NORpak

Burdekin and NQ coastal dry tropics

Cotton production and management guidelines

Cotton Catchment Communities CRC

Best Practice

NORpak: Cotton production and management guidelines for the Burdekin and north Queensland coastal dry tropics region 2012

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Cotton production and management guidelines for the Burdekin and north Queensland coastal dry tropics region

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Foreword

Deregulation of the Australian sugar industry and subsequent global competitive pressures from lower cost producers, recurring droughts in southern Australia, and the success of new transgenic cotton varieties provided impetus for local and outside interest in the potential of cotton in the Burdekin during 2004-09.

In response to this interest and attempts by local growers to produce cotton, the Queensland Department of Agriculture, Fisheries & Forestry and the Cotton Catchment Communities CRC invested in a project to examine the feasibility of cotton production in the Burdekin region in 2007. With a number of growers attempting to grow cotton in the region with mixed success, the R&D program was further bolstered in 2009 with additional investment from Commonwealth Scientific Industrial Research Organisation, the Cotton Research and Development Organisation and the Cotton CRC to fast track much needed additional research on nutrition and farming systems constraints.

The need for a high value annual broadacre rotation crop for sugarcane to assist with arresting yield decline issues associated with the Burdekin's primarily monoculture farming system was a significant driver of sugar grower interest. A relaxation of competitive pressures due to record sugar prices since 2009 and a run of wetter than average seasons have more recently caused this interest to abate. However, the issues associated with monoculture production practices still remain and cotton may yet have a valuable role to play as a rotation crop for sugarcane. Cotton potentially provides both a diversified source of income and farming system benefits, as many people who have grown a cotton rotation crop during the last 6 years have reported improvements for subsequent sugarcane production.

In 2012, the region is home to the largest hub of the Queensland sugar industry with approximately 80,000 ha under production, supplying 8.5 MT of cane to four mills annually. In addition there are a range of horticultural enterprises, occupying approximately 8000 ha, producing a range of cucurbits, sweet corn and mangoes. A remaining 15,000 ha could be developed and irrigated with the completion of works associated with the Elliot supply channel. There is also potential for additional irrigation land development along the Burdekin to Bowen corridor or the upper Burdekin region such as Collinsville and surrounds.

Genetically modified varieties have enabled major improvement in the way that pests and weeds are managed. For 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 high pesticide input conventional production systems, the advent of transgenic varieties allow cotton production to be considered.

Whilst grower interest, land and water resources, and transgenic varieties are key ingredients for a future cotton industry, historical experience from other centres throughout northern Australia has shown that new industries have a high likelihood of failure, particularly if not preceded by appropriate R&D that seeks to understand local factors and tailor production systems accordingly. The collapse of commercial cotton production in the Ord River Irrigation Area in the 1970s stands as a testament to the folly of imposing a production system that, in hindsight, failed to recognise the environmental limitations of the region.

As a region that varies considerably both climatically and environmentally from all other cotton growing areas of Australia, this manual documents the knowledge derived from the collaborative work undertaken by the Cotton CRC partners and pioneer growers and agribusiness in the Burdekin region. It also serves as a testament to the diverse research, development and extension skills of Dr Paul Grundy of DAFF Qld and Dr Stephen Yeates of CSIRO.

Research has demonstrated that high cotton yields with exceptional fibre quality can be grown in the Burdekin region, however reaching this potential requires a tailored agronomic package that accounts for climatic constraints, combined with a high degree of grower skill.

Philip Armytage

CEO, Cotton Catchment Communities CRC Ltd

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Why grow cotton in the Burdekin?

The Burdekin is Australia's largest tropical irrigation region and is home to a vibrant agricultural industry.

The region's water supply is sourced from the Burdekin and Haughton Rivers. The Burdekin River is augmented by water released from the upstream Burdekin Falls Dam that holds 1.9M ML. Water from this dam is used to supply both an extensive channel irrigation system in the Burdekin River Irrigation Area (hereafter referred to as the Burdekin) and supplementary flow to recharge the extensive underground aquifer and surface lagoon system that supplies the Delta irrigation area. The catchment for the Burdekin River is extensive, covering an area of 130,000 km^2, stretching from west of Ingham to the south near Emerald and the coastal ranges west of Mackay. The geographic spread of the catchment ensures the high reliability of the region's irrigation infrastructure with an estimated supply of full irrigation allocation in 95% of seasons.

The security of irrigation allocation enables forward selling of cotton 1-3 years in advance of what might be possible in some southern production regions, enabling growers the potential to achieve a higher aggregate price per bale. The returns from cotton have the potential to be highly profitable and as an internationally-traded commodity are not constrained by limited market access as can occur for maize and some horticultural crops.

The Burdekin is utilised primarily for broad-acre cane production and most fields are sufficiently developed in terms of size and irrigation infrastructure to allow cotton production with minimal modification.

The Burdekin climate is warm enough to allow cotton production as part of a continuous cropping program with other rotation crops. **Cotton can be grown in between sugarcane crops during the usual summer bare fallow period that occurs every 4-5 years**. In this system cotton offers the opportunity to use a tap-rooted, herbicide tolerant crop rotation option that allows problem weeds such as nutgrass to be targeted. 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.

Cotton can be an excellent rotation option for sugarcane during the summer fallow.

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 would otherwise 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. Cotton is also largely resistant to attack from animals such as magpie geese and pigs, which can rapidly decimate grain crops in the Burdekin.

Excellent fibre quality has been a consistent characteristic of cotton produced in the Burdekin since commercial trials commenced in 2008. A significant proportion of the bales produced have been of a premium grade due to long staple length combined with optimal micronaire, strength and colour characteristics. Only a small percentage (<10%) of all bales produced so far have received a quality discount with these discounts being primarily due to sub-optimal defoliating and picking practices (colour and leaf contamination) rather than inherent fibre characteristics. The likelihood of receiving a poor quality related bale discount is minimal in the Burdekin climate.

The marketing of cotton and fibre classing is a highly evolved and transparent process. There is significant flexibility in how cotton can be marketed and the classing of quality can be conducted independently of the organisation that operates the processing gin to ensure complete transparency.

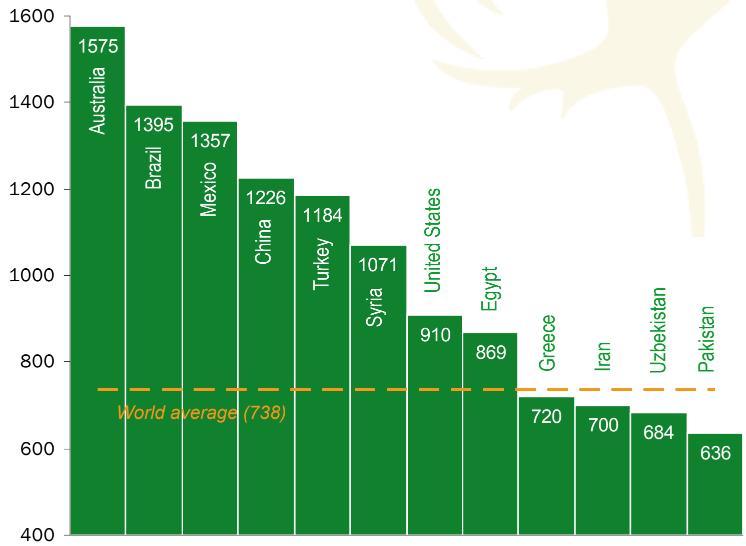
After picking, cotton does not need immediate transportation to the gin and can be stored on farm in the compressed modules for a period of time. This provides a significant advantage over highly perishable horticultural produce or grain crops that require contained storage.

Cotton production in Australia

Cotton production in Australia demands a high degree of attention to detail to produce high yield, high quality crops reliably against the vagaries of pests, water supply and weather, however it is these challenges that make it an exciting and rewarding crop to grow.

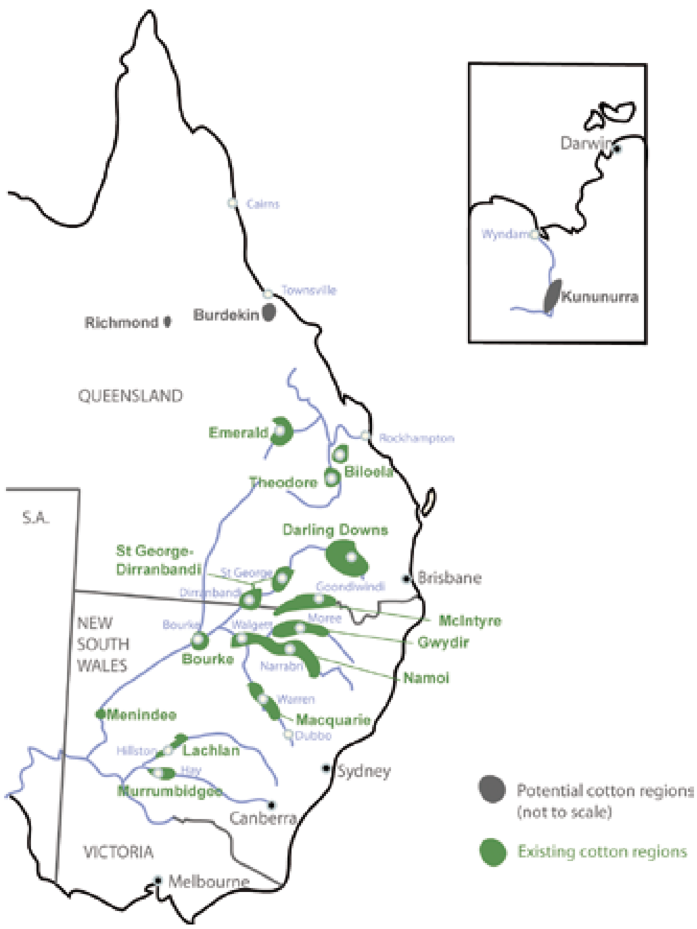
While cotton production systems only joined the mainstream Australian farmscape in the 1960s, they are now among the most productive and efficient in the world with many growers subscribing to and certified under an industry Best Management Practices program. Australia's place in the global industry has been underpinned by a culture of innovation and sharing of success, supported by strong investment in research and development which targets every step in the production chain.

The size of the Australian crop varies each season depending on irrigation water availability but is typically 250-400 thousand hectares, with the majority grown using some in-crop irrigation. About 70% of production occurs in NSW with the remainder in southern and central Queensland.



Average yields (kg lint/ha) by country as of 2011 (source ICAC). Australia leads the world in terms of yield per hectare. Interestingly, over the past decade Brazil's yields have nearly doubled (from 720 kg lint/ha in 2002 to 1395 kg/ha in 2011), and this has been achieved under high rainfall conditions similar to the Burdekin.

The catchment for the Burdekin River is extensive, covering an area of 130,000 km². Map produced by the Queensland Department of Natural Resources and Mines 2001.



Australia's cotton growing regions are spread between southern NSW and the Central Highlands (Emerald) in central Queensland, with major regions in northern NSW. More recently cotton has been produced in northern Australia in the Ord River (WA), Richmond (Qld) and the Burdekin.

The cotton plant

A diverse range of wild cotton species occur in a number of tropical and sub-tropical regions throughout the world, including Australia. Although several cotton species are grown for fibre production, Australia's commercial crop is primarily based on *Gossypium hirsutum*, or 'upland cotton', which originated from central America and makes up about 90% of world production.

Cotton belongs to the Malvaceae family of plants that includes rosella, okra and ornamental flowering hibiscus. As a perennial shrub, cotton may reach 3.5 m in height, but grown commercially as an annual crop, it rarely exceeds 1.6 m in height. Cotton is sown, harvested and ploughed out each year. A cotton tap root may reach depths of 1.8 m.

Cotton fibre forms around the developing seeds inside a protective capsule called a boll. When the seed is mature the boll ruptures and opens, allowing the fibre to dry and unfurl. A cotton plant's primary purpose is to produce seeds — the lint is just a by-product. The original purpose of these fibres was to aid in seed dispersal on water, however domestication and modern breeding of the cotton plant has generated varieties that produce a very large amount of fibre attached to each seed. When cotton is picked, both the seed and the attached fibre are harvested. The 'seed cotton' is compressed into modules on-farm and transported to a gin where the seeds and majority of typical field harvest contaminants such as leaf and twigs are separated from the fibre. The cotton lint is then compressed into 227 kg bales, classed according to fibre quality, and exported around the world to textile mills.

A by-product of the ginning process, cotton seed is a valuable commodity and sold separately. Approximately 300 kg of seed is produced for each bale of lint. It has very high energy and protein content and is either processed for oil for human consumption (vegetable oil), or more commonly used as a stock feed supplement for intensive animal production.

Cotton fibre is almost pure cellulose, non-allergenic, and has unique breathable characteristics that make it widely sought after to use in clothing, from undergarments to high-end fashion. Varieties developed by the CSIRO and grown extensively in Australia produce some of the highest yields and quality in the world. As such, Australian cotton is highly regarded and sought after in the international marketplace.

What is transgenic cotton?

The way cotton is grown in Australia has undergone significant transformation over the last decade due to the introduction of genetically modified cotton varieties. There are cotton varieties available today that have been purposely engineered to withstand the normally devastating attacks of caterpillar pests and/or over-the-top applications of broad-spectrum herbicides such as glyphosate to control in crop weeds. These technologies have allowed tropical regions like the Burdekin to be considered for cotton production as they significantly reduce the need for chemical use and minimise reliance on soil-applied herbicides that are increasingly regarded as potential environmental contaminants. The various transgenic technology options are detailed in the varieties section, starting on page 31. Cotton production based on conventional varieties is NOT recommended for the tropics due to the potential for excessive production costs, production system failure, environmental contamination and likelihood of poor community acceptance.

The only cotton production system recommended by NORpak is one based on the use of transgenic varieties.

Common terms for cotton plant structures

Emergence of the first true leaf after the initial cotyledon (seed leaf) stage.

Cotyledons. Seed leaves that appear as a symmetrical pair of leaves at seedling emergence.

First true leaf. The first leaf developed by a seedling with the appearance and arrangement of a normal cotton leaf.

Nodes. The junction between leaves or branches and the main stem. The internode is the space on the main stem between successive leaves or branches. Nodes on the dominant or main stem are known as main stem nodes, and are usually numbered upwards starting from the first node produced after the cotyledons.

Plant terminal. The growing point on the main stem. Also present on the vegetative/lateral branches. If the terminal is damaged (known as 'tipping out'), one or more new terminals can be initiated from dormant auxiliary buds below the damaged section.

Square. The flower 'bud'.

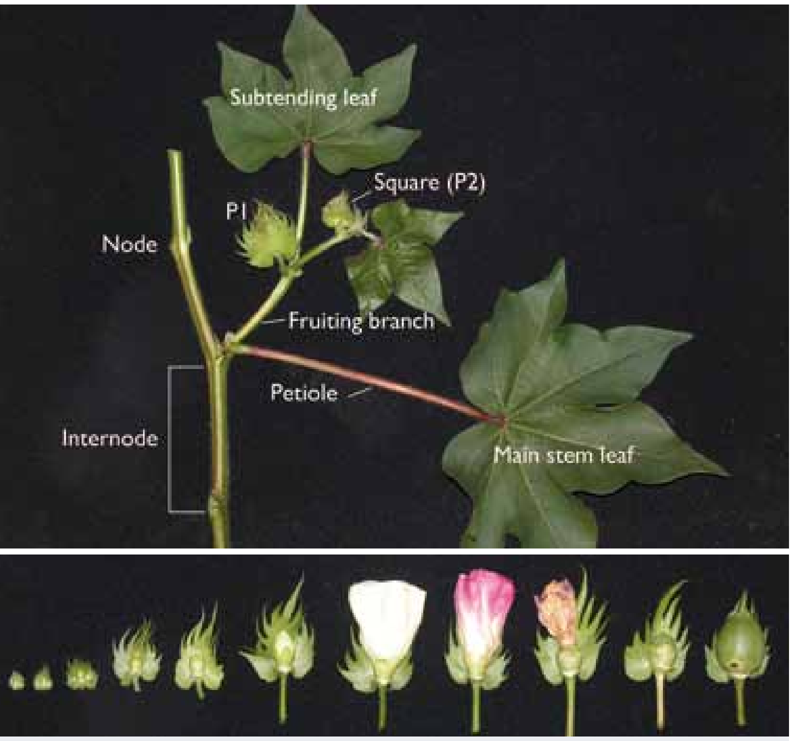
Flower. White with five petals, the cotton flower normally opens before midday. Self-pollination occurs very shortly after opening. The flower turns pink after one day, then withers and falls off.

