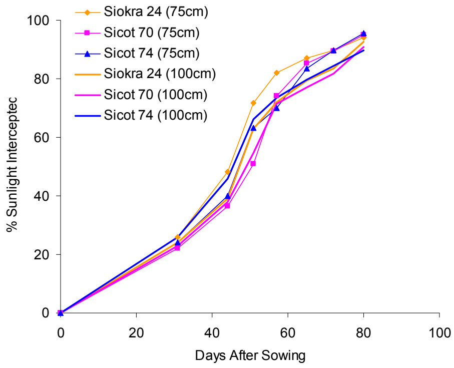


Fig 3.9. Sunlight interception by developing crop canopies for December sown cultivars on 76 and 102 cm row spacing treatments 2011.

Fig 3.10. Sunlight interception by developing crop canopies for January sown cultivars on 76 and 102 cm row spacing treatments 2011.



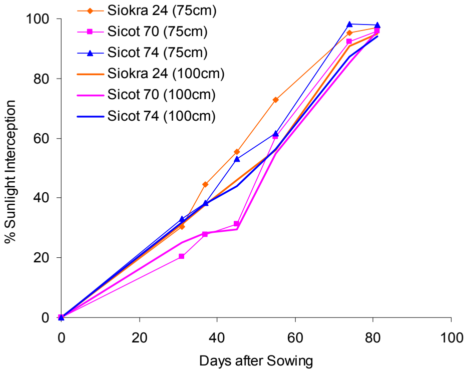
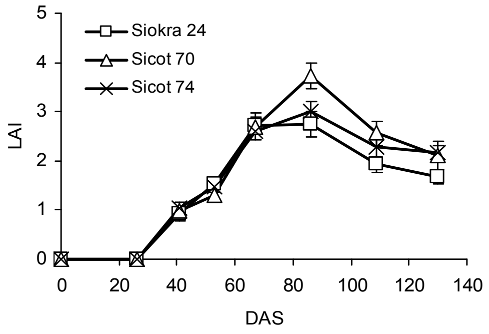


Fig 3.11. Sunlight interception by developing crop canopies for December sown cultivars on 76 and 102 cm row spacing treatments 2012.

Fig 3.12. Sunlight interception by developing crop canopies for January sown cultivars on 76 and 102 cm row spacing treatments 2012.

Leaf Area Index (LAI) was similar for all row spacings and planting dates within each season. For season 4 (2011) the January planted cotton generally achieved peak LAI after 60DAS whereas the December treatments were delayed until 80DAS (Figs 3.13-3.16). This was similar to the delay observed between the two planting dates for 95% light interception.



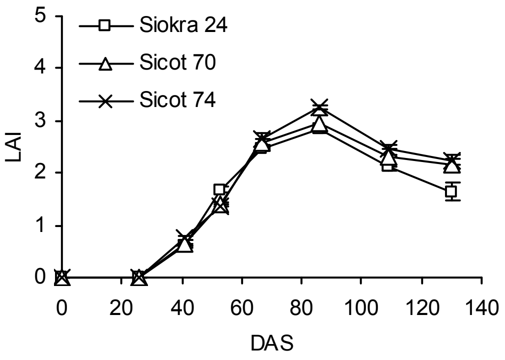


Fig 3.13 LAI for cultivars sown on 76cm row spacing in December 2011.

Fig 3.14 LAI for cultivars sown on 102cm row spacing in December 2011.

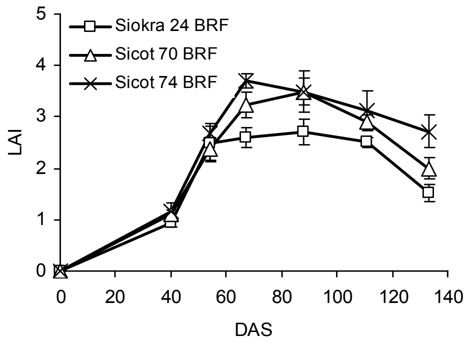


Fig 3.15 LAI for cultivars sown on 76cm row spacing in January 2011.

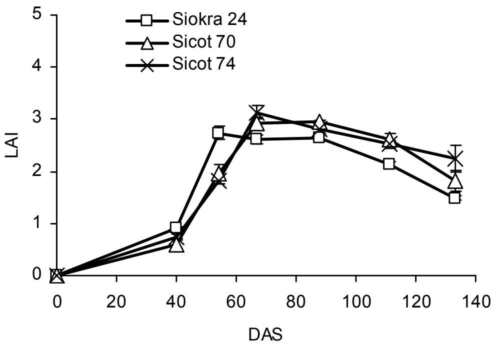


Fig 3.16 LAI for cultivars sown on 102cm row spacing in January 2011.

For season 5 (2012) the January planted cotton generally achieved lower LAI than for the December sown treatments with the 76cm spaced rows generally peaking prior to the 102 cm spaced rows (Figs 3.17-3.20).

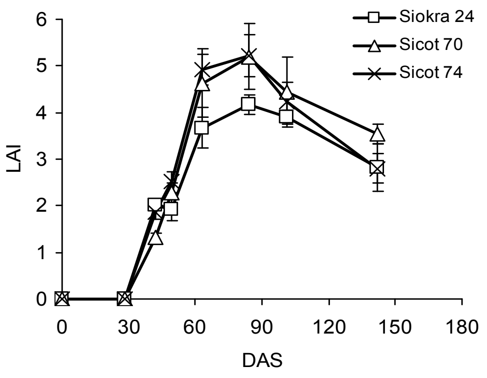


Fig 3.17 LAI for cultivars sown on 76cm row spacing in December 2012.

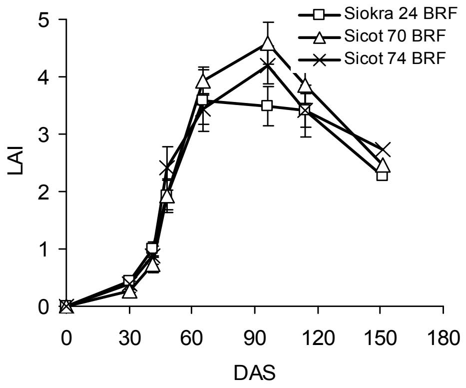


Fig 3.18 LAI for cultivars sown on 76cm row spacing in January 2012.

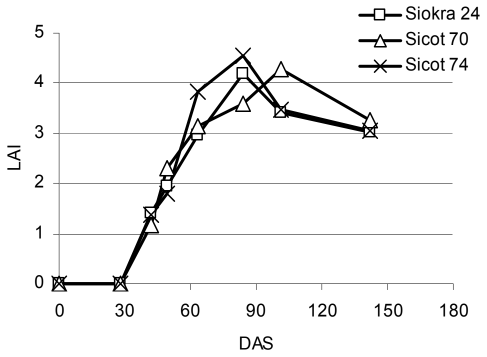


Fig 3.19 LAI for cultivars sown on 102cm row spacing in December 2012.

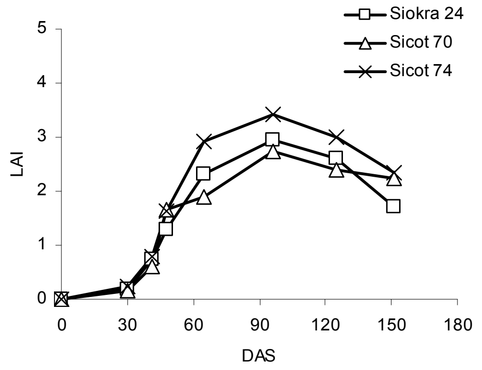


Fig 3.20 LAI for cultivars sown on 102cm row spacing in January 2012.

Fruiting factors and Biomass accumulation

Row spacing altered the pattern of fruit production and biomass accumulation. Generally the 76 cm row spacing treatments produced 4.5-19% more fruiting sites per m^2 than the 102 cm spaced treatments. However, the retention of these sites was generally lower in the 76 cm spaced cotton than for 102 cm although the total average number of bolls was 1-15% higher in the narrower row spacing (Tables 3.1 & 3.2).

Table 3.1. Fruiting factors for 76 and 102cm row spaced cotton planted on 20 December and 7 January 2011.

Final Crop Fruiting factors	**Time of Sowing**	
	20 December	**7 January**
Total Site Production		
102cm Row Spacing		
Siokra 24 BRF	355	385
Sicot 70 BRF	307	332
Sicot 74 BRF	329	322
Mean	**330**	**346**
76cm Row Spacing		
Siokra 24 BRF	467	422
Sicot 70 BRF	384	397
Sicot 74 BRF	330	405
Mean	**393**	**408**
76cm Site Production verses 102cm (%)	**19.1%**	**%18.0**
Final Boll Numbers		
102cm Row Spacing		
Siokra 24 BRF	124	108
Sicot 70 BRF	140	119
Sicot 74 BRF	121	124
Mean	**128**	**117**
76cm Row Spacing		
Siokra 24 BRF	138	113
Sicot 70 BRF	131	118
Sicot 74 BRF	135	124
Mean	**134**	**118**
76cm Boll Retention verses 102cm (%)	**4.6%**	**1.0%**
Final Retention %		
102cm Row Spacing		
Siokra 24 BRF	34.9	28.1
Sicot 70 BRF	45.6	35.8
Sicot 74 BRF	36.8	38.5
Mean	**39.1**	**34.1**
76cm Row Spacing		
Siokra 24 BRF	29.6	26.8
Sicot 70 BRF	34.1	29.7
Sicot 74 BRF	40.9	30.6
Mean	**34.8**	**29.0**
76cm Retention vs 102cm	**-4.3**	**-5.1**

Table 3.2. Fruiting factors for 76 and 102cm row spaced cotton planted on 20 December and 7 January 2012.

Final Crop Fruiting factors	**Time of Sowing**	
	20 December	**7 January**
Total Site Production		
102cm Row Spacing		
Siokra 24 BRF	451	409
Sicot 70 BRF	473	423
Sicot 74 BRF	511	359
Mean	**478.3**	**397.6**
76cm Row Spacing		
Siokra 24 BRF	471	381
Sicot 70 BRF	525	433
Sicot 74 BRF	502	461
Mean	**499.6**	**425.0**
76cm Site Production verses 102cm (%)	**4.5%**	**7.1%**
Final Boll Numbers		
102cm Row Spacing		
Siokra 24 BRF	57.5	97.7
Sicot 70 BRF	66.6	107.1
Sicot 74 BRF	78.5	124.3
Mean	**67.5**	**109.7**
76cm Row Spacing		
Siokra 24 BRF	75.7	102.4
Sicot 70 BRF	74.6	112.3
Sicot 74 BRF	82.8	119.3
Mean	**77.7**	**111.3**
76cm Boll Retention verses 102cm (%)	**15.1%**	**1.8%**
Final Retention %		
102cm Row Spacing		
Siokra 24 BRF	12.7	23.9
Sicot 70 BRF	14.1	25.3
Sicot 74 BRF	15.4	34.6
Mean	**14.1**	**27.6**
76cm Row Spacing		
Siokra 24 BRF	16.1	26.9
Sicot 70 BRF	14.2	25.9
Sicot 74 BRF	16.5	25.9
Mean	**15.6**	**26.2**
76cm Retention vs 102cm	**10%**	**-5.3%**

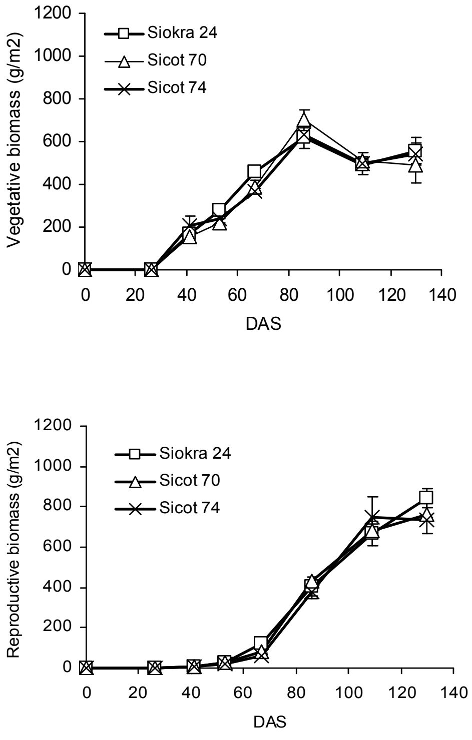


Fig 3.21. Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 18 December 2010 on 76cm.

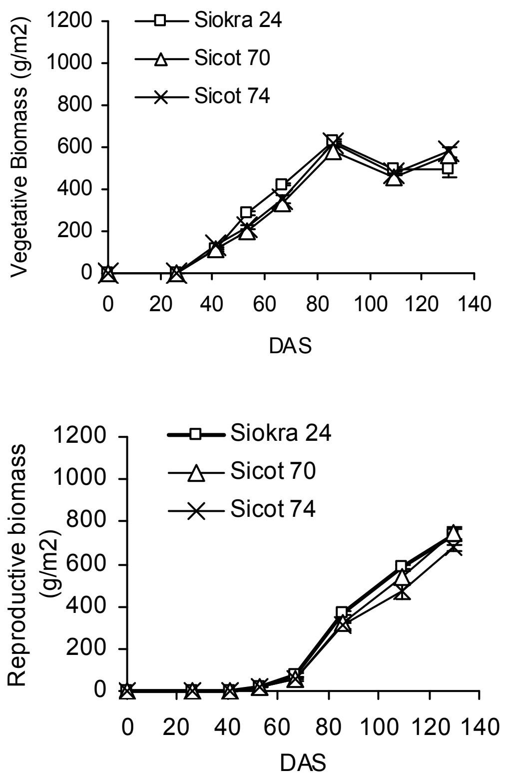


Fig 3.22. Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 18 December 2010 on 102cm.

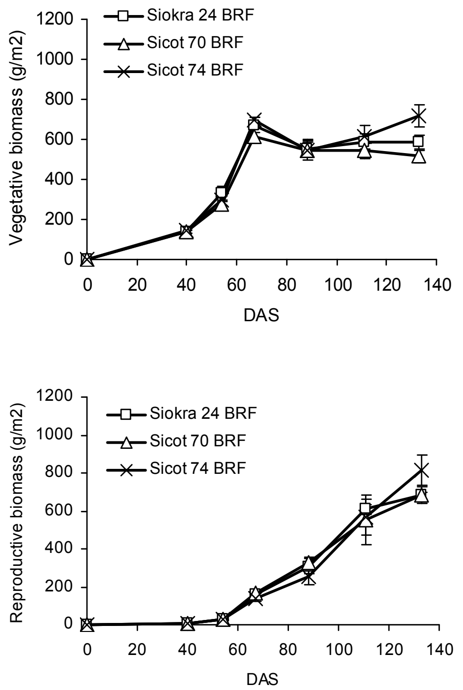


Fig 3.23. Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2011 on 76cm.

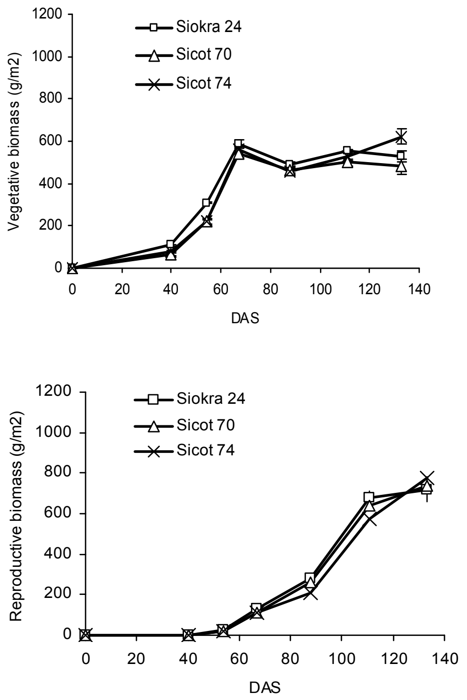


Fig 3.24. Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2011 on 102cm.

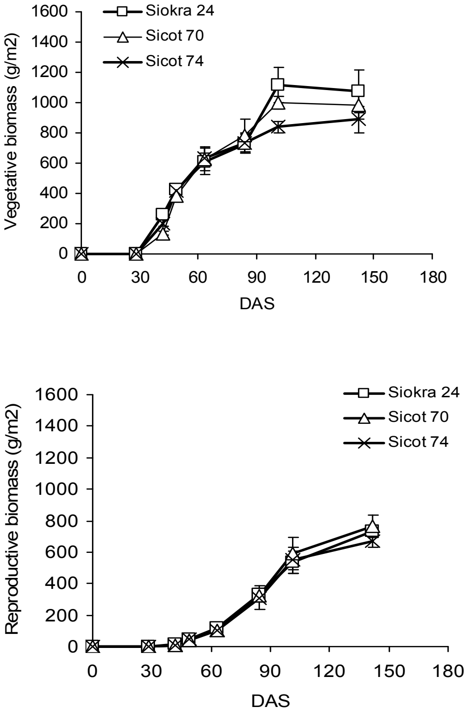


Fig 3.25 Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 19 December 2011 on 76cm.

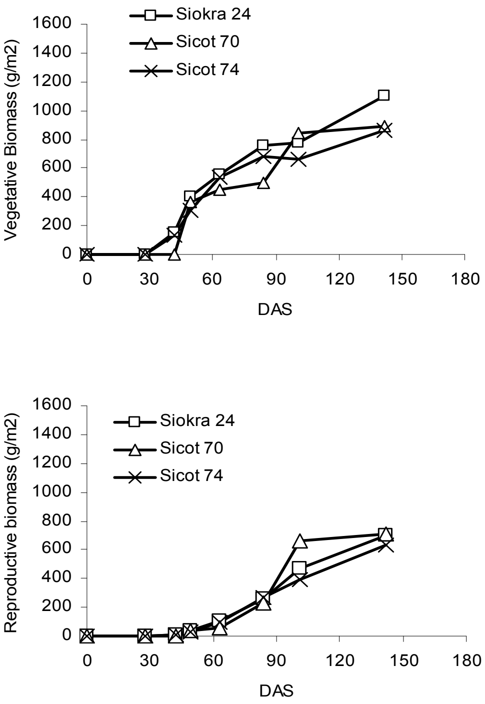


Fig 3.26 Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 19 December 2011 on 102cm.

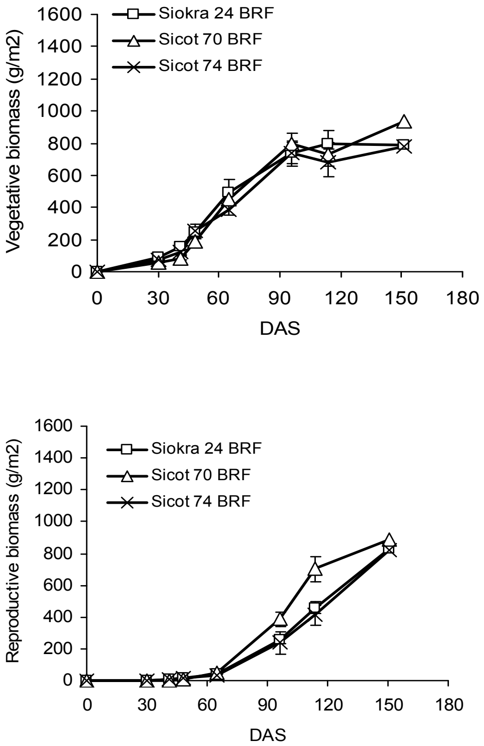


Fig 3.27 Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2012 on 76cm.

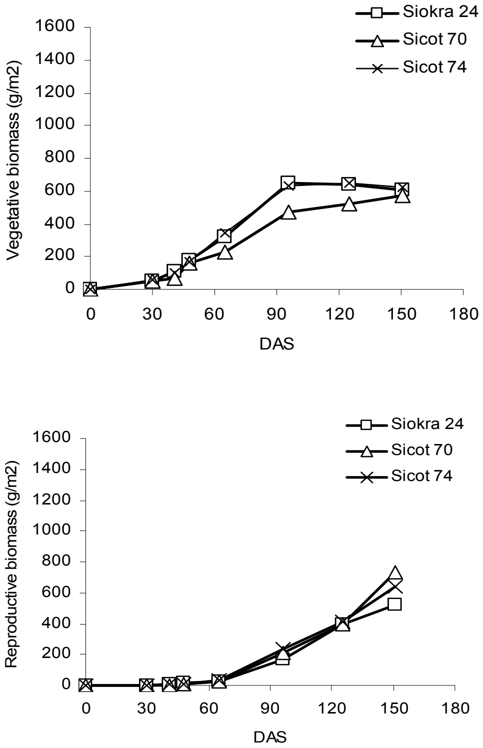


Fig 3.28 Vegetative (Stems, leaves & petioles) and reproductive (Squares, flowers and bolls) biomass accumulation for varieties of cotton sown 7 January 2012 on 102cm.

The accumulation of biomass between the two planting dates and row spacing treatments was similar with little in the way of apparent large differences in the rate of growth (Figs 3.21-3.28).

The proportion of total biomass partitioned into bolls at maturity was generally the same between the two row spacings with little in the way of major differences recorded. (Table 3.2).

Table 3.2 Final crop biomass (m^2) for each row spacing, planting date and cultivar and proportion of biomass as bolls.

	2011 Experiment		**2012 Experiment**	
Time of Sowing	**20 Dec**	**7 Jan**	**20 Dec**	**7 Jan**
Final Crop Biomass (g/m)				
76cm Row Spacing				
Siokra 24 BRF	1400	1268	1811	1268
Sicot 70 BRF	1255	1198	1750	1198
Sicot 74 BRF	1278	1533	1558	1533
102cm Row Spacing				
Siokra 24 BRF	1235	1143	1799	1134
Sicot 70 BRF	1304	1218	1595	1311
Sicot 74 BRF	1155	1396	1491	1260
Boll Proportion (%)				
76cm Row Spacing				
Siokra 24 BRF	60.3	53.8	40.6	51.0
Sicot 70 BRF	60.9	57.0	43.7	48.3
Sicot 74 BRF	57.6	53.2	43.0	51.3
102cm Row Spacing				
Siokra 24 BRF	59.8	53.7	39.0	46.3
Sicot 70 BRF	56.9	60.5	44.2	56.1
Sicot 74 BRF	49.9	55.5	42.3	50.7

Crop Height and Node Production

Row spacing had minimal impact on the total number of nodes produced for each sowing date. Crop height was 3.8-14% taller for cotton grown on 102 cm rows than 76 cm rows.

Table 3.3 Final crop height and number of nodes for each row spacing, planting date and cultivar.

Crop Measurement & Cultivar	**2011 Season 4**		**2012 Season 5**	
Time of Sowing	**18 December**	**7 January**	**19 December**	**7 January**
Total Nodes				
102cm Row Spacing				
Siokra 24 BRF	25.7	23.0	24.5	23.2
Sicot 70 BRF	23.6	20.2	21.2	21.4
Sicot 74 BRF	24.2	21.0	22.1	23.5
Mean	**24.5**	**21.4**	**22.6**	**22.7**
76cm Row Spacing				
Siokra 24 BRF	24.6	21.6	24.6	22.9
Sicot 70 BRF	22.5	18.8	21.4	20.7
Sicot 74 BRF	23.2	20.7	22.6	20.9
Mean	**23.4**	**20.4**	22.8	21.5
76cm Final Nodes verses 102cm (%)	**-4.5%**	**-4.9%**	**0.0%**	**1.5%**
Total Height				
102cm Row Spacing				
Siokra 24 BRF	109.0	116.9	143.8	128.2
Sicot 70 BRF	104.1	94.1	106.7	94.7
Sicot 74 BRF	110.7	100.3	116.5	115.1
Mean	**107.9**	**103.8**	**122.3**	**112.6**
76cm Row Spacing				
Siokra 24 BRF	97.6	109.2	130.2	122.8
Sicot 70 BRF	86.3	85.0	105.1	96.8
Sicot 74 BRF	98.1	96.2	117.6	103.2
Mean	**94**	**96.8**	117.6	107.6
76cm height verses 102cm (%)	**-14.7%**	**-7.23%**	**-3.8%**	**-4.6%**

3.4. Discussion

The purpose for examining row spacing was to address a question posed by sugarcane growers as to whether they needed to grow cotton on a conventional 102 cm spaced system or whether they could use a 76-81 cm system which would allow simple integration with sugarcane.

Experimental comparisons between 76 cm (30 inch) and 102 cm (40 inch) row spacing systems have shown no disadvantage for 76 cm spacing in the Burdekin. The narrower 76 cm spacing was associated with yield increases in the range of 4–19% depending on cultivar and planting date during 2011 and 2012 when these experiments were conducted.

This is consistent with overseas research in the Mississippi Delta (which can have similar climatic constraints as the Burdekin) where a five year study showed an aggregate yield increase of 6.5-9.0% (depending on soil type) with 76 cm rows compared to 102 cm rows (Williford, 1992). Individual seasonal differences of up to 19% were observed for 76 cm rows during the study (Wiliford, 1990) with recorded increases highest in seasons where the crops endured climatic related field stresses (Heitholt *et al.*, 1996). This is similar to the Burdekin study, which was subject to field stresses in the form of periods of cloudy weather during flowering.

Similar to these studies as well, the 76 cm spaced cotton produced higher numbers of fruiting sites per m^2 than the 102 cm spaced rows although final retentions were reduced. Light interception was also greater for a period between first flower and 60-80DAS for the narrower spaced 76 cm cotton treatments. Crop height was also reduced for 76cm cotton compared to the 102 cm spaced treatments.

Much of the Burdekin's sugarcane crop is grown on 152-162 cm spaced beds (5-5.3 feet centred bed systems). Cotton is well suited to these bed centre spacings, which enable the production of two rows per bed spaced approximately 76-81 cm apart. In some seasons this row spacing may provide an improvement in yield potential compared to conventional 102 cm row spaced cotton. Sugarcane producers do not need to utilise a traditional row spacing of 100-102 cm rows.