Boll. The fruit of the cotton plant that develops after the flower has opened and been fertilised. The boll is divided into segments of 3-5 capsules called locks, each containing lint and 6-9 seeds. Once mature, the boll walls crack and fold outwards and the cotton seed and fibre expand out of the capsule to form a white fluffy bundle of seed and lint.

Vegetative branches (Laterals). Similar in form to the main stem. These branches most frequently emerge from the main stem nodes below the fruiting branches (in nodes 2–6). Vegetative branches may produce their own fruiting branches that give rise to pickable bolls.

Fruiting branches. Usually arising from 6 or more main stem nodes above the soil surface (and often above several vegetative branches), these branches have several nodes, each with a square and subtending leaf. Fruiting branches have a zigzag growth habit.

Fruit position. The location of a boll upon the fruiting branch. The first position (P1) is the boll closest to the main stem (if present, or there may only be an abscission scar where the boll once was). Sequential bolls are numbered outwards (P2, P3 etc).



A section of main stem from a cotton plant showing a developing fruiting branch and associated structures (top) and progression from square to boll (bottom).

Development growth stages of cotton

The rate of development for a cotton plant is largely determined by temperature and can be predicted against a measure of cumulative temperature. 'Day degrees' describes the accumulation of heat units related to the daily maximum and minimum temperature that a crop experiences each day. In temperate latitudes crop development is reliably predicted from seasonal temperature records by calculating day degrees. This relationship is less clear in the tropics (e.g. the Ord) due to temperature extremes prior to squaring and the possibility of delayed flowering due to shedding (see Yeates et al., 2010). Unlike temperate environments, cotton grown in the Burdekin is unlikely to experience temperatures below 12°C (called cold shocks, these can significantly delay development) for most of the growing season, nor experience the high temperature extremes of more northerly tropical regions. Summer and early autumn temperatures are relatively stable and therefore most crop growth stages can be reliably predicted with a simple measure of days after sowing (DAS).

Plant development

The cotton plant has an indeterminate growth habit, which means fruit, leaves and stem are grown concurrently and the terminal of the main stem and other vegetative branches ends with a vegetative bud. Growth occurs over an extended period of time. Flowering happens sequentially both vertically, from the first to the last developed fruiting branch, and laterally along each fruiting branch. The rate of fruit development is driven mainly by temperature and can be predicted using day degrees, then monitored and diagrammatically recorded throughout the season. The length of the cotton fibres is set during the first 20 days as the boll expands to full size, while the micronaire of the fibre is determined during the second half of boll development as the fibres are matured.

Good crop management aims to keep the reproductive and vegetative growth in balance and to maximise the number of mature fruit (bolls) at harvest. Certain growth parameters (e.g. node production and fruit retention) should be measured and recorded to help with management decisions for maximum yield (see the canopy management section on page 45).

Terms used to describe key cotton crop development stages and typical time frames from sowing in days and Day Degrees.

Development stage	Notes (Burdekin climate)	Days after sowing (DAS) for the Burdekin	Sum Day Degrees * (DDS) after planting for Burdekin crops 2008-11
Germination	As soon as a cotton seed touches moist soil, it will take in (imbibe) moisture and the germination process begins.	1	0
Emergence	The two cotyledons (seed leaves) break the soil surface and unfold.	3-5 depending on soil moisture and temperature conditions	70
Vegetative development	The plant will add another node or main stem leaf every 2-4 days.	Continuous	
Squaring	Occurs on the first fruiting branch at the 5-7th nodal position above the cotyledons. Additional fruiting structures develop about every 2-4 days at the first position location on successive branches.	Starts at 28-33	463 (±40)
Flowering	Occurs 15-20 days after squaring.	Starts at 45-50	807 (±55)
Boll filling	After fertilisation, the boll or fruit begins to develop, and increases in size rapidly, reaching full size in about 20-25 days. Total time from fertilisation to an open pickable boll is about 50-60 days.	Continuous	
Cut-out	Occurs when the plant's demand for assimilate (products of photosynthesis) finally exceeds supply so that further growth and production of new squares virtually ceases. It normally occurs when the plant reaches about 3-4 NAWF. Earlier set bolls will start to open and measurements of the number of nodes above the most recent cracked boll (see below) should be used to determine the date of the last irrigation and defoliation.	Starts at 95-110	1603 (±108)
Crop maturity	Occurs when all bolls have completed fibre development. Generally defoliation (see below) begins just prior to full maturity so that the complete loss of leaves coincides with the opening of the last pickable boll.	Starts at 145-180	2053 (±149)

* See Appendix 3 for more details.

Common cotton production terms

Tipping is the loss of the terminal growing point (terminal), causing the plant to develop multiple stems.

First square describes the stage when the first flower bud is produced on the first (lowest) fruiting branch and has its subtending leaf unfurled on 50% of the plants.

First flower is the time at which there is an average of one open flower per metre of row.

Retention is the proportion of fruiting sites on a plant that are present verses those that have been lost (see hypothetical cotton plant diagram).

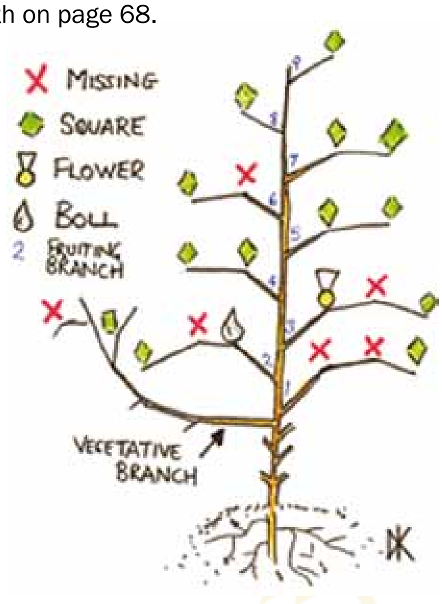
Shedding describes the abortion and loss of squares and bolls from the cotton plant. Shedding can be due to the plant balancing the supply and demand for the products of photosynthesis, and can be strongly influenced by factors that negatively affect photosynthesis (such as cloudy weather), or in response to pest damage to the fruit.

Cut-out or Last effective flower are terms used to describe the point in crop development when all of the bolls that will be harvested are on the plant. This point signals the end of reproductive growth (i.e. no more new fruiting sites will be established on the plant and it will instead focus on maturing existing bolls). This stage is most easily recognised when the plant reaches three to four Nodes Above White Flower (NAWF).

Nodes above white flower (NAWF) describes the number of nodes from the uppermost first position white (freshly opened) flower to the plant terminal. This measurement is used to determine a crop's growth rate or vigour and can be used to assess crop cut-out.

Nodes above cracked boll (NACB) describes the number of nodes between the very top of the plant and the nearest underlying branch that has a boll in the first position (closest to the main stem) that has begun to split and open. This measurement is used to assess crop maturity and determine when to start defoliation.

Defoliation is when the crop is treated with defoliant chemicals to remove the leaves and open the last remaining bolls in preparation for harvest. This is covered in more depth on page 68.



A hypothetical cotton plant just after flowering commences. In this example, there are 9 fruiting branches and the NAWF is 6. Retention is measured as the number of retained fruiting sites (squares, flowers and bolls) compared to aborted positions (crosses). Diagram by Dave Kelly.

Is Burdekin cotton production for me?

Cotton production demands attention to detail to reliably achieve high yields and quality against the vagaries of the weather and pests. It is these challenges that make it an exciting and often rewarding crop to grow. The motivation for growing cotton in the Burdekin during the last decade has been driven by a myriad of purposes ranging from water security to possible financial or crop rotation benefits to the perception that cotton might be used to gain leverage in local sugar industry negotiations.

Local research and commercial cotton production activity over the last five years has demonstrated that excellent potential exists for cotton production in the Burdekin. However, cotton production requires a commitment to crop production practice excellence and should not be attempted without considering the topics covered by NORpak.

There are some important generalisations regarding cotton production in the Burdekin region associated with the wet season planting window that should be very carefully considered by potential growers.

The ideal time to plant cotton in the Burdekin falls between 20 December and 20 January. Consequently a high degree of preparedness and agronomic management skill is required as crop production will span the wet season. This is particularly relevant for wetter than average years which occur about a third of the time. **A significant challenge is that prior to sowing it is impossible to predict whether or not the ensuing 3 months will be much wetter or drier than average**. The primary research period spanning 2008 to 2012 encountered a succession of wet years. No two wet seasons are the same and variations within the monsoon trough can result in rapid changes in weather conditions and downpours of hundreds of millimetres. **Therefore all cotton growers in the Burdekin should anticipate that every season will be wetter than average and plan their management accordingly**. There are virtually no penalties associated with this approach if the season actually turns out to be dry. Much of this book details strategies that will help prospective growers to prepare for wet season variation.

Things to consider

To maximise the opportunity for success, growers should consider the following pre-season actions:

- **Select fields early.** Ensure chosen areas have adequate wet season drainage to allow rapid escape of runoff from heavy downpours.
- If possible, **prepare beds at least one month before planting** and allow time for pre-irrigation and bed consolidation. Growing an interim cover crop of legumes or millet may also be advantageous if early bed preparation is possible. Cover crops can generate stubble that will help to maintain bed integrity during the early stages of the cotton crop, then break down and release nitrogen.
- **Be weather-aware.** Bookmark and follow a number of internet-based weather forecasting websites (see Appendix 2). Unstable weather conditions from December until April mean high intensity rainfall may occur with only 12-48 hours forecasting notice. It is critical that on-farm capacity exists to plant, fertilise or spray your cotton areas at minimal notice.
- **Have a flexible fertiliser and chemical application strategy.** The ability to side-dress nitrogen and capacity to apply growth regulants, herbicides and insecticides at the right time is one of the most important management factors for crop success post-sowing in the Burdekin. Establishing and compacting controlled traffic lanes throughout the crop and minimising boggy field end drains to enable the passage of high clearance boom spray rigs within 3-4 days of rainfall provides the greatest flexibility for side-dressing liquid nitrogen or spraying of growth regulant or herbicide. Alternatively, develop a relationship with a reliable contractor whom you can trust to provide timely service and that you can be certain will take all appropriate measures to decontaminate the spray rig for phenoxy herbicides.
- **Secure the services of a qualified and experienced crop consultant/agronomist** who can advise you on crop agronomy and pest management issues appropriate for the dry tropics region. Ensure that you are comfortable with their experience and have an agreed understanding of the costs and expectations associated with their service. It

is very easy to run well over budget on crop operations that may have minimal return, so ensure you are aware of the cost:benefit of management operations. Getting the most from your agronomist depends on YOUR interest and involvement. NORpak highlights examples of topics that may be discussed with your agronomist at various crop stages.

- **Develop a relationship with your local Technology Service Provider (TSP) & Reseller.** These businesses will be able to advise you on your potential obligations to grow transgenic cotton varieties. Ensure your selected reseller stocks the products that you may need to apply to your cotton crop at short notice (e.g. the appropriate herbicide to compliment your transgenic variety, growth regulators, and some insecticides).
- Prior to planting, **secure the services of a picking contractor** who will be able to pick and form the cotton into either traditional large rectangle-shaped modules or the more recent round modules. While either method is suitable, consider the most cost-effective option for the transport options available at the time. Freight rates can vary considerably depending on the type of modules used, the availability of southern-bound transport, and the type of semi-trailer decks available.
- **Plan transport of cotton to the gin**. Consider transport logistics and likely costs. Transport options will vary depending on whether conventional rectangular modules or the newer round bale type are used.
- **Plan your marketing strategy.** Forward selling requires consideration of likely price fluctuations and an estimate of the crop's yield potential. See the following sections on returns and marketing for more details.

The importance of operational timeliness

Successful cotton production in the Burdekin, particularly during the wet season, is largely dependent on having a 'can do' attitude and conducting necessary operations on time. The best varieties, fertiliser blends, soil type, irrigation infrastructure, or on farm equipment will not compensate for crop management operations not completed within recommended time frames. Those that approach crop management proactively and are prepared to conduct field operations at short notice in response to changes in the weather or agronomist recommendations are likely to enjoy the most success.

'Do not put off until tomorrow what should be done today' is a golden rule for Burdekin cotton production.

Being timely extends beyond personal availability and means considering what equipment and materials you might need to have on hand or have ready-access to at short notice. If you do not have your own chemical application and planting equipment make certain you have reliable access to someone who does.

Before planting, ensure that your retailer consistently has a full range of products available at short notice (ask your agronomist or agribusiness reseller for a season forecast of what you are likely to need). Chemicals used on cotton may not be registered for other crops and therefore will not form part of the standard inventories kept by some agribusinesses. Chemicals can also be in short supply in some seasons depending on usage in southern production regions. Multinational chemical companies often import product based on seasonal planting forecasts to minimise end of season inventories. Unforeseen pest problems or seasonal variation in southern regions can result in unexpected demand for some products and constrained supply. With the Burdekin season commencing 2-4 months after the rest of the Australian crop, the shortage of certain products is a potential risk, and industry shortages of certain growth regulants, defoliants and insecticides have occurred in recent seasons.

Timeliness is about being available and having made the necessary preparations to be able to conduct crop operations on time.


The importance of good drainage cannot be overstated. Waterlogging due to poor drainage at the end of this field post planting during the wet season (left) has significantly reduced the yield potential of this field by more than 10% at picking (right).

Margins, risks and returns

It is important to consider gross margins and production risks and how these may affect potential returns. The variable climate of the Burdekin region requires a thoughtful approach for managing crop inputs and taking forward marketing positions.

Consider the possibility of crop loss due to a cyclone or reduced yield potential for seasons where the wet weather extends well into autumn. Opportunity often exists to take part in 'pool' marketing arrangements, or obtain 'force majeure' contracts that reduce forward marketing production risks.

Likewise, inputs should be considered on a 'pay as you go' basis, whereby the potential of the crop is regularly assessed as the season progresses when determining continuing expenditure on crop inputs such as fertilisers and pesticides. **Failure to regularly assess expenditure on crop inputs can result in lost profits, particularly mid-season**. An underlying aim of NORpak is to mitigate wet season risks by using agronomic tactics that minimise up-front costs until crops near flowering, and crop potential and seasonal weather characteristics can be better determined. Decisions can then be made for further crop inputs such as fertiliser and crop protection products.

Gross margin returns from successful cotton crops (>7 bales/ha) in the Burdekin between 2008 and 2011 have varied between $300-3000/ha. The variability has mainly been due to fluctuations in the cotton bale price, yield and mid-season input costs. Yields for first-time growers have often been lower than expected due to mistakes associated with inexperience, or other factors such as in-field variability. A common Burdekin example is poor field drainage. Sodden field ends, even when small in relative area, can have a significant impact on overall yield potential, particularly during wetter than average years (see above photographs).

Many agronomic practices may have a marginal or minimal return. For example, the cost per unit of elements supplied in foliar fertiliser blends can be excessive when the product and application costs are compared against potential yield benefits. Ensure that your advisor can explain the value of different crop operations in terms of potential yield return.

Gross margin spreadsheets are useful tools for planning a pre-season budget and monitoring real costs against expected costs. These tools are available from various resellers and industry companies such as Cotton Seed Distributors (CSD) and the Cotton Catchment Communities CRC who have a range of web tools available online at www.csd.net.au and www.cottoncrc.org.au.

Successful Burdekin cotton production requires careful preparation, timely operations, consideration of costs, and pre-planning of marketing strategies.

Marketing cotton

Before growing cotton it is important to consider where the cotton will be processed or 'ginned' and how you might market the crop.

The closest gins to the Burdekin are near Emerald in central Queensland (650 km away). A gin processes the raw cotton by removing the lint from the seed and other field contaminants (twigs, leaf and boll shell) in return for a ginning fee. At the end of the ginning process the lint is compressed into 227 kg bales and sold to an end user.