4.0 Mepiquat Chloride Research

Summary

Research has demonstrated that Mepiquat Chloride (MC) can be used to reduce crop height and balance reproductive with vegetative growth but its use needs to be carefully considered. Apart from reducing crop height no other tangible benefits in terms of yield or crop maturity were identified with the use of MC. The overuse of MC was found to reduce yield potential through a reduction of outer branch fruiting sites combined with reduced lint turnout. MC usage was found to increase the retention of lower bolls during monsoon conditions, however these bolls were often later subject to boll rots and effectively lost prior to harvest.

Without MC burdekin crops can become very tall which presents difficulties for insects scouting and control as well as machine harvesting. However, balancing the management of crop height without impinging yield potential or a crops capacity to compensate after monsoonal weather is critical to success. Data generated from this project has been used to develop a prototype model for managing canopy development in the Burdekin. This model can be used to determine whether or not growth AND development are on track and whether or not MC may be beneficial or alternatively if growth needs to be encouraged to avoid premature cut-out. When MC is used only low doses of 7.6-19mg/ha (200-500mL) are used and only after taking into account total crop height, node number and Nodes Above White Flower (NAWF) if flowering has commenced. The application of this model is presented in the discussion of this chapter.

4.1 Background

Foliar application of mepiquat chloride (N,Ndimethylpiperidinium chloride), generally at flowering or as multiple low doses commencing at squaring, are accepted cultural practices for the management of excessive vegetative growth of cotton in temperate climates (Kerby, 1985; Constable, 1995; Edmisten, 1995). Mepiquat chloride (MC) can prevent undesired vegetative growth by reducing internode length (Gausman *et al.* 1979; Fernandez *et al.* 1991). However, yield response has been found to be variable (York, 1983a; Boman and Westerman, 1994; McConnell *et al.*, 1992; Reddy, 1993). Predicting crop response to MC has required the monitoring of crop growth, with a variety of regional techniques being employed (Constable, 1995; Shumway, 1997; Landivar *et al.*, 1996; Bourland *et al.*, 1994; Edmisten, 1995). For summer grown crops in temperate Australia the yield response to MC has been correlated with the rate of main-stem node elongation at first flower (Constable, 1995). Presumably a yield increase occurs because assimilate partitioning is rebalanced between vegetative and reproductive organs. A yield decrease occurs where MC is applied to non-vigorous crops because vegetative growth is suppressed to the extent that new nodes, and therefore, fruiting sites do not develop (Cothren, 1995; Kerby, 1985).

Growing cotton in the tropics presents new challenges for managing vegetative growth compared to Australia's temperate regions. For the Ord region, crops are sown in April, and high early season temperatures (35°C) favour vigorous growth. Growth then slows as the crops progress through winter, when daily minimum temperatures are lowest and most variable, between 5 and 22°C (Cook and Russell, 1983). In response to this challenge research was conducted to determine the impact of MC on growth and morphology under Ord River region conditions. This research suggested that a strategy whereby MC was applied primarily in the early vegetative phases prior to flowering as low doses (9-18 g/ha) was likely to be the most successful in reducing early season rank growth but not reducing the potential number of fruiting branches produced. MC applied after flowering and at higher dosages was found to reduce the number of fruiting branches and therefore fruiting sites and consequently reduced yield potential (Yeates *et al.* 2002). Irrigation management was also found to be a useful tool for manipulating early season growth in the Ord whereby avoiding excessive irrigation was found to reduce the rate of vegetative expansion and rank growth. The avoidance of MC applications post-flowering due to increased sensitivity of cotton due to winter conditions was also a significant departure from southern Australia practices whereby post flowering MC usage is common (Yeates et al. 2002).

The wet season planting window used in the Burdekin, presents additional challenges for vegetative management compared to both southern Australia and the Ord Irrigation area. With planting coinciding with the onset of the monsoon, the ability to regulate growth with irrigation scheduling is highly unlikely due to regular rainfall therefore a greater emphasis on MC usage is likely. Regular rainfall combined with high temperatures (30-32°C daytime and 20-25°C overnight) and cloudy weather creates the potential for rapid growth during the first 2-3 months post-sowing. An additional complication is the likelihood of weather related shedding of early fruit for which compensatory positions will need to be grown. The loss of lower fruit has two impacts that need to be accounted for. The first is the need to generate future compensatory fruiting branches and fruiting sites often several weeks after the shedding has occurred and the second complication is the temporary loss of lower fruit that would normally compete for assimilates with ongoing vegetative expansion which then allows for accelerated growth. This accelerated growth needs to be managed so as to avoid rankness but without detrimentally affecting the future production of compensatory fruiting sites that will arise from this growth. These factors suggest that a cautionary tailored approach will be required where MC is used in the Burdekin climate.

Collectively there is very little research reporting the use of MC in the management of vegetative growth in tropical regions. Research conducted in tropical and subtropical southern Africa whereby, excessive vegetative growth occurs during the summer wet season demonstrated that excessive growth needed to be managed prior to flowering (Dippenaar *et al.*, 1990). Research at Katherine, NT, Australia, during the summer season, found that yield was increased by 30% by the application of MC on rank cotton (Yeates and Kahl, 1995). However, this research was conducted with non-transgenic whereby the rate of retention due to insect damage could be very different to the higher pattern of retention that would be expected with BT transgenic crops.

The aim of this research was to evaluate the use of MC in the management of vegetative growth of cotton in the tropical wet season and later transition into the normally drier autumn period. Particular emphasis was placed on: (1) confirming the need to manage early growth; (2) evaluating MC rate and timing of application interactions with crop canopy development, maturity and yield and (3) compatibility of MC usage with the potential need to grow additional fruiting sites after the wet season to compensate for earlier wet season induced physiological fruit abortion.

4.2 Methods

Experiments were conducted between 2008 and 2011. A large scale experiment conducted on farm in 2008 was abandoned mid-season as the grower collaborator applied differential rates of nitrogen throughout the experiment confounding treatment effects.

2009

Two replicated block experiments were conducted during the 2009 season. The first experiment was established at the Ayr research station. This experiment was planted on 20 December 2008 using Sicala 60BRF and utilised the same agronomic inputs and management techniques as described for the climate study experiments for season 2. Treatment plots were 6 rows wide by 12 m long separated by a 3 metre buffer of either bare earth (plot ends) and 2 rows of cotton (untreated with MC on the plot sides). Each treatment was replicated four times. This experiment was partly affected by phenoxy herbicide contamination at the 7 node stage. The experiment was continued on however, as the contamination impact was relatively uniform throughout the trial area and the cotton in the treatment plots ceased expressing damage by the 12 node growth stage.

The MC treatments were applied with a calibrated high clearance spray rig equipped with 4 x 002 flat fan air-inducted nozzles that delivered 100L/ha spray volume. Pests were managed according to accepted economic thresholds.

The second experiment was conducted in a field of cotton sown to Sicot 70BRF on December 23 at Dongamere Farming located in the BRIA near the township of Clare. This field was flood irrigated and situated on a sandy alluvial soil. Nitrogen was applied (200kg/ha) with half as a pre-plant and the remainder as a side-dressing around first flower. This experiment was badly damaged due to a phenoxy herbicide contaminated aerial application of insecticide mid-season resulting in severe disruption to flowering and consequent trial site abandonment.

The MC treatments were applied in a randomised complete block design. The treatment structure is given in Table 4.1.

Table 4.1 The 2009 MC experiment treatment structure showing the rate of MC (g/ha) applied at each growth stage.

Treatment	Nodes 5-6	Nodes 9-10	Nodes 14-15 (FF)	Total Applied (g/ha)
1	0	0	0	0
2	15.2	0	0	15.2
3	15.2	15.2	0	30.4
4	15.2	15.2	15.2	45.6
5	15.2	22.8	7.6	45.6
6	15.2	19	19	53.2

2010

A replicated block experiment with split plots was conducted during the 2010 season at the Ayr Research Station. This experiment was planted on 20 December 2009 with Sicala 60 and Siokra 24BRF and utilised the same agronomic inputs and management techniques as described for the climate study experiments for season 3. Treatment plots were 12 rows wide by 12 m long (6 rows of each variety adjacent to one and other) separated by a 3 metre buffer of either bare earth (plot ends) and 2 rows of cotton (untreated with MC on the plot sides). Each treatment was replicated four times. The same agronomic inputs and management techniques as described for the climate study experiments for season 3 were used for this experiment. The MC treatment structure is given below.

The MC treatments were applied with a calibrated high clearance spray rig equipped with 4 x 002 flat fan air-inducted nozzles that delivered 100L/ha spray volume.

Table 4.2 The 2010 MC experiments treatment structure showing the rate of MC (g/ha) applied at each growth stage.

Treatment	Nodes 5-6	Nodes 9-10	Nodes 14-15 (FF)	Nodes 19-20	Total Applied (g/ha)
1	0	0	0	0	0
2	15.2	0	0	0	15.2
3	15.2	15.2	0	0	30.4
4	15.2	15.2	15.2	0	45.6
5	15.2	15.2	15.2	15.2	60.8

2011

Three experiments were established at Dongamere farming in the BRIA near the township of Clare to compare increasing dosages of MC on cotton growth and yield potential during 2011 season. The experiments were conducted on Siokra 24, Sicot 74 and Sicot 71BRF which had been planted in separate fields. The experiments were replicated block designs with treatments randomly allocated within one of three replicates within each experiment.

Table 4.3 The 2011 MC experiments treatment structure showing the rate of MC (g/ha) applied at each growth stage.

Treatment	Node 5	Node 10	Node 15 (FF)	Node 20	Node 25	Total Applied (g/ha)
1	0	0	0	0	0	0
2	15.2	0	0	0	0	15.2
3	15.2	15.2	0	0	0	30.4
4	15.2	15.2	15.2	0	0	45.6
5	15.2	15.2	15.2	15.2	15.2	60.8
6	7.6	7.6	7.6	7.6	7.6	38.0
7	30.4	30.4	0	0	0	60.8
8	0	30.4	30.4	15.2	15.2	91.2
9	30.4	30.4	15.2	0	0	76.0
10	15.2	30.4	30.4	15.2	15.2	106.4

MC was applied to each treatment at approximately 2 week intervals which coincided with development nodes 5, 10, 15, 20 and 25. Doses of 7.6, 15.2 and 30.4 g/ha were used singularly or in repeated dosages to arrive at the total applied dosages that ranged from no MC to 106.4 g/ha (see table). The MC treatments were applied with a calibrated hand held boom (2 m wide) equipped with 4 x 002 flat fan air-inducted nozzles that delivered 80L/ha spray volume.

Nitrogen was applied to provide equivalent of (200 kg/ha) (taking into account available soil nitrogen present at planting) with half applied as a pre-plant and the remainder as a side-dressing around first flower. Pests were managed according to accepted economic thresholds.

Plant Measurements

Measurements were taken of total crop height, number of nodes and nodes above white flower at weekly intervals until flowers reached 2 nodes from the terminal which indicated the cessation of continued canopy growth.

Crop maturity was determined by measuring out 3 linear metres of crop row within each plot and hand picking and counting the number of open bolls from the first open boll stage until complete crop maturity. Segmented handpicking was used to determine within canopy partitioning and contribution that different canopy sections made to overall crop yield just prior to machine picking. Two treatment rows were machine picked with a spindle picker from the middle of each plot for all experiments and sub-samples of seed cotton were taken from the machine picked lint to determine lint turnout and fibre quality parameters.

4.3 Results

2009 Experiment

Final crop height was significantly reduced with a negatively linear response (r^2=0.97) to increasing dosages of MC whilst the total number of nodes was also affected but to a lesser degree over the dosage range tested (Fig 4.1 & 4.2). An average decrease of 30cm in height was achieved in comparing the control and the highest total rate of MC (53.2g/ha) (Fig 4.1).

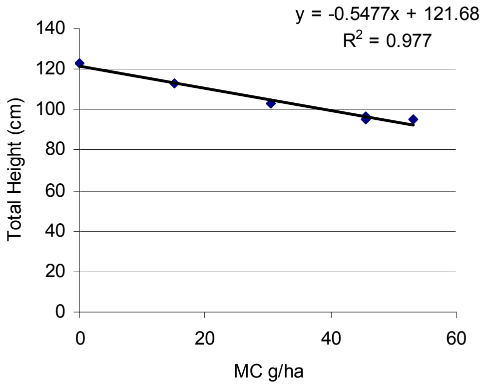


Fig 4.1. Response of final crop height to increasing quantities of applied MC for Sicala 60 BRF.

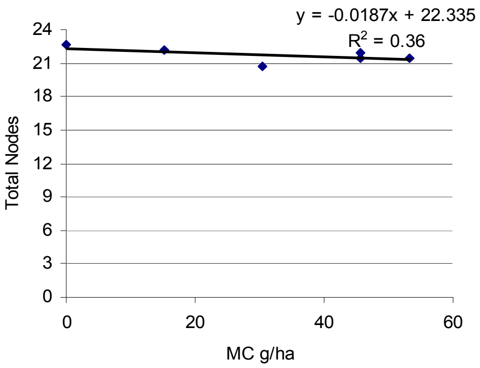


Fig 4.2. Response of final number of crop nodes to increasing quantities of applied MC for Sicala 60 BRF.

Treatment yield was not significantly affected (*P*>0.05) by the dosages of MC utilised in the experiment. Similarly the time from planting to crop maturity was not significantly impacted by MC with treatment variations being within 1 week (Table 4.4).

Table 4.4 2009 Treatment yield and Crop maturity for Sicala 60BRF

Treatment	Total MC	Time till 80% Maturity	Lint yield	
	(g/ha)	DAS	(kg/ha)	(bales/ha
1	0	146	1582a	6.97
2	15.2	146	1580a	6.96
3	30.4	141	1598a	7.04
4	45.6	143	1590a	7.00
5	45.6	141	1572a	6.92
6	53.2	146	1520a	6.69

2010 Experiments

Final crop height was again significantly reduced with increasing dosages of MC (with an average decrease of 20-30cm in height when compared with the control (Fig 4.3). The total number of nodes also had a negative linear response with increasing dosages of MC tested (Fig 4.4).

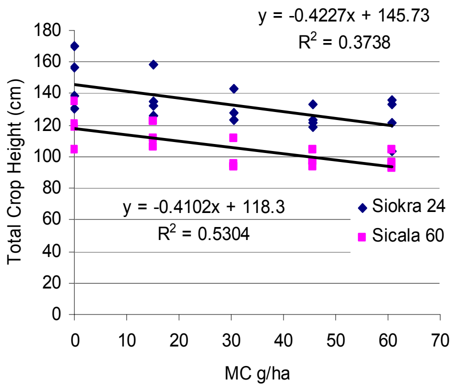


Fig 4.3 Response of final crop height to increasing quantities of applied MC for Sicala 60 and Siokra 24BRF.

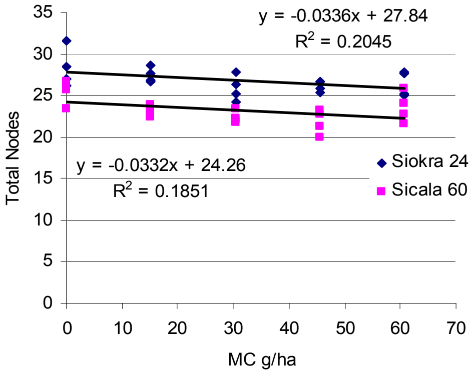


Fig 4.4 Response of final number of crop nodes to increasing quantities of applied MC for Sicala 60 and Siokra 24BRF.

Treatment yield x MC interaction was not significant (*P*>0.05) for the dosages of MC utilised in the experiment for either variety. Similarly the time from planting to crop maturity was not tangibly impacted by MC with final times to crop maturity being within a week for all treatments (Table 4.5).

Table 4.5 2010 Treatment yield and crop maturity for Siokra 24 and Sicala 60BRF

Treatment	Total Applied (g/ha)	80% Maturity DAS	Lint yield (kg/ha)	(bales/ha
Siokra 24				
1	0	135	2175a	9.58
2	15.2	135	1928a	8.49
3	30.4	139	1994a	8.78
4	45.6	135	1972a	8.69
5	60.8	139	2091a	9.21
Sicala 60				
1	0	135	1933a	8.51
2	15.2	139	2055a	9.05
3	30.4	135	2008a	8.84
4	45.6	135	2011a	8.85
5	60.8	139	2074a	9.13

2011

Crop height again had a negatively linear response to increasing dosages of MC for each cultivar (Fig 4.5).

The total number of main stem nodes was affected to a lesser extent with a minor linear decrease in total node number for Siokra 24BRF and Sicot 71BRF whilst Sicot 74 was virtually non-responsive over the treatment range used. (Fig 4.6).

Yield was significantly impacted (*P*<0.05) by increasing dosages of MC for Sicot 74 and 71BRF (Table 4.6 & Figure 4.7). The response from Siokra 24BRF was more variable with no overall significant differences recorded over the dosage range of MC applied in the experiment (Table 4.6 & Figure 4.7). Increasing dosages of MC caused a significant decline in gin turnout for all varieties (Figure 4.8).

Segmented picking results suggest that the reduction in yield observed in Sicot 71 and 74 is due primarily to a reduction in total fruiting sites and relative partitioning within the crop canopy. Put simply the higher applied rates of MC caused a reduction in the number and size of upper and outer canopy bolls (e.g. top P1s and outer branch P2s and 3s.). These reductions are evident in the figures (4.9) that compare the controls with 106.4g/ha MC and visually in the below photo (Photo 4.10) which shows a control plot beside a 106.4g/ha treatment plot.

Table 4.6. 2011 Treatment yield and Crop maturity for Siokra 24, Sicot 71 and Sicot 74BRF

Experiment and Treatment	**Total Applied**	**80% Maturity**	**Lint yield**	
	(g/ha)	**DAS**	**(kg/ha)**	**(bales/ha**
Siokra 24 BRF				
1	0	166	1789a	7.88
2	15.2	166	1780a	7.84
3	30.4	166	1768a	7.79
4	45.6	162	1842a	8.12
5	60.8	166	1823a	8.03
6	38.0	169	1830a	8.06
7	60.8	166	1805a	7.95
8	91.2	169	1698a	7.48
9	76.0	166	1776a	7.83
10	106.4	169	1729a	7.62
Sicot 71 BRF				
1	0	171	2052a	9.04
2	15.2	168	1984ab	8.74
3	30.4	168	1887abc	8.31
4	45.6	168	1858bc	8.19
5	60.8	171	1723c	7.59
6	38.0	168	1851bc	8.15
7	60.8	168	1785c	7.86
8	91.2	171	1553d	6.84
9	76.0	168	1723c	7.59
10	106.4	174	1513d	6.66
Sicot 74 BRF				
1	0	170	2147a	9.46
2	15.2	170	2029ab	8.94
3	30.4	173	2035ab	8.97
4	45.6	170	2046ab	9.01
5	60.8	173	1976bc	8.70
6	38.0	173	2126ab	9.36
7	60.8	170	2056ab	9.06
8	91.2	173	1785d	7.86
9	76.0	173	1850cd	8.15
10	106.4	176	1828cd	8.05

Treatment means for each variety with a different letter are significantly different (*P*>0.05).

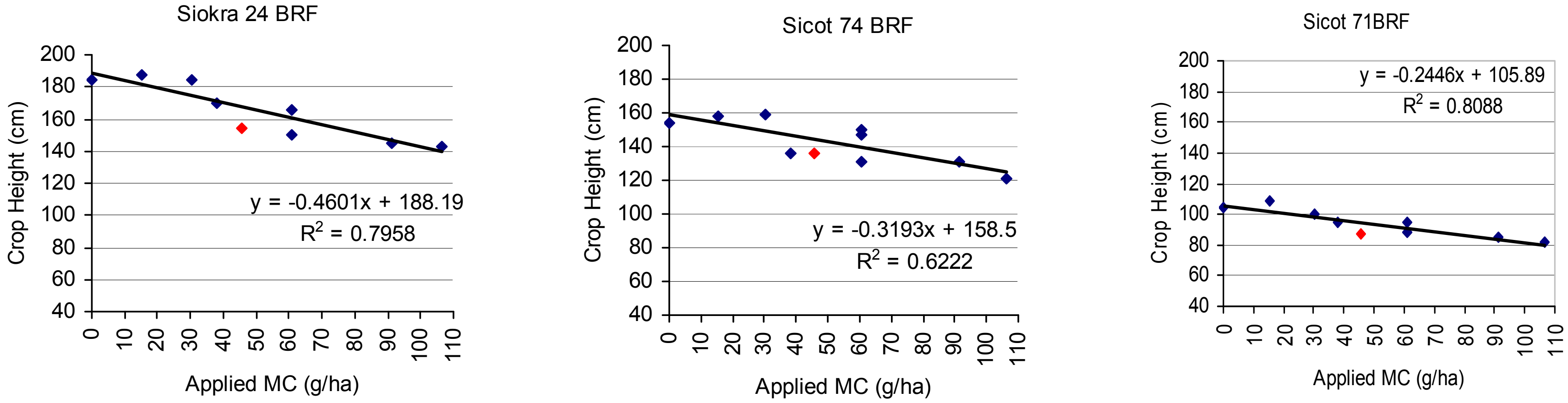


Figure 4.5. Response of crop height to increasing quantities of applied MC for Siokra 24, Sicot 74 and Sicot 71BRF. Note the response to 1L MC applied as 5 x 200mL.

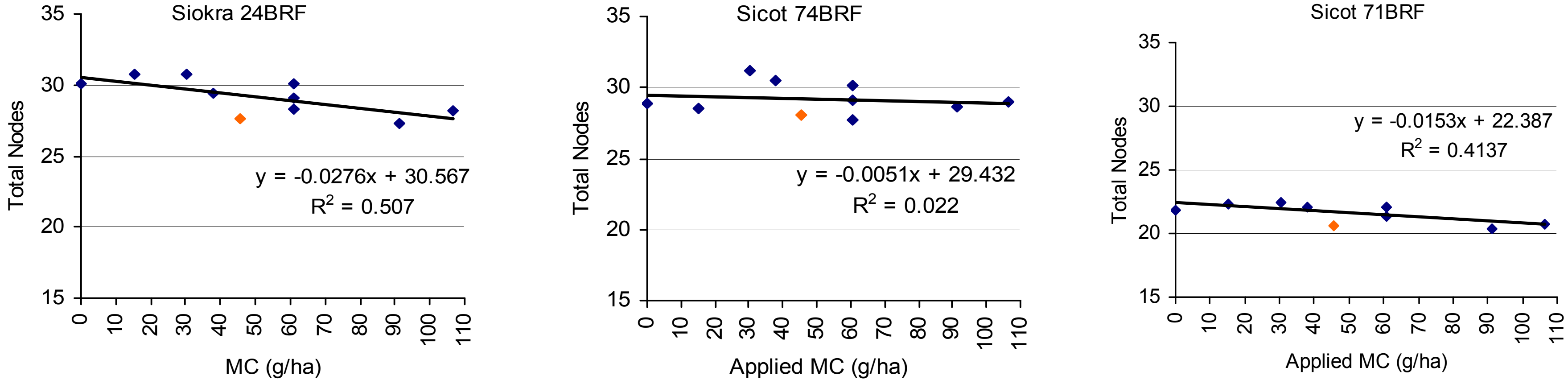


Figure 4.6. Response of total crop nodes to increasing quantities of applied MC for Siokra 24, Sicot 74 and Sicot 71BRF.

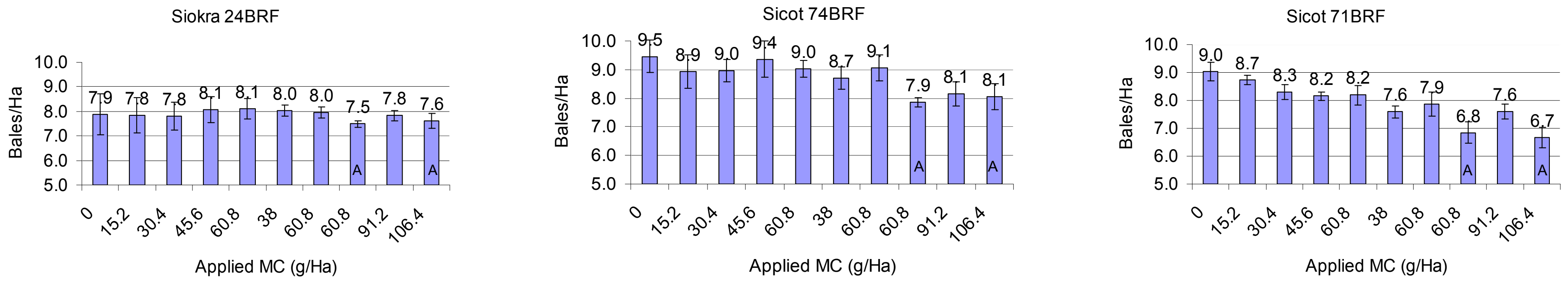


Figure 4.7. Yields from the MC experiments - Siokra 24, Sicot 74 and Sicot 71BRF. (A) denotes where 800mL/ha doses were used.