The options for marketing cotton are many and varied. Cotton can be sold to the company who provides the ginning service or a merchant separate from the gin. Cotton is an internationally traded commodity and the price changes daily (even hourly) depending on currency exchange rates, commodity markets and futures trading. Your merchant will be able to provide daily price information and guidance on market conditions and outlooks.

Usually growers elect to sell cotton in one or a combination of three ways*:

1. **Forward marketing of fixed bales.** Pre-selling allows growers to secure a sale price before the cotton is produced. This may be six months to three years ahead of actual cotton production. Whilst this is often an attractive option, forward marketing typically involves entering into a binding contract whereby the grower is expected to fulfil a pre-nominated cotton bale supply obligation. Therefore, carefully consider potential production risks, expected yields, and likely market fluctuations before committing to forward sell a nominated (fixed) number of cotton bales. If the fixed bales are not produced, these contracts need to be met by being paid out (washed out) or bales sought from another grower to fulfil the contract. Actual returns for this scenario will depend on whether the daily bale price is higher or lower relative to the forward sold price. It is also possible to sell a contract to another grower and make a profit if prices have fallen during the interim. A 'force majeure' fixed bale contract removes a grower's liability to provide or pay out any production shortfalls. However this style of contract will have a discounted price compared to a standard forward-selling fixed bale price. Growers may choose to pre-sell only a portion of the expected yield (e.g. 4-5 bales/ha) to lock in some price certainly and then sell the balance at a later stage.
2. **Grower pools.** Available from some merchants (depending on market conditions) are grower or area marketing pools, where a merchant will 'pool' together the likely bales of cotton to be produced from a number of growers and sell these in the futures market to achieve an acceptable aggregate price per bale. A participating grower is usually required to nominate an acreage rather than a fixed number of bales, and the given price will be paid for every bale of cotton produced per nominated hectare regardless of yield. The price offered for each pool will vary depending on market conditions, and merchants have discretion over who may participate, how long the pool remains open, and the total crop acreage within the pool. The price offered is usually less than a fixed price contract on the same day, so compare the pool price to fixed bale pricing and consider the relative merits of each for your circumstances.
3. **At market.** Cotton can be marketed at picking. For the Burdekin, which has substantial costs for transporting cotton to ginning facilities (between $40-80 per bale since 2008), this can be a high risk option because a drop in international cotton prices between planting and harvest could expose growers to significant losses.

Generally, most growers believe that securing an acceptable price prior to planting is a better approach than accepting the market price at ginning. At the time of writing, many growers in Australia consider $500/bale a sound price.

Fuzzy cotton seed is an additional marketable commodity and is sold separately to cotton bales. The price varies considerably from year to year (ranging between $150-300/tonne), with seed yield from a 7.5 bale crop generally exceeding 2 tonnes/ha. The returns from seed are often sufficient to fully offset the costs of ginning, and may provide significant additional returns in some seasons. In Queensland most cotton seed is utilised as stock feed and therefore the value will depend on the relative availability and cost of other feed stock commodities.

* Marketing options may change into the future and growers should always seek current advice from a marketing agent.

Gin turnout

A module of field picked cotton that is sent to a gin for processing consists of lint, seeds, and field trash (bits of leaf and boll shell). Gin turnout refers to the overall percentage of lint that is recovered during ginning compared with the seed and trash components. A high gin turnout is desirable as the lint is a more valuable commodity than the seed. In Australia turnouts usually vary between 35-44% depending on variety grown and the climate where the cotton was produced. The most recently released varieties such as Sicot 74BRF have provided significant gains for gin turnout due to reduced seed size.

Turnouts from commercial Burdekin cotton crops have generally been between 34-37%, due primarily to the production of bigger seeds under Burdekin conditions, thus reducing the relative percentage of lint within each picked module. Although gin turnout has been lower than expected, the fibre produced has generally been of very high quality.

Fibre quality

Fibre quality is an important aspect of cotton production. Australian cotton is renowned for its high quality fibre and as such is sought within the international marketplace. Generally the market desires a white fibre that is long and fine yet strong, and free of contaminants such as leaf trash. Quality assessment can be done by the ginning and marketing company handling the cotton or independently by specialised classing companies. Each bale is individually assessed for length, strength, micronaire, colour and purity characteristics. If fibre quality exceeds base grade levels, a premium is paid, but if any of these characteristics are lacking, a penalty discount is subtracted from the agreed price per bale. Since the dollar value of discounts is generally greater than that of premiums, production focus should be on avoiding quality problems.

In Australia, the fibre characteristics of current varieties should exceed all basic measurements of fibre quality, assuming good management and no adverse climatic events.

To maximise mid to late season lint quality:

- Select a variety appropriate to local climatic conditions (see "Varieties" on page 31).
- Ensure the crop is sown within the recommended planting window and don't let flowering extend beyond 25 April as cooler nights in May/June can result in low micronaire penalties.
- Ensure crop is fully mature before defoliation to minimise the number of undeveloped fibres (see defoliation section on page 68).
- Ensure the defoliation process is complete before picking to minimise leaf trash contamination (see page 68).

Avoid the temptation to continue growing crops on and set flowers during May in a bid to increase yield as this approach is inherently risky in most seasons.

The relatively low incidence (<10%) of discounts applied to cotton bales produced in the Burdekin has been due to the warm autumn conditions that are ideal for boll development. Discounts that have occurred have been generally due to inappropriate defoliation practices resulting in trash and colour downgrades, or low micronaire associated with either late sown cotton (post 20 January) or cotton that was late finishing (cool night temperatures affected fibre development). This was particularly evident in 2011 as the May–July period was cooler than average and crops that cut-out in May produced cotton with a higher incidence of low micronaire bale discounts. See FIBREpak (available online from www.cottoncrc.org.au) for more details.

> **"The key tactics for maximising fibre quality in the Burdekin are to sow on time, manage the crop for last effective flowers by 25 April, ensure adequate crop maturity at defoliation and allow sufficient time for leaves to properly senesce and drop from the plant to minimise contaminants during picking."**

Cotton and the Burdekin climate

The wet season climate is the single biggest factor that sets the Burdekin apart from traditional cotton production areas. It is critical to understand crop-weather interactions and ensure that agronomic crop management is tailored to suit.

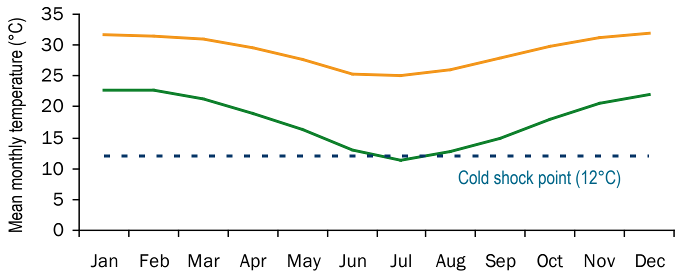
The Burdekin has two distinct seasons, wet and dry. Cotton is sown in a window from late December through to mid January so that early growth (the least susceptible crop phase) occurs in the peak rainfall months of January and February whilst the more important boll growing phase occurs during the increasingly drier months of March, April and May with picking occurring in the middle of the dry season (June/July). Wet season rainfall (December to March) is highly variable, both between and within years. In most seasons total rainfall will deviate greatly from the average, as will the pattern of rainfall within the season. Cotton can be successfully grown in the Burdekin even during wetter than average seasons, but understanding how a cotton plant is likely to respond to different weather events in the local climate is the first step to achieving a reliable yield. **Agronomic research and early attempts at commercial cropping have clearly demonstrated that ignorance of the region's climate and a failure to tailor crop management accordingly leads to a high risk of reduced yield potential**.

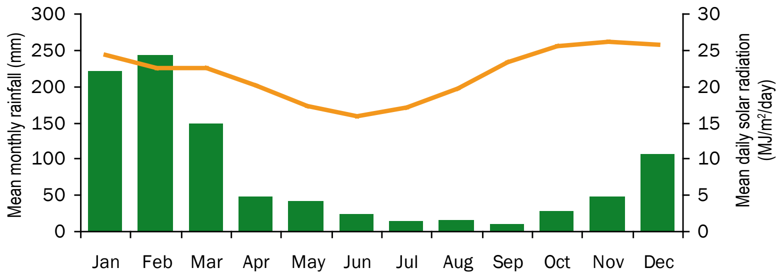
Ideal conditions for cotton entail sunny warm days with maximum temperatures spanning 27-32 °C with overnight minimums of 16-20 °C. Daytime temperatures in excess of 32 °C place additional stresses upon the plant which has to transpire more water to keep cool. Night-time temperatures above 22 °C will begin to impede respiration processes whilst temperatures below 12 °C will result in a shock to the plant that temporarily arrests development (Constable and Shaw, 1988).

The following sections deal with the issue of crop response to climate in the Burdekin and are a foundation for the later sections on agronomic management.

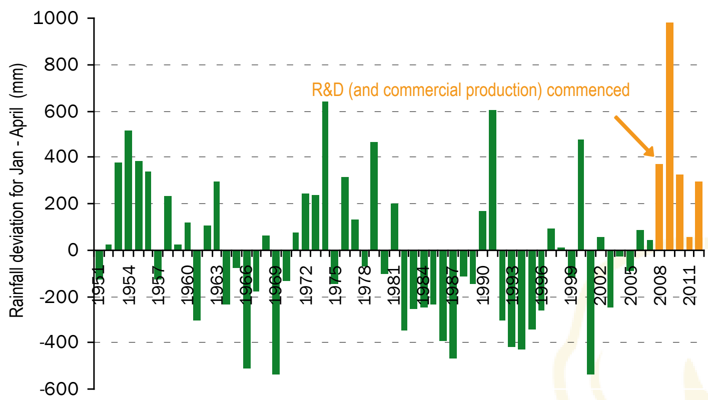
The Burdekin climate

The Burdekin is situated within the dry tropics region of the north Queensland coast. Its average annual rainfall of 952 mm is characterised by a monsoonal pattern between December and March followed by drier conditions for the remainder of the year (see monthly rainfall graph below). The region is considered to have good radiation, averaging over 300 sunny days per annum (higher than most other north Queensland cropping areas). Radiation is most variable during January to March due to frequent periods of cloudy weather.





Mean monthly minimum and maximum temperatures (top), and monthly rainfall (green bars) and daily solar radiation (orange line) (bottom) for the Burdekin measured at the Bureau of Meteorology Ayr DPI Research Station site 033002.



Mean rainfall for the January to April period expressed as a deviation from the long term mean for the Burdekin region from 1951–2012. This figure shows the variability between seasons (about a third of seasons were much wetter than average). The cotton trial years have coincided with a run of wetter than average conditions.

The key climatic challenge to growing cotton in the Burdekin is the variability of cloud cover and rainfall intensity during boll growth that occurs from late February until the end of May. In dry years cotton production will be very similar to central Queensland, however in wetter or cloudier than average autumns, agronomic management needs to be tailored to suit these conditions.

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

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

When to grow cotton

What works in the Burdekin climate?

The best option for Burdekin cotton production is a mid-summer sowing. This aims to establish a crop near the start of the wet season, so that the production of bolls (which generally begin to gain momentum 50 days after sowing) will coincide with typically drier and less cloudy conditions during the months of autumn, allowing for boll maturation ready for harvest by early winter, the driest time of year. This planting window, defined as the period between 20 December and 20 January, aims to capitalise on the consistent March-May daily temperatures (27-31°C during the day and 16-20°C overnight) which are optimal for photosynthesis and fibre growth.

Within the recommended planting window:

- Pre-Christmas December-sown crops flower during mid February (statistically the wettest month) and are more likely to suffer losses of early flowers due to shedding in wet years. Good yields can be attained in most seasons but crop management is more challenging, particularly for wet years.
- 1-10 January-sown crops commence flowering a little later around the onset of autumn in late February to March (a period likely to have statistically drier weather and better conditions for the onset of boll setting). **This planting period is most likely to be optimal for cotton production in the majority of seasons, but the chances of wet weather interruptions to sowing are higher.**
- Crops sown towards the end of the planting window (11-20 January) have less time to reach maturity before the onset of cool temperatures. Recorded data from experiments suggest that every day that planting is delayed after 5 January will delay crop maturity by approximately 2 days. Therefore, if planting after 10 January use earlier maturing varieties and manage the crop so that cut-out occurs by 25 April to avoid a late July or August harvest and increased risk of fibre quality penalties.

The relative merits and trade-offs of December versus January plantings are discussed in more detail in following sections.

This Burdekin sowing window differs significantly from other cotton growing regions in Australia and consequently requires a different agronomic approach tailored to overcoming potentially high early season rainfall that may be followed by very dry conditions (see comparative calendar opposite). On average, about a third of seasons are significantly wetter than average (see the January to April rainfall graph on page 11), resulting in increased production challenges. This manual suggests many simple strategies that maximise the opportunity for success in these wetter than average seasons.

In northern Australia no two wet seasons are exactly the same. As the intensity and timing of wet weather is likely to vary from year to year, it is important to enact 'best bet' management tactics to maximise yield potential regardless of whether or not a season is wetter or drier than average.

Comparative calendar – planting to harvest for various Australian regions compared with the Burdekin.

Region	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Burdekin	P			F	F	F	F	F		H	H	H	H	H	H									P
Ord					P	P	P	P			F	F	F	F	F		H	H	H	H	H			
Central Qld	F	F	F	H	H	H	H	H										P	P	P	P		F	F
Darling Downs	F	F	F			H	H	H	H										P	P	P		F	F
Namoi	F	F	F			H	H	H	H										P	P			F	F

P=planting F=flowering H=harvest (defoliation and picking)

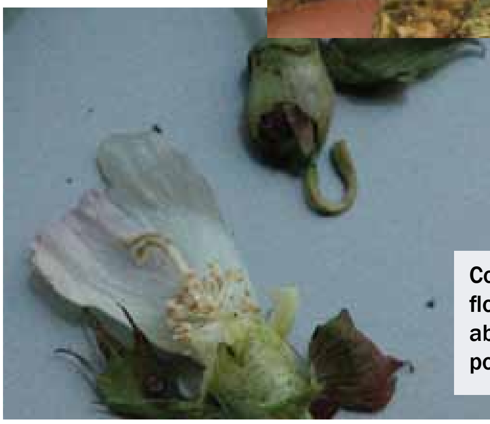
Why not plant during the drier months of the year?

Unlike the Ord River and Katherine regions of north western Australia where research has demonstrated the advantage of dry season winter production (mainly for the avoidance of local insect pests) that makes use of the suitable temperatures through the middle of the year (Yeates et al., 2007), the Burdekin's low monthly minimums during July to August (average near 12°C or less) would result in poor plant growth and increased risk of boll abnormalities that could reduce yield. Further, the Burdekin also regularly experiences heavy dews throughout late autumn and winter due its proximity to the coast, which encourages outbreaks of leaf disease caused by *Alternaria* spp. This disease can severely reduce the canopy viability (and hence yield potential) of Burdekin crops sown in April or May. Test plantings at this time of year in 2004 and 2009 failed to produce acceptable yields (<6.5 bales/ha).

In the Burdekin a delay of sowing until June (tested in 2009) delayed flowering and boll fill until spring, coinciding with warmer temperatures and increasing solar radiation levels. However, crop maturity for this planting date occurred in late December, posing an unacceptably high risk of wet weather impeding or preventing harvest and causing lint discolouration.

A traditional spring planting window similar to central Queensland is also unsuitable as crops would reach peak flower, boll fill and boll opening during the wettest and cloudiest months of January and February, dramatically reducing yield potential in the majority of years due to reduced plant photosynthesis performance and boll rot losses.

Cotton foliage badly affected by fungal *Alternaria* spp. disease lesions. There are no resistant varieties or registered fungicides available.



Cool nights induced flower development abnormalities and poor pollination (July 2004).

This cotton was planted in the Burdekin in early November and commenced boll opening in February – coinciding with wet conditions resulting in extensive boll rots. Planting in the recommended window minimises the likelihood of problematic boll rot levels.

How does the monsoon affect cotton?

The monsoon is characterised by periods of rainfall, cloud cover and high night temperatures, which all interact to affect cotton growth.