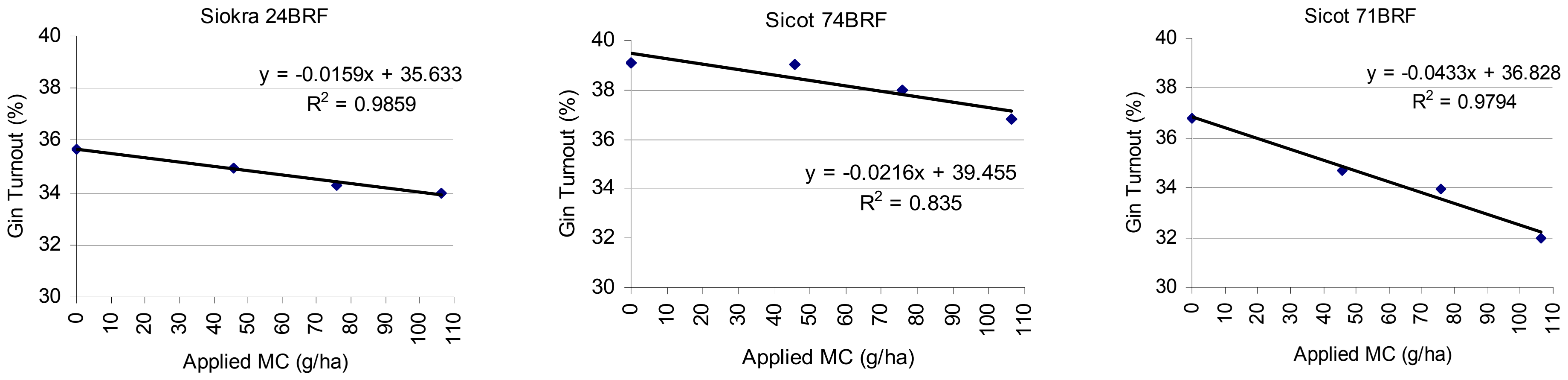


Figure 4.8 Gin Turnouts for the MC Experiments - Siokra 24, Sicot 74 and Sicot 71BRF.

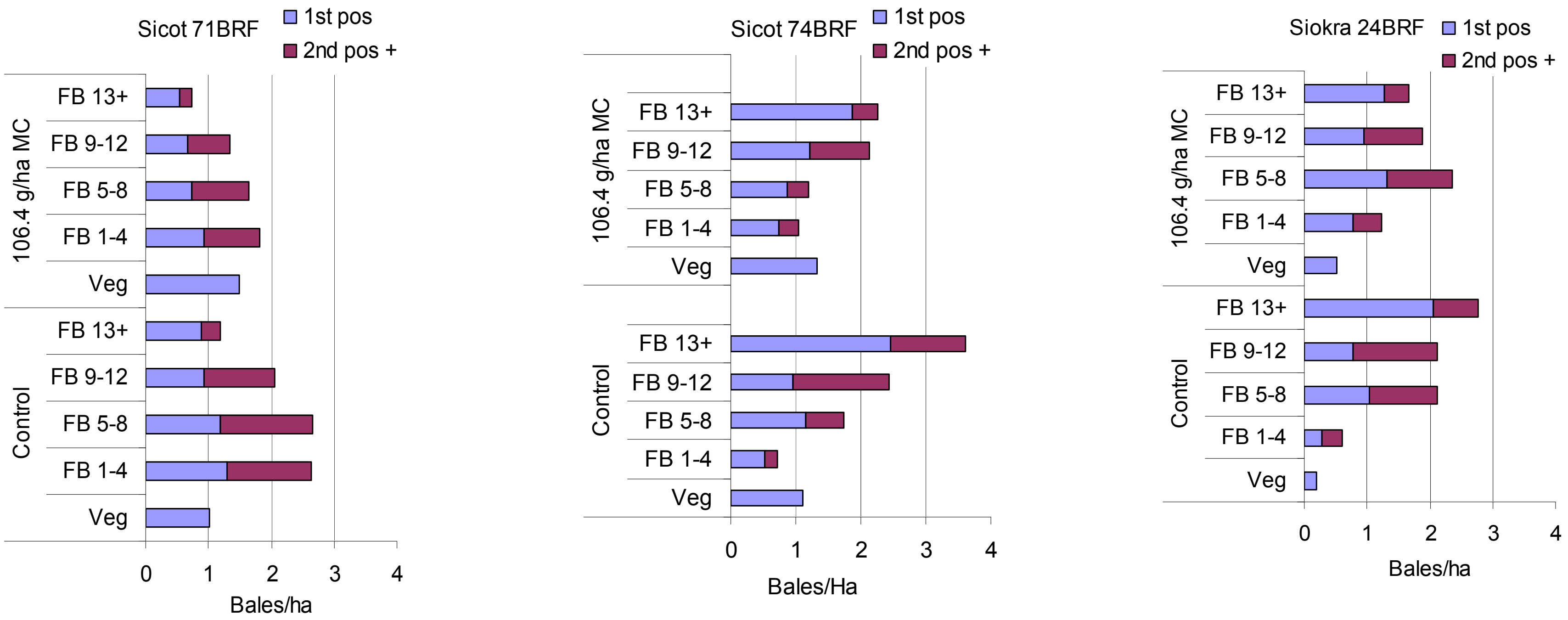


Figure 4.9. Segmented picking for the control and highest MC treatment (106.4g/ha). In each example the number of second position fruit are less when a high rate of MC is applied. A reduction in outer nodes/fruiting sites has occurred for the 2011 season with increased MC usage. This resulted in significant decreases in overall yield for Sicot 74 and 71BRF. Siokra 24BRF being more indeterminate was less affected although the distribution of yield within the canopy is altered by MC application.

Photo 4.1 Control plot Sicot 71BRF (left) and highest MC rate treatment (106.4g/ha) (right). The reduction in crop size (biomass) and boll numbers is clearly evident in this photo which reflect yield and segmented picking results. Over use of MC on this treatment has also adversely impacted radiation use efficiency in a radiation limited environment. A crop on 30 inch rows may not have been as significantly affected due to better space utilisation with a smaller plant and higher number of plants per hectare.

4.4 Discussion

Cotton crops are clearly sensitive to MC in a tropical environment and perhaps more so in a season such as 2011 which was characterised by periods of overcast weather during the boll filling period and an un-seasonally cool finish in May/June.

As a generalisation MC was found to decrease crop height without causing a substantial reduction in main stem node numbers. Similar to the Ord, cotton growth was found to be rapid early season due to warm temperatures and often saturated soil conditions due to the monsoon. However, the impact of MC on node growth in terms of fruiting sites on outer branch positions was found to reduce significantly curtailing yield potential in 2011. MC was also found to decrease turnout in 2011 when higher doses were tested which may be consistent with the hypothesis that MC causes a plant to direct more assimilates to boll production (Cothren, 1995; Kerby, 1985). In this case this resulted in larger seeds - reducing the ratio of lint to seed. Crop maturity was not found to be hastened by the application of MC in any experiment. The sensitivity of cotton to MC is not dissimilar to responses recorded in the Ord River region of NW Australia although in this instance this was due to curtailed fruiting branch elongation and development as opposed to the main stem.

Since R&D commenced in the Burdekin in 2008, a cautious approach to MC application was advocated in the Burdekin. The reason for this approach has been primarily due to the un-predictable nature of NQ weather and the need to maintain a flexible approach to canopy growth management to enable rapid compensatory fruit set to occur should extended cloudy weather result in significant boll losses. Low rates of MC have been advocated for this purpose (7.6-15.2 g/ha or 200-400 mL/ha) as high rates reduce subsequent management flexibility and were also found to be deleterious to yield potential in the Ord environment. Likewise local results indicate that cotton crops in the Burdekin are clearly sensitive to MC with significant reductions in height being recorded where multiple low dosages have been used.

The challenge for MC usage on Burdekin crops is the balance between avoiding excessive height but maintaining acceptable rates of canopy expansion to ensure that compensatory bolls can be set if required to offset shedding losses. In this regard, early season MC applications are likely to be helpful in reducing final crop height as early season growth is often very vigorous. However, as conditions during early flowering can often be wet, MC may still be required to avoid excessive inter-node expansion. However, achieving a balance between this and fruiting branch expansion so as to not reduce yield potential is a challenge.

In the absence of a locally validated methodology for MC decision making, the Ord MC decision tool developed by Yeates was suggested as a conservative alternative to the traditional southern

Vegetative Growth Rate (VGR) method - as an interim measure. The VGR method was found to have significant shortcomings in other tropical environments (Ord and Katherine) for its tendency to over-prescribe MC in tropical crops. Yeates (2007) presented a tool for MC decision making which was based on development and height averages for high yielding ORIA crops over a period of seasons during the 1990s. However, the use of MC in the ORIA maybe potentially different to the Burdekin. The two regions share the same challenge of early season vigorous growth. However, the rate of vegetative expansion during early to mid flowering is slower in ORIA primarily due to cooler winter temperatures and the ability to control soil moisture through controlling irrigation deficits. The Burdekin in comparison, still has warm temperatures at this time and may require vigorous growth to overcome monsoon related shedding losses.

The below model is a prototype tool for MC decision making based on the concept proposed by Yeates *et al.* 2007. This tool bases MC application decisions on the rate of height increase against total node production but **ALSO** considers NAWF as a measure of crop vigour and lower branch fruit retention (FIG 4.11). For this model we have taken 18 height and node data sets across a range of seasons and cultivars where crop and treatment plot yields exceeded 8.0bales/ha. The height by node development line is the mean of this combined data set whilst the upper and lower dotted lines represent the expected variance around the mean. The NAWF data from these crops was separated into two groups being crops that suffered extensive shedding of lower branch bolls from the first 4 or more fruiting branches and those where retention on these branches was high. The mean for these two groups are given with the blue line representing NAWF for crops that have shed lower branch fruit and the red line representing the trend for NAWF from high retention crops. An analysis of data from various experiments over 4 seasons shows that crop height or internode length alone has a poor correlation with yield potential. Instead a better approach may be to assess mid-season crop vigour in a combined assessment of total node production, total crop height and NAWF. The pattern of NAWF will change relative to early season shedding and therefore the proposed tool takes this into account by providing a measure for when early season retention with a high (70-80% P1 fruit retained on first 4-6 branches) and low retention (less than 30% P1 fruit retained on first 6 branches).

This model tracks growth and development in terms of the crop height in relation to each development node (black line) and shows the range of acceptable and typical variation that might be expected between different crops and varieties.

The model also depicts the likely relationship between the number of nodes above white flower (NAWF) and crop development nodes under Burdekin conditions. This relationship will change if wet season conditions cause shedding of early bolls. Therefore the data sets on which these calculations were made were split into two scenarios. The first is for crops that have had early season fruit shedding - loss of P1 fruit from first 4 or more fruiting branches (blue line) and crops where shedding of early boll positions was minimal (red line). Crops with early season fruiting site losses tend to be more vigorous with a higher measure of NAWF and extension of flowering past 25 nodes.

This model can be used as a tool to determine if growth is excessive and might benefit from restrictive management actions such as applying Mepiquat chloride or decreasing irrigation frequency. It can also be used to identify crops that may be lacking vigour and are in danger of premature cut-out at a stage early enough to take corrective actions (e.g. increase irrigation frequency, avoid MC or adjust the nitrogen program).

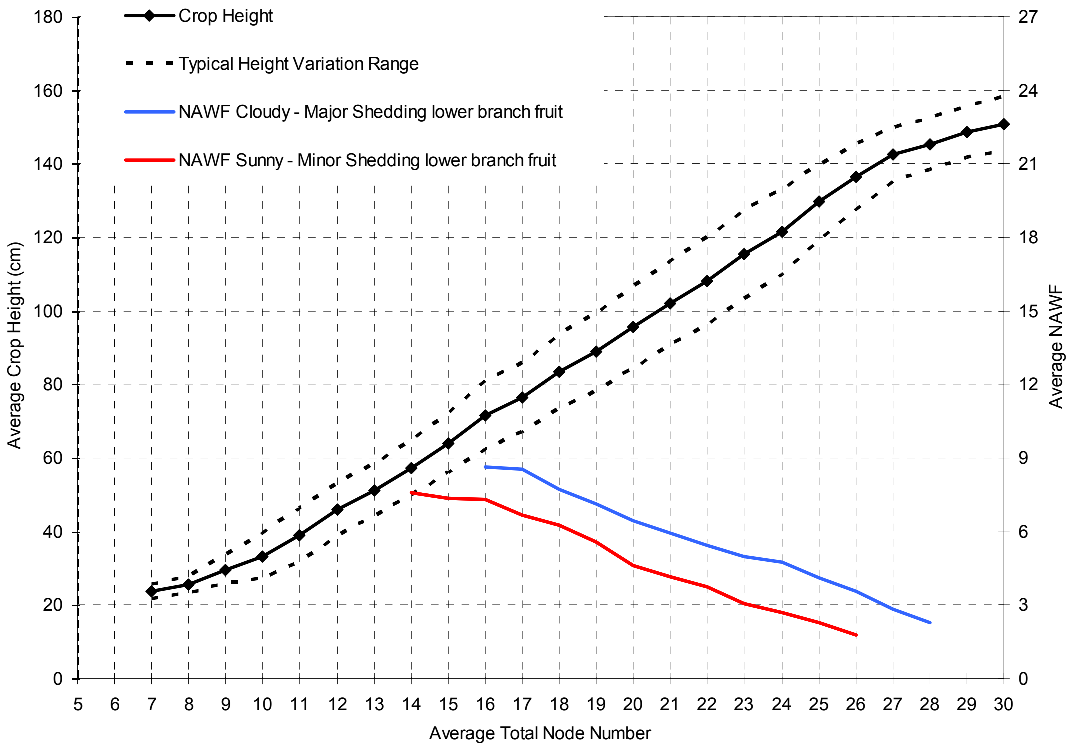


Fig 4.11 Prototype Burdekin Growth Model tool for assessing crop development.

A crop manager using this model would make weekly assessments of crop height and total number of nodes weekly together with bottom fruiting branch shedding and NAWF and use this collected information to plot crop development on the proposed tool. A comparison can then be made as to whether or not current development is above or below the expected trend and therefore determine if MC is required or alternatively if the rate of growth is faltering and in need of corrective management actions. Therefore this prototype model has applications beyond MC decision making.

When MC is required, **only low doses of 7.6-19 g/ha (200-500 mL/ha)** per application are used.

MC applications in excess of 19g/ha or 500mL/ha per 10 days are not recommended for the Burdekin. Whilst only 2 treatments in our experiments during 2011 utilised higher doses (30.4 g/ha or 800 mL/ha) it would appear from data that MC applied in large singular doses may have further deleterious effects on yield potential.

The VGR method is NOT recommended for Burdekin conditions. The application of this equation on weekly height and node data from the 2011 experiments retrospectively shows that this technique would have recommended significant further applications of MC to have been made to the treatment that had already received 106.4g/ha treatment in each experiment (see figure 4.12 below for Sicot 71). For Sicot 71 the VGR equation suggested a further 45.6 g/ha over and above the 106.4 g/ha already used on this treatment. Clearly this method is not well calibrated for Burdekin conditions and if used has a high probability of over-prescribing MC which may significantly reduce yield potential and reduce gin turnout.

Photo 4.2 The use of the VGR method to schedule MC on this crop has resulted in significant curtailment of canopy development mid season with the NAWF rapidly approaching the top of the plant.

NORpak excerpt

The following section is an excerpt from NORpak and discusses the use of this model for canopy management

Canopy management and maximising yield potential

Canopy management is a critical issue from first flower onwards. The aim is to grow and retain as many bolls per metre of crop row as possible within the timeframe of a normal season. As cotton is a perennial plant, a season is defined as the period most favourable for boll production. In the Burdekin this period begins when sunny conditions return after the monsoon and ends with the onset of cool late autumn/early winter night temperatures (see figures in chapter 1).

Managing crop growth is an important part of agronomic decision-making under Burdekin wet season conditions. With the specified planting window, there is only 6-9 weeks in which to set a crop. Regardless of when flowering commences, last effective flowers should be set by late April. The shorter flowering period of January-sown crops is typically offset by a higher proportion of sunny days. Early boll losses (first 3 weeks of flowering) in some seasons for December-sown crops can be compensated for when conditions turn dry in autumn. Ultimately, the success of a cotton crop will depend on a combination of agronomic management practices and climatic conditions during March and April. Therefore, assess crop development and make adjustments to in-field management on a weekly basis.

To those experienced with growth regulation in southern climates, tropical crop canopies may appear rank, however cotton grown in the coastal tropical environment will naturally be taller and have larger leaves than temperate-grown crops in most seasons. This phenotypic expression is a normal response to more humid cloudy conditions and high night temperatures and is often independent of crop management.

Up until 2012 all high yielding crops in the Burdekin (>8 bales/ha) have been taller than 140 cm. It is unrealistic to expect a crop to be short during cloudy years as crops must grow additional nodes to generate new squares to make up for previous shedding. Continued late season growth can be a serious problem. In sunny seasons most crops will set sufficient bolls during March/early April and cut-out naturally by 25 April. However, crop management factors such as excessive nitrogen or irrigation, or weather-related shedding in late March or April may extend flowering into May resulting in delayed crop maturity. Research data has demonstrated that every day of delay at this stage will add a minimum of 2-3 days delay in reaching final crop maturity. If cut out is delayed by 2 weeks, final crop maturity will be delayed by a month or more.

Of greater importance is avoiding premature cut-out (a crop finishes flowering before creating enough bolls to secure a high yield potential). The loss of vigour and early termination of growth (commonly seen as the flowering period reducing from 40-60 days back to 10-20 days) is nearly always due to a stress factor related to agronomic management — either a moisture or nutrition deficiency (inadequate or ill-timed application of fertiliser or irrigation), excessive application of mepiquat chloride, or aggressive inter-row cultivation, combined with inclement weather conditions. It is essential to regularly assess canopy development, particularly from first flower onwards as premature cut-out is difficult to remedy if not detected early. Once premature cut-out symptoms are visually apparent from the field edge it is too late to reverse the process within the cropping season.

The extent to which excess vegetative growth or premature cut-out may occur generally depends on one or a combination of the following factors:

- Varietal type. Determinate varieties are more susceptible to premature cut-out.
- Seasonal conditions. Sudden changes (e.g. from cloudy wet weather to hot dry conditions) can result in premature cut-out unless managed appropriately.

- Fruit retention. Loss of fruit can lead to excessive growth.
- Planting density. Plant stands of ≥9 per linear metre lead to increased height in cloudy years.
- Soil type and moisture availability. Over- or under-irrigation can have major influence on canopy development.
- Soil nitrate availability. Insufficient or excess nitrogen is a major determinant of crop vigour.

A user guide for the Burdekin Growth Model (BGM)

When the plants are at 6-7 nodes, select at least 2 or 3 representative areas within each field (avoid field edges) that you will be able to visit weekly to make in-crop measurements. The purpose is to track plant development over time, so mark your selected field areas to ensure you sample the same spots each week.

At each sampling, measure the plant height from the soil surface and count the number of main stem nodes for five consecutive plants within a row. Do this at a minimum of 2 separate locations within the crop and then calculate an average total height and node number for the plants sampled.

Once the crop begins to flower, also count the number of nodes above the upper most first position white flower on the main stem (you may need to check more than 5 consecutive plants as not all plants will have a main stem white flower every day). Calculate an average NAWF for the plants sampled.

To determine which NAWF shedding line to use as a point of comparison on the growth model, inspect the lower fruiting branches for fruit retention. Find the first fruiting branch and check for the presence of bolls on the first and second positions (P1 and P2). Repeat this for the next 3-5 fruiting branches and assess whether retention is high (most bolls retained) or low (loss of 4 or more P1 and P2 positions on the lower branches). If monsoon conditions have been active during early flowering it is likely that shedding will have occurred.

Plot the development of your crop against the Burdekin Growth Model (BGM) by:

1. On a printed copy of the BGM, locate your average number of nodes on the bottom (x) axis and your average plant height on the left hand (y) axis. Mark a plot point where lines from these two points would intersect (if you don't have a set square, anything with a right angle is useful to achieve accurate plot points).
2. Similarly, plot and mark a separate point for your average NAWF using the right hand (y2) axis against your average node number.
3. Repeat this process weekly to develop new plot points and join each new point with a line to develop a development track for height and NAWF. Sample twice weekly in the first 2-3 weeks of flowering.

By plotting crop height plot points over time, it will quickly become apparent whether or not the most recent data point represents a significant departure from expected growth. Effectively managing Burdekin cotton crop growth requires making predictions about the short term future. The best way of achieving this is to review the recent past.

NAWF is a relative measure of crop vigour. If a crop has experienced significant shedding of early fruit positions, the onset of flowering might be delayed (e.g. will start at a higher number of overall nodes) and the initial number of NAWF are likely to be higher. The blue line should be used for comparison for this scenario. If retention of lower bolls is high (if conditions have been sunny), the red line is more indicative of the likely trend for NAWF. The two NAWF lines are a general guide only and early season shedding will vary each season depending on conditions.

Plotting the progression of NAWF is critically important as this can be an effective early indicator of prematurely declining vigour. Once NAWF gets to 5 or less it becomes very difficult to arrest premature decline and therefore it is critical to identify this problem early. Typically a trend of premature decline will emerge within 10 days after first flower, so it is strongly recommended that you sample NAWF twice per week during the first 2-3 weeks of flowering.

Excessive growth

Mepiquat chloride (MC), commonly referred to by many in the cotton industry as pix, is a chemical compound that acts to lower the cotton plant's internal levels of a hormone (gibberalic acid), which in turn reduces the rate of cell division and expansion.

The result is a decrease of internode lengths between branches and smaller leaves. Under Burdekin conditions, the application of MC can be beneficial in re-balancing the plant from excessively tall and leafy growth to a more compact, better proportioned canopy (node extension in relation to square production).

In southern production systems, MC is commonly not applied until mid-season after flowering commences. In the Burdekin, MC use is more likely to start during the vegetative growth stage within weeks of emergence as high early season temperatures and rainfall often cause very vigorous growth.

The BGM tool brings together important aspects of crop growth and development that should be considered when making an MC application decision. Prior to flowering, MC applications may be useful if data indicates that growth is travelling above the given Burdekin trend-line or if successive measurements indicate that the rate of growth is accelerating (sharper slope).

Once flowering commences, the emerging trend of NAWF must be considered before making a MC application decision. If a crop is below the appropriate trend line (blue or red depending on retention) by 2 NAWF or more, MC is NOT recommended even if crop height is above trend. In this case the rate of growth is already slowing and MC application will hasten the decline in NAWF and potentially reduce yield potential. If NAWF is close to trend (within 2 NAWF) whilst height is above trend MC can be used with caution.

Essentially MC usage needs to take into account current crop height, the change over time in node elongation, and NAWF to be utilised with a margin of safety in the Burdekin. Making MC applications on crop height or fifth internode length alone is highly risky, particularly after first flower.

Cotton was found to be very responsive to MC under Burdekin conditions and only low doses of 7.6-19 g/ha or 200-500 mL/ha per application should be used. Dosages at the top end of this range are likely to be appropriate for vigorous varieties such as Siokra 24BRF whilst more determinate varieties such as Sicot 71BRF and Sicala 60BRF may respond equally well to 200-300 mL/ha.

MC applications in excess of 19 g/ha or 500 mL/ha per 10 days are not recommended for the Burdekin. Data from various Burdekin MC experiments demonstrated significant negative impact on crop yield if more than 500 mL/ha was used per application. When using MC, remember that the impact can be exacerbated by other stress factors such as a nitrogen deficiency, moisture stress or inter-row cultivation.

Various scenarios when using the Burdekin growth model

Table 4.7 BGM Decisions – Scenario Combinations

		Crop Height		
		Below	**At Trend**	**Above**
NAWF	**N/A (Pre-Flowering)**	Check for causes of reduced vigour e.g. nutrition or inappropriate soil moisture (too dry or too wet). A sudden change from wet to dry may be causing plants to partition towards root development.	Keep a check on height and node development	Excess soil moisture combined with adequate nitrogen will regularly cause above trend early season vigour. Apply MC and keep assessing development.
	Below	Take immediate steps to identify and if possible remedy cause of low vigour e.g. nutrition or soil moisture. Has the weather changed from wet to dry suddenly?	Unless crop is at the late stages of flowering the crop may be at risk of premature cut-out, Cause may be high retention or a hidden deficiency. Count boll numbers to determine how much more growth is required to set a high yield and take steps to increase vegetative expansion if required and season length constraints allow.	NAWF ≥2 below: MC not recommended NAWF <2 below: use MC with caution. Be careful not to induce other crop stress factors within 10 days of MC application (e.g. soil moisture, inter-row cultivation). Keep assessing development.
	Trend	Continue to monitor NAWF closely. If conditions have been sunny and dry resulting in good retention then this is likely to represent normal growth	Continue to monitor NAWF and retention. This is likely if retention is good and conditions are sunny and the crop has adequate inputs.	Adjust irrigation deficits (lengthen interval by 1-3 days initially) if it has been dry and sunny. If it has been rainy or soil moisture is high, apply MC or and keep assessing development.
	Above	Continue to monitor NAWF closely, shedding may be cause of above trend NAWF.	Continue to monitor NAWF closely, shedding and/or wet weather may be cause of above trend NAWF.	Apply MC and keep assessing development. Also check that irrigation or nitrogen is not excessive. If rainfall is occurring MC will be the primary management tool.

Mepiquat chloride and the Burdekin

Excessive use of MC can limit the ability of a crop to rapidly compensate and recover (by producing additional fruiting sites) after periods of prolonged cloudy weather and associated fruit shedding losses. This can be further exacerbated if excessive MC and cloudy weather conditions are combined with sub-optimal nutrition and irrigation management, resulting in rapid premature cut-out. Contributing factors to premature cut-out and lost yield potential in some past Burdekin crops have included a lack of data to validate appropriate MC, nitrogen use, and canopy management strategies for local conditions, and a general misconception as to what constitutes excessive growth during wet season conditions.

In temperate climates, a common tool for determining the timing and rate of MC to be used on a cotton crop is the Vegetative Growth Rate (VGR). This method is unsuitable for the Burdekin as it has a very high risk of over-prescribing MC. The VGR method does not directly account for NAWF and lower fruiting branch shedding, both of which are important aspects to consider when making MC decisions in the Burdekin. Therefore despite being an effective tool for MC decision making in southern regions, the VGR method is NOT recommended for Burdekin conditions.