The impact of rain

It is likely that crops in most seasons will be affected by rainfall. The actual impact is highly dependent on a range of inter-related factors as rainfall in itself is not a significant issue for the cotton plant. What is important is how the rainfall occurs (e.g. volume, time of day, intensity, duration and crop stage) as well as field factors such as soil type, drainage etc.

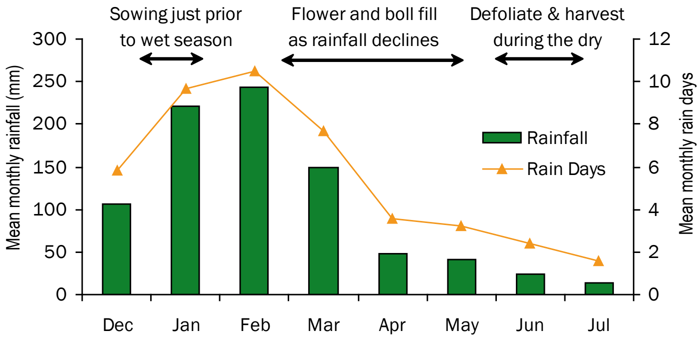
Cotton easily tolerates tropical downpours early in the season provided fields have good drainage.

Rainfall in **January and February** generally coincides with the vegetative or early flowering growth stages of the crop and has minimal effect on crop development. Rainfall on newly opened flowers can kill the pollen and lead to flower abortion, although flowers are only susceptible for several hours in the morning during pollen shedding (Pennington et al., 1989, and Burke, 2003). Hence the timing of rainfall will influence its effect with afternoon rainfall having less impact compared to mid-morning showers.

The potentially more significant impact of rainfall during this time is where extended periods of wet weather impede field trafficability and the ability to side-dress fertiliser or apply herbicide. Extended wet weather can also cause a crop to develop a shallow root system, making it sensitive to later moisture stress. High volumes of rain can leach nitrogen either out of soil beds and into the furrows where it is lost in tail water, or downwards beyond the reach of root systems (sandy soils).

By **March and April**, the crop will be more sensitive to weather conditions as it sets large numbers of bolls per day. Again, evening storms with sunny days are unlikely to cause direct losses, although sunny days and high soil moisture can be a recipe for excess vegetative growth. If rainfall occurs with cloudy daytime conditions that extend beyond a couple of days, yield potential can be reduced. This is generally due to reduced sunlight (radiation) rather than the direct impact of rainfall.

Rainfall is unlikely in the Burdekin in **May and June**, and any impact is mainly confined to interfering with boll opening. Rainfall on bolls that are just cracking may result in boll rot with the lint failing to fluff out, making the opened boll unpickable. This is commonly referred to as ‘tight locking’. Extensive losses only occur if rainy conditions persist for several days or more. Rainfall during defoliation or at picking generally only causes operational delays, or higher trash rates as dropping leaves can become ‘caught up’ in the canopy. Other fibre quality issues such as colour downgrades have been uncommon provided that picking is delayed until the crop has dried out.



Mean monthly rainfall and rain days for the Burdekin region (measured at the Bureau of Meteorology Ayr DPI Research Station site 033002) between December and July from 1951–2011 and suggested cropping calendar for the region.

This crop (February 2009) has excellent vigour despite a record wet season due to adequate field drainage.

The impact of solar radiation and temperature

Solar radiation (sunshine) is required for the process of photosynthesis. Cloud cover during the monsoon season (generally most active between December and March) causes highly variable rates of solar radiation. When combined with high night temperatures (22-25°C during December–February), this may reduce yield potential compared to summer cropping in temperate climates. Solar radiation often becomes less variable early to mid autumn as the dry season commences and sunnier weather returns.

Yield potential for cotton is dependent on solar radiation (energy from sunlight) from flowering to defoliation.

The Burdekin planting window largely avoids flowering and setting bolls during January/February when radiation is most variable and night temperatures highest. Flowering and boll filling occurs from late February to early June, when daily radiation is generally more reliable but declining due to decreasing day length. Although Burdekin cotton receives on average 20% less radiation during flowering and boll fill than summer crops in temperate climates such as Narrabri or Dalby, this is partially compensated for by favourable autumn temperatures that allow for efficient photosynthesis, fibre development and boll filling. Burdekin cotton plants further compensate for lower radiation by growing larger, thinner leaves much earlier in the season to intercept more sunlight.

Cloudy conditions, high temperatures and humidity can lead to the production of large paper-thin leaves that help to compensate for low radiation levels.

Narrabri (left) and Burdekin (right) crops at first flower. Many people not acquainted with the look of tropical crops will consider this growth to be excessive.

In about one third of seasons, cloudy conditions and higher night temperatures will persist throughout March, and can reduce yield potential. During early flowering the shedding of lower canopy fruit in response to persistent cloud is an advantage, as the plant will have more resources to set additional (and potentially larger) bolls later, when sunshine returns. If radiation is limiting, the retention of bolls at this time can be counter-productive and compromise yield potential via reduced boll size and/or competition with future canopy growth and square/boll production.

First position bolls from the bottom three fruiting branches (bottom row) and the top three fruiting branches (top row). The bottom bolls (set during late February) were smaller due to radiation limitations from cloudy weather compared to bolls set later in early April during sunny autumn conditions. These later top bolls are an important component of high-yielding crops.

Newly set bolls take 45-55 days to develop, so as the season progresses the time available for recouping shedding losses diminishes. This is why cloudy weather begins to affect yield potential when it occurs from mid-March onwards.

What is shedding, why does it occur and how is yield potential affected?

Shedding is the abscission of squares (flower buds), flowers and young bolls from the plant. Generally bolls that have developed to a size larger than thumbnail cannot be shed and will be retained on the plant until boll maturity.

The type of shedding that is referred to throughout this document is not the normal loss of squares and early bolls that often occurs at or just after cut-out when a plant has reached a point where no further fruit can be held and surplus squares and young bolls are discarded. Instead we are referring to shedding that can occur much earlier in the life of a crop and is in response to monsoon conditions.

Weather-related shedding is a survival mechanism in response to unexpected changes in the external environment. In the Burdekin, this shedding response is associated with extended periods of cloud (low radiation) where the plant rebalances its internal demand for assimilates by shedding current fruiting positions. This allows continued vegetative expansion and associated production of future fruiting sites that might develop into bolls when sunnier weather resumes.

Wet season shedding generally takes two forms, and is caused by:

1. **cloudy wet weather that extends beyond 4-5 days.** This is the most common form of shedding affecting young bolls, flowers and advanced squares. Medium to large size squares turn yellow and drop off (top right). Young bolls up to thumbnail size desiccate (mummify) and may remain attached to the fruiting branch for several weeks (right). The shedding generally progresses from the most mature fruiting site positions to the least developed (e.g. first position fruit and squares will abscise before second positions on the same branch).
2. **a sudden weather change from extended cloudy weather to sunny dry conditions.** Confined to very young squares, this shedding can affect all squares of a similar age regardless of location within the crop canopy (below).

Note that cotton plants generally produce 60% more squares than they could ever physiologically retain. This is a survival strategy where the plant can compensate in the event of weather and pest-related losses. Therefore some shedding is normal and may not necessarily impact on final yield potential.

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

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

This plant has shed bolls that started to form after pollination. Note that desiccated early bolls are often retained for several weeks.

The significant decrease in radiation and night 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. Ideally, all bolls need to be initiated by late April. Bolls set in May onwards will be smaller and result in significant crop maturity delays.

Cloudy weather that occurs intermittently in periods of three or more days during autumn can be a problem. Conditions are sunny enough to allow effective boll set and minimal shedding but boll size is reduced. Prolonged cloudy weather in March or April can result in significant shedding. Compensation for such late shedding will be limited because the necessary additional fruit would be developing even later, during May to June, and have reduced boll size.

Despite climate-related limitations for boll filling in some seasons, cotton is capable of very rapid growth during March and April with research data showing that sufficient bolls can be set within 6 weeks of sunny weather and produce yields of 10 bales per hectare or more.

Ensure that a crop has excellent vigour at the end of the wet season so that bolls can be set rapidly with the onset of sunny weather in autumn.

As cloudiness is difficult to predict, a significant focus of local research has been to better understand the influence of cloudy weather and resultant periods of decreased solar radiation on crop growth, development and yield and use this knowledge to develop appropriate management strategies.

Extended cloudy weather (3 days or more) reduces photosynthesis and depending on the growth phase of the crop and severity and duration of cloud cover a number of effects may be observed (see the impact of cloud cover table below).

Cloudy weather during February to early March

The impact of cloud may be minimal provided crop vigour is maintained and lost squares, flowers and early bolls are replaced with compensatory growth during sunnier conditions in March and April. Strategies to maximise compensation are discussed throughout the agronomy section.

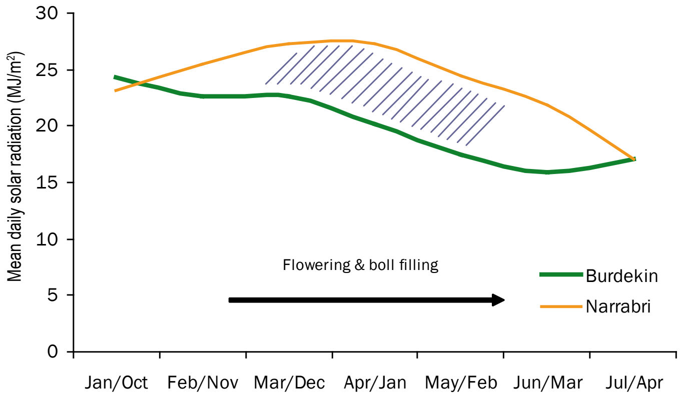
Cloudy weather during mid March to April

Although less likely than February cloudiness, the impact of extended cloudy weather, particularly in March (see radiation and rainfall records graph on page 18), is difficult to overcome as there is limited season remaining to recoup fruit losses through compensatory growth. Retained bolls compete with new squares/bolls and may cause the plant to shed aggressively in response to the reduction in photosynthesis. The result may be premature cut-out or delayed setting of bolls. In well advanced crops, reductions in boll size may also reduce yield potential. Crops with fruit counts indicative of a 10 bale/ha yield can shed several bales of yield potential with a week of continuously cloudy weather.

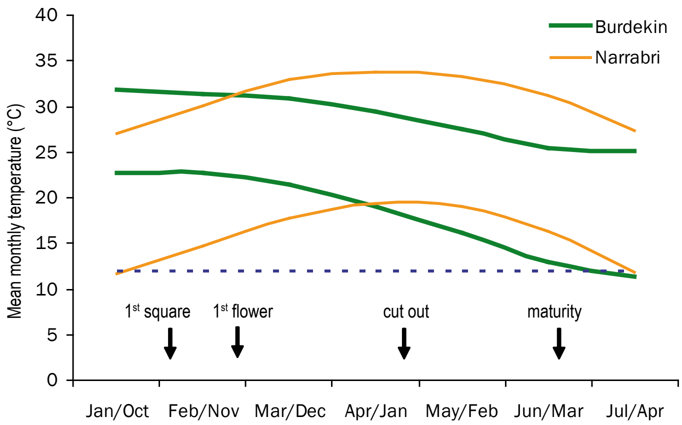
There are limited options for managing cloudy weather in March and April apart from ensuring that good crop vigour is maintained prior to expected cut-out so that shed positions have a chance of being compensated for by adjacent outer squares (P2 and P3 sites) on existing fruiting branches.

The possible impact and management implications of cloud cover during different crop development phases

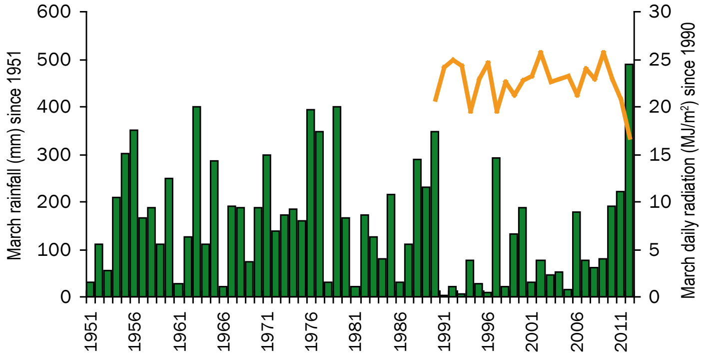
Plant phase	Physiological consequences	Management implication	Yield implication
Pre-flowering	Larger thinner leaves.	Potential for rapid growth due to additional photosynthetic area. or Increased transpiration losses if conditions turn sunny and dry.	Rapid growth can assist with production of large numbers of new squares and increase boll numbers if conditions turn sunny.
	Shallow root system.	Potential for moisture stress when conditions turn dry which may contribute to premature cut-out.	Premature cut-out can severely reduce yield potential.
	Shedding of squares (if overcast for more than a week).	Maximise square production that will give rise to compensatory bolls.	Yield potential should be maintained if compensatory bolls are grown.
Flowering onwards	Shedding of flowers, squares and early bolls.	Additional time required to set compensatory bolls. Challenges for effectively managing canopy growth.	Yield potential will depend on the rate and timing of compensatory bolls set. Crop maturity may be delayed.
Cut-out onwards	Reduced boll size.	Minimal opportunity to redress losses through compensation.	Reduced yield is likely outcome.



Comparison of mean daily solar radiation between the tropical wet and first half of the dry season in the Burdekin (January to July) and the temperate summer growing season at Narrabri (October to April). The likely flowering and boll filling period for both regions is indicated by the arrow. The shaded area represents the radiation difference between the two climates during the flowering/boll filling period in their respective growing seasons.



Average growing season showing mean monthly temperatures for the Burdekin (January to July) and Narrabri (October to April). Approximate critical growth stage dates for a January sown cotton crop in the Burdekin are marked with arrows.



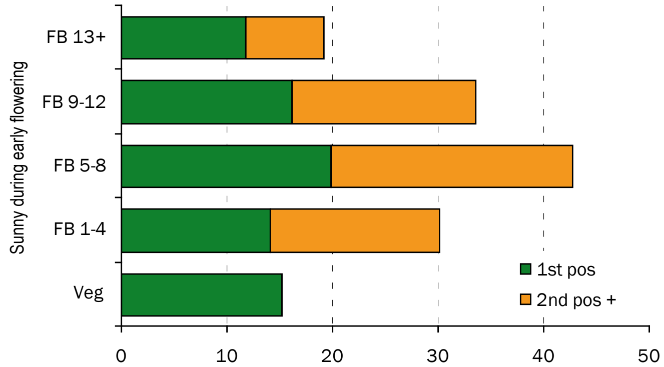
Radiation and rainfall records for March measured at the Bureau of Meteorology Ayr DPI Research Station site 033002. Records for radiation commenced in 1991, coinciding with a higher percentage of drier weather compared to 1950-1990.

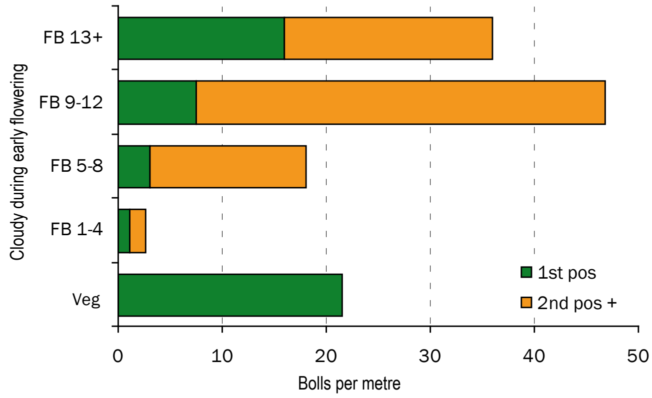
Predicting cloudy weather and yield potential

The frequency of cloudy weather is difficult to predict as meteorological records for radiation since the 1950s are sketchy and regular records for the Bureau of Meteorology's Ayr site only began in 1990 (since which March has been characterised by a higher frequency of drier weather). Rainfall and cloudiness are not always well correlated as March in particular can often have sunny days with evening rainfall or cloudy weather with very little rainfall.

Research data and commercial crop yields suggest that 7-8 bales per hectare is attainable for seasons with very cloudy weather in March and April on loam soil types. In these seasons, higher yields are unlikely regardless of crop management inputs as radiation becomes the most limiting factor. Increasing crop inputs such as fertiliser in a bid to overcome and compensate for cloudy weather during March is only likely to delay crop maturity because as sunny weather returns later in the season, late applied nitrogen will drive crop growth at a time when a crop should be cutting out and maturing. Focus instead on maintaining crop growth through timely irrigation and take a cautious approach with growth regulants, particularly if fruit have been shed. **Yields on clay soils have been lower (6-7 bales/ha) during this period although this has been primarily due to soil type constraints (nitrogen and soil moisture availability, and overall trafficability) rather than radiation.** Improved nitrogen management techniques developed from these experiments have not yet had a chance to be field tested in a high radiation season.

During March and April mid-flowering shedding of first position bolls (P1) can be compensated for through the sideways expansion of existing fruiting branches where second (P2), third (P3) or fourth position (P4) bolls may be produced. These bolls can be set very rapidly due to simultaneous expansion of existing fruiting branches. This was regularly observed during climate studies whereby cotton had lost significant fruit numbers during the first half of flowering and was able to compensate by growing replacement bolls on the outer branch parts of the canopy and uppermost fruiting branches (see crop response example photos on page 19). Growing new fruiting branches only from the plant terminal shoot compared to expansion of existing branches takes considerably longer and thus risks delaying crop maturity.





Crop yield display from the four main-stem fruiting branch (FB) sections (branches 1-4, 5-8, 9-12 and 13+) and vegetative branches (veg). Fruiting branch lint has been further partitioned into first position (P1) fruit and second position and above (P2+P3+P4) fruit.

Note that the contribution of lint from P1 fruit on the first 8 fruit branches was minimal under cloudy conditions. A large proportion of total crop yield was grown on the outer branch positions on the upper canopy. These bolls can only be created with continued crop growth and canopy expansion. Caution should be taken when using growth regulants after a shedding event as mepiquat chloride (MC) can reduce the extension of existing fruiting branches and significantly curtail yield potential (see MC section starting on page 49).

Tropical cyclones and low pressure systems

Tropical cyclones, low pressure systems and depressions are the most significant rainfall events associated with the annual monsoon season. These weather systems are part of the north Queensland climate, however the frequency, severity and impact of these events is impossible to predict. The potential for crop damage or destruction from tropical cyclones and depressions is a climatic risk for cotton production in the Burdekin.

Historical records suggest that direct coastal crossings of tropical cyclones into the Burdekin region 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. Limited records exist regarding cyclone size and wind severity, both of which are important determinants for likely crop damage.

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. More than 20 years then passed 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 still young at the time.

Therefore, while tropical cyclones will occur in a small percentage of seasons, the impact will vary markedly depending on the stage of the crop and 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, the Burdekin has a very low probability of other extreme weather events such as hailstorms, riverine flooding or drought (see climate risk table on page 12), 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.

Examples of crop response to radiation during early flowering. The plant on the left had relatively sunny conditions and retained many of its early set bolls, while cloudy weather has caused shedding of most lower fruit positions (right).

Crop growth phases and climate

Because of the uniqueness of the proposed wet season planting window for the Burdekin compared to all other Australian production regions, it is important to consider the impact of climate on different crop growth phases.

Germination to first flower and the onset of the wet season

For many seasons Burdekin crops will experience periods of near saturated soil and overcast weather for 1-3 months post-sowing, potentially affecting early to mid crop development.

Roots

Root exploration will vary greatly between seasons. Of greatest concern for crop management are the wetter than average years when Burdekin crops typically develop very shallow root systems, mostly confined to the top 20 cm of soil. This is because the most freely drained soil usually occurs between the surface of the bed and the base of the irrigation furrow. These root systems may have short carrot-like tap roots with lateral roots extending sideways across the entire planting bed. An adaptive strategy that avoids the anaerobic waterlogged conditions deeper in the soil profile, the root network also allows effective scavenging of nutrients in the upper soil layers.

Shallow root systems have implications for fertiliser placement and irrigation scheduling. Appropriate nitrogen and irrigation management will be covered in depth later in the text.

Two examples of shallow rooted crops where conditions have meant the plants have explored laterally to avoid water-logging in the lower soil profile. This has important ramifications for subsequent farming operations.

Take a cautionary approach to inter-row cultivation as a large proportion of a crop's root system (due to confinement in the upper soil layer) may be disturbed and cause significant crop stress.

Canopy development

The function of the crop canopy is to produce and support the leaves and numerous buds (squares) that will develop into bolls. Early season canopy development during the wet season tends to be lush and vigorous compared with summer-grown cotton crops in temperate regions. Crop leaves are often large and thin with minimal development of a waxy cuticle. Growing a larger photosynthetic area (by increasing the size of the plant's solar panels) is an adaptive strategy to low radiation and high humidity. However, crops can develop a skewed ratio of vegetative to reproductive growth and become excessively tall and leafy with elongated petiole and inter-node lengths, particularly when grown on sandy textured soils with high levels of nitrogen. Excessive vegetative growth may require management with applications of mepiquat chloride (MC). Pre-plant nitrogen needs to be carefully planned and only minimum necessary rates used to avoid associated excessive growth problems. The practice of using well-spaced irrigations early season to manage canopy development is only likely to be useful in seasons when rainfall is below average. Nitrogen and MC therefore remain the primary management factors available to influence early season canopy development in the majority of years.

Cloudy conditions, high temperatures and humidity can produce large paper-thin leaves.

Large 'soft' leaves are susceptible to high transpiration losses when conditions turn drier, resulting in rapid water stress if soil moisture is inadequate. This is of more concern during flowering when crop stress can lead to premature cut-out, reducing yield potential. In comparison, dry periods during the pre-flowering vegetative stage can encourage the roots to explore more of the soil profile without the same risks of premature cut-out.

Crop growth in the Burdekin is very rapid early season. The plantings above are only 18 days apart.

Fruit development

As the crop canopy develops, the production of buds (squares) commences from about 6-7 nodes onwards (approximately 28-33 DAS). As the canopy rapidly develops, increasing numbers of new squares are produced each week. Generally by the time a Burdekin crop reaches first flower (defined as one white flower per metre of row) at around 45-50 DAS each plant will have 20-45 squares across a range of sizes.

In Bollgard II® crops it is normal to expect that the retention of squares may be very high up until early flowering. Lower total retentions (40-60% of positions) will not adversely impact on yield potential during the vegetative stage, however it is important to monitor and identify the cause of these losses, as factors such as insect damage or spray contamination may require management intervention. Management for shedding, due to uncontrollable factors such as cloudy weather, is discussed in detail in the canopy management section, starting on page 45.

Discuss with your agronomist

From establishment to first flower:

- Crop establishment and adequacy of plant stand
- Root development and early season vigour
- Nitrogen management
- Irrigation/drainage issues
- Square retention (and potential causes if low)
- Pest and weed management
- Implications of root development for crop management

Flowering to crop cut-out and the onset of the dry season

The onset of flowering represents the most critical turning point for cotton production in the Burdekin.

From this point onwards an internal battle for resources begins within the plant as it finds a daily balance between the competing needs of newly setting bolls and the continuing growth of the terminal shoots and roots.

- If a crop is supplied with too much nitrogen or water, the internal balance may tip towards excessive leaf and stem growth and reduced boll development, and the plant may abort today's bolls in lieu of future ones. If prolonged, this response can delay maturity. It is also likely to reduce yield as the potential of late set bolls could be constrained by cool night temperatures and short day radiation limitations during May/June.
- If photosynthesis cannot supply both a quickly accumulating boll load and growing shoots and roots, canopy expansion can slow down prematurely and may even cease before enough bolls can be set for a high yield. Reductions in photosynthesis will occur if a crop becomes stressed from a resource deficiency for example nitrogen, soil moisture or sunshine.

The challenge is that canopy growth needs to be maintained for 6-8 weeks after first flower to ensure a large enough canopy to hold and develop a high number of bolls. Therefore the period from first flower to cut-out (late February until late April), is the most critical period for cotton production in the Burdekin. The time available and yield potential is ultimately dependent on the onset and duration of favourable weather between late February and late April and ensuring that a crop is well managed to best capitalise on sunny conditions during this period.

As we cannot control the weather, the aim of NORpak is to help guide you to grow the best performing plants possible with whatever conditions and resources are available.

In most seasons March heralds the end of the wet season and the start of sunnier, drier conditions. The purpose of the Burdekin planting window is to increase the likelihood that flowering will coincide with improving autumn conditions (sunnier weather for photosynthesis). In December-sown crops, flowering will be well underway. If large numbers of early fruit have been lost due to wet weather-related shedding, maintaining yield potential will require extended canopy growth to produce enough additional flowers throughout March and into April to ensure adequate compensation for early losses. In January-sown crops, flowering will have just begun and excessive vegetative growth could be of concern as these younger crops will have large canopies and a minimal boll load. These plants may respond to a return of sunnier conditions with very rapid vegetative growth at the expense of boll production, particularly if available nitrogen or soil moisture is high.

The key objective during early to mid flowering in March is to maximise the production of new squares and then retain a high proportion of these as they develop into bolls whilst avoiding excessive vegetative growth.

Roots

The often rapid change from wet to dry conditions can have significant implications for crop management, particularly from flowering onwards.

Check crop root development and effective root zone depth using a shovel to dig a hole in the planting bed. If the root system is predominantly shallow, the crop will be more susceptible to the onset of rapid moisture stress when rainfall stops. More regular irrigation may be required. **This is critically important if flowering has commenced.** Insufficient irrigation frequency at the onset of drier conditions will encourage the crop to grow roots at the expense of canopy development, resulting in a rapid rise of white flowers on the main stem to the top of the plant and premature cut-out. Ensure that soil moisture via irrigation is sufficient to allow root development whilst maintaining active canopy expansion. See the irrigation section on page 41 for more information.

Tillage operations such as inter-row cultivation should be avoided as they can cause significant disturbance to shallow roots and exacerbate moisture stress and premature cut-out. If it is necessary to cultivate to clear irrigation furrows or to control herbicide escapes or problem weeds, only cultivate shallowly and irrigate within 24 hours.

Canopy development

Aim to maintain balanced growth by monitoring the crop weekly and enacting appropriate management when required. Excessive growth is most likely to occur from 8 to 10 nodes until several weeks after first flower (e.g. 8–18 nodes), particularly on free draining loam soil types. Crops on these soils can often grow large internodes with rapidly expanding leaf areas and a comparatively small fruit load. Provided that nitrogen and other factors are sufficient, the onset of sunnier weather combined with wet season enlarged canopies provides the crop with a burst of additional photosynthates. The resultant rapid terminal shoot growth should be monitored and managed with low dosages of mepiquat chloride if required (see page 49). This growth is often characterised by a lime green stripe when looking up the crop rows.

A lime green stripe visible along the crop rows is an indicator of rapid terminal shoot growth.

Cotton crops deficient in nitrogen or moisture stressed during early flowering, particularly on clay soils, can rapidly lose canopy vigour, reducing both the production of fruiting sites and yield potential. If required, ensure prompt irrigation or apply nitrogen as soon as practical. See the sections on nitrogen (page 39) and irrigation (page 41) for more information.

Crop protection becomes critically important from first flower onwards, as the crop will become increasingly attractive and susceptible to attack from insects such as *Spodoptera* and sucking bugs (see the insect management section on page 53).

Fruit development

Cotton flowers generally self-pollinate within hours of opening. Boll growth is an energy-intensive process due to the high oil content of the seed, and once set, the developing bolls will take priority over the production of new leaves, stems and squares. As boll numbers increase, the resources available for the growth of new squares and leaves gradually diminish until canopy expansion ceases. This is referred to as cut-out, and shedding of surplus young bolls and squares will also occur at this time.

What is excessive growth and why does it occur?

Unlike most other broad acre crops that grow vegetatively to full size and then reproduce, cotton develops vegetative (stems and leaves) and reproductive (square and bolls) parts simultaneously. Growth is considered to be excessive when the plant favours the development of new stems and leaves at the expense of setting and filling bolls. In the tropical Burdekin climate this is usually characterised by the growth of increasingly large main-stem inter-nodes (>10 cm) that span 3 or more consecutive nodes as well as elongated fruiting branch internodes and leaf petioles. Reproductive structures will appear unchanged and therefore smaller in comparison to expanded branches.

By 6-7 nodes, squares start to develop whilst new stems and leaves continue to be produced until growth becomes limited by either the demand of resultant bolls or limitations in the environment (plant runs out of water or nitrogen, or climatic conditions become unfavourable). At this point canopy growth will pause for a period until the existing bolls mature (the seed and lint are released) and/or environmental conditions again become favourable. Removal of these restraints allows the plant to resume canopy growth and develop new flowers and bolls.

Having evolved as a perennial plant in a flood plain environment characterised by seasonal influxes of water and nutrient rich sediment, cotton is particularly effective at growing very rapidly to take advantage of temporararily favourable conditions. An abundance of nutrients and prolonged soil moisture will promote a very large canopy that will support as many future developing bolls as possible.

Partitioning internal resources in favour of growing additional stem and leaves instead of bolls works well if resources and climate remain favourable, as hundreds of bolls can be initiated and matured over an extended period. However, this characteristic has been a challenge in domesticating cotton as a 5-6 month annual crop where a canopy of sufficient size to support enough bolls for a high yield in a relatively short 6-8 week flowering period is required.

High rainfall and very warm conditions may continue through until early to mid flowering in the Burdekin, and particularly if nitrogen availability is high, a plant may forgo the setting of early season bolls and direct these resources towards expanded canopy growth. However, the rapid cooling of night temperatures at the end of May exposes these large plants (that may be difficult to spray or pick) to significantly delayed maturity and associated lint quality issues due to temperature effects on late maturing bolls.

Therefore the balance for the Burdekin is to achieve rapid canopy expansion to enable the production of a large number of bolls, but for this expansion to happen simultaneously with boll setting. If conditions are favourable (sunny) for reproduction the plant needs to begin retaining and developing bolls whilst still producing new squares so that over the period from first flower to cutout in late April a crop has retained and developed as many bolls as possible to maximise yield, avoid excessive crop height, and ensure timely harvest maturity.

The nitrogen, irrigation and canopy management sections of NORpak will assist you in making crop management decisions that help achieve this outcome for the array of likely weather scenarios that could be expected in the Burdekin.

These two crops are the same variety, with the same plant date, sowing rate and row spacing. Both crops have the same number of nodes and fruiting branches. The shorter crop on the left has a better balance of reproductive to vegetative growth. The number of squares, flowers and early bolls are well proportioned with the crop canopy.

The squares, flowers and bolls are less evident for the 'waist-high' crop on the right because the expansive vegetative growth of the internodes and petioles has spread these positions out. This crop is exhibiting signs of excessive growth with energy balance tipped towards leaf and stem production. The canopy management section starting on page 45 details a tool that can be used to measure growth and accurately make this determination so that remedial steps such as the application of a growth regulant can be taken.

During the period between first flower and cut-out, aim to maximise the production of reproductive sites (through canopy expansion) but IMPORTANTLY also retain as many bolls as possible. The nutrition, canopy management, irrigation and pest management sections will help you achieve this objective.

Discuss with your agronomist

From first flower to crop cut-out:

- Root development and depth and implications for irrigation and crop nutrition
- Crop vigour and canopy growth
- Management of nitrogen and other nutrients
- Irrigation scheduling for transitioning to the dry season
- Insect and weed management
- Rate of boll retention
- Crop maturity trajectory and achieving last effective flowers by 25 April

Late-season crop development (cut-out to maturity)

Beyond cut-out, the crop is filling bolls and crop managers should focus on insect protection and timely irrigation. From late April onwards, crop development and growth slows significantly with cooler night temperatures and decreasing day length. Irrigation intervals will increase during May and June as pan evaporation rates decrease dramatically. Over-irrigating crops at this stage potentially contributes to delayed crop maturity and an increase of humidity within the crop canopy that can encourage boll rots (see page 63).

Roots

Burdekin crops usually continue to grow root systems until cut-out with root depth determined by the frequency of rainfall or irrigation. Some crops on loam soils may access leached nitrogen deep within the soil profile (1 metre or more). This can result in crops taking up too much nitrogen late in the season, which can be detrimental to maturity, yield and quality (see nitrogen section on page 39). If crops continue to grow, cut-out can be encouraged with more restrictive irrigation scheduling and mepiquat chloride (MC) applications. Aim to have crops cut-out by 25 April.