Other techniques that are unreliable for MC decision making in the Burdekin include measuring internode lengths with the aim of keeping expansion within 5-6 cm or ‘three fingers’. With intermittent monsoonal conditions, this goal will be virtually impossible to achieve and again runs the risk of excessive MC use.

Another common assumption is that MC can be used to hasten crop maturity. Research data from six separate experiments across three seasons in the Burdekin failed to find any time to crop maturity advantages for MC usage.

Ideally, MC usage in the Burdekin requires an ability to predict future field conditions for at least 2 weeks after application takes place. Although the BGM cannot predict the future, it can make good use of current information (crop height, nodes, NAWF and shedding) to gauge the need for MC. When MC is applied, only low dosages are recommended, as you can always add more MC, but once applied you cannot take it off.

It is common to apply MC during monsoonal weather. Fortunately the soft leaves developed by Burdekin crops at this time allow for rapid uptake after application with anecdotal observations suggesting that uptake is effective within 2 hours of application. This concurs with experience using MC in Brazil, which has a similar climate and the risk of rainfall occurring within 6 hours of application.

Photo 4.3 The use of the Vegetative Growth Rate (VGR) model for determining when and how much MC to be applied does not reliably work in the tropics and in this case has significantly bunched the upper canopy when a top crop was requires to compensate for earlier shedding losses. Note the reduction in the number of P2 fruit number and the reduced size of these bolls. cv Siokra 24BRF 2011.

Photo 4.4 The application of the prototype Burdekin Growth Model (BGM) for MC decision making has allowed the plant to develop a better balanced canopy and boll set. Note the number of P2 and some P3 fruit. cv Siokra 24BRF 2011.

Using MC to assist cut-out of cotton in the Burdekin

Various attempts have been made to use high rates of MC to bring about timely crop cut-out and avoid delayed crop maturity in a range of Burdekin crops. In most instances these crops had suffered early season shedding, or premature cut-out and growth was re-stimulated by either the application of mid-season nitrogen or crop roots encountering leached nitrogen at depth (a phenomenon encountered exclusively on sandy soil types). A third factor may be monsoonal conditions during late March or early April which induce shedding and cause the crop to compensate in late April or May.

A practice commonly referred to as 'cut-out pix' was used — high rates of MC (1.5-2.5 L/ha) were applied to prevent further development of the terminal shoot and halt the production of new fruiting sites. These applications had mixed success with plants often induced to 'back fruit' and continue to flower on the side branches. Time to maturity was generally not hastened when compared to untreated strips for these scenarios.

The issue of delayed maturity is usually created by low retention (excessive shedding), too much nitrogen and freely available soil moisture. With improved nitrogen management practices developed from local research, this problem should become less common. A crop not tracking towards cut out by late April may be effectively managed by steadily increasing the moisture deficit (time interval) between crop irrigations, combined with the application of 500 mL/ha dosages of MC every 10 days until cut-out is achieved. Burdekin conditions during April when the last effective flowers are set are generally mild, allowing significant flexibility for modifying irrigation scheduling without rapidly compromising yield potential. However, rainfall in April can compromise this approach.

Managing the crop canopy to avoid premature cut-out

A crop that does not want to grow is a much worse problem than one that does not want to stop.

Premature cut-out occurs when photosynthesis cannot meet both the demands from developing bolls and canopy growth, resulting in the cessation of canopy growth and early termination of flowering. It is generally caused by a deficiency or stress (that reduces photosynthesis) just before or early in flowering. Premature cut-out was observed in many Burdekin crops grown between 2008-2010 and again in 2012, particularly on clay soils. Losses due to premature cut-out have been much greater than those related to excessive growth.

Deficiencies that may lead to premature cut-out include a lack of:

- nitrogen or other nutrient deficiency (inability to apply side-dressings, or wet weather related nitrogen loss)
- soil moisture (excessively delayed irrigation)
- soil oxygen (water-logging)
- carbohydrate (cloudy weather).

Stresses that can contribute to premature cut-out include:

- excessive MC application
- herbicide contamination or drift that disrupts growth
- aggressive inter-row cultivation that reduces effective root zone area and root biomass (plant may redirect carbohydrates from continued canopy growth to compensatory root recovery)
- subsoil constraints (e.g. compaction or sodicity).

Once a crop starts flowering it is important to closely monitor crop vigour which can be assessed with the Burdekin Growth Model (BGM). This model can be used to contrast real-time growth against the expected trend for a healthy Burdekin crop so that a premature decline in canopy expansion and NAWF can be detected early, allowing more time to take corrective action. Premature cut-out can occur very fast with many crops cutting out within 10-20 days after first flower. Therefore it is critical that sampling crop growth parameters such as height, node number, and NAWF be conducted more frequently during the first 2-3 weeks of flowering to detect any changes early. A reduction of 2 or more NAWF against the relevant trend line (see how to use BGM above) indicates that premature cut-out is a risk and remedial action needs to be considered.

Aspects to take into account include irrigation frequency, varietal determinacy, fruit retention, nitrogen availability, and other abiotic stresses.

Remedial action to arrest premature cut-out will involve modification to the timing of irrigation and fertiliser application. This may include increased irrigation, a corrective side-dressing of fertiliser or remedying a drainage problem (if possible). Unfortunately premature cut-out is difficult to overcome when prolonged cloud cover, waterlogging, or excessive MC are causal or exacerbating stress factors.

Crops grown on clay soils are more prone to premature cut-out than those on sandy soils. This is generally due to the additional challenges of providing well timed nitrogen as clay fields present greater difficulties for trafficability, are readily susceptible to wet season losses of nitrogen, and have inherently less nitrogen fertility than sand/ loam soil types. Clay soils also often have less available soil oxygen and tend to produce a more compact, lower vigour plant during monsoon conditions, reducing the buffer against premature cut-out. Sodicity at depth can also be a constraint as it limits the effective rooting depth for crops on clays, leading to earlier moisture stress. Particular attention should be given to assessing the development of these crops in the weeks leading up to and after first flower.

Cultivar selection can play a significant role in reducing the risk of premature cut-out particularly on clay soils. The selection of the most vigorous indeterminate varieties such as Siokra 24BRF provide an additional buffer against premature cut-out. This variety has a tendency to commence flowering with NAWF levels generally 1-2 higher than varieties such as Sicot 71 or 74BRF, and is particularly responsive to remedial action such as increased irrigation frequency or side-dressing of nitrogen compared with other varieties. The most responsive commercially available variety for clay soils at the time of writing is Siokra 24BRF.

Regularly measuring plant height and node number is an essential component for managing canopy growth.

The below figure 4.12 depicts how the tool might be used to make an MC decision using actual data for Siokra 24BRF grown during 2009.

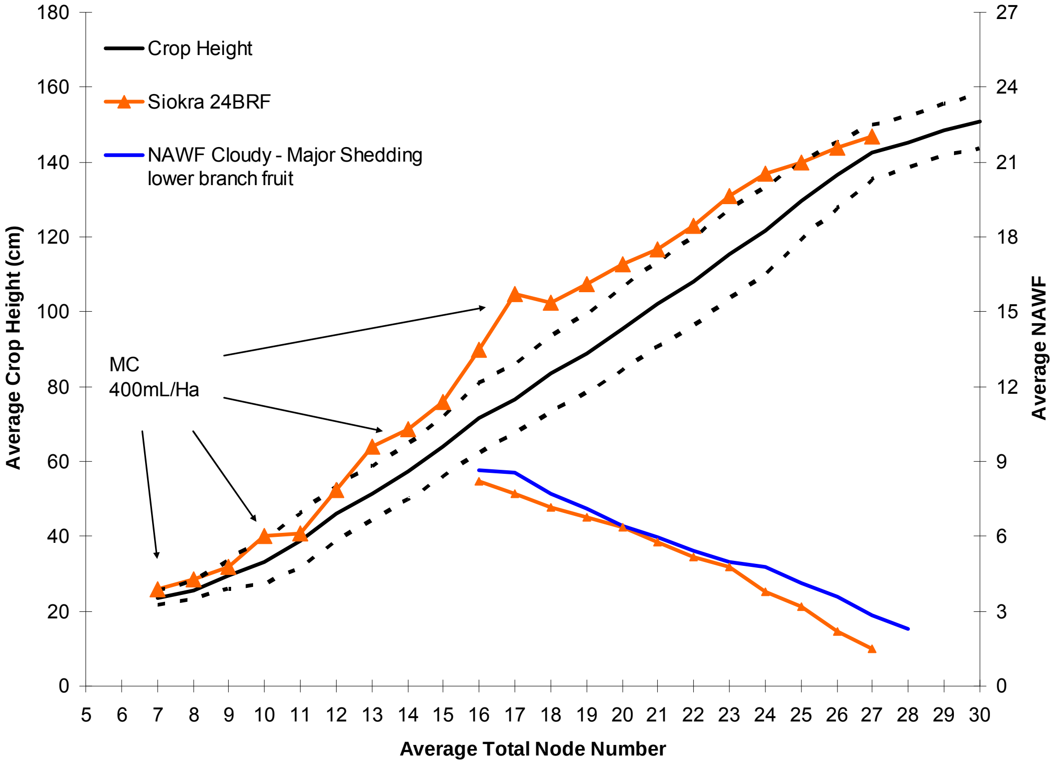


Figure 4.12 The above figure is data from Siokra 24BRF sown at the Ayr Research Station during December 2008. This crop suffered extensive early shedding during wet weather therefore the shedding NAWF mean is used as a comparison. As the impacts of MC were under investigation at this stage a similar approach to the Ord Irrigation Area model had been used which entailed 3 early season applications of 400mL/ha. When the data for Siokra 24BRF is presented against the Burdekin MC tool it is apparent that crop height could have been reduced further with additional applications of MC at flowering and beyond given that crop height was trending above average AND the crop had good vigour indicated by the comparison of the NAWF recorded against the Burdekin average for high yielding crops that have had extensive early season shedding. This crop still produced a yield of 8.5b/ha despite being a bit taller at times during its growth.

5.0 Evaluation of cotton trimming as a wet season agronomic management tactic

Summary

Several replicated experiments were conducted between 2009 and 2011 to investigate whether pruning the terminal sections from pre-flowering cotton crops (trimming) could be used to manipulate time of flowering and fruit set in the Burdekin climate. Trimming was found to be effective at delaying the onset of flowering by 350-400DD or 17-21 days under Burdekin conditions in February. Comparisons between the timing and severity of trimming demonstrated that removing 3-4 nodes of growth from the crop terminal was sufficient to provide a treatment response from cotton that was between the 8 and 15-16 node growth stages (first flower). The interuption to flowering induced by crop trimming (when 3-4 nodes were removed) was found to not affect the time until final crop maturity.

Trimming more than 3-4 nodes from the plants whilst not detrimental to subsequent regrowth did in some cases significantly delay final crop maturity.

5.1 Introduction

The Burdekin has a well-defined climatic challenge of having a high probability of crops experiencing periodic wet overcast conditions for the first 50-60 days after planting. Within the 20 December to 20 January planting window, the climate experiments have shown that the impacts of this weather can often be partly avoided by planting around January 10, which delays flowering until the usually drier month of March. However, the risk of not getting a suitable weather for sowing in January is higher than December particularly during wetter-than-average seasons, the years in which a delayed sowing would be most beneficial. A lower risk sowing option is to plant during December, although these crops will flower in February (the wettest month). Side dressing nitrogen prior to flowering can be more problematic for December grown crops whilst also having an increased risk of environmental loss in rainfall runoff. December sown crops are also more likely to shed early bolls, which requires an effective crop management strategy to ensure that compensatory bolls are later set. Due to the early onset of flowering and associated issues, growers have generally found December grown crops more difficult to manage but easier to sow. As the sowing of crops cannot always be delayed until January alternative options for postponing the onset of flowering post sowing were investigated.

The concept of utilising chemical defoliants such as Ethephon to remove early fruiting sites and hence delay the onset of flowering was considered. However, the likely crop response may be difficult to control and predict depending on environmental circumstances at the time.

Post-establishment mechanical pruning of the crop canopy was investigated as an alternate method for delaying the onset of flowering. The effects that both the timing and severity of pruning had on flowering, boll setting, crop maturity and yield potential were assessed.

5.2 Materials and Methods

2009 and 2010 Experiments

These experiments were conducted at the Ayr Research Station, 7km SW of Ayr Queensland Australia (19°62'S, Long. 147°38'E) in the Burdekin Irrigation Area during 2009 and 2010.

The first experiment utilised a randomised complete block design with various mechanical trimming treatments sown to Sicot 70BRF. The second experiment was a split plot design, where main plots were the mechanical trimming with four replications in randomised blocks. Subplots were two different cultivars Sicot 70 and Siokra 24BRF. The treatment structure for each experiment is given in (Table 5.1).

Table 5.1. Treatment structure for 2009 and 2010 trimming experiments.

Experiment	Treatment	Growth Stage	Severity of trimming
2009	1	7 Nodes	Trim off 3 nodes from top
	2	7 Nodes	Trim off all nodes leaving only cotyledons
	3	11 Nodes	Trim off 3 nodes from top
	4	11 Nodes	Trim off all nodes to the first fruiting branch (remove 5-6 nodes)
	5	First Flower (15-16 Nodes)	Trim off 3 nodes from top
	6	First Flower (15-16 Nodes)	Trim off nodes leaving 3-4 fruiting branches from top (remove 5-6 nodes)
	7	First Flower (15-16 Nodes)	Trim off all nodes down to to the first fruiting branch (remove 9-10 nodes)
	Control		No trimming
2010			
	1	7 Nodes	Trim off 3 nodes from top
	2	11 Nodes	Trim off 3 nodes from top
	3	First Flower (15-16 Nodes)	Trim off 3 nodes from top
	Control		No trimming

The same field was utilised for the two experiments. Each crop followed a cover crop of Siberian millet, *Setaria italicawas* L Beauv. established in August and grown until October after which it was incorporated during bed preparation for re-sowing of cotton in the same field.

A plant population of 5-6 plants per metre row were established on 76 cm spaced rows (6.6-8 plants/m^2). The experiments were established using a row configuration of 2 rows per bed separated by 75cm with irrigation furrows between beds. Cotton was sown on 4 December 2008 and 20 December 2009 for the 2009 and 2010 experiments respectively. Plots were 8 rows wide by 15 m long.

The cotton was managed using the same agronomic (fertiliser, irrigation, tillage etc) and pest management practices utilised for the climate experiment plots.

2011 Experiments

Trimming experiments were implemented on commercial cotton fields at Dongamere Farming near the township of Clare (19°78'S, Long. 147°23'E) within the BRIA. The cotton in these fields followed a previous mungbean rotation crop.

Two trimming experiments were implemented in separate fields. The first was within a field of Siokra 24BRF whilst the other was Sicot 74 BRF. Each experiment was a randomised complete block design with three mechanical trimming treatments and an un-trimmed control. (Table 5.2).

Table 5.2. Treatment structure for 2011 trimming experiments.

Experiment	Treatment	Growth Stage	Severity of trimming
Siokra 24BRF	1	7 Nodes	Trim off 3 nodes from top
	2	11 Nodes	Trim off 3 nodes from top
	3	First Flower (15-16 Nodes)	Trim off 3 nodes from top
	Control		No trimming
Sicot 74BRF	1	7 Nodes	Trim off 3 nodes from top
	2	11 Nodes	Trim off 3 nodes from top
	3	First Flower (15-16 Nodes)	Trim off 3 nodes from top
	Control		No trimming

Populations of 8-9 plants per metre row were established on 100 cm spaced rows. Plots were 20 rows wide by 20 m long.

Fertiliser, 140 kg/ha N half as urea, plus 20 kg/ha P and 85 kg/ha K placed in a band 10cm deep and 15 cm within the crop row. No further nitrogen was applied as pre-season soil testing indicated significant residual nitrates from the previous crop cycle.

Implementation of trimming

Trimming was conducted in the plots for all experiments utilising a petrol driven hedge trimmer with a 50cm cutter bar which was mounted on a mobile steel frame with wheels. This frame allowed trimming height to be accurately set and controlled. The hedging machine allowed the cotton to be trimmed with a neat cut (Photos 5.1-5.3).

Photo 5.1 The experimental trimmer used to implement the trimming treatments.

Photo 5.2 Only the top 3-5 nodes are removed with a clean cut during trimming.

Photo 5.3 The aim is to just trim off the tops, not to cut the crop harshly as shown above.

Measurements

Dates of first flower and first open boll were defined as when one per meter of row per plot was present.

The total number of squares and bolls was recorded at fortnightly intervals from first flower (as recorded in the un-trimmed control plots) onwards in all treatment plots for the 2010 and 2011 experiments.

Crop maturity was determined when 60% of the bolls were open and pickable in each plot. This was determined by counting and hand harvesting open bolls from 3 meters of row within each plot every 5-7 days from first open boll to complete crop maturity.

Seed cotton was machine harvested with a spindle picker from the entire length of 4 plot rows that had not been used for other destructive plot assessments. Larger plot end plants were manually removed prior to machine picking. Lint yield was calculated by ginning a 400g subsample with a 10 saw gin. Ginning was conducted at the CSIRO Plant Industry laboratory at

Narrabri in NSW except 2010 when the seed cotton subsamples were ginned locally. Because the turnout from a small 10 saw gin is higher than a commercial scale gin, the gin turnout was adjusted each season to the commercial value using data from concurrent commercial cotton plantings in the Burdekin. Adjustments to gin turnout was made relative to commercial crop averages for one of the cultivars sown on the same date.

5.3 Results

2009

The 2009 experiment demonstrated that the response to trimming in terms of delayed flowering compared with the control was similar for each crop stage when trimming was conducted with the removal of the top three to four nodes. More severe trimming that removed a greater proportion of canopy did not extend the delay in flowering except when the crop had reached 15-16 nodes. Severe trimming of these plants at this development stage did further delay flowering and crop maturity. Trimming delayed the onset of flowering by 17-28 DAS compared to the control.

Yields response was relatively unaffected by trimming in this experiment. The delay in flowering was not sufficient to avoid cloudy weather for the first half of flowering and therefore conditions that might have provided a yield advantage by better coinciding flowering with sunnier weather were not realised. The treatment (2) where only the cotyledons remained after trimming had significantly lower lint yield ($P<0.05$) than all other treatments due to trimming induced plant mortality and a consequently patchy stand (Table 5.3).

Ginned lint quality parameters were the same for the trimmed and control treatments and fulfilled base grade characteristics.

The experiment indicated that trimming could be successfully conducted from 7 nodes until 16 nodes and that the removal of the top three nodes is sufficient to delay flowering for nearly 2.5-3 weeks (Table 5.3).

Table 5.3 Trimming results from first experiment in 2009

Treatment	Growth Stage	Severity of trimming	DAS to Flowering	DAS to 80% Open Bolls	Lint per hectare (kg)**
Control		No trimming	46	165	2092_{a}
1	7 Nodes	Trim off 3 nodes from top	63	164	2131_{a}
2	7 Nodes	Trim off all nodes leaving only cotyledons	64	163	1723_{b}
3	11 Nodes	Trim off 3 nodes from top	63	164	2143_{a}
4	11 Nodes	Trim off all nodes to the first fruiting branch (remove 5-6 nodes)	67	163	2167_{a}
5	First Flower (16 Nodes)	Trim off 3 nodes from top	67	163	2204_{a}
6	First Flower (16 Nodes)	Trim off nodes leaving 3-4 fruiting branches from top (remove 5-6 nodes)	69	168	2124_{a}
7	First Flower (16 Nodes)	Trim off all nodes down to the first fruiting branch (remove 5-6 nodes)	74	177	2136_{a}

** Treatments with different letter are significantly different at ($P<0.05$)

2010

Only the timing of trimming implementation was compared for the 2010 experiments as results from 2009 indicated that the trimming of the top 3-4 nodes was sufficient to induce an effective delay in flowering treatment response and therefore no further work was conducted on trimming severity. The recorded time to first flower indicated that each of the 2010 trimming treatments delayed the onset of flowering by 17-21 days compared to the respective controls. Fruiting dynamics were altered by the trimming treatments with the production of squares being initially delayed before later peaking (Figs 5.4 & 5.5). This corresponded with a delay in the production of bolls that was later compensated for by the increased production of squares on the lateral branches (Figs 5.4 & 5.5).

Despite the delays in peak square production and flowering no significant differences were observed between total time to maturity and yield (Table 5.4). Ginned lint quality parameters were the same for the trimmed and control treatments and fulfilled base grade standards.

Table 5.4 Trimming results from 2010 trimming experiments

Experiment	Treatment	Growth Stage	Severity of trimming	DAS to Flowering	DAS to 80% Open Bolls	Lint per hectare (kg)**
Siokra 24BRF	1	7 Nodes	Trim off 3 nodes from top	63	151	1850$_a$
	2	11 Nodes	Trim off 3 nodes from top	62	151	1922$_a$
	3	First Flower (16 Nodes)	Trim off 3 nodes from top	66	154	1770$_a$
	Control		No trimming	45	151	1859$_a$
Sicala 60BRF	1	7 Nodes	Trim off 3 nodes from top	63	147	1922$_a$
	2	11 Nodes	Trim off 3 nodes from top	62	147	1964$_a$
	3	First Flower (16 Nodes)	Trim off 3 nodes from top	66	151	1968$_a$
	Control		No trimming	46	147	1924$_a$

** Treatments with different letter are significantly different at (P<0.05).

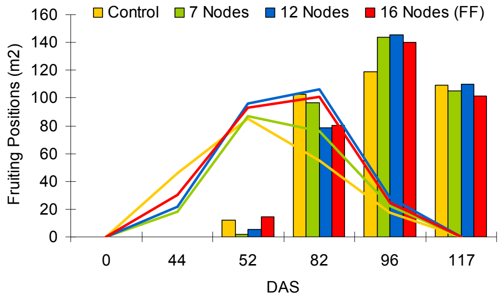


Figure 5.4. Fruiting dynamics for trimmed verses control treatment in the Sicala 60BRF experiment. The lines represent square numbers and the bars denote boll numbers.

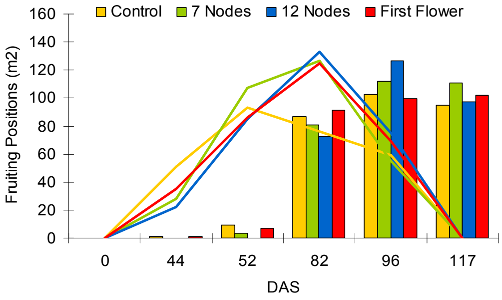


Figure 5.5. Fruiting dynamics for trimmed verses control treatment in the Siokra 24BRF experiment. The lines represent square numbers and the bars denote boll numbers.

2011

The trimming treatments implemented during the 2011 experiments with Siokra 24BRF and Sicot 74BRF again produced very similar treatment responses. However the un-trimmed control plots for Siokra 24 BRF produced significantly more lint P<0.05 than each of the trimmed treatments (Table 5.5). The commencement of flowering in the trimmed treatments coincided with the onset of 2 weeks of cloudy conditions during the latter half of March which coincided with peak flower in the trimmed treatments. The trimming-induced compressed flowering exposed a greater proportion of early developing bolls to this period of inclement weather compared to the control plots that flowered over a 6-7 week period whilst setting a top crop. Ginned lint quality parameters were the same for the trimmed and control treatments.

Table 5.5. Trimming results from 2011 trimming experiments

Experiment	Treatment	Growth Stage	Severity of trimming	DAS to Flowering	DAS to 80% Open Bolls	Lint per hectare (kg)**
Siokra 24	1	7 Nodes	Trim off 3 nodes from top	64	177	1893$_a$
	2	11 Nodes	Trim off 3 nodes from top	63	177	1976$_a$
	3	First Flower (16 Nodes)	Trim off 3 nodes from top	66	177	1977$_a$
	Control		No trimming	44	172	2242$_b$
Sicot 74	1	7 Nodes	Trim off 3 nodes from top	64	182	1893$_a$
	2	11 Nodes	Trim off 3 nodes from top	64	182	1949$_a$
	3	First Flower (16 Nodes)	Trim off 3 nodes from top	66	184	2031$_a$
	Control		No trimming	45	177	2065$_a$

** Treatments with different letter are significantly different at (*P*<0.05)

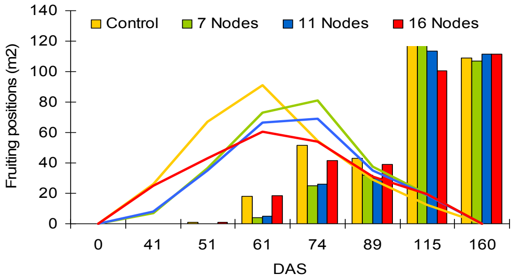


Figure 5.6. Fruiting dynamics for trimmed verses control treatment in the Sicot 74BRF experiment. The lines represent square numbers and the bars denote boll numbers.

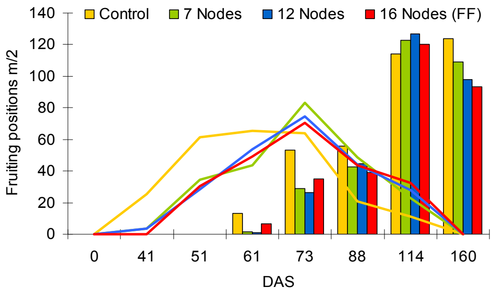


Figure 5.7. Fruiting dynamics for trimmed verses control treatment in the Siokra 24BRF experiment. The lines represent square numbers and the bars denote boll numbers.