Canopy development

As late bolls (top and outside of plant canopy) fill and earlier set lower bolls begin to open, it is normal for the crop canopy to lose its dark green colour as the plant redirects nutrients stored in the leaves to the growing bolls. Leaves commonly redden during the later stages of boll filling and leaf blight caused by *Alternaria* spp. becomes more prevalent, particularly in crops with high boll loads. As the plant is in a natural state of decline, these symptoms are not generally a cause for concern in terms of yield, particularly for high retention crops.

Fruit development

After cut-out, the crop stops producing new vegetative growth and instead directs assimilates to the development and maturation of existing bolls. The numbers of bolls per unit of area is largely fixed, however boll size (an important factor in final yield) is dependent on favourable growing conditions between cut-out and maturity.

Lower canopy bolls typically begin to open at or soon after crop cut-out and continue to do so until the uppermost bolls mature and open. When 60% or more of bolls are open the timing of defoliation can be calculated. Defoliation decision-making is covered in detail on page 68.

It is common for a crop canopy to redden in colour during the later stages of boll filling.

Discuss with your agronomist

From cut-out to maturity:

- Irrigation scheduling and timing of last irrigation
- Insect management
- Boll opening & crop maturity
- Crop defoliation

Cropping calendar for Burdekin cotton season

Cotton production in the Burdekin generally occurs as either

(i) a rotation crop for sugarcane grown during the summer fallow that occurs every 4-5 years, or

(ii) alternating with grains in a 12 month perpetuating cycle.

Cropping calendars are given for the two systems below.

Typical timing of crop stages for Burdekin cotton as a rotation for sugarcane

Stage/operation	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
Removal of cane, land prep, and pre-irrigate																	■	■	■	■	■	■		
Mungbean cover crop, stubble retained*																			■	■	■	■	■	■
Cotton planting	■																							■
Emergence to first flower	■	■	■	■	■																			■
First flower to last effective flower				■	■	■	■	■																
Last effective flower to defoliation								■	■	■	■	■	■											
Defoliation to picking										■	■	■	■	■	■									
Post-picking crop removal										■	■	■	■	■	■	■								
Planting Sugarcane											■	■	■	■	■	■	■	■						
Sugarcane ratoons for 4-5 years	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

* if time permits

Typical timing of crop stages for Burdekin cotton in rotation with grains

Stage/operation	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
Cotton planting	■																							■
Emergence to first flower	■	■	■	■	■																			■
First flower to last effective flower				■	■	■	■	■																
Last effective flower to defoliation								■	■	■	■	■	■											
Defoliation to picking										■	■	■	■	■	■									
Post-picking crop removal										■	■	■	■	■	■	■								
GRAINS ROTATION (stubble retained)																								
Planting maize											■	■	■	■	■									
Maize emergence to harvest												■	■	■	■	■	■	■	■	■	■	■	■	■
OR																								
Pre-irrigate beds and spray out cotton volunteers											■	■	■	■	■									
Planting mungbeans																■								
Mungbean emergence to harvest																■	■	■	■	■	■	■		

Crop management considerations — early season (pre-plant to flowering)

Field selection

Choosing an appropriate field is critical for successful cotton production in the Burdekin. Important aspects to consider include:

- **Flooding and field drainage.** Ensure sufficient drainage. Avoid low-lying fields that are likely to be submerged for more than 12 hours during wet season deluges.
- **Accessibility.** Avoid fields that do not have reliable wet season access due to seasonal flooding of water courses or lack of internal access roads. Your agronomist will need to visit each field twice a week.
- **Soil type** can significantly influence agronomic practices required and field trafficability. From a production perspective, loam soils are generally easier for cotton production in wet years than clay soils.
- **Field length.** Avoid fields with irrigation run lengths over 800 m as they are more difficult to flood irrigate without waterlogging.
- **Field history.** Avoid fields that may contain residual herbicides that could affect cotton growth or fields that have less than 2 months for field preparations between sugarcane plough-out and cotton sowing.
- **Field location.** Avoid fields that are near sensitive areas such as watercourses or dwellings as these can limit spray application opportunities.

The ability to drain away excess surface water during wet season deluges is essential.

The field in the top image had excellent drainage, which allowed a deluge of rain (>120 mm in two hours) to drain away within several hours. The field in the lower image during the same deluge had restricted drainage through a roadway culvert (only 380 mm diameter) resulting in significant runoff water backup which took 2 days to completely drain.

Many fields within the Burdekin have minimal slope over field lengths of 800-1500 m. During the wet season it is not uncommon for 100-200 mm of rain to fall within a 24 hour period causing field run-off rates of 1-2 ML per hectare. For long fields this can result in run-off water backing up hundreds of meters from the tail end, as many fields share common drainage channels with narrow restrictions. Select fields that can drain away these deluges quickly (<12 hours) as prolonged waterlogging or repeated crop submersion can result in plant death, loss of vigour, or loss of fertiliser. With appropriate drainage between rainfall events, cotton will withstand multiple wet season deluges.

Maintenance of soil cover and using controlled traffic is recommended for cotton production in all Burdekin soils. Examples include mungbean stubble on clay (top) and corn stubble on loam (bottom).

Burdekin soils and cotton production

The lower Burdekin is divided into the delta and levee areas and the more recently developed (late 1980s) Burdekin River Irrigation Area (BRIA). More cotton is likely to be planted in the BRIA due to larger paddocks and greater distance from the coast (less likelihood of coastal showers) than the delta area.

Delta and levee regions

Provided field drainage is good, the soils in these areas are unlikely to provide any major limitations to cotton growth, although they can form surface crusts when finely tilled. Soil crusts can impede the emergence of cotton seedlings resulting in a patchy plant stand or occasionally the need to re-plant.
To reduce the risk of soil crusting, direct drill into a surface stubble mulch (avoid sowing too deeply).
Following sowing with irrigation may also delay crusting on some soil types and allow enough time for cotton seedlings to emerge.

BRIA

Many of the BRIA soils are clay textured and may be sodic. Classified into four broad groups, their occurrence is:

- Cracking clays 43%
- Sodic duplex soils 35%
- Non sodic duplex soils 12%
- Gradational & uniform non cracking soils 10%.

See Donnollan (1991) for more details.

Summary of the challenges and management options for cotton production on the broad soil groups of the lower Burdekin.

Soil group	Positives	Challenges	Management options
Cracking clays	Suitable provided drainage is good. Highest plant available soil water (PAWC). Reasonable levels of Phosphorous (P) and & Potassium (K) may be available. Soil test to confirm.	Waterlogging if drainage is poor. Generally sodic at depth — rooting depth and PAWC limited if sodicity is near the soil surface. Ca:Mg ratio may be limiting to structure as many soils are <2, particularly deeper in profile. Trafficability after wet weather. Can be difficult to wet soil surface in the centre of the bed during irrigation. This can be a constraint for activating soil surface-applied liquid nitrogen fertiliser to the centre of the bed.	Ensure good drainage e.g. tail drains designed to exit runoff water quickly. Reasonable slope 0.1%. Avoid run lengths >600 m. High beds about 15 cm above furrow. Use a gypsum program similar to other crops if the Ca:Mg ratio is low. Appropriate nitrogen management is essential (see nutrition section on page 38).
Sodic duplex	Suitable if A horizon is at least 90 cm.	B horizon impermeable and chemically unstable, so unsuitable unless A horizon at least 90 cm. Surface crusting is likely when cultivated. Lower PAWC than cracking clays. Furrow irrigation can be inefficient if beds crust or if water infiltration is too high.	Retain past crop residues on soil surface and use immediate post-sowing irrigation to aid seedling emergence. Use a gypsum program similar to that used in other crops. Soil test and adjust nutrition program for high pH and sodicity. May be better suited to overhead or drip delivery systems.
Non-sodic duplex	Suitable if A horizon is at least 90 cm.	Unsuitable for cotton unless A horizon is at least 90 cm.	Similar to sodic duplex except nutrient imbalances due to high pH and sodium are not a constraint.
Gradational clays	Suitable for cotton.	Waterlogging if poorly drained.	Similar to cracking clays.
Levee / alluvial	Best suited for wet season trafficability. Deep root exploration (180 cm) can capture leached nutrients, reducing additional fertiliser requirements.	Surface crusting is a risk where silt is present and soil has been cultivated. Furrow irrigation can be inefficient if beds crust or if water infiltration is too high. Water soluble nutrients such as nitrate are easily leached.	Needs careful management of nitrogen and sulphur. Soil test for other nutrients (e.g. Zn may be required). Controlled traffic + minimum tillage (zero tillage of bed top preferable) with trash retained on soil surface. Better suited to overhead or drip delivery systems.

Crop rotation, minimum tillage & pre-season land preparation

Field preparation has a major influence on the ability to successfully establish a cotton crop during the early phases of the wet season.

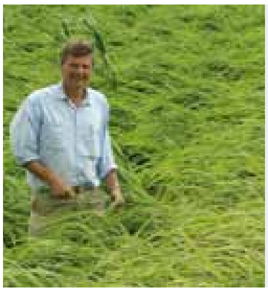
Depending on the type of farming operation, cotton in the Burdekin will follow either a late season plough-out cane crop (grown for 4-5 years), a grain crop (grain or legume), or a cover crop (millet, legume). When using crop rotations, it is important to consider herbicide selections in advance as the use of certain residual herbicides can severely limit alternate cropping choices.

Cotton after sugarcane

Research on optimising field preparation for cotton after late cane removal is ongoing. However, preliminary results and experience from commercial crops after cane suggest that it may be beneficial to:

- **Harvest cane by late October or early November** to allow sufficient time to complete various tillage operations (field laser level, incorporate cane stool and create new planting beds).
- **Build the planting beds as high and evenly as practical.** Cotton benefits from better drainage and planting bed uniformity. However in some fields, higher beds may not infiltrate irrigation water to the surface in the centre. Placement of in-crop nitrogen will need to account for this.
- **Use a bed formation that will suit the re-planting of sugar cane.** Cotton can be grown on spacings from 71-102 cm so choose a spacing that suits your sugarcane system (see row spacing section on page 37). Sugarcane should be able to be direct drilled into cotton beds after picking with a double disc opener billet planter without the need to renovate the planting bed.
- **Establish a cover crop if time allows.** Mungbeans can produce cover in as little as 6-8 weeks then be sprayed out with herbicide just prior to planting and cotton direct drilled into the standing stubble. This can provide up to 40 units of early season nitrogen and help maintain bed integrity during the early phases of the wet season until cotton establishes a root system. A green cover crop of mungbeans or millet can also assist in drying out a field if storm rainfall occurs prior to planting. Avoid forage sorghum as it can have short-term allelopathic effects on a subsequent cotton crop. Ensure that furrows remain clear of stubble for later wet season drainage.
- **Irrigate pre-formed beds at least one month before planting cotton** to allow soil consolidation and encourage microbial breakdown of incorporated sugarcane roots, stools and trash. It also germinates weed seeds that are brought close to the surface during preparatory cultivation and allows the pre-planting application of herbicide to reduce early season weed populations.
- **Conduct a soil test.** It is likely that soil nitrogen levels will be very low after sugar cane removal. Many Burdekin soils are also deficient in potassium (K) and sulphur (S) but may have high levels of phosphorous (P) therefore a soil test will be helpful in identifying the likely fertiliser blend of P, K & S at planting. Determining the rates and timing for nitrogen application is more complex and covered in detail later (nutrition section begins on page 38).
- **Ensure that field drainage is adequate** to allow the prompt run-off of heavy rainfall within 12 hours. Many cane fields have inadequate drainage for cotton in wetter-than-average seasons (wet ends or insufficient drainage culverts).

A legume cover crop will assist early cotton crop development. This mungbean crop has been sprayed out the day before direct drilling cotton seed. Note the clean furrows.



A cover crop of millet can assist with pre-cotton field preparation, allowing for bed consolidation and providing stubble that will protect the soil surface and return valuable slow release nitrogen over several months during the wet season.

Pre-irrigating new beds allows important consolidation. If done 6-8 weeks prior to planting it also allows breakdown of cane residues.

Cotton after grains

When rotating cotton with grains such as maize and mungbeans, opportunity exists to use minimum tillage and retain standing crop stubble rather than reforming new beds.

Advantages of a minimum or reduced tillage approach may include:

- **Increased field trafficability.** Retained consolidated beds and furrows with residual crop root structures may allow earlier trafficability after rainfall compared with a freshly bedded-up field.
- **Increased timeliness for planting** particularly when rotating two long season crops such as maize and cotton. This may mitigate the effect of unforeseen delays due to rainfall or harvest contractors.
- **Increased soil surface protection** through stubble retention and **reduced sediment losses** during intense rainfall.
- **Reduced nitrogen applications.** Standing stubble breaks down more slowly, decreasing short-term nitrogen tie-up and returning valuable nitrogen to the system at a slower rate over time.
- **Reduced early season weed densities.** By avoiding cultivation and soil inversion, many dormant weed seeds remain buried and inactive.
- **Reduced on-farm inputs.** Minimum tillage decreases the need for energy intensive cultivation, herbicides and applied fertiliser.
- **Improved seedling establishment.** Planting into a consolidated bed with stubble cover, allows more control over seeding depth and the soil surface is less likely to rapidly crust or hard set after planting, allowing seedlings to emerge more evenly and quickly.

Disadvantages of a minimal tillage approach may include:

- **Restriction of water flow within irrigation furrows** by excessive surface trash after grain crop harvesting. Trash raking can provide a solution to this problem.
- **Difficulty gaining soil soakage** to the plant line on some light soils.
- **Difficulty controlling cotton volunteers**.
- **Additional machinery** such as disc opener style planters with trash wipers may be required.
- **Gradual collapse of bed** and hill profile over time may limit the life span of minimum tillage requiring an occasional full bed renovation with tillage.
- **Limitations on herbicides** that can be used on grain crops as there may be plant back constraints for following cotton crops (***e.g. Spinnaker® (imazethapyr) cannot be used on a legume grain crop if cotton is to follow***).

Growers rotating cotton with maize need to take into account nitrogen cycling (early season nitrogen tie-up followed by nitrogen release) when planning and budgeting nitrogen inputs. This is covered in further detail on page 39.

Immediate field turn-around. Cotton was mulched and sugarcane billets direct sown into the centre of the beds. Within a few months the sugar cane is established and cotton remnants are mostly gone due to the herbicide program and early season sugarcane inter-row tillage operations.

Sugarcane and grains after cotton

Cotton has a potentially good fit as a rotation option for both sugarcane and grains.

In a sugarcane system, cotton can utilise ground that is typically bare during the summer fallow period. As cotton is a 5-6 month crop, sugarcane cannot be replanted until after late May or June, which is later than the traditional Burdekin sugarcane planting window of March–May. However, anecdotal evidence from a series of commercial sugarcane crops planted after cotton on all soil types since 2007 strongly suggests no loss of subsequent yield in both the plant crop and subsequent ratoons. The interaction between sugarcane planting date and various crop rotations including cotton is currently the subject of new research (by DAFF, BSES & CSIRO) due to be completed by 2016.

Planted in late April 2010 after a bare summer fallow.

Planted in early August 2010 after a cotton crop picked in June.

These sugarcane crops are within the same heavy clay soil field used to grow an earlier cotton rotation crop. A third of the field was left as a bare fallow to provide an on farm comparison with the cotton rotation. Both crops yielded similar tonnages of cane (approximately 135 t/ha) at the first cut despite the 4 month delay in planting for the field section that grew the cotton rotation crop. Photos taken early March 2011.

The field turn-around time for planting sugarcane after cotton can be nearly immediate. A successful strategy has been to mulch (and if possible root cut) the cotton after picking and then direct drill sugar cane billets into the same bed with a disc opener style billet planter. While the cotton plants may re-grow, particularly if only mulching is used, the usual broad leaf weed management program used in plant sugarcane will control ratoon cotton plants. As the sugarcane grows, any escaping cotton plants will be rapidly smothered.

A similar strategy can be used for maize following cotton although root cutting must be used together with mulching, as maize is a poor competitor with ratoon cotton and does not offer the same flexibility as cane crops for cotton control with herbicides. Maize is an attractive host for *Helicoverpa* and the risk of pest exposure to surviving Bollgard II® cotton plants may have adverse implications for long term resistance management and viability of Bt technology. Ratoon cotton plants within maize crops also provide a 'green bridge' allowing pests such as mealybugs and aphids to survive on farm and re-infest the next cotton crop. Effectively killing all cotton plants prior to planting maize is essential.

If conventional tillage is required in a cotton–maize rotation it is preferable to do this prior to sowing the maize crop. As a dry season operation, rainfall delays to tillage and planting are unlikely, any cotton regrowth or volunteers will be destroyed, and the beds and track furrows will be consolidated allowing easier field trafficability for planting and spraying during the next wet season cotton crop.

Maize has been sown into mulched and root cut cotton stubble. Volunteers from dropped seeds will be controlled with group I herbicides such as Starane® (fluroxypyr).

Discuss with your agronomist

Crop rotations:

- Cropping options
- Tillage requirements and constraints
- Stubble management and crop transitional strategies
- Potential herbicide limitations due to plant back considerations
- Management strategies for volunteer cotton plants
- Crop rotation implications for nitrogen recycling

Varieties

A cotton variety and its transgenic technology traits are often confused.

- A **variety** is a fixed line that has certain morphological characteristics (e.g. okra leaf or short season). At the current time all Australian varieties have been developed by CSIRO and commercialised by Cotton Seed Distributors (CSD) who arrange for seed increase, processing and on-selling to growers. Varieties are protected by Plant Breeders Rights (PBR), and part of the price paid for a bag of cotton seed includes a royalty that is returned to the breeder to fund the development of future varieties.
- **Technology traits** are independent of varieties and are genetically-based characteristics owned by a third party that may be included into certain cotton varieties. For example, a conventional variety such as Sicot 71 can be grown with or without transgenic technology (Sicot 71RRF contains the Roundup Ready Flex® trait; Sicot 71B contains the Bollgard II® trait; Sicot 71BRF contains both traits). Each transgenic trait remains the property of the third party (e.g. Bollgard II® or Roundup Ready Flex® traits are owned by Monsanto and Liberty Link® by Bayer) and a licensing fee is payable by the grower. See "Transgenic cotton traits" on page 33 for further details.

The breeding and release of new cotton varieties is ongoing, however the following comments are valid as of May 2012.

Indeterminate or 'full season' varieties are recommended for sowings prior to 10 January. Varieties such as Siokra 24BRF or Sicot 74BRF are capable of setting large numbers of compensatory bolls after extended periods of cloudy weather and will offer significant crop management flexibility during wetter-than-average seasons. These varieties will also perform equally well under sunnier drier conditions.

More determinate or 'short season' varieties are recommended for planting after 10 January as the earlier maturing tendencies of cultivars such as Sicala 60BRF and Siokra V-18BRF are useful during a cooler finish.

Okra leaf varieties may offer additional advantages in cloudier years due to their less dense canopies and reduced within-plant shading. These varieties (e.g. Siokra V-18BRF or Siokra 24BRF) compensate quickly after cloudy weather and are relatively easy to defoliate, with many crops only requiring a single application of defoliant or reduced rates per hectare.

Transgenic varieties such as Bollgard II® based on *Bacillus thuringiensis* (Bt) toxins are the only varieties recommended for all tropical regions of northern Australia. Varieties that incorporate the Bt trait allow implementation of Integrated Pest Management (IPM) strategies and largely negate the need for repeated insecticide applications against *Helicoverpa*, increasing the reliability of insect control, thus reducing environmental impacts and offering improved production cost control compared with conventional cotton production.

Transgenic herbicide tolerant stacked varieties such as Roundup Ready Flex® and Liberty Link® are ESSENTIAL for wet season production in the Burdekin, as they eliminate the need for soil applied herbicides, some of which have been recorded as key environmental contaminants in Burdekin waterways and underground aquifers (Davis et al., 2008). The ability to control most weeds with over-the-top applications of glyphosate or glufosinate offers significant flexibility for weed management using products with excellent efficacy but minimal environmental impact from runoff or leaching.

Shedding and varietal type

Research data has shown that early season shedding associated with low radiation and wet weather, particularly during February or early March, can be a favourable response. This early season shedding allows a plant to "free up" internal resources that can be used to grow new squares and form bolls that are more likely to coincide with sunnier weather as autumn progresses. The failure to shed early bolls during extended cloudy weather can result in reduced yield potential because these bolls will be much smaller in size, and compete with the production of new fruiting sites that are likely to receive sunnier autumn conditions and become larger bolls.

Shedding allows the plant the opportunity to exchange early set bolls with limited potential during cloudy wet season weather for future bolls that might coincide with better weather and be larger (see shedding case study on page 32). This is particularly important for December-sown crops that are more likely to experience cloudy wet weather during early flowering. If sowing during the first half of the planting window, select a vigorous indeterminate variety that will shed positions (e.g. Siokra 24BRF) and compensate with later growth.

Shedding case study

The value of early season shedding in response to cloudy weather was demonstrated by comparing the growth habits of Sicot 70BRF and Siokra 24BRF. Sicot 70BRF has a determinate growth habit and retained high numbers of bolls during cloudy weather whereas the indeterminate variety Siokra 24BRF generally shed fruit during wet, overcast weather but rapidly set later compensatory bolls when conditions improved.

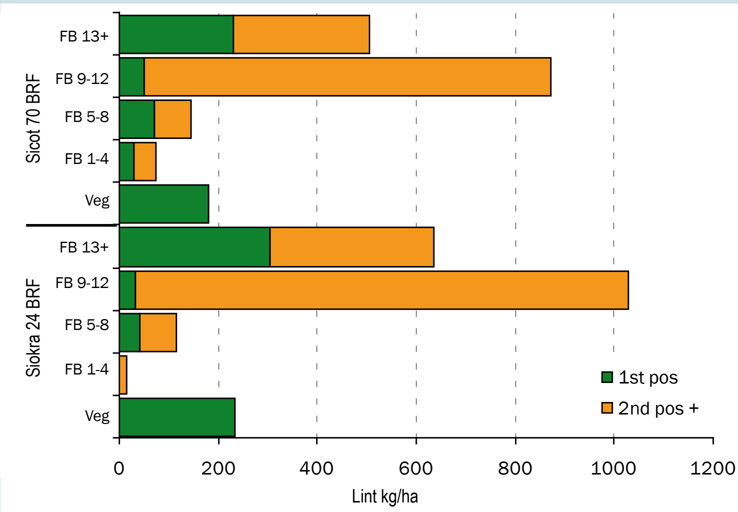
Although Sicot 70BRF was very popular and successful in temperate Australia at the time, it was ill-suited to Burdekin conditions. Recently Sicot 70BRF was superseded by Sicot 71BRF and Sicot 74BRF. Under trial conditions Sicot 71BRF has had a very similar growth habit to Sicot 70BRF and is therefore not a preferred variety for the Burdekin, particularly for early window planting or wetter than average seasons.

The most recent release, Sicot 74BRF also has a tendency to retain early season bolls during cloudy wet weather. However, unlike Sicot 70BRF and 71BRF which tend to prematurely 'cut-out' in this situation, Sicot 74BRF is more indeterminate and will extend the flowering period and continue to grow on at a reduced rate. This results in a compensatory top crop, but often with a maturity delay up to 1-3 weeks compared to Siokra 24BRF.

It should be noted that these experimental growth responses were not due to 'second flowering' whereby a crop prematurely cuts-out and then re-grows. No nitrogen was applied beyond first flower.

Successful management of crop compensation is dependent on effective nitrogen and irrigation management as well as improved radiation conditions in autumn. These management aspects will be addressed specifically in later sections.

This December-sown crop of Siokra 24BRF underwent extensive shedding during February but grew compensatory bolls in March and April to yield over 9 bales/ha.



The contribution of the different canopy segments to overall lint yield for Siokra 24BRF and Sicot 70BRF for the case study crops. The Siokra 24BRF produced very little lint from the lower fruitung branches (1-4) due to the shedding of bolls but compensated by producing large lint-filled bolls on the upper and outer branch sections.

Sicot 70BRF (below left) has a more determinate growth habit and will retain fruit during wet overcast conditions, in this case resulting in small and tight-locked bolls that reduced the opportunity for later compensation. Siokra 24BRF (below right) shed fruit during earlier cloudy weather and instead grew a larger compensatory top crop by setting most bolls during autumn. In this experiment the Siokra 24BRF yielded significantly more (9.4 bales/ha) than the Sicot 70BRF (8.2 bales/ha).

Retaining fruit during extended wet overcast weather during February and early March can reduce yield potential.

Transgenic cotton traits

Prior to planting transgenic cotton, growers need to obtain

(i) a user agreement from the relevant technology provider, and
(ii) appropriate accreditation qualifications.

Talk to your agronomist or reseller about transgenic traits and be sure to discuss any accreditation requirements.

Bt transgenic traits

The soil bacterium *Bacillus thuringiensis* (Bt) is a naturally occurring pathogen that produces a number of toxins that each affect particular groups of insects (e.g. moth caterpillars, beetles, or mosquito larvae). Scientists have incorporated the relevant genetic material from this bacterium into crop plants. Currently available cotton varieties include Bollgard® II, which is based on two toxins known as Cry1Ac and Cry2Ab, that specifically target moth larvae. Two separate protein toxins is a very good resistance management combination, as any individual *Helicoverpa* larvae resistant to one protein will be killed by the other protein. Bt cotton therefore provides very good levels of caterpillar control, but it does not control other insects such as aphids or stink bugs. Several companies have other similar Bt-based toxin traits under commercial development at the time of writing.

An important part of the deployment of Bt technologies has been the development of strategies that aim to minimise the potential for caterpillar pests to develop resistance to these products over time. This strategy is commonly referred to as the Resistance Management Plan or RMP. Each cotton production region has an RMP that is tailored to local conditions and the likely biology of keys pests in that environment. Generally the RMP will specify conditions such as annual dates within which cotton may be planted and post-harvest crop destruction guidelines.

At the time of writing it has been a requirement that growers also plant a set percentage of the proposed cotton area to a refuge. The refuge provides an area on-farm whereby caterpillar pests such as *Helicoverpa* can freely breed so that potentially resistant moths emerging from the adjacent Bt crop are likely to be swamped and mate with non-Bt exposed moths emerging from the refuge area.

Also required in the Burdekin is a trap crop, a small area planted to chickpeas intended to attract egg lay from the last generation of *Helicoverpa* moths where they can be destroyed with cultivation after the cotton crop has been picked.

In utilising Bt technologies, growers need to be accredited and have a signed technology user agreement (TUA) in place. The TUA is a legal contract between the grower and the technology provider (e.g. Monsanto or Bayer). Under this contract, growers planting transgenic cotton must adhere to the current RMP at the time of production. The RMP is updated annually and will specify the terms and conditions related to planting dates, refuges and trap crops.

The use of Bt transgenic traits is a cornerstone for cotton production in the Burdekin. Failure to adhere to the contractual requirements of the Resistance Management Plan (RMP) poses a serious risk to long term viability of this technology. Before undertaking to grow cotton, growers must understand, accept, and budget for the needs of the RMP to ensure a fulfilment of requirements. These requirements generally include growing an additional prescribed area of the field to a refuge crop and a trap crop as well as adhering to the specified planting date.

The widespread adoption of transgenic Bt cotton varieties by the Australian cotton industry has seen a substantial reduction in the amount of insecticide used, making the industry much more sustainable.

This unsprayed cotton field demonstrates the impact of caterpillar pests on yield of non-transgenic cotton (left) compared with Bt cotton (right). Photo by Gary Fitt, CSIRO.

Herbicide tolerant traits

Herbicide tolerant traits allow cotton plants to deactivate and survive applied herbicides that would normally be toxic. Current examples are Roundup Ready Flex® (RRF) and Liberty Link® (L).

The RRF trait developed by Monsanto allows glyphosate to be applied over the top of cotton crops without crop damage, enabling excellent control of a broad range of weeds. Previously, weed control in cotton relied solely on traditional methods such as:

- inter-row cultivation
- pre-emergent herbicides applied prior to planting
- post-emergent herbicides applied after planting
- shielded and directed spraying
- layby spraying (applying a residual herbicide just prior to row closure).

In the Burdekin the RRF technology has been critically important for weed control during the wet season, eliminating the need for other soil-applied herbicides. The formulation of glyphosate specifically developed to treat RRF cotton gives excellent control of most commonly encountered grass, sedges and broadleaf weeds in the Burdekin.

The ability to utilise a broadacre spray boom or aerial application for weed control provides significant savings in time, labour, and machinery running costs. Head ditches, tail ditches and sides of fields can also be sprayed, although care must be taken when utilising aerial application and spraying close to susceptible crops such as sugarcane, grain and vegetable crops. Roundup Ready® herbicide is non-selective. Overspraying of the edges of adjacent sugarcane crops with glyphosate has occurred in the Burdekin, particularly with poor aerial application practices. Ensure that wind conditions are monitored closely when applying glyphosate to ensure that the risk of overspray onto adjacent crops areas is minimised.

The Liberty Link® (L) trait developed recently by Bayer CropScience is available in a number of cotton varieties stacked with Bollgard II® (e.g. Siokra V-18BL and Sicot 72BL). Liberty Link® cotton is tolerant to 'over the top' applications of Liberty 200® herbicide that contains glufosinate ammonium and surfactant. Liberty 200® herbicide has a different mode of action and no known cross-resistance with glyphosate making it an excellent technology option to rotate with RRF cotton to limit the development of herbicide resistant weeds.

This herbicide trait may offer cotton growers benefits including:

- another option for weed management and to reduce the risk of resistance or shift in weed species
- control of Roundup Ready Flex® volunteer cotton plants
- improved control of hard to kill broadleaf weeds including peach vine.

Liberty Link® cotton can be sprayed over the top with Liberty 200® all season but there is a 70 day withholding period prior to harvest. The Liberty Link® trait has not been deployed either commercially or experimentally in the Burdekin and therefore its suitability during the monsoon season is not yet known. However, Liberty Link® cotton may be a very valuable technology for weed management and rotation option for RRF when cotton is grown with grains as a continual rotation.

DISCUSS WITH YOUR AGRONOMIST

SELECTING VARIETIES AND TRAITS:

- **Locally adapted varietal and technology traits options**
- **Requirements for the current Resistance Management Plan (RMP) or Crop Management Plan (CMP)**
- **Soil type and field constraints**
- **Planting date**
- **Field history**
- **Capacity to manage nitrogen**


An example of excellent weed control provided by glyphosate on Roundup Ready Flex® cotton during the wet season.

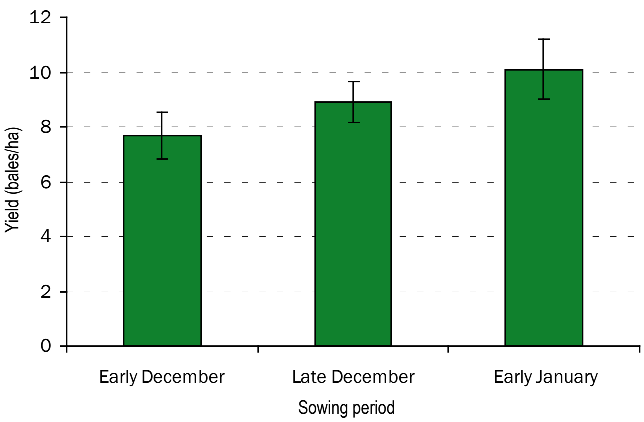
Sowing date

Modelling and field validation experiments have confirmed that sowing between 20 December and 20 January is the most suitable for Burdekin conditions. **Planting before December 20 is not recommended.**

Within this period, sowing between 1-10 January is the most desirable period for optimising boll setting in most seasons with flowering commencing very late February to early March. However there is an increased risk of wet weather interruptions to planting operations after Christmas, particularly on less trafficable clay soils. Growers therefore need to be prepared and ready to plant earlier should wet weather threaten to develop.