5.4 Discussion

Trimming off the terminal 3-4 nodes at any growth stage between 7 nodes and first flower (or 15-16 nodes) provided a 17-21 day delay to the onset of flowering. Trimming primarily disrupts the succession of fruiting branch production on the main stem and consequently delays flower production. Trimmed plants are forced to grow lateral branches on which new fruiting branches and flowers are grown. Observations during 2011 between the untrimmed controls and trimmed treatments indicated that the commencement of flowering on the trimmed treatments simply matched the commencement of flowering on the vegetative branches in the controls. Therefore in essence, the act of trimming does not induce a direct set-back to development but rather allows the vegetative branches to become dominant and these branches are developmentally behind the succession of the main stem in terms of flowering. As bolls on the vegetative branches on normal crops mature in sync with the last of the main stem bolls it is not surprising that bolls produced on the laterals from trimmed plants have a similar maturity to the top bolls on the control plots. Aggressive trimming of the plants where by more than 3-4 nodes were removed did cause maturity delays. This was due to the damage caused to the terminal shoots of the lateral branches that were emerging. Damage to emerging vegetative branches further disrupts growth and consequently delays flowering and maturity. Therefore when trimming a crop, care should be taken to ensure that the trimming height is set at a level where the terminals of the vegetative branches are un-harmed.

The initial disruption to the usual progression of flowers on the main stem is compensated for by tandem flowering on multiple laterals (Photo 5.8). This results in a similar boll set across treatments and crop maturity, however the flowering period is compressed and therefore conditions during the shortened flowering period are potentially more important compared to an un-trimmed plant that sets bolls at a slower rate over an extended period. The response by Siokra 24BRF in 2011 shows demonstrates this risk whereby the compressed flowering in the trimmed treatments coincided with 2 weeks of very cloudy weather resulting in a large cohort of affected bolls being produced. The proportional cohort of bolls in the control plots in comparison was smaller with a greater proportion of bolls being set in the weeks before and after the cloudy period. The Sicot 74BRF experiment did not have the same negative impact due to trimming, however the rate of daily boll retention is slower for this variety and therefore flowering even in the trimmed treatments occurred over a longer period (hence the later crop maturity) meaning that a smaller proportion of bolls were subject to the cloudy weather.

Photo 5.8. A trimmed cotton plant at first flower. Note the tandem flowering occurring on the multiple vegetative branches.

Photo 5.9 Crop response as at "cutout" from trimming performed earlier at different growth stages. Note that the bolls on the trimmed treatments are well away from ground level and that the age of the top positions is the similar between the trimmed and untrimmed plants. Also note the Candelabra affect that trimming has had on plant architecture.

The first 3-5 nodes of vegetative branch growth after trimming occurs rapidly and can look rank. However, this level of inter-node expansion was observed to rapidly decrease once the vegetative branches produce fruiting sites. The early expansion of these vegetative branch inter-nodes does raise the distance of the first set bolls early bolls from the soil surface and in some seasons this will help mitigate losses to boll rots (Photo 5.9).

The Burdekin has a high probability of crops experiencing periodic wet overcast conditions for the first 50-60 days after planting. These weather impacts can often be either partly avoided by encouraging later compensatory growth or planting around January 10. While many growers find January sown crops easier to manage than December-sown crops, there is high risk of not getting a suitable sowing period in January, particularly during wetter-than-average seasons when a delayed sowing would be most beneficial.

The mechanical trimming of crops to delay the onset of flowering is another tool that growers might use to delay the flowering of December sown crops until early March by which time conditions are likely to be sunnier. Trimming will delay the onset of flowering by 300-400 day degrees (about 15-20 days under mid-summer Burdekin conditions).

Potential advantages:

- Avoidance of February rain on flowers for December-sown crops
- Improved light interception due to the creation of a 'open-vase' like canopy
- Marginally reduced crop height as growth is spread over multiple growing points
- An additional 2-3 weeks (created by the delay in flowering) to complete nitrogen side-dressing.

Potential disadvantages:

- Cloudy weather effects in mid-March could be compounded as flowering is compressed into this period e.g. 2011 experiment results
- Poor equipment setup can result in patchy response or poor recovery
- Insects may be more difficult to scout in trimmed crops.

Trimming is NOT recommended for:

- Crops sown after 5 January as these crops will already flower in March and further delays in flowering may reduce yield potential, particularly in seasons with cooler than average autumn temperatures.
- Okra leaf varieties such as Siokra 24. These have had variable responses to trimming and are therefore not recommended at this time.

To successfully trim a crop it is recommended that a cutter bar or sharp, height controllable flail mower be used. ***Remove the top few nodes in a controlled manner with as clean a cut as possible.*** Avoid swinging blade rotary style slashers as they tend to 'smash' the main stem and can significantly damage a crop. When cutting it is important not to damage the terminals of the vegetative branches. If these branches are damaged crop maturity can be delayed by several weeks.

6.0 Cotton production in the Dry Season - Could Trimming avoid cool night temperatures at flowering?

Summary

A basic experiment was conducted during the 2009 dry season to fulfil two objectives. Firstly a number of growers wanted to see a dry season test planting of cotton as many individuals did not accept the modelling outputs that had been presented by the project team which strongly suggested that dry season cotton was unlikely to be successful due to cold overnight temperatures in July and August. The second reason was to investigate whether or not trimming could be used to manipulate flowering and fruit setting dynamics in such a way as to avoid cold weather on flowers and allow crop maturity well before December.

The study demonstrated that cool night temperatures caused major disruption to boll production and reduced yield potential in the Burdekin. Leaf blight caused by *Alternaria* spp was also prevalent in the May sown cotton. The June sowing of cotton had much better yield potential and avoided flowering during August. However, despite a high yield, final crop maturity was unacceptably late for this sowing date.

This experiment validated modelling results that suggested dry season cotton production is not a viable option for the Burdekin due to cool night temperatures, leaf blight and risk of delayed maturity that could coincide picking with monsoon conditions.

6.1 Background.

A basic experiment was conducted to revisit the potential for dry season cotton production in the Burdekin and to examine whether or not "trimming" could be used to manipulate the time of flowering in such a way as to avoid setting bolls during July and August but achieve crop maturity before the end of November. Essentially, could a crop be sown and then trimmed to delay the onset of flowering (thereby avoiding the coolest night temperatures) and then possibly making up the lost time with tandem flowering on the laterals during improving weather in spring and allow a late November harvest.

This study examined an early May and early June sowing both with and without terminal shoot trimming treatments.

6.2 Materials and Methods

The experiment was conducted at the Ayr Research Station, 7 km SW of Ayr Queensland Australia (19°62'S, Long. 147°38'E) in the Burdekin Irrigation Area during 2009 and 2010.

The experiment was a randomised complete block design with split plots, where main plots were two sowing dates with four replications in randomised blocks. Subplots were different trimming treatments (Table 5.1). The first sowing date was commenced on 8 May and the second planting on 9 June 2009. Trimming treatments were implemented utilising the petrol driven hedge trimmer machine with a 50cm cutter bar as described in section 5 and in photos 5.1-5.3.

Sicot 70BRF was sown at each planting date to establish 6 plants per linear metre row. The experiments were established using a row configuration of 2 rows per bed separated by 76 cm. Drip tape irrigation was used to irrigate the plots. The tape being buried 5 cm deep in the middle of each bed leaving the between bed furrows to provide runoff drainage. Plots were 6 rows wide by 15 m long and were separated on plot ends by 2 metres of bare earth.

Insect pests were managed by scouting 2-3 times each week with insecticide decisions being made when pest densities reached levels at half of those used recommended for temperate regions. This was done to ensure that pest activity had minimal impact on fruit abortion.

Fertiliser, 90 kg/ha N half as urea, plus 20 kg/ha P and 85 kg/ha K placed in a band 10 cm deep and 15 cm within the crop row within a week of sowing. A further 90 kg/ha N and 108 kg/ha S was applied as a side-dressing within the same location 4-6 weeks after crop emergence. A foliar application of $ZnSO_4.7H_2O$ at 100g element/ha at the 3rd true leaf stage.

Measurements of first flower, maturity and final yield were made along with climatic variables using the techniques outlined for the climate study experiments.

Table 5.1. Treatment structure for 2009 and 2010 trimming experiments.

Planting Date	Treatment	Growth Stage	Severity of trimming
8 May 2009	1	7 Nodes	Trim off 3 nodes from top
	2	11 Nodes	Trim off 5 nodes from top
	3	First Flower (16 Nodes)	Trim off 5 nodes from top
	Control		No trimming
8 June 2009	1	7 Nodes	Trim off 3 nodes from top
	2	11 Nodes	Trim off 5 nodes from top
	3	First Flower (16 Nodes)	Trim off 3 nodes from top
	Control		No trimming

6.3 Results

Observed Climate during study

Conditions during the experiment were both drier than average and warmer than average particularly for night temperatures during July and August (Fig 6.1A). The May sowing was subject to 26 nights where the minima fell below 12ºC and the June planting 21 nights. August was notably warmer than average with minimum temperatures remaining above 10ºC throughout (Fig 6.1B). Daily radiation levels were below the long term average for the period from May to August before becoming much sunnier from September till December (Fig 6.1C).

Flowering and Yield Response

Trimming caused a significant delay in the onset of flowering for all treatments compared to the control. For the May planting flowering was delayed from 3 August (untrimmed controls) until the last week of August (25th -31st). For the June sown cotton flowering was delayed from the 20 August until 16–22 September.

Yield was significantly lower for the May sown plots compared to June with there being no significant differences ($P<0.05$) between trimming treatments compared to the controls for either sowing date.

The low yields picked from the May treatments reflect the generally poor health of the plants in this treatment that showed visible fruit deformities due to cool night temperatures as well as reddened foliage and prevalence of *Alternaria* leaf blight. The foliage symptoms became acute around first flower during early August for the May treatment plots.

The June plantings were visibly less affected by these foliage, boll and leaf blight symptoms with flowering commencing from late August onwards when temperatures were increasing.

The May treatments were machine picked 7 December and the June treatments 22 December 2009.

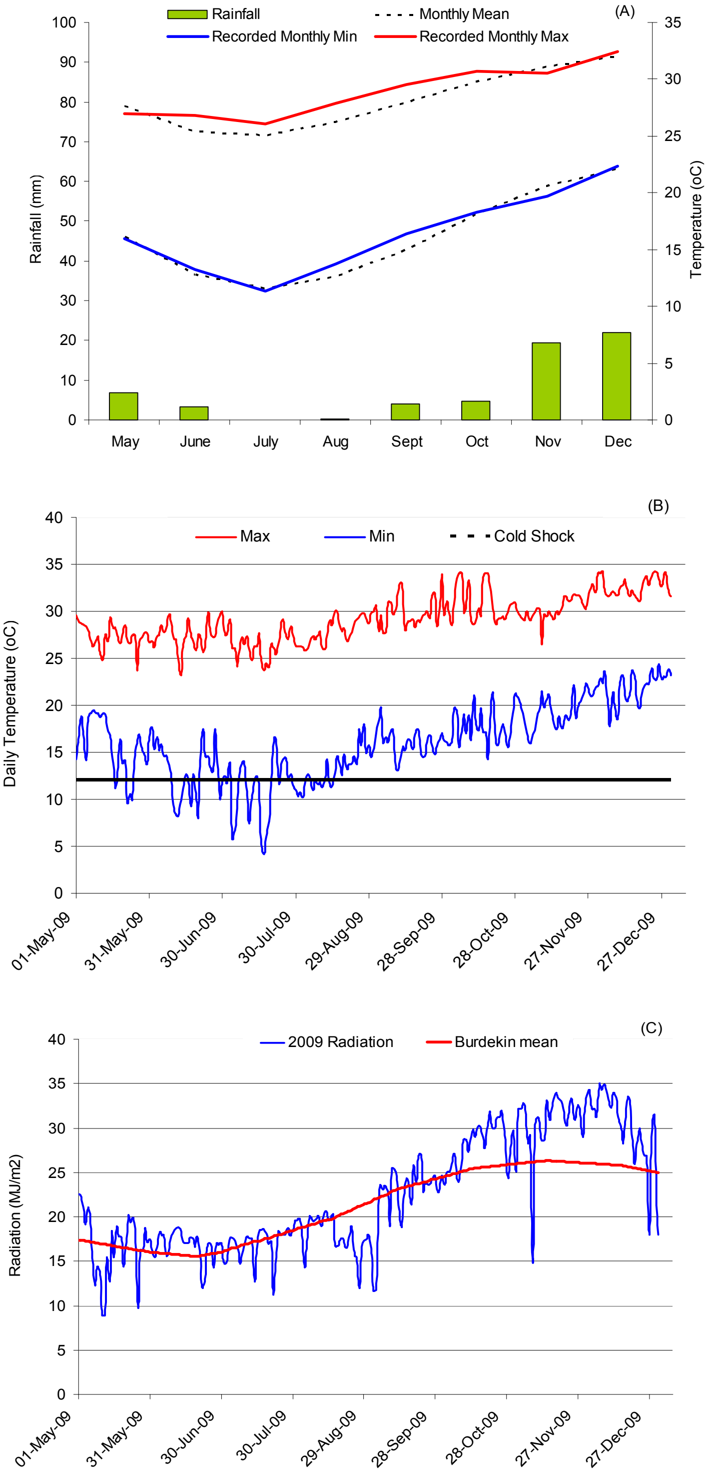


Fig 6.1 Climatic data for the 2009 season for May till December: (A) monthly rainfall and recorded mean monthly temperatures and the long term mean; (B) Daily minimum and maximum temperatures and (C) daily solar radiation against the long term mean.

Table 6.2. Trimming results from 2011 trimming experiments

Experiment	Treatment	Growth Stage when trimmed	DAS to Flowering	DAS to 60% Open Bolls	Lint per hectare (kg)**
8 May 2009	1	7 Nodes	108	203	1501.8a
	2	11 Nodes	110	203	1496.2a
	3	First Flower (16 Nodes)	114	205	1414.6a
	Control		86	188	1503.9a
9 June 2009	1	7 Nodes	99	183	2275.3b
	2	11 Nodes	102	183	2292.6b
	3	First Flower (16 Nodes)	112	185	2069.9b
	Control		78	181	2298.9b

** Treatments with different letter are significantly different at ($P<0.05$)

6.4 Discussion

This experiment although limited in scope demonstrated the limitations associated with the potential for dry season cotton production in the Burdekin. Firstly the 2009 winter was much warmer than average with only 29 nights where temperatures fell below 12°C. Long term records since 1951 suggest that the mean number of cold shocks for the Burdekin is closer to 45 between May and September. The 2009 season was markedly warmer than 2004 when two fields of cotton were sown under permit during late May. These 2004 crops were subject to a cooler than average winter and received 74 cold shocks.

The plant response for both the cooler than average 2004 and warmer than average 2009 winter seasons shared a number of similarities. In both years the crop canopies were affected by Alternaria leaf blight and the production of bolls was severely affected by cool night temperatures resulting in shedding, miss-shapen and deformed bolls. In both seasons these plantings had delayed maturity being picked 23 December 2004 and 7 December 2009.

The June sowings better avoided the impact of cool night temperatures on fruit set and boll development with flowering commencing in late August in the controls and mid September for the trimming treatments. The severity of *Alternaria* leaf blight was also reduced for these treatments compared to the May sowings. Crop yields were excellent being in the vicinity of 10bales/ha and crop maturity was achieved within 185 days.

This planting date was un-complicated to grow with no shedding and high retention. Pest activity in both sowings was minimal with no insecticides required throughout the season.

However, the major shortcoming of the June planting despite these potential advantages was that maturity occurred in late December which coincides with the start of the wet season, presenting an unacceptable climatic risk on which to base a cotton farming system. The logistics of a late December harvest period with the prospect of increasingly wet weather would be diabolical in some seasons in terms of securing sufficient picking days for large acreages as well as the subsequent on farm trafficability required for module storage and movement.

Photo 6.1 Winter Dry season trimming trial 2009.

Photo 6.2 *Alternaria* leaf blight was particularly common on the May sowing treatments in 2009.

Photo 6.3 Abortion of fruiting sites in the May 2009 plantings due to cool night temperatures in July and August (Photo taken early September)

Photo 6.4 Reduced boll size due to cool night temperatures and reduced canopy vigour from *Alternaria* leaf blight in the May sowing 2009. Note first position boll is smaller than second position boll.

Photo 6.5 Cotton growing during the dry season (sown May 2004). Photo taken in August.

Photo 6.6 *Alternaria* leaf blight afflicting the 2004 dry season cotton trials. Photo taken September 2004.

Photo 6.7 The bolls taken from a cotton plant in 2004 in September. Note the reduced size and deformities

Photo 6.8 Similar to 2009, early boll retention was low during 2004 due to shedding from cold night temperatures.

Photo 6.9 Shows the four May sown treatments at 13 September. Note the lack of lower canopy bolls in the control with better bolls being set further out and many compensatory squares being produced on the control (top left). The trimmed treatments are developmentally delayed and are beginning to set bolls.

Photo 6.10 Shows the four June sown treatments at 13 September. That the control has only recently began flowering which coincides with better improving conditions. The trimmed treatments have not commenced flowering (except for a few remaining main stem fruiting branches on the FF trimmed treatment which will flower for a short time before re-flowering on the lateral branches.

7.0 Case Study for Inclusion of Pigeon Peas as a Refuge Option for Burdekin Bowen Basin RMP

Summary

Side by side plantings of unsprayed non-bt cotton and pigeon pea at multiple sites (heavy clay & sandy soil types) during 2010 and 2011 were compared for *Helicoverpa* pupae productivity and flowering phenology in the Burdekin region. Additionally 18 pigeon pea cultivars were sown and comparisons made with the industry standard pigeon pea "Quest" under Burdekin conditions. The study period was characterised by low abundance of *Helicoverpa* with only very low numbers of viable pupae being recorded from all refuges. Agronomically pigeon pea refuges grew well during two wetter than average seasons on both soil types and had similar flowering phenology to unsprayed cotton. An assessment of alternate cultivars showed that more indeterminate varieties would be better suited to Burdekin conditions compared to cv Quest. One cultivar QPL 847 has shown particular suitability in having a pre-flowering period of only 55 days compared to 46 days for unsprayed cotton and continuing to flower and remain attractive until June by which time Bollgard cotton crops are defoliated for picking.

This study found no agronomic factors that should preclude the use of pigeon pea as a refuge option for the Burdekin Bowen Basin. It is recommended that pigeon peas be included as a refuge option for the Burdekin Bowen Basin as per the usual RMP conventions together with the additional stipulation that growers plant pigeon pea refuges up to 14 days prior or at least not after Bollgard cotton crops are sown so as to mitigate wet weather refuge establishment risk. An appropriate seed inoculums treatment should also be used at planting to ensure effective colonisation of the root system with nitrogen fixing *Rhizobium* bacterium.

7.1 Why was this work undertaken?

The Burdekin had only one refuge option of 10% unsprayed cotton. Pigeon pea was not included as an option despite being available for all other regions (ORIA and South) due to a lack of information on the agronomic performance of pigeon peas during the NQ wet season when cotton is grown. The primary concern centred on whether or not pigeon peas would grow well during the wet season in January and February. Pigeon peas are successfully grown in other countries (e.g. Africa and India) at similar latitudes and conditions as the Burdekin. However, it was possible that the current variety "Quest" used throughout the southern Australian cotton industry may not be a suitable cultivar for Burdekin conditions. Therefore the aim of the study was to-

a) Conduct side by side comparisons between pigeon pea (Quest) and unsprayed cotton on Burdekin cotton farms.

b) Compare the flowering phenology of different varieties originally screened at Katherine (NT) during the 1980's with the commercial standard cv "Quest" to establish if there were better suited varieties for the Burdekin Bowen region.

7.2 Methods

Side by side comparisons

A permit was obtained by Monsanto from the AVPMA (11717) to allow pigeon peas to be grown in conjunction with unsprayed cotton as a structured refuge option for Burdekin cotton growers. In each case pigeon peas were planted beside unsprayed cotton on two commercial enterprises on the two main soil types (Barratta clay and sandy alluvial) during late December and early January prior to the commencement of the wet season during 2010 and 2011. All seed was treated with group K bacterial inoculum just prior to sowing to ensure adequate colonisation of the root system with beneficial nitrogen fixing bacteria.

The refuges were monitored for *Helicoverpa* activity from the commencement of flowering (late February) and upon establishing the presence of larvae, pupae were then sampled every 2-3 weeks throughout March and April after which both the pigeon pea and cotton became unattractive in May. Pupae were sampled by digging the soil surface in the inter-row area in 3 metre quadrats. Four quadrats were taken from each plot on each occasion with the need to take additional samples being determined by the number of pupae found in the first 4 samples. Due to low numbers of pupae only the initial numbers of samples were taken at each interval in both seasons.

Observations were also made of the phenology of pigeon peas (e.g. flowering) relative to the adjacent unsprayed cotton refuges.

Refuges were subject to up to 1250 mm and 750 mm of in-crop rainfall between January and March for the 2010 and 2011 seasons respectively, exceeding the long term wet season average of 614 mm for this period.

Varietal assessment

18 cultivars were selected from a collection of 300 lines stored at the DAFF Biloela Genetic Resource centre. These varieties were selected based on earlier research conducted at Katherine NT which suggested some varieties might have a very indeterminate flowering pattern which might make them more attractive to *Helicoverpa* over a longer period. Small samples (10-20 seeds) of these varieties were treated with group K inoculum and planted on 20 December 2009. Comparisons of the flowering phenology of these varieties with the commercial cultivar Quest were made over a 6 month period after sowing.

2 varieties QPL 847 and 875 showed considerable promise were placed into a seed increase program so that commercial quantities of these varieties could be made available to growers in the future.

7.3 Results

Side by side comparisons

Very low numbers of *Helicoverpa* in the Burdekin for 2010 resulted in low levels of recruitment in the refuges and therefore meaningful comparison between the recruitment efficacy of cotton and pigeon pea are not easily made. The results of sampling are given in Table 7.1.

Table 7.1. Pupae sampling results for Pigeon Pea and Un-sprayed non-Bt Cotton (pupae/m^2 inter-row area) 2010 season.

	Clay Site		Sandy Site	
Sample Date	**Cotton**	**Pigeon Pea**	**Cotton**	**Pigeon Pea**
23 March 2010	0.00	0.00	0.16	0.08
15 April 2010	0.00	0.16	0.33	0.16
5 May 2010	0.00	0.00	0.00	0.16

2011 was also characterised by low numbers of *Helicoverpa* in the Burdekin and low levels of recruitment in the refuges. Sampling results are given in Table 6.2 and the total data pooled for pigeon pea and cotton in figure 7.1.

The pigeon pea refuges were observed to grow in a similar manner to refuges grown in other regions with excellent vigour and flowering synergy with adjacent Bollgard® crops. Below pictures of pigeon peas from the 2010 season for both soil types (Photo 7.1 & 7.2) show excellent vigour despite receiving over 1000 mm of rain.

Table 7.2. Pupae sampling results for Pigeon Pea and Un-sprayed non-Bt Cotton (pupae/m^2 inter-row area) 2011 season.

	Clay Site		Sandy Site	
Sample Date	**Cotton**	**Pigeon Pea**	**Cotton**	**Pigeon Pea**
15 March 2011	0.08	0.42	0.00	0.00
30 March 2011	0.33	0.92	0.08	0.25
14 April 2011	0.00	0.00	0.00	0.00
28 April 2011	0.25	0.25	0.42	0.33

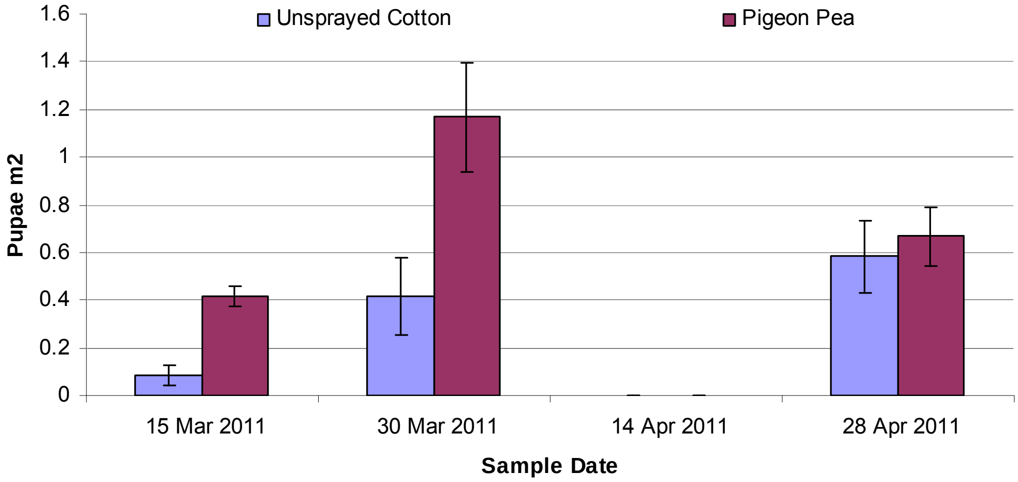


Figure 7.1. Pooled data for mean *Helicoverpa* spp. abundance (pupae per m2) for pigeon pea and cotton 2011. Error bars denote s.e.

Photo 7.1 Pigeon pea refuge grown on heavy clay soil sown on 20 December 2009. Photo taken late March 2010. Total in crop rainfall 1162 mm (Jan–Mar).

Photo 7.2 Pigeon pea refuge grown on sandy loam soil sown on 4 January 2010. Photo taken late March 2010. Total infield rainfall 1233 mm (Jan–Mar).

Varietal assessment

The flowering results of the 18 varieties are given in table 6.3. Of the cultivars tested QPL 847, 875, 941 and Quantam had the best flowering synchrony with cotton commencing flowering within a 10 days of cotton first flower (generally 45-50 DAS) and extending until the end of May well past the last effective flower date for cotton in the Burdekin. Quest in comparison flowered within 53DAS but had a shorter total flowering period (43 days) and fell short of the final flowering of commercial cotton crops by 1-2 weeks. This variety did set a large number of pods and it could be presumed that in a year with some more typical insect pressure that it might have a more extended flowering period. It would appear from this trial that more indeterminate varieties such as those identified might have greater flexibility and flowering synchrony within the Burdekin environment.

During attempts to increase the seed of QPL 847, 875, 941 and Quantam, QPL 875 and 847 have proven to have the most robust and uniform in growth habit. These two varieties were placed into a commercial seed increase and after a recent grain harvest will be available for Burdekin growers to use for the 2012/13 season (Photo 7.3).

Photo 7.3 Pigeon pea cultivar 847 in seed increase planting at the Ayr Research Station April 2012.

Table 7.3. Flowering phenology for pigeon pea varieties assessed under Burdekin conditions.

Variety	Time Until First Flowering (DAS)	Cessation of Flowering (DAS)	Flowering Period
ICPL 4		Did not germinate	
Hy3C		Did not flower	
Pusa agetti	53	81	28
QPL 717	53	81	28
QPL 687	53	81	28
QPL 753	53	81	28
QPL 892	60	96	36
QPL 1003	60	96	36
QPL 67	60	96	36
QPL 929	60	96	36
Quest	53	89	43
QPL 968	67	131	64
QPL 574	60	131	71
QPL 914	60	138	78
Quantam	60	138	78
QPL 875	67	153	86
QPL 847	60	153	93
QPL 941	60	153	93

7.4 Conclusions

Low *Helicoverpa* spp. recruitment prevented a more meaningful comparison of refuge productivity. However, from an agronomic viewpoint pigeon peas grew well during two "wetter than average" seasons in the Burdekin and remained attractive for the period for which Bollgard cotton flowered in March and April. Pigeon peas grew well on both sandy and heavy clay soil types during and after the wet season and with the exception of weed management presented no obvious additional agronomic risks compared to refuges of un-sprayed Roundup Ready Flex cotton. Acceptable weed management was achieved with the post-emergence application of Haloxyfop (Verdict 520®) at 100 mL/Ha and Metribuzin (Mentor®) 470 g/ha for grass and broadleaf weeds. Pigeon pea was advantageous in that no nitrogenous fertilisers (which might be subject to environmental loss during the wet season) were required. An assessment of alternate cultivars suggests that there are potentially better, more indeterminate plant types than Quest which may prove advantageous in being attractive to *Helicoverpa* for a period that extends well after the last effective flower stage of Bollgard cotton crops. This growth characteristic may also serve the purpose of being an embedded trap crop at season's end.

Based on the observed ability of pigeon peas to grow un-impeded during extended wet weather conditions often experienced in the Burdekin post-plant, a recommendation was made to the Monsanto and the AVPMA s that pigeon pea be included as a refuge option for the Burdekin Bowen Basin RMP as per the conventions used in other cotton production regions. This amendment was accepted and approved by the AVPMA in July 2012.

A key recommendation given the wet weather risk to the establishment of all crops in the Burdekin during December and January it that pigeon pea refuges be sown anywhere up to 14 days BEFORE any Bollgard cotton to ensure that the correct area of refuge is planted. At the very least pigeon peas should be planted prior to any cotton being sown. Given the sensitivity of pigeon pea varieties to daylength an earlier sowing in December will just extend the pre-flowering period resulting in a larger more robust plant by the time flowering commences in March. A suitable seed inoculant treatment (group K) must be used on all pigeon pea seed according to usual best practice to ensure effective root system colonization by nitrogen fixing *Rhizobium* bacterium.

8.0 Insect Pests in the Burdekin

8.1 Insect management Overview

A range of insect pests were observed on cotton crops both commercially and in the research trial plots. Within this pest spectrum was the Solenopsis mealybug, an exotic mealybug species not previously observed in cotton in Australia. This project was the first to identify that this pest would be extremely difficult to manage with insecticides and that a range of naturally occurring predators could provide acceptable levels of control provided that an integrated pest management program is adopted and the use of broad spectrum disruptive insecticides is avoided.

Table 8.1 Insect pests recorded on cotton in the Burdekin region between 2007 and 2012.

Principal pests	**Susceptible crop stage**	**Other comments**
1. Green vegetable bug, *Nezara viridula*	FF - 60% Open bolls	Often appear at the end of wet season in late March as surrounding weeds dry out and weedy summer fallow fields are prepared for sugarcane planting
2. Red Banded shield bug, *Piezodorus hybneri*	FF - 60% Open bolls	As above
3. Cluster caterpillar, *Spodoptera litura*	FF - Cut-out	Often active during wet season and until May. Larvae are generally non-damaging until FF after which flower feeding can result in losses.
4. Aphids, *Aphis gossypii* & *Myzus persicae*	FF - defoliation	Often active at the end of wet season with peach aphids becoming more prevalent late Autumn. Natural enemies have generally provided effective control.
5. Mealybug, *Solenopsis solani*	All season	A new pest in the Burdekin. Most common in back to back cotton fields or in weedy pre-plant fields, although regularly found in fields following sugarcane and no prior cotton history.
6. Redshouldered leaf beetle, *Monolepta australis*	Squaring - cut-out	Very common during wet season. Often appears overnight after rainfall. Generally declines in abundance after March.
Occasional/possible future pests		
1. *Helicoverpa* spp.	FF - Cut out	Particular attention should be paid during the transition from wet season to dry as Bt expression may temporarily lapse in crops under stress.
2. Silverleaf whitefly – *Bemesia tabaci*	FF - 60% open	Often more common April onwards as surrounding weeds dry off. Control has not generally been needed and the parasitoid *E. hyartii* is generally very active.
3. Mirids, *Creontiades* spp.	Squaring - Cut out	Have been very uncommon
4. Pale cotton stainer, *Dysdercus sidae*	FF - 60% open	Have been uncommon. Typically seen from late April onwards.
5. Spider mites – *Tetrancychus* spp.	FF - 60% open	Generally seen during the first month of dry weather
6. Cotton harlequin bug, *Tectocoris diophthalmus*	FF - 60% open	Commonly found in Burdekin cotton crops but not at levels of economic significance.

Green vegetable and redbanded shield bugs

Major pests of cotton in the Burdekin in some seasons, these two insects also affect grain legume crops such as soybeans and mungbeans and are very difficult to control within cotton IPM programs because:

- **Shield bugs can rapidly infest a crop and reach threshold levels within a few days**. Infestations tend to occur at the end of the wet season as the ‘drying off’ of surrounding weeds and bushland causes bug populations to immigrate and concentrate in alternate attractive host plants such as cotton crops.

- **Peak cotton attractiveness coincides with the pest's migration pattern**. Bugs feed on the seeds within the developing bolls. Cotton is therefore at its most attractive and susceptible stage during the first phase of the dry season.

- **The threshold for green vegetable bugs is very low** (0.3-1 bugs per linear metre crop row). In crops already compensating for weather-related fruit losses, the threshold may be even lower. In the Burdekin climate these pests have also been found to occasionally transmit boll-rotting fungi, which may exacerbate damage potential. A threshold for red banded shield bugs is not known at this time but would be expected to be similar although a higher number may be tolerated given the much smaller size of this species compared to green vegetable bugs.

- **Sampling can be time-consuming.** Bugs can be difficult to detect and can have a clumped distribution. Beat-sheet sampling provides an adequate compromise between the time required for sampling and accuracy.

- **There are no rapidly effective biological control agents for shield bugs**. Two wasp parasitoids, *Trissolcus basalis* and *Trichopoda giacomellii* are both established in the Burdekin but generally work to reduce overall population densities of green vegetable bugs in the broader environment rather than providing immediate within-field biological control. In other words crop infestations may be less frequent due to the activity of these parasitoids but once threshold levels of green vegetable bugs have been identified the only course of action is typically insecticide control.

- **No 'soft option' or selective insecticide options are available** for shield bugs (at the time of writing). The only registered products that provide good efficacy, such as clothianidin, carbaryl and pyrethroids, are all broad spectrum and can lead to flaring of secondary pests. The addition of salt at 1kg/ha can assist efficacy and reduce the quantity of active ingredient required. See the most recent Pest Management Guidelines for more details.

- **Both the nymphs and adults stages of these pests are damaging to the crop**.

Photo 8.1 Green vegetable bugs

Photo 8.2 Red banded shield bug

Cluster caterpillar

Spodoptera is a common pest of Burdekin cotton crops, encountered from early squaring until cut-out but generally most abundant during the wet season and the first months of the dry. Unlike most cotton caterpillar pests, *Spodoptera* have a natural degree of tolerance to the Cry1AC and Cry2AB toxins in Bollgard II cotton varieties.

Spodoptera usually feed on crop foliage, but when in sufficient numbers (>2/m row) have been observed to cause significant damage, particularly to flowers and early bolls. *Spodoptera* rarely damage buds during early squaring and are generally only of concern for 3-6 weeks after first flower.

Population densities can be readily assessed with a beat sheet. Only 3rd instar larvae onwards should be counted as a high proportion of very small larvae (less than 10 mm) will not survive exposure to Bollgard II cotton. Late squares, flowers and early bolls should be also checked for caterpillar damage when considering whether control is necessary. There are no established thresholds for *Spodoptera* on cotton, however anecdotal experience from Burdekin crops suggests that more than 2-3 medium larvae per linear metre of crop row combined with chewing damage on flowers maybe sufficient to warrant control.

Indoxacarb at 200mL/ha has been found to be highly efficacious for *Spodoptera* control in the Burdekin.

Photo 8.3. *Spodoperta* egg raft

Photo 8.4. *Spodoptera* larvae

Aphids

Aphids can be a major but somewhat sporadic pest of cotton in the Burdekin, generally appearing after the onset of drier weather in March. Both the cotton aphid, *Aphis gossypii* and green peach aphid, *Myzus persicae* are found in the Burdekin as pests of a number of horticultural crops and cotton. In horticultural crops, aphids are key vectors for the transfer of a number of viral diseases that drastically reduce yield and quality. For this reason aphids are heavily targeted by horticultural producers and high levels of resistance to conventional insecticides (pirimicarb and dimethoate) may be encountered in Burdekin aphid populations.

Aphids feed on phloem tissues and penetration of leaves with their stylets (mouth parts) can cause damage. Further, as they are feeding on carbohydrate-rich phloem sap they in turn excrete a sugary substance called honeydew. In cotton, feeding damage from severe aphid infestations can cause leaf distortion and reduced photosynthesis, sooty moulds may also grow on honeydew deposits on leaves, further reducing photosynthesis. However the biggest threat is honeydew contamination of cotton lint. Cotton aphid is also a vector for the disease Cotton Bunchy Top, but this has not been recorded in the Burdekin.

Aphids have rarely caused economic damage in Burdekin crops to date, primarily due to high levels of predator and parasitoid activity in most crops, however standard industry control thresholds for aphids may be too high for the Burdekin particularly in April when day length and effective radiation are decreasing. Control should be considered if more than 50% of plants are infested *AND* natural enemies are not abundantly present or if honey dew levels are increasing when open bolls are present and threaten lint contamination.

Good control of cotton volunteers and ratoon plants between seasons (cultural control and farm hygiene) will reduce the survival of this pest between cotton crops.

Mealybugs

The solenopsis mealybug, *Solenopsis solani* is an exotic pest first encountered in Australian cotton crops both in the Burdekin and the central Highlands during 2009. This pest has been responsible for major economic losses in cotton in Pakistan and India. It is not known how this pest entered Australia but since its initial detection it has been found to be widely spread from Darwin in the Northern Territory and throughout eastern Queensland, with moderate to severe outbreaks in 2009 Burdekin crops and 2010 Central Highland crops.

As a new pest, little was known about its impact on cotton or appropriate control measures and thresholds. *Solenopsis* is thought to enter cotton fields at any stage during crop production from populations on alternate hosts, or be transported via overland water flow, wind or the movement of machinery and people. Once established they produce large quantities of honeydew which can contaminate lint and reduce photosynthetic function of the leaves. Early infestations can cause reduced plant vigour, stunting and even death. Late crop stage infestations are less severe but can present a lint contamination risk.

Mealybug were found to commonly occur first in field margins (particularly beside weedy areas) but could later spread throughout the field. Pest abundance can often be characterised by 'hot spots' where mealybug presence is very high and plants are badly stunted. This pest was observed to congregate on the main stem or structural joints such as leaf petioles or where the pedicel joins the boll, and observations suggest that small colonies of densely packed individuals appear to be a pre-cursor to a more severe outbreak. A future threshold may therefore consider not only the presence of absence of this pest but its rate of change and population characteristics.

Photo 8.5 A plant badly infested with mealybug and a close up of Mealybug infesting the base of a cotton boll (right).

At the time of writing there are no registered insecticide control options for *Solenopsis* mealybug and research is currently underway. The most effective control methods to date have been on-farm hygiene and avoidance of broad spectrum insecticide usage to allow the unimpeded activity of various natural enemies whose impact can be significant.

Fields that were weedy prior to planting or had populations of ratoon cotton were more likely to have mealybug hot spots emerge during the following season. Local growers were advised to remove all cotton volunteers and ratoon plants in fields used for annual cotton production to minimise population carry-over between cotton seasons. Also control alternate broadleaf weed hosts such as black pigweed and vines which are common in the Burdekin.

A complex of predators were observed to provide effective biological control of *Solenopsis* in Burdekin cotton crops. These predators included lacewings, lady birds, earwigs and endemic cockroaches (no parasitoids have yet been observed). The most abundant predators were lady birds *Harmonia octomaculata* and *Cryptolaemus montrouzeri*, green lacewing, *Mallada signatus*, and the Australian arboreal cockroach, *Ellipsidion australe.*

After the 2009 outbreak, *Solenopsis* have been managed effectively in the Burdekin through the deployment of good on farm hygiene and avoidance of broad spectrum insecticide use, particularly before boll setting. This has generally allowed natural enemies to establish and exert effective levels of biological control. By the time that broad spectrum insecticides have been used on pests such as stink bugs, the levels of mealybugs present have been low enough so as to not build back up to problematic levels before defoliation.

Photo 8.6 *Cryptolaemus montrouzeri* larvae feeding on solenopsis mealybug (Photo Zara Hall DAFF)

Photo 8.7 Three banded ladybird feeding on mealybug

Photo 8.8 Lacewing larvae that has camouflaged itself to look like mealybug Note the head and mouthparts

Photo 8.9 Adult lacewing

Red shouldered leaf beetles

The adult stage of red shouldered leaf beetles, *Monolepta australis* can be a pest of cotton in some seasons in the Burdekin. Swarms of beetles migrate into a crop, usually overnight and can severely defoliate patches of plants. These hot spots generally tend to look more extensive than they might really be as the damage creates a large contrast against an otherwise healthy crop canopy. Feeding beetles are thought to produce an aggregative pheromone that attracts other beetles. The damage inflicted is generally confined to the loss of leaves and hot spots typically occur around field margins. A wet season pest, the beetles become less common from March onwards. Patches of damaged crops generally fully recover and control is usually not warranted unless beetle activity is continuous, or fields are long and narrow (proportionally more field edge to overall area) and thus a greater percentage of area may be affected.

The larvae develop in the soil, where they feed on the roots of grasses and sugarcane is considered to be a host.

Photo 8.11 Red Shouldered Leaf Beetle

Photo 8.12 Damage patches

9.0 Preliminary study of runoff water quality from Burdekin cotton production systems

Summary

A sampling program was conducted to determine the possible dynamics of pesticide and nutrient movement from cotton fields in surface water runoff during 2009 and 2010. Six herbicides and three insecticides were detected mostly at trace levels. The most frequently detected compounds (Atrazine, Tebuthiuron and Diuron) were not used on cotton and were associated with previous cane or maize cropping field history. Cotton production related products detected were Fipronil, Carbaryl and Glyphosate. Imidacloprid was also detected at trace amounts in some samples although it was unclear as to whether this originated from previous usage for cane production or due to a seed dressing treatment applied to the cotton seed prior to planting.

Significant levels of nitrogen in its various forms (nitrate, nitrite and ammonia) were detected in run-off water on different occasions. The highest levels were generally associated with the application of fertiliser and the breakdown of legume cover crop residues followed by rainfall or irrigation. The potential for nitrogen to be lost from cotton cropping systems during the wet season will be an important issue for any future industry to consider from both agronomic and environmental viewpoints. Current research on nitrogen dynamics within the cotton farming system will provide guidance on future best practices.

9.1 Background

As with many agricultural industries, pesticide and fertiliser usage is an essential component of high-yielding viable cotton production systems, however, cotton's reputation for high pesticide usage is due to the dependence of conventionally grown cotton on many insecticide inputs (Fitt 1994). For this reason cotton production in the tropics with conventional production systems has been both un-reliable and un-economic (Strickland *et al.* 2003).

Recent advances in biotechnology have enabled the development of new cotton varieties that incorporate insect and herbicide tolerant traits and have enabled significant reductions in pesticide usage. The first insecticidal transgenic cotton became available in Australia in 1996 marketed as INGARD® and was based on varieties that express an endotoxin from the soil bacterium *Bacillus thuringiensis*. These varieties were replaced in 2005 with Bollgard® II technology that incorporated a stack of two bacterial based endotoxins providing a more robust basis for pest management and crops that are mostly non-susceptible to caterpillar attack (Tabashnik *et al.* 2003). The uptake of this technology by the Australian cotton industry over the last 5 years has reduced use of conventional insecticides by 75% (Naranjo *et al.* 2008). These varieties have also been engineered to be non-susceptible to glyphosate (Roundup Ready Flex™) and enables this herbicide to be applied over the top of planted crops giving excellent control of both grasses and broadleaf weeds. The ability to use over the top glyphosate applications has greatly reduced the use of soil applied herbicides such as diuron which are known to persist in the environment well after a crop is grown (Davis *et al.* 2008).

The advent of these new transgenic cotton varieties has created an opportunity to investigate cotton production in tropical regions that were previously considered unviable due to higher incidence of pests and consequent over-reliance on conventional pesticides.

In 2008 a cotton R&D program commenced in the Burdekin due to interest shown by (i) local cane producers who had identified cotton as a potentially high value break cropping option for cane, and (ii) southern growers who saw the Burdekin as a potentially drought-proof production region. However, the Burdekin has a different climate compared to existing regions where cotton has been successfully grown in Australia. It is 2°C on average too cool in winter to allow dry season production which has been successful in the Ord and summer is too wet to finish a traditional spring planted crop as would be the case in southern Australia.

Therefore, the starting point for the R&D program was to consider and assess the interaction between cotton plant physiology and the Burdekin climate to determine when and how crops might be grown and in particular to understand plant response to tropical cloudy wet weather.

A range of planting date and crop response scenarios were examined with the CSIRO OzCot model using historical weather records to identify where an optimal period for crop production might exist. This analysis suggested that a sowing window between December 20 and January 20 would be sufficient to avoid cloudy, wet conditions during flowering in the majority of years and enable high yields.

This planting window has been tested over the last 5 years, most of which have been characterised by wetter than average seasons and found to be effective with cotton being successfully grown with tailored agronomic management. However, the current run of wetter than average seasons has also demonstrated that crop management is more difficult with regard to crop operations and nutrition compared to more average or drier seasons.

Whilst necessary for crop yield potential, the planting window for cotton just prior to the wet season poses additional environmental considerations compared with dry season cropping. With a mean wet season rainfall after planting of approximately 650 mm, losses of pesticides and nutrients need to be considered, particularly as run-off volumes are often too large to be contained on farm.

The potential for nutrient and pesticide losses during the wet season have been a primary consideration for the development of agronomic practices that a future cotton industry might utilise. A prudent approach has been to identify where early crop inputs can be minimised or avoided without compromising later yield potential. Secondly, where a pesticide input might be required preference is given to products that are likely to have the least environmental impact. In this regard the use of Roundup Ready Flex™ varieties has eliminated the use of all pre-plant soil applied herbicides that have been commonly detected as contaminants in other Burdekin farm runoff studies (Davis et al 2008). Instead glyphosate, which has low non-target toxicity and minimal residual capacity, has been the only herbicide used on Burdekin cotton crops since 2007.

Similarly insecticide usage on Burdekin cotton crops has been low due to the utilisation of Bollgard II transgenic varieties. Records from crops grown since 2007 show that most crops received a range from zero to four applications of insecticide for sucking pests that were not controlled by the Bollgard® technology. Where insecticides are required local growers have agreed to not use products with a significant environmental hazard risks such as organochlorines (endosulfan) and avoid where possible organophosphates and synthetic pyrethroids (NORCOM 2007). Over three seasons of cropping growers have complied with these arrangements with no organochlorines used and very limited use of dimethoate and deltamethrin (one application to less than 20% area during 3 cropping years). The likely-hood of pesticides entering tailwater is also reduced as cotton does not become susceptible to insect attack until after the wet season when fruiting structures are being set. Therefore insecticide usage will generally be confined to the drier period from March to May. A schedule of possible pesticides and likely usage periods is given in table 9.1.

Nitrogen management has been a significant concern for cotton cropping in the Burdekin region. Due to a lack of locally-validated information on crop requirements and application timing coupled with concerns about potential for losses (leaching or de-nitrification) and different soil type interactions, many growers have taken a precautionary approach and applied large amounts of nitrogen at planting (80-250 kg/ha), and in some cases followed this with additional nitrogen side-dressing in March. This approach has been unsuccessful with growers achieving low yield responses from large up-front fertiliser applications particularly on heavy clay soils. To address this problem a trial program was commenced by CSIRO to investigate how nitrogen might be better managed from a crop response and environmental perspectives. Preliminary data from this work confirms that large applications of nitrogen at planting are not effective particularly on clay soils. Instead, data suggest that a better strategy is to use lower pre-plant application rates of nitrogen followed by side-dressing at the end of the wet season with an amount of nitrogen that considers the interim contribution from mineralising crop stubble during the wet season. Such an approach uses less nitrogen, limits the potential for early season losses and better assures availability during the critical period of flowering in March.

Table 9.1. Summary of the main pesticides that maybe used for cotton production in the lower Burdekin region with target pests, likely application timing and frequency of use.

Active ingredient	Target pest	Application window	Potential number of applications per season
Herbicides			
Glyphosate	Grass & broadleaf weed control	Dec-April	2-4
Insecticides			
Diafenthiuron	Whitefly or Aphid species	April- May	0.33
Carbaryl	*Nezara viridula* (green vegetable bug)	March-May	0.5
Clothiodan	*Nezara viridula*	March-May	1-2
Fipronil	*Creontiades dilutes* (mirids)	March April	0.33
Indoxacarb	*Spodoptera litura* (cluster caterpillar)	February-April	0.5

The primary purpose of this study was to benchmark the impact that current cotton cropping practices have on tail water quality with a view to identifying potential problems that may require improved management practices. The results presented should not be used to interpret the likely impact of a future cotton industry as the agronomic practices deployed on the study sites have not been optimised, and are under development and therefore likely to change.

9.2 Methodology

Study sites

Runoff water quality was monitored at two sites during 2009 and 2010. These sites were selected to represent alluvial and heavy clay soil types. The alluvial site was a field from which the cane in was removed in 2007 to enable the back to back production of cotton and grains (corn and mungbeans). Two separate fields were used for a clay soil comparison, each being used to grow cotton as a 6 month break crop within the typical cane cropping cycle. The agronomic operations conducted on these fields until the final irrigation is given in table 8.2.

Sample collection

Water quality monitoring was limited to manual collection of applied irrigation water and the runoff associated with these operations. Where practical several samples were taken over the duration of a tailwater runoff from a field. These were typically first flush (within 1 hour of commencement of tailwater run-off from paddocks; mid-flush and end-flush (final 1-2 hours of tailwater run-off from paddocks). During the second season collections were made where practical of surface runoff following significant rainfall events. This was done in lieu of multiple samples at each irrigation event as the standard deviation observed within each irrigation runoff event during 2009 were generally within ± 15% of the event mean. It was concluded that the collection of more samples from a greater number of run-off events over time would be more instructive for a preliminary study of this nature. Pesticide sample collections were primarily collected from the first half of an irrigation event as other studies (Milla and ACTFR, unpublished data) suggest that the majority of losses occur during this period of runoff.

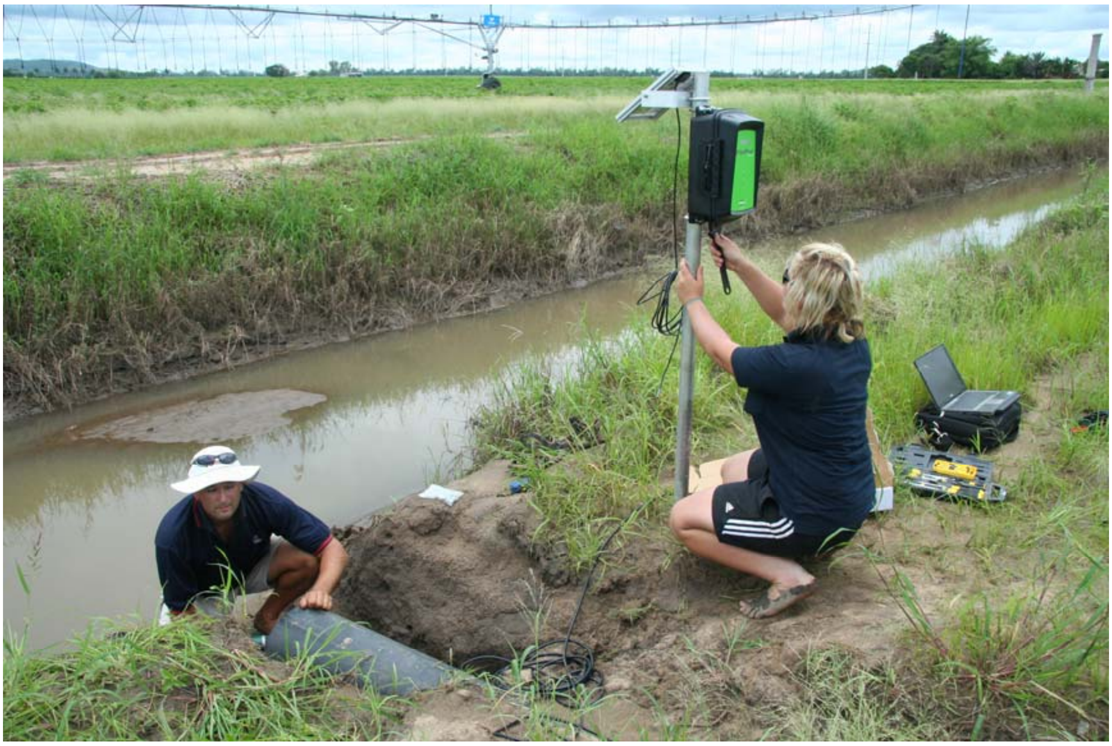


Photo 9.1 Installation of run-off monitoring equipment at the sandy field site.

Sample analysis (nutrients)

Unfiltered nutrient samples (TN) were collected in 60 mL Sarstedt polypropylene vials, with filterable nutrients filtered on-site through a syringe with sterile, pre-rinsed filter modules (Sartorius MiniSart 0.45 μm cellulose acetate) into six 10 mL Sarstedt polypropylene vials. Nutrient samples were immediately placed on ice or refrigerated upon collection and frozen within 12 hours of sampling. Water samples were analysed at the Australian Centre for Tropical Freshwater Research laboratory (James Cook University). Samples for TN were digested in an autoclave using an alkaline persulfate technique (modified from Hosomi and Sudo, 1987) and the resulting solution analysed for NOX-N by segmented flow auto-analysis using an ALPKEM Flow Solution II. The analyses for NOX-N (nitrate and nitrite) and ammonia were also conducted using segmented flow auto-analysis techniques following standard methods (APHA, 2005). Particulate nitrogen concentrations were estimated by the subtraction of the total filterable nitrogen concentrations from the total nitrogen concentrations. Similarly, dissolved (filterable) organic nitrogen (DON) was estimated by the subtraction of NOX-N and ammonia from the TFN concentration.

Table 9.2. Farm management events for period of runoff water quality monitoring.

Site	Event	Rate
2009 Clay Soil, Hall Farming Enterprises, Clare		
22 December 2008	Cotton Sown	
23 December 2008	Fertiliser blend applied (at planting)	220 N, 40P, 80K, 30S & 4Zn (kg/ha)
15 January 2009	Glyphosate application	1.035kg/ha ai
24 February 2009	Glyphosate application	1.035kg/ha ai
15 March 2009	Dunder application	70 N (kg/ha)
21 March 2009	Irrigation	1.3ML
18 March 2009	Glyphosate application	1.035kg/ha ai
7 April 2009	Carbaryl application	1.05L/ha
8 April 2009	Irrigation	1.1ML
22 April 2009	Irrigation	1.3ML
2009 Alluvial soil, Dongamere Farming corner of Dearness and Clare Rd		
11 January 2009	Cotton sown	
20 January 2009	Sulphate Ammonia application	40N (kg/ha)
21 January 2009	Glyphosate application	1.035kg/ha ai
29 January 2009	Sulphate Ammonia application	48 N (kg/ha)
3 March 2009	Glyphosate application	1.035kg/ha ai
10 March 2009	Fipronil application	0.065mL/ha ai
20 March 2009	Irrigation	1.1ML/ha
24 March 2009	Indoxacarb application	0.610mL/ha ai
28 March 2009	Irrigation	1.1ML/ha
6 April 2009	Glyphosate application	1.035kg/ha ai
9 April 2009	Irrigation	1.1ML/ha
1 May 2009	Irrigation	1.1ML/ha
21 May 2009	Irrigation	1.1ML/ha
2010 Clay Soil, Hatch Farming, Mulgrave Rd Clare		
15 October 2009	Mungbean cover crop sown	
15 December 2009	Fertiliser applied (pre-planting)	180 N, 40P, 80K, 30S & 4Zn (kg/ha)
17 December 20009	Pre-plant Paraquat application.*	0.375kg/ha ai
20 December 2009	Cotton Sown	
26 December 2009	Irrigation	0.6ML
22 January 2010	Glyphosate application	1.035kg/ha ai
20 February 2010	Glyphosate application	1.035kg/ha ai
24 February2010	Side-dress Urea drilled into centre of bed	70 N (kg/ha)
9 March 2010	Indoxacarb application	0.06kg/ha ai
10 March 2010	Irrigation	0.5ML
1 April 2010	Irrigation	0.5ML
10 April 2010	Irrigation	0.5 ML
16 April 2010	Irrigation	0.5ML
2010 Alluvial soil, Dongamere Farming corner of Dearness and Clare Rd		
19 December 2009	Fertiliser blend applied	180 N, 10P & 50K(kg/ha)
11 January 2010	Glyphosate application	0.9kg/ha ai
15 January 2010	Cotton Sown	
3 February 2010	Glyphosate application	1.035kg/ha ai
24 February 2010	Direct drill side dress Urea fertiliser	160 N/ha
16 March 2010	Irrigation	0.2 ML/ha
30 March 2010	Glyphosate application	Applied to field drains perimeter including fluming
31 March 2010	Irrigation	0.15 ML/ha
8 April 2010	Irrigation	0.25 ML/ha
15 April 2010	Indoxacarb application	0.06kg/ha ai
23 April 2010	Irrigation	0.4 ML/ha
7 May 2010	Clothianidin application	0.05mL/ha ai
13 May 2010	Irrigation	0.6 ML/ha

*to kill standing mungbean cover crop.

Sample analysis (pesticides)

One litre amber glass bottles, supplied by the Queensland Health and Forensic Scientific Services (QHFSS) laboratory, were used to collect pesticide samples which were kept refrigerated (4°C) and couriered to the QHFSS laboratory in Brisbane, Queensland for analysis. The water samples were analysed by liquid chromatography mass spectrometry (LCMS) and gas chromatography mass spectrometry (GCMS) at the National Association of Testing Authorities accredited

QHFSS Laboratory. Organochlorine, organophosphorus and synthetic pyrethroid pesticides, urea and triazine herbicides and polychlorinated biphenyls were extracted from the sample with dichloromethane. The dichloromethane extract was concentrated prior to instrumentation quantification by GCMS and LCMS (QHFSS method number 16315). Phenoxyacid herbicide water samples were acidified and extracted with diethyl-ether. After evaporation and methylation (methanol, concentrated sulfuric acid and heat) the samples were extracted with petroleum ether and analysed by GCMS (QHFSS method number 16631). Glyphosate and AMPA were extracted in water, derivatised and analysis conducted by LC-MS/MS, QHFSS, (In House method QIS26601).

9.3 Results

Nitrogen runoff monitoring

2009 Clay site

Three irrigation events were monitored for nutrient concentrations in both the applied irrigation water and tailwater draining from the field. Figure 9.1 depicts the total nitrogen concentrations in the applied irrigation water (single value), as well as the mean and standard deviation values associated with the multiple run-off samples collected during each irrigation event. The source water had detectable levels of total nitrogen around the 500-900 μg/L range which was higher than expected and most probably due to a proportion of this water being sourced from the on farm tailwater re-circulation system. The high tailwater reading of 6916 μg/L on the first irrigation after the wet season cooincides with the application of dunder to the inter-row space between the beds by the grower on 15 March. This application delivered the equivalent of 70 kg/N per ha over the site and is the likely cause for the elevated levels observed during the first irrigation that continued albeit at much lower levels for the remaining crop irrigations.

2009 Alluvial site

Four irrigation events were monitored on the alluvial site for nutrient concentrations in applied irrigation water and tailwater draining from the field. Figure 9.2 depicts the total nitrogen concentrations in the applied irrigation water (single value), as well as the mean and standard deviation of nitrogen values associated with the multiple run-off samples collected during each irrigation event. Notably the inflow water sourced from the farm bore had consistently high levels of total nitrogen. These levels were very high compared to the clay site which used river water via the channel delivery system, but were consistent with other studies that have shown elevated nitrogen levels in Burdekin groundwater supplies due to the leaching of fertilisers into the underlying aquifer (Thorburn *et. al.* 2003 & Weir 1999).

The higher total nitrogen levels recorded in tailwater compared to the source water during the first two irrigations suggest losses of nitrogen from the application of sulphate of ammonia to the field during early March with a fertiliser spreader followed by inter-row cultivation for partial incorporation.

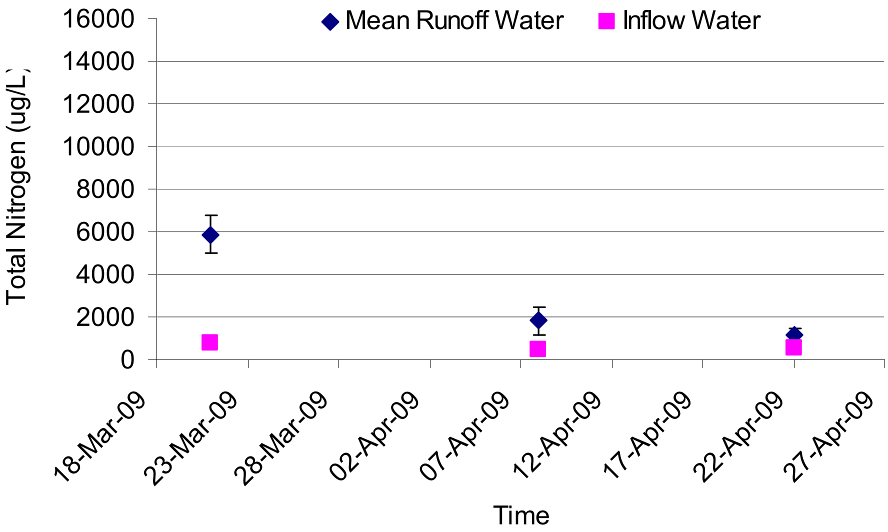


Figure 9.1. Total nitrogen present in both inflow and runoff water for the clay site 2009.

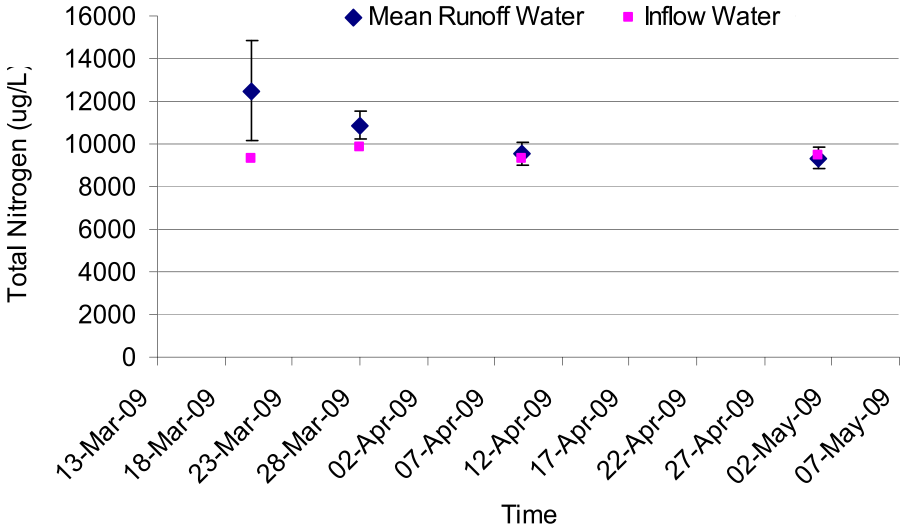


Figure 9.2. Total nitrogen present in both inflow and runoff water for the alluvial site 2009.

2010 Clay site

Runoff from major rainfall events during late January and mid February were monitored as well as ensuing irrigations during autumn. Figure 9.3 depicts the total nitrogen concentrations from both rainfall and irrigation runoff over the course of the cotton crop. The runoff values recorded during January and February are associated with significant rainfall events. The levels of nitrogen particularly in the January measurements were very high (>50000 µg/L) for the first two days of rainfall before then declining over the remaining 2 days of the first major rain event. A further reduction in nitrogen concentration in runoff was observed during a second period of wetter weather in February. A mungbean cover crop that had been grown and sprayed out just prior to planting cotton and left as standing stubble decayed rapidly in January with little stubble remaining by February. During the irrigation events the level of nitrogen found in runoff water was the same as that of the source water applied. The elevated nitrogen levels in the source water for the final irrigation is probably due to the water being drawn from a re-circulation pit that had drained an adjacent field days earlier which had been planted to a cover crop of soybeans and then planted to cane.

2010 Alluvial site

The water sourced from a bore at the same alluvial site continued to have elevated total nitrogen levels in the range of 8000-10000 µg/L. Similarly to the clay site, the level of total nitrogen recorded in rainfall runoff spiked during the initial January rain event, but unlike the clay site tailed off more quickly with much lower levels recorded during the last 2 days of the four day rain event and similar low levels recorded again in February (Fig 9.4). During the irrigation events the level of nitrogen found in runoff water was similar to that of the source water applied. This differs from the previous year where tailwater levels were 1000 µg/L higher than the source water indicating field losses for the first irrigation after side-dressing. The practice difference in the second season was the direct drilling of urea directly into the bed instead of sulphate of ammonia that was broadcast over the field and partially incorporated with inter-row cultivation.

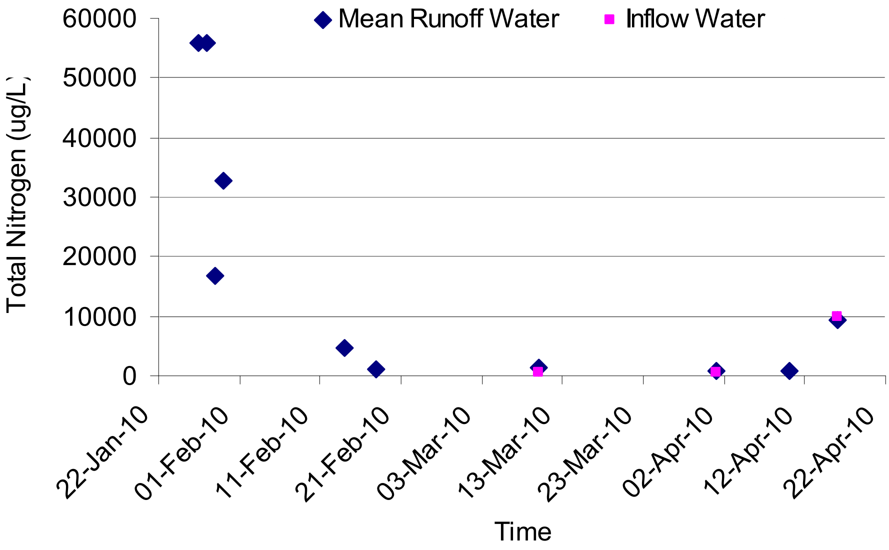


Figure 9.3. Total nitrogen present in both inflow and runoff water for the clay site 2010.

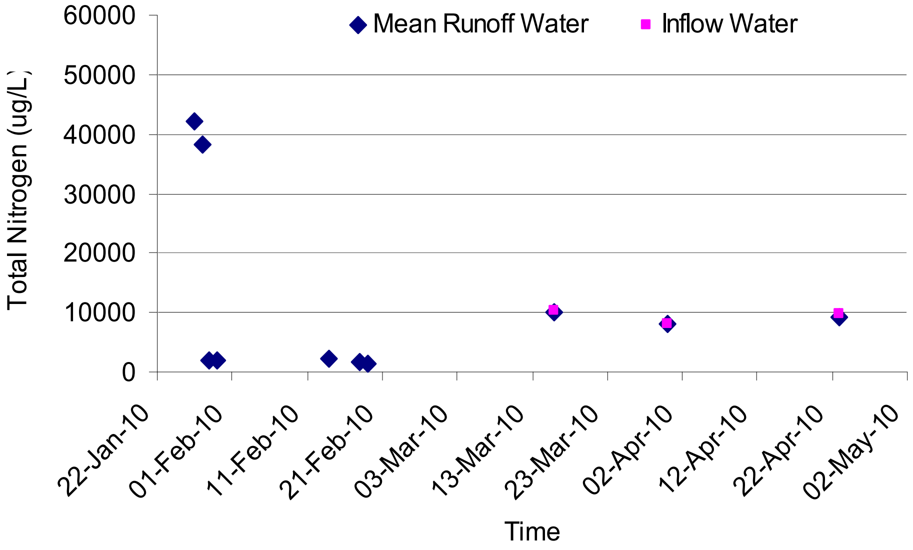


Figure 9.4. Total nitrogen present in both inflow and runoff water for the alluvial site 2010.

Pesticide monitoring

The pesticides recorded from the clay and alluvial sites are summarised in table 9.3. All of the herbicides detected with the exception of gyphosate were associated with previous cane or maize cropping activities and demonstrate the residual characteristics of some soil-applied herbicides particularly products such as atrazine, diuron, metolachlor and tebuthiuron, which were consistently found at trace levels in nearly all runoff samples throughout the study. Diuron was also evident in the source water taken from the bore from the alluvial site at Dongamere Farming on the corner of Clare and Dearness Roads. The trace levels of diuron recorded in the source water at this site like the elevated nitrogen levels suggest that leaching of both fertilisers and chemicals is a problem on alluvial soil types that overly the relatively shallow aquifer system.

Glyphosate was found at trace levels on several occasions at all sites. These measurements were generally associated with recent over the top applications of Roundup Ready™ herbicide to the cotton crops. Generally glyphosate was non-detectable in tail water by the time a second irrigation was applied. The highest recording (glyphosate (83 μg/L), taken from the alluvial site in 2010 on 31 March, correlated with a field border spraying event the previous day whereby the fluming and field end and drains were treated with RoundUp CT® for the control of weeds. The level of glyphosate was markedly lower by the following irrigation on 23/4/10 at (1.2 μg/L) which is similar to other recordings. All herbicide levels recorded were at concentrations below risk guidelines identified for human health and Great Barrier Reef Marine Park Protection Authority ecosystem protection guidelines (Table 9.4).

Trace level concentrations of insecticides were recorded infrequently in tailwater collected throughout the study. The exception to this was the recording of carbaryl at (42 μg/L) on 8 March 2009 on the clay site. This irrigation followed an application of carbaryl to the crop the previous day for the control of *Nezara viridula*, green vegetable bugs. Whilst no GBRMPA guidelines exist for carbaryl the level recorded exceeded human health guidelines by 12 μg/L. Levels of carbaryl went on to be non-detectable for water sampled from the second irrigation after this pesticide application.

Imidacloprid was recorded in tailwater from each of the sites during the study. The source of this chemical is uncertain as it is commonly used for cane beetle control in cane but was also applied as a seed coating treatment for the cotton seed sown. In either case the levels recorded were at trace levels and guidelines for this product are non-specific.

Table 9.3. Pesticide concentrations in source and tail water 2009

Site	Sample date & type	Pesticide & Concentrations
2009 Clay Soil, Hall Farming Enterprises, Clare		
	Inflow water	**Run off water**
21 March 2009	Tebuthiuron (0.03 µg/L)	Atrazine (0.05 µg/L) Diuron (0.02 µg/L) Tebuthiuron (0.02 µg/L) Metolachlor (0.19 µg/L) Glyphosate (1.6 µg/L) Imidacloprid (0.05 µg/L)
8 April 2009	Tebuthiuron (0.03 µg/L)	Atrazine (0.04 µg/L) Diuron (0.03 µg/L) Tebuthiuron (0.02 µg/L) Metolachlor (0.16 µg/L) Carbaryl (42 µg/L) Imidacloprid (0.04 µg/L)
22 April 2009	Tebuthiuron (0.04 µg/L) Atrazine (0.02 µg/L)	Atrazine (0.04 µg/L) Diuron (0.01 µg/L) Tebuthiuron (0.02 µg/L) Metolachlor (0.11 µg/L) Imidacloprid (0.05 µg/L)
2009 Alluvial soil, Dongamere Farming corner of Dearness and Clare Rd		
	Inflow water	**Run off water**
20 March 2009	Atrazine (0.04 µg/L) Diuron (0.09 µg/L)	Atrazine (0.08 µg/L) Diuron (0.07 µg/L) Fipronil (0.2 µg/L) Imidacloprid (0.21 µg/L)
28 March 2009	Atrazine (0.05 µg/L) Diuron (0.08 µg/L)	Atrazine (0.05 µg/L) Diuron (0.01 µg/L) Imidacloprid (0.11 µg/L)
9 April 2009	Atrazine (0.04 µg/L) Diuron (0.08 µg/L)	Atrazine (0.04 µg/L) Diuron (0.04 µg/L) Imidacloprid (0.06 µg/L)
1 May 2009	Not sampled as no chemical use had occurred since March.	
2010 Clay soil, Hatch Farming, Mulgrave Rd Clare		
	Inflow water	**Run off water**
27 January 2010	Rainfall	Atrazine (0.08 µg/L) Diuron (0.05 µg/L) Hexazinone (0.06 µg/L) Glyphosate (1.2 µg/L)
15 February 2010	Rainfall	Atrazine (0.07 µg/L) Diuron (0.03 µg/L) Hexazinone (0.03 µg/L) Glyphosate (1.7 µg/L)
10 March 2010	Glyphosate (0.6 µg/L)	Atrazine (0.06 µg/L) Diuron (0.08 µg/L) Hexazinone (0.03 µg/L) Glyphosate (1.8 µg/L)
1 April 2010	No- detectable	Atrazine (0.02 µg/L) Diuron (0.01 µg/L) Glyphosate (1.2 µg/L)
10 April	Not sampled as no chemical use had occurred since early March.	
16 April	Not sampled as no chemical use had occurred since early March.	
2010 Alluvial soil, Dongamere Farming corner of Dearness and Clare Rd		
	Inflow water	**Run off water**
27 January 2010	Rainfall	Atrazine (0.26 µg/L)

Site	Sample date & type	Pesticide & Concentrations
		Diuron (0.02 µg/L) Prometryn (1.2 µg/L) Glyphosate (12 µg/L) Imidacloprid (0.85 µg/L)
29 January 2010	Rainfall	Atrazine (0.11 µg/L) Diuron (0.02 µg/L) Prometryn (0.58 µg/L) Glyphosate (2.1 µg/L) Imidacloprid (0.82 µg/L)
18 February 2010	Rainfall	Atrazine (0.1 µg/L) Diuron (0.02 µg/L) Prometryn (0.11 µg/L) Glyphosate (<0.5 µg/L) Imidacloprid (0.49 µg/L)
16 March 2010	Diuron (0.02 µg/L)	Diuron (0.02 µg/L) Prometryn (0.11 µg/L) Imidacloprid (0.31 µg/L)
31 March 2010	Tebuthiuron (0.02 µg/L) Glyphosate (4.1 µg/L)	Tebuthiuron (0.02 µg/L) Glyphosate (83 µg/L) Imidacloprid (0.15 µg/L)
23 April 2010	Diuron (0.02 µg/L)	Glyphosate (1.2 µg/L) Imidacloprid (0.12 µg/L)

Table 9.4. Existing water quality guidelines identifying risks to drinking water and aquatic ecosystems.

Chemical	Drinking water[a] (µg/L)	GBRMPA ecosystem protection[b] (µg/L)
Atrazine	40	0.6
Ametryn	50	0.5
Diuron	30	0.9
Glyphosate	1000	N/A
Hexazinone	300	1.2
Metolachlor	300	N/A
Prometryn	N/A	N/A
Tebuthiron	N/A	0.02
Carbaryl	30	N/A
Fiprinol	0.7	N/A
Indoxacarb	N/A	N/A
Imadocloprid	N/A	N/A
Clothianidan	N/A	N/A

a NRMMC (2009) Drinking Water Guideline Values;
b GBRMPA (2009) Water Quality Guidelines for the Great Barrier Reef Marine Park.

9.4 Discussion

These results from this study should be viewed as preliminary on the basis that measurements were taken during wetter than average seasons and from crops where the agronomic management practices used have later changed in response to evolving R&D that has identified better practices. Despite this caveat, this study did highlighted two aspects that are of critical importance to a future Burdekin cotton industry. First is that the potential for nitrogen losses are significant during the wet season and therefore strategies that overcome this challenge will be pivotal to the success of a future industry from both environmental and cost of production viewpoints. Secondly, data shows that applied insecticides and herbicides have the potential to enter runoff water and therefore the use of transgenic varieties which virtually eliminate the use of soil applied herbicides and very much reduce insecticide usage is of critical importance to a future cotton industry in a climate that can be conducive to losses and is in close proximity to sensitive wetland and marine receiving environments. The environmental footprint of a future industry will depend on the maintenance of effective transgenic technologies and therefore industry stewardship and adherence to pest resistance management strategies is of fundamental importance. The alternative of growing cotton conventionally with a high dependence on pesticide inputs is unlikely to be acceptable in the Burdekin environment.

The pesticide levels recorded in run-off samples were mostly at trace levels and well below guidelines for human health and ecological protection. The use of carbaryl within 24 hours of commencing irrigation is the likely cause of the only pesticide level recorded that was above these guidelines at the clay site in 2009. However, these guidelines are intended for drinking water or the quality of water at the point of receival within a sensitive environment rather than the end of a field where these measurements were taken. Therefore, tailwater concentrations are likely to be significantly diluted in most cases before reaching local water courses. Nonetheless this event highlighted the scope for pesticides to move off-farm if not managed properly. In this case field tail water entered a recirculation pit where it was contained on farm. Avoiding the application of pesticides just prior to irrigation would also be a prudent best management practice that may have been beneficial in this instance.

This study has shown the potential for significant losses of nitrogen to occur from cotton fields particularly during the early stages of the wet season soon after planting. The practice during the first three years of production in the Burdekin (in the absence of alternate information) was for growers to apply the total nitrogen requirement of a crop (200-250 kg/ha) at planting. This approach has been particularly popular for heavy clay soils where the risks of being unable to apply a later more timely side-dressing due to wet weather has been a valid concern. A fundamental problem with this approach is that crops planted from late December till mid-January have limited physiological capacity to utilise large quantities of applied nitrogen before wet season losses take place. The result has been crop nitrogen deficiency soon after the commencement of flowering, (the time when nitrogen uptake is critical) resulting in low crop yields. The potential for wet season losses (particularly exacerbated during the recent run of wetter than average seasons) is a distinct challenge for a future Burdekin industry and represents a significant departure in practice compared to southern Australia where pre-plant nitrogen application is commonplace. More recent research conducted since 2010 by Dr Stephen Yeates has demonstrated that an approach whereby the amount of nitrogen applied up front is significantly reduced (30-40% of total nitrogen) and instead the bulk of a crops requirement is applied later in the season just prior to flowering is likely to offer significant improvement in terms of minimising nitrogen losses.

This approach has been since demonstrated to better target nitrogen availability with the commencement of crop flowering and also coincide with a likely decrease in rainfall and associated risk of loss. This strategy was partly utilised at both monitoring sites for 2010 where

150-180 kg/ha of nitrogen at planting and then followed with a second application later in the season to provide a total of 250-300kg/ha. Whilst >250kg/ha appears high for cotton production, this was deemed at the time to be the most prudent approach until better information for managing nitrogen could be developed and the risks of deficiency observed during the 2008 and 2009 avoided. In the case of the clay site a mungbean cover crop was also grown prior to the cotton crop to act as a slower release source of nitrogen from the standing stubble during the wet season.

The concentrations of nitrogen recorded in tailwater collected after the initial large rain events of the 2010 wet season at both sites suggest that significant losses of the pre-plant applied fertiliser occurred during the first 2 days of rainfall before rapidly tailing off. The highest values were recorded from the clay site which may indicate that the legume-derived nitrogen from the decaying mungbean stubble might have also contributed to the levels recorded. Similar levels of nitrogen in tail water have been observed by other researchers studying the use of soybean cover crops residues for cane production systems in the Burdekin (Milla, unpublished data).

Regardless of the source, the levels observed early season during 2010 suggest that nitrogen losses from the cotton system are likely to occur after planting and that the use of high levels of fertiliser at this stage would only serve to exacerbate the environmental and economic risk. The most recent research data suggest that crop yield may be significantly increased with the reduced nitrogen at planting followed by more timely side-dressing (Yeates unpublished data) and rates now recommended at planting are typically below 100 units of nitrogen per hectare. This approach is under ongoing investigation.

The uptake efficiency of nitrogen applied in crop just prior at flowering is likely to be higher as a cotton crop by this stage has a well developed root system and biomass that can rapidly absorb applied nitrogen compared to a newly emerged seedling. Rainfall volume and frequency is also likely to be declining going into autumn. Interestingly, there was little evidence of nitrogen losses in tail water collected from both 2010 sites from late February side-dressing operations that were direct drilled into the soil at the base of the plants compared to the earlier pre-plant application.

The high economic cost and limited success of current nitrogen management practices is likely to be a potent driver for ensuring the rapid adoption of the types of strategies outlined as they develop. Nitrogen management is an area of ongoing research and it is likely that more efficient practices will evolve in the near term future. If successful, improvements in nitrogen uptake efficiency are likely to have a positive impact on runoff water quality due to reduced system losses. This study will provide a benchmark against which run-off quality from future systems can be compared.

Appendix 1. Nutrient Analysis for source and tail water samples taken 2009

Sample date	Sample Time	Sample Type	Total Nitrogen (µg N/L)	Total Filterable N (µg N/L)	Ammonia (µg N/L)	Total Phosphorus (µg P/L)	Total Filterable P (µg P/L)	NO_X	Particulate N (µg N/L)	PN proportion of TN	DON (µg N/L)	NO_X proportion of TN	Particulate P (µg P/L	TN:TP Molar Ratio
2009 Alluvial soil, Dongamere Farming corner of Dearness and Clare Rd														
20/03/2009	17:00	Alluvial inflow	9304	8779	1	102	93	6757	525	5.6%	2021	72.6%	9	201.7
20/03/2009	10:09	Alluvial tail Water	15180	11444	1075	954	492	10286	3736	24.6%	83	67.8%	462	35.2
20/03/2009	13:00	Alluvial tail Water	11193	9730	400	520	301	9296	1463	13.1%	34	83.1%	219	47.6
20/03/2009	17:30	Alluvial tail Water	11054	9622	18	206	144	8292	1432	13.0%	1312	75.0%	62	118.7
28/03/2009	12:30	Alluvial inflow	9849	9573	2	80	67	6633	276	2.8%	2938	67.3%	13	299.0
28/03/2009	13:00	Alluvial tail Water	11124	9676	209	363	223	8794	1448	13.0%	673	79.1%	141	83.1
28/03/2009	16:30	Alluvial tail Water	10617	9801	12	200	165	8360	816	7.7%	1429	78.7%	35	117.6
9/04/2009	7:45	Alluvial inflow	9271	9084	28	238	167	6413	187	2.0%	2644	69.2%	71	219.7
9/04/2009	8:00	Alluvial tail Water	9180	8873	26	291	231	7077	307	3.3%	1770	77.1%	60	79.2
9/04/2009	12:30	Alluvial tail Water	9899	9337	19	245	198	7718	562	5.7%	1600	78.0%	47	98
1/05/2009	11:00	Alluvial inflow	9424	9130	15	165	124	6554	294	3.1%	2562	69.5%	41	235
1/05/2009	11:15	Alluvial tail Water	9344	8903	20	214	178	6983	441	4.7%	1901	74.7%	36	114
1/05/2009	14:30	Alluvial tail Water	9659	9193	11	144	129	7487	466	4.8%	1695	77.5%	16	156
2009 Clay Soil, Hall Farming Enterprises, Clare														
20/03/2009	17:50	Clay Inflow	771	360	35	131	19	37	411	53.3%	288	4.8%	112	13.0
21/03/2009	5:45	Clay Tail Water	10992	7660	2465	195	121	3247	3332	30.3%	1948	29.5%	74	124.7
21/03/2009	16:00	Clay Tail Water	6123	4987	1798	261	154	3057	1136	18.6%	132	49.9%	107	51.9
22/03/2009	9:00	Clay Tail Water	6279	4977	1913	173	131	2573	1302	20.7%	491	41.0%	42	80.3
23/03/2009	9:30	Clay Tail Water	4575	4359	2011	193	117	1353	216	4.7%	995	29.6%	76	52.4
24/03/2009	14:30	Clay Tail Water	6553	5045	1789	175	131	1810	1508	23.0%	1446	27.6%	44	82.8
8/04/2009	12:45	Clay Inflow	442	201	2	45	6	12	241	54.5%	187	2.7%	39	21.7
8/04/2009	12:45	Clay Tail Water	2255	1227	44	284	123	1128	1028	45.6%	55	50.0%	161	17.6
8/04/2009	17:45	Clay Tail Water	1365	476	150	736	529	30	889	65.1%	296	2.2%	207	4.1
22/04/2009	11:00	Clay Inflow	541	201	2	45	6	12	241	54.5%	187	2.7%	39	21.7
22/04/2009	11:00	Clay Tail Water	904	374	162	631	532	39	530	58.6%	173	4.3%	99	3.2
22/04/2009	17:00	Clay Tail Water	1365	476	150	736	529	30	889	65.1%	296	2.2%	207	4.1

Appendix 2. Nutrient Analysis for source and tail water samples taken 2010

Sample Date	Sample Time	Sample Type	Total Nitrogen (µg N/L)	Total Filterable N (µg N/L)	Ammonia (µg N/L)	Total Phosphorus (µg P/L)	Total Filterable P (µg P/L)	NO$_x$	Particulate N (µg N/L)	PN proportion of TN	DON (µg N/L)	NO$_x$ proportion of TN	Particulate P (µg P/L	TN:TP Molar Ratio
2010 Alluvial soil, Dongamere Farming corner of Dearness and Clare Rd														
27/01/2010	8:00	Tail Drain	42105	40984	164	1592	1201	16794	332	0.8%	21218	39.9%	417	54.3
28/01/2010	8:30	Tail Drain	38205	37881	154	1574	1168	16682	324	0.8%	21045	43.7%	406	53.7
29/01/2010	17:00	Tail Drain	2079	1799	69	1036	728	956	280	13.5%	774	46.0%	308	4.4
30/01/2010	10:00	Tail Drain	2081	1538	61	1100	762	793	543	26.1%	684	38.1%	338	4.2
14/02/2010	9:00	Tail Drain	2301	475	81	1792	631	150	1826	79.4%	244	6.5%	1161	2.8
18/02/2010	8:30	Tail Drain	1792	325	31	1264	493	80	1467	81.9%	214	4.5%	771	3.1
19/02/2010	9:00	Tail Drain	1318	267	13	978	463	28	1051	79.7%	226	2.1%	515	3.0
16/03/2010	12:00	Source Water	10394	10367	3	58	41	6509	27	0.3%	3855	62.6%	17	396.3
16/03/2010	8:30	Tail Drain	10180	9980	6	193	186	8428	200	2.0%	1546	82.8%	7	116.6
31/03/2010	9:00	Source Water	8368	8101	20	102	100	6010	267	3.2%	2071	71.8%	2	181.4
31/03/2010	13:20	Tail Drain	8148	7801	52	418	293	6317	347	4.3%	1432	77.5%	125	43.1
23/04/2010	16:00	Source Water	9993	9678	1	131	121	8092	315	3.2%	1585	81.0%	10	168.7
23/04/2010	16:00	Tail Drain	9212	8837	20	262	214	6485	375	4.1%	2332	70.4%	48	77.8
2010 Clay Soil, Hatch Farming, Mulgrave Rd Clare.														
27/01/2010	11:00	Tail Drain	55943	55462	185	118	102	35622	481	0.9%	19655	63.7%	16	1048.4
28/01/2010	8:00	Tail Drain	55842	55086	361	50	40	34110	756	1.4%	20615	61.1%	10	2469.7
29/01/2010	10:30	Tail Drain	32742	30798	88	661	611	17103	1944	5.9%	13607	52.2%	50	109.5
30/01/2010	17:00	Tail Drain	16878	15933	231	154	131	11551	945	5.6%	4151	68.4%	23	242.4
14/02/2010	9:30	Tail Drain	4786	4761	49	205	67	3185	25	0.5%	1527	66.5%	138	51.6
18/02/2010	15:00	Tail Drain	1176	999	14	220	105	577	177	15.1%	408	49.1%	115	11.8
28/02/2010	10:00	Tail Drain	3782	3741	38	207	65	2985	25	0.7%	1527	78.9%	139	51.7
10/03/2010	16:30	Source Water	519	286	9	123	63	14	233	44.9%	263	2.7%	60	9.3
10/03/2010	16:30	Tail Drain	1271	849	74	209	92	302	422	33.2%	473	23.8%	117	13.4
1/04/2010	14:00	Source Water	622	504	10	83	55	272	118	19.0%	222	43.7%	28	16.6
1/04/2010	14:00	Tail Drain	817	679	6	209	156	372	138	16.9%	301	45.5%	53	8.6
10/04/2010	13:00	Tail Drain	845	698	4	197	141	348	129	15.4%	287	43.2%	50	8.1
16/04/2010	15:00	Source Water	9997	9961	1	130	124	7295	36	0.4%	2665	73.0%	6	170.1
16/04/2010	15:00	Tail Drain	9265	9017	12	314	259	7846	248	2.7%	1159	84.7%	55	65.2

10.0 Grower Extension and Project Communications

10.1 Grower Extension

Regular extension activities to rapidly disseminate results arising from the research program have been a prominent feature of this project. This project commenced soon after federal Government approval was given to grow transgenic varieties in Northern Australia and as such a number of growers began commercial scale testing of cotton in 2007/08. Many of these growers attempted cotton production with minimal information being available regarding the simplest production aspects such as cultivar selection and fertiliser strategies.

At the commencement of this project there were a number of identified unknowns that featured prominently in the types of questions that local growers asked. These included:

- Potential yields for forward selling?
- Winter would be too cold for reliable production
- Suitable varieties?
- Fertiliser requirements?
- Growth management in-season with MC?
- Tillage systems and stubble conservation? (enhanced nutrient retention & recycling, and minimising runoff losses)
- Crop performance in wetter-than-average years?

These questions informed some of the earlier research questions investigated by the project.

However, during 2008 with 12 first time growers a number of "unknown unknowns" that would hamper commercial cotton production quickly became apparent. These included

Many sugarcane fields in the BRIA having insufficient drainage to allow rapid drainage of wet season deluges (above left) or having poorly constructed field end drainage that allowed water to lie in the furrows waterlogging adjacent cotton and impeding field trafficability (above right).

The failure of growers and commercial spraying contractors to properly decontaminate spray application equipment which resulted in 17% of all crops planted in 2008 and 2009 being badly affected by Phenoxy herbicide contamination.

Under-estimating the experience and knowledge of local sugarcane growers when it came to planting row crops. Inexperience with simple operations such as sowing seeds resulted in hundreds of acres of cotton requiring replanting in the first few years due to poor plant stands (above right) or errors in the application of fertilisers under the pressure of wet season conditions often led to errors (above left) that were difficult to fix when field trafficability was regularly impeded by wet weather.

The development of root systems during wetter than average conditions was also an under-estimated unknown during 2008. Many growers were caught out by this phenomena in two ways. Firstly many crops had root systems that were too shallow to access fertiliser that had been placed deep in the soil profile. Secondly many of these crops were further impacted when rainfall stopped and crops went into moisture stress within 7 days of the last rainfall as the top 10cm of soil dried out. These two factors led to the rapid onset of premature cutout for many crops and example of which is in the above photo which shows a small plant with a white flower at the top with a shallow root system that was confined to the top 10 cm of the bed. This crop was also lacking in nitrogen (see yellow lower leaves) due to the roots not reaching the band of fertiliser placed at 18cm depth.

Under-estimated the differences between the performance of varieties that were available for use in the Burdekin in 2008. Average yields calculated for the two main varieties across 6 field areas (each) showed that Sicot 80BRF (above right) averaged 4 bales/ha whilst Sicala 60BRF (above left) averaged 8.7 bales/ha. For growers selecting varieties before any local validation could be completed was a needlessly costly exercise.

Consequently a number of growers suffered significant losses in the first couple of seasons due to a lack of information being available regarding effective cotton management in the Burdekin climate. It became quickly apparent during the first season that a lot of growers needed all sorts of assistance and the rapid development of good information was going to be critical in helping to avoid the situation of too many people accruing serious financial losses.

As commercial development ran well ahead of R&D, a priority of this project was to provide information and advice to Burdekin growers as quickly as possible from the research program. The project team conducted 16 field walks, 5 agronomy research half day workshops and 4 industry bus tours over the last four years together with countless hours of one on one discussions with consultants and growers all in an effort to ensure the rapid uptake of suitable production practices. By the commencement of the 2010 season a clearer picture for basic practices was emerging and for the growers who continued with cotton production, yields markedly improved. A testament to this improvement is demonstrated by a comparison between yields from the climate study and the top farm and valley average for each season

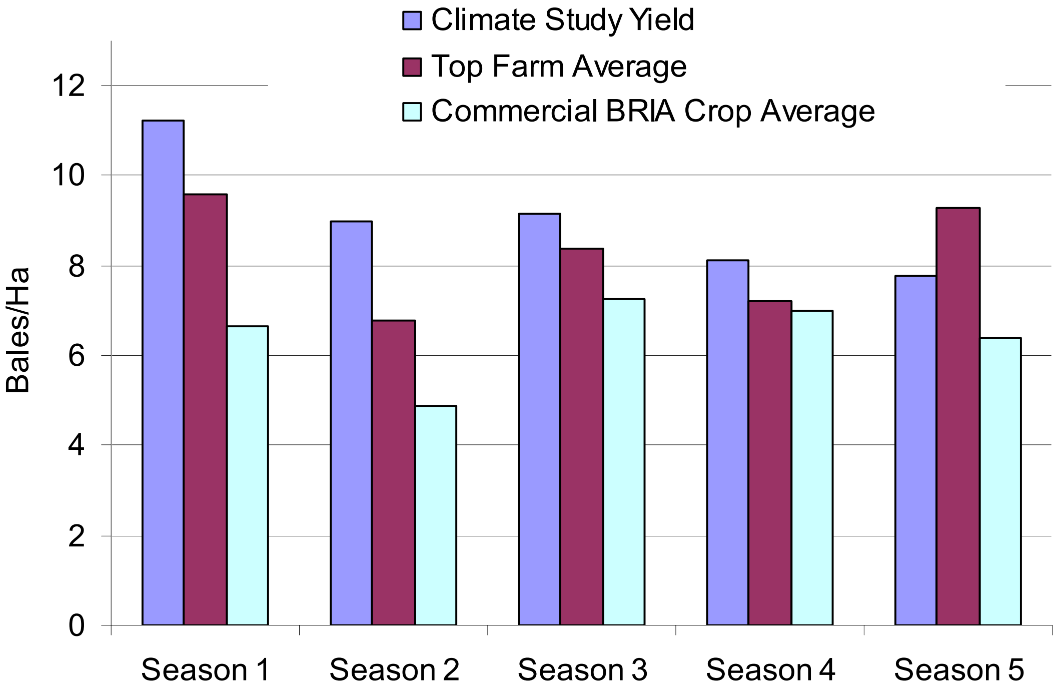


Figure 10.1 Yields from the climate experiment, top commercial farm average and Burdekin valley average (all farms) for 2008-2012. The yield presented from the climate study is the aggregate yield across cultivars for the planting date that represents the window in which the majority of the commercial crop were sown e.g. All commercial crops in 2008 and 2009 were sown between December 20 and 30 hence the yield from the December 20 plantings in seasons 1 & 2 are used for comparison. The yield from the January sowings is used for seasons 3-5 as this is representative of commercial plantings. The valley average is an estimate at the time of writing based on module weights.

10.2 Community Engagement and project communications

This project attempted to engage with the local community at numerous levels. The project made regular media releases through the local newspaper with regular updates on both the commercial and R&D progress being made with cotton in the Burdekin region. The project team also facilitated a number of visits for primary school children in the region around harvest time to explain how cotton is grown and the uses of cotton in people's daily lives.

Together with Cotton Australia and Qld Cotton the project team also provided a cotton display at the last 2009 Ayr show. When concerns had been raised by other industries in the region such as local vegetable growers regarding the potential impact of cotton for management of pests such as silver leaf whitefly, project staff regularly participated in meetings to share information and build working cross-industry relationships at a local level.

Where research discoveries have had broader implications for other parts of the cotton industry such as central Queensland which has suffered significant wet weather and flood damage over the last 4 seasons efforts have been made to extend the knowledge gained to those areas as well. Five field days have been conducted at Emerald regarding the potential application of Burdekin research findings during 2010 and 2011.

This project has also facilitated an industry development committee – NORCOM, which has met on a biannual basis with the aim of assisting new growers, solving industry development challenges and ensuring a co-ordinated response to any cotton related issues that arose over the 5 year period. These meetings have been chaired by Cotton Australia and the CRC project team.

The agronomic updates held in November of each year have been a structured half day presentation and discussion of learnings from the R&D and commercial cropping each season and have been well attended by local growers, consultants and visiting cotton industry people and organisations.

Photo 10.1 Clare State School children investigate picking of the first commercial cotton crops in the Burdekin 2008.

Photo 10.2 Lyndsay Hall talks about the development of his cotton crop at a grower field day in 2008.

Photo 10.3 Alastair Mace (Qld Cotton), Greg Kauter (Cotton Australia), Merv Parker (President of Ayr Show Society) and Paul Grundy (Cotton CRC) at the 2009 Centenary celebration of the Ayr Rural Show.

Photo 10.4 Paul Grundy (Cotton CRC) explains cotton production to a member of the public at the 2009 Ayr Rural Show.

Photo 10.5 Paul Grundy (Cotton CRC) explains physiological responses of cotton to wet conditions at a field day February 2009.

Photo 10.6 Growers, advisors and industry visitors attend one of the annual pre-season agronomic updates held each year in November.

Conclusions

The key take home message from this project is that high quality, high yielding cotton can be successfully grown in the Burdekin climate on course textured Burdekin soils and that during wetter than average seasons (the key climatic impediment) acceptable yields can be grown provided that a locally tailored agronomic tactics are used. This project has shown the potential for cotton production in the region, and demonstrated that some southern production techniques cannot be directly transferred to this region. This project has developed a measured range of tactics that can be deployed to minimise the impact of cloudy wet weather.

Key Findings include:

- Using the locally tailored management package, profitable high quality cotton can be reliably produced on course textured Burdekin soils. Crop management practices were locally developed (e.g. Pix, nitrogen, variety, plant density) as southern practices were usually unsuitable and at a minimum required validation for the Burdekin region.
- The optimum planting window was confirmed to be between 20 December and 20 January, which effectively mitigates many of the Burdekin's key climatic risks.
- More indeterminate varieties with the ability to shed fruiting sites during periods of poor radiation and then rapidly replace these shed fruit with new squares can be advantageous during the wet season, allowing production of compensatory bolls when sunny conditions return.
- Effective pre-season field preparation is essential. Wet season conditions exacerbate negative plant responses to subtle factors such as previous cropping history, uneven beds, unsuitable fertiliser application or poor drainage.
- The management practices developed in by this project can increase the probability of reaching higher yield potential in seasons with high rainfall and low radiation occur during January and February.
- Low radiation during boll growth (the most critical period) due to prolonged cloudy weather in March/April (occurring in at least 20-30% of years) is the main climatic constraint in the Burdekin, reducing both boll size and numbers. However, crops can still achieve acceptable yields of 7-8 bales/ha in these seasons.
- Sunny conditions during boll growth during March and April provide the potential to grow high yields of cotton (>10 bales/ha). Long-term climatic records indicate that the majority of seasons have excellent levels of solar radiation at this time.
- A 76 cm row spacing may offer significant advantages in low radiation seasons compared to standard 102 cm spacing. The narrower row spacing also allows effective farming system and tillage integration of sugarcane with cotton.
- Canopy management can be challenging. A Burdekin growth model has been devised that allows growers to identify and manage crop height or better avoid premature cut-out.
- Early "trimming" may be an effective tactic for delaying the onset of flowering (typically 44-50 DAS) by 2-3 weeks, allowing more time for nitrogen side-dressing and better coinciding flowering of December planted crops with improved sunny weather without delaying overall crop maturity.
- A new pigeon pea refuge variety suited to Burdekin conditions is now available for growers to use and the local RMP has been amended to allow the use of this refuge option.
- Cotton under wetter than average conditions which prevailed during this project was shown to be sensitive to applications of MC. Excessive use of MC was shown to have negative impact on yield via a reduction in P2 and P3 fruiting sites and lint turnout. These impacts were more pronounced for more determinate varieties such as Sicot 71BRF compared with the indeterminate Siokra 24BRF. A cautionary approach should be taken with regard to MC application in the Burdekin.

- A prototype tool (Burdekin Growth Model) for assessing canopy development has been developed from a broad range of data sets. This model can be used to assess crop development over time and assist with decision making for MC applications or taking action to avoid premature cut-out.
- The potential for the loss of nitrogen during the monsoon on both course textured and clay soil types has been demonstrated by this project. Management tactics to minimise the potential for these losses to occur have been proposed and being developed by the complimentary project 1.04.17CRC1001 led by Dr Stephen Yeates (CSIRO).
- Anecdotal data from commercial sugarcane producers who have grown cotton as a rotation with sugarcane have been positive. There have been no growers (of which the project team are aware) that claim a loss in sugar productivity due to using a summer cotton rotation crop despite the associated delay in sugarcane planting to accommodate a cotton crop. Rotation benefits are the subject of ongoing research.
- The mealybug *Solenopsis solani* was a new pest first encountered in the Burdekin. This pest was found to have a devastating effect on the health of affected cotton plants. The deployment of typical practices that might be used against this type of pests in other commodities (e.g. avoidance of broad spectrum insecticides and exercising good on farm hygiene) were found to be largely effective with this pest. The use of these approaches has enabled a complex of predators to provide effective biological control under commercial conditions.

Extension Opportunities

Much of the research that has been conducted over the last 5 years has been rapidly extended in the local Burdekin region. This has been done with numerous field walks and an annual agronomy update. The results from this season will again be presented at the pre-season update in November 2012.

Importantly the knowledge and experience gained over the last 5 years has been effectively captured in the comprehensive publication NORpak – Burdekin & NQ Coastal Dry Tropics Cotton production and management guidelines 2012. This book was released as a printed hard copy in July 2012 with a local launch in the Burdekin region. This publication is also available online and it is anticipated that an updated future version will be completed in the next 3 years.

Recommendations for further research and extension are:

Finish the BIG gaps in agronomic management and complete the climatic risk assessment – These relate mainly to the clay soils (50% of potential cotton area) as the majority of research up until now has been conducted on course textured soil. Commercial test farming on the Burdekin's clay soils has only been moderately successful, specifically due to nitrogen and water management issues and an inability to always achieve timely operations on clay soils during the monsoon. A full analysis remains to be completed utilising the vast data sets collected during the 5 year climate study conducted by this project. This data will be mined to develop a comprehensive understanding of the relationship between crop development and biomass accumulation and solar radiation. Specifically this information needs to be analysed and converted into a format whereby it can be used to update the CSIRO Ozcot. It is only then that more accurate simulations will be able to be made regarding the yield potential of cotton across the range of historical climatic data sets for the region. Essentially this would allow a better extrapolation of the data gathered during this study to a broad cross-section of likely seasonal variation.

Incorporation of cotton into sugar or grain farming systems - this is essential for a future Burdekin cotton industry (as sugarcane is the dominant system). Additional measurements of the rotational benefits and issues of cotton in cane and grain farming systems are required.

Continue to build human capacity for the future. If cotton is to be grown in the Burdekin, there is a need to build the skills of local growers and advisors to enable successful production utilising tactics that are appropriate for the local climate.

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