A December-sown crop will flower during mid-February, and is more likely to be subject to cloudy wet weather during the first weeks of flowering. As this may result in the shedding of many early flowers and squares, a management strategy geared towards growing later compensatory flowers and bolls during sunnier weather in March is essential. Local experience since 2008 suggests that many growers have found December-sown crops more difficult to manage for high yield potential than January-sown crops. However, gaining field access to actually plant in December is often easier than January, particularly on clay soils.

Planting beyond 20 January poses significant risks during cooler-than-average seasons, with the potential for greatly increased risk of bale price discounts from poorer fibre quality. If planting between 10-20 January, use an early maturing variety such as Siokra V-18BRF, Sicala 60BRF or equivalent. Avoid planting Siokra 24BRF and Sicot 74BRF at this time.



The effect of sowing date on lint yield presented as an overall mean of seasons and varieties from 2008–2011 climate studies. January sowing has achieved the highest aggregate yield for this period.

Sowing and wet season risk

The recommended sowing window carries a significant risk of wet weather interrupting (or possibly preventing) sowing. This is of concern particularly where forward marketing contracts that involve a physical bale commitment have been made. However there are a number of management options that will minimise the likelihood of wet weather impeding sowing or emergence.

- **Prepare fields early.** Have beds or hills prepared 1-2 months ahead of time to allow soil to consolidate and permit rapid runoff/ drainage (minimising access delays). A late sown cover crop such as mungbeans or millet may dry out the upper soil profile more quickly, improve furrow trafficability, and consolidate the shoulders of the beds. These cover crops can be sprayed out just prior to or at planting.
- **Design field tail drains to shed water quickly.** Ponding at field ends can affect crop growth, and impede trafficability long after the rest of the field is dry enough to plant.
- **Have ready access to a planter.** If using a contractor, ensure that they are aware of your potential need for service at short notice. Once the planting window commences, frequently check the various weather forecast services for signs of rainfall (see Appendix 2) and adjust planting operations accordingly.
- **Do not plant too deeply.** Tropical downpours post-sowing can cause hard setting or crusting, particularly on loam soil types, which may impede seedling emergence for seeds sown more than 35 mm deep.

Crop trimming – a tactic for avoiding wet weather impacts on flowering crops

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

An alternate method for mitigating this risk for December-sown crops is to mechanically 'trim' crops after sowing to delay the onset of flowering. Trimming off the terminal shoot, at any stage from seven nodes until first flower, disrupts the onset of flowering and boll setting by between 300-400 day degrees (about 15-20 days under mid-summer

Burdekin conditions). The trimming interrupts the usual progression of main stem flowers and forces the plant to rely on the production of new squares on vegetative branches. Despite the 2-3 week delay in flowering, crop maturity and yield remain relatively unchanged, as the initial delay in flowering is offset by rapid flowering occurring on multiple vegetative branches.

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.
- Potentially easier to manage compared to growing a compensatory top crop.

Potential disadvantages:

- Cloudy weather effects in mid-March could be compounded as flowering is compressed into this period.
- Poorly set up trimming equipment could cause patchy response or poor plant recovery.
- Insects may be more difficult to scout in trimmed crops.

Trimming is NOT recommended for:

- Crops sown after 5 January as these plants will already flower in late February/early March and a delay in flowering may reduce yield potential, particularly in seasons with cooler than average autumn temperatures.
- Okra leaf varieties, such as Siokra 24BRF, which have had variable responses to trimming under experimental conditions.

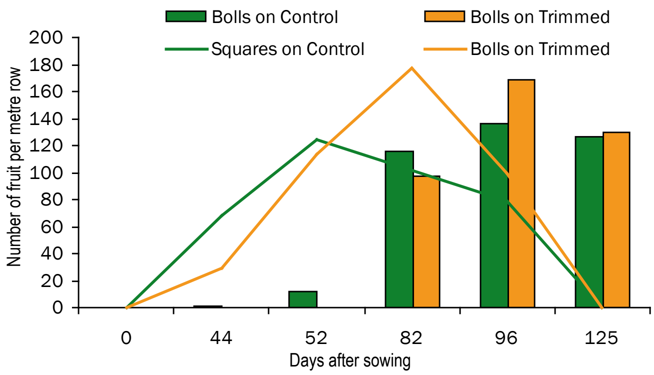
This trimmed plant at first flower shows the progression of flowering on multiple branches that will make up for the initial delay in flowering.

How to trim

To successfully trim a crop use a cutter bar or sharp, height controllable flail mower. Remove the top few nodes 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. It is important not to damage the terminals of the vegetative branches, as this can delay crop maturity by several weeks.

The first 3-5 nodes of vegetative branch growth after trimming is often rapid and will look rank, however this rapid growth will cease once fruiting branches and squares begin to be produced on these laterals. The early expansion of these inter-nodes can provide a benefit by lifting early bolls further away from the soil surface which in some seasons will help mitigate losses to boll rots (see Appendix 7).

Only the top 3-5 nodes need to be removed during trimming. The aim is to just trim off the tops, not cut the crop harshly.



Fruiting dynamics for trimmed compared to untrimmed (control) cotton. The lines represent square numbers and the bars denote boll numbers over time from sowing. Note that peak square production (and therefore flowering) is delayed in the trimmed cotton. Final time to crop maturity was the same.

Crop response at cut-out from trimming performed at three growth stages (7, 12, and 16 nodes) with untrimmed control (left). All treatments had very similar boll cohort maturity.

Row spacing

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.

Therefore, in a practical sense and at the time of writing, choose a row spacing that fits your existing farming system and other crop types. Avoid rows narrower than 71.2 cm (28 inches) due to an inability to harvest the crop with a conventional spindle head picker. Cotton may be grown on wider spacing than the traditional 102 cm (e.g. dryland cotton is often grown on a skip row configuration), but in a fully irrigated system characterised by solar radiation limitations, wider row spacings may decrease yield potential on a per hectare basis and/ or delay crop maturity.

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.

Planting

Strategies for ensuring effective establishment include:

- **Do not sow too deeply.** The high risk of rainfall post-sowing can result in soil crusting or hard setting (particularly on loam soils), leading to poor plant stand and replanting. Sow seed 20-35 mm or 1-1½ knuckles deep and cover with soil preferably settled with a press wheel, taking care not to use too much pressure. Cotton may be sown into soil moisture or sown dry and 'watered up'. **Generally, seedlings should emerge within 4 days of imbibing moisture**. Delays beyond 4 days may indicate potential problems and should be investigated (see trouble shooting guidelines on page 72).
- **Plant at recommended rates.** Aim for 6-7 seeds per linear metre regardless of what row spacing is used. Provided seeds are sown at the correct depth, seedling mortality is generally very low under warm Burdekin planting conditions, and nearly all sown seeds are likely to emerge. Planting additional seeds to compensate for establishment failure is not required in the Burdekin, and densities of nine or more plants per metre face increased competition for light and run a higher risk of exaggerated shedding and additional crop height. Lower densities cause plants to set bolls over a wider array of canopy positions (first, second and third branch positions as well as increased vegetative branch yield), which may provide a potential advantage in years when cloudy weather is intermittent. Plant density is more important for December plantings as these crops are more likely to be subject to cloudy, wet conditions during early flowering.

Planting:

- Varieties for different planting dates
- Planter calibration and seed placement depth setting
- Pre-plant fertiliser placement
- Acreage requirements for sowing of refuges and trap crops as per the current RMP
- Field conditions at planting
- Is post-plant watering up required?
- Expected weather pre- and post-sowing
- Assessing crop establishment

Discuss with your agronomist

Crop management considerations — throughout the production season

Crop nutrition

Nutrient requirements and management

At the time of writing research was incomplete so presented here are 'best bet' strategies from available knowledge.

The nutrients taken up and removed by a high yielding cotton crop (10 bales/ha) are shown in the table below. The high requirement for nitrogen makes it the major component of any fertiliser program for cotton grown in the Burdekin.

The average weight of nutrients taken up and removed by a 10 bale/ha cotton crop grown in southern Australia.

Nutrient	Uptake	Removal at harvest
Macro nutrients	**kg/ha**	**kg/ha**
Nitrogen (N)	200	100
Potassium (K)	200	50
Phosphorous (P)	30	20
Sulphur (S)	40	10
Calcium (Ca)	220	10
Magnesium (Mg)	30	12
Micro-nutrients	**g/ha**	**g/ha**
Zinc (Zn)	125	100
Copper (Cu)	50	20
Manganese (Mn)	450	60
Iron (Fe)	300	80
Boron (B)	400	100
Molybdenum (Mo)	10	5

Source: NUTRIpak. Note: Nutrient removal is roughly proportional to lint yield so a crop yielding 8 bales/ha will remove 20% less of each nutrient than shown.

The management of highly soluble negatively charged nutrients such as nitrates and sulphates has always been challenging in the tropical wet season. Large rainfall events can occur at any time and have the capacity to leach or erode significant amounts of these nutrients from the root zone or the field. Nitrogen can be converted to nitrous oxide when the soil becomes waterlogged and be lost to the crop by volatilisation. All forms of nitrogen, whether sourced from fertiliser, manures, plant residues, or soil organic carbon can be easily lost by these processes. Organic matter from previous crop stubble will decompose (mineralise) rapidly in this wet and warm environment. Legume stubble either from grain or cover crops is high in nitrogen and particularly susceptible to rapid mineralisation. When converted to nitrate this nitrogen can be leached below the root zone or into the furrow to be lost in tail water.

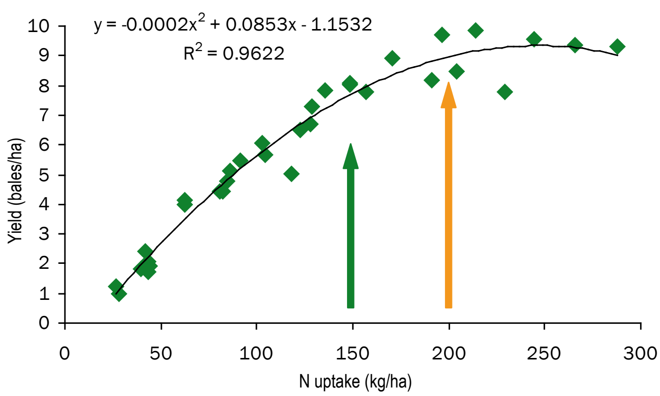
The timing and volume of wet season rainfall combined with the nutrient status of Burdekin soils will determine the amount of nitrogen and sulphur fertiliser required and the timing of their application each season.

Some points to consider include:

- **Rooting depth.** Prolonged wet weather will suppress root exploration and roots will only access nutrients near the soil surface. It is important to know where both the roots and nitrogen are in the profile during the season.
- **Previous crop.** Nutrient depletion by proceeding crops (from high to low) is sugar > maize > grain soybean > grain mungbean. Mungbean/ soybean or millet cover crops (where the grain is not harvested) have the least impact. A full sugar cycle (plant cane and 3-4 ratoons) will deplete the soil of N, S and potentially other nutrients, including organic carbon. As little as 9 kg of available N (to 1.2 m) has been measured following cane. Although legume cover crops provide nutrients, rapid stubble breakdown means there is a risk of quick mineralisation and losses to leaching or runoff.
- **The time between the previous crop and cotton.** Mineralisation of the remaining stubble and roots after sugar and maize can be very slow due to a high proportion of carbon to nitrogen (C:N ratio) and significant amounts of N can be 'tied up'. The longer the break between cotton and these crops, the more efficiently fertiliser N will be used by the cotton crop (meaning less fertiliser will be required). On the other hand, legume crops can break down too fast for the cotton crop to capture the released N before losses might occur.
- **Soil type.** Leaching of N below the roots is more likely in sandy or loamy textured soils. Stubble breakdown is usually faster in sandier textured soils than clay soils. Experiments on sandy loams in the Burdekin have measured mineralised N from corn stubble becoming available to cotton crops by mid flowering (late

March). Presumably other nutrients (e.g. K) are also mineralised at this time. It is important to account for this N when planning mid-season nitrogen applications as over-fertilisation late in flowering can delay maturity and reduce gin turnout. In clay soils anaerobic conditions due to waterlogging are more likely to affect the fate of crop stubble nitrogen. In experiments only small proportions of the N contained in maize or mungbean stubble has been available for the following cotton crop on clay soils.

Field experiments in the Burdekin on clay and sandy textured soils have found that yield is highly dependent on the crop taking up sufficient quantities of nitrogen. Insufficient nitrogen uptake has been a major limitation to yield on clay soils.



Cotton yield in the Burdekin is very dependent on the amount of nitrogen taken up by the crop. Yield is proportional to N uptake up to a yield of 8 bales/ha (green arrow). Thereafter the increase in yield per unit of uptake declines and yield peaks (around 9 bales) at about 200 kg N/ha uptake (orange arrow). The range of yields at the upper end of N uptake is due to other limiting factors such as solar radiation, which was lower than average during these experiments. If conditions had been sunnier yields may have been more responsive to nitrogen and a plateau above 10 bales/ha may have been achieved.

Nitrogen (N) management

Yield increased in these experiments until about 150 kg N/ha is taken up, which produced about 8 bales/ha. Above this level, other factors such as cloudy weather had more impact on yield than nitrogen. Yield peaked when plant uptake reached 200 kg N/ha (consistent with southern Australia). Lower than average solar radiation in late March–early April reduced potential yield, and it is probable if solar radiation was greater the yield potential would be higher. But adding more nitrogen without considering a range of factors isn't likely to provide a simple risk-free solution. Excessive nitrogen risks growing tall crops with delayed maturity, particularly in wetter than average seasons.

N uptake did not exceed 150 kg/ha on the clay soil in either season.

Burdekin soils have low inherent nitrogen fertility with little organic carbon and leaching/volatilisation is likely prior to flowering. As a consequence there is often a high dependence on fertiliser to provide nitrogen and considerable management skill is required to ensure sufficient and efficient uptake by the crop.

Planning seasonal nitrogen requirement

To estimate the total nitrogen fertiliser requirement for the coming cotton season, knowledge of the previous crop, the inherent fertility of the soil, seasonal rainfall outlook and the time and management between harvesting the previous crop and sowing cotton is required. The predicted total nitrogen requirement can be adjusted with mid season nitrogen application once crop growth and climatic conditions can be better determined.

Likely total nitrogen fertiliser requirement calculated prior to cotton sowing.*

Soil	Previous crop(s)	Break	Likely total N (kg/ha) as fertiliser	
			March rain forecast average or above	March forecast rain below average
Clay	Sugar	≤ 4 weeks	250	300
	Sugar	Legume (mungbean) cover crop of at least 2 months	200 - 220	250 – 270
	Corn	≤ 4 weeks	230-250	270 – 300
	Cotton /Mungbean grain or cover	≤ 4 weeks	200 - 220	250 – 270
Sandy-loam, loam or levee	Sugar	≤ 4 weeks	220	270
	Corn – grain	2 to 6 weeks	180	220
	Mungbean – grain or cover crop	2 to 6 weeks	180	220

* Higher rates are suggested for the drier than average scenario as radiation is more likely to be non-limiting and rate of growth, uptake and yield potential will be higher.

Nitrogen application at sowing

Clay soils: apply between a third and half the total required nitrogen at sowing. This is because in seasons receiving average or above average rainfall during January and February the efficiency of uptake of nitrogen fertiliser applied at sowing is generally low (20-40%).

- If the previous management of the field is favourable to soil nitrogen and field layout (good drainage or controlled traffic) permits entry by machinery within a week of significant rainfall, then apply a third of the total nitrogen required.
- Where entry to a field is more likely to be delayed by rainfall apply half the total nitrogen required. The efficiency of this pre-plant fertiliser could be poor so anticipate that increased nitrogen may need to be applied in-crop.

Sandy or loam soils: the amount of nitrogen applied at sowing is determined by the risk of fertiliser burn to seedlings. Applying as little as one third of the total required nitrogen at sowing will minimise fertiliser burn provided there is separation between the seed and fertiliser. Because N uptake efficiency at sowing is usually higher (35-60%), there is less chance of running out of nitrogen before the second application is made. Good trafficability on these soils reduces the risk of late application of the remaining fertiliser.

Pre-plant fertiliser banding at depths >120 mm (common in other regions) is a risky strategy in the Burdekin, as shallow root systems may not reach the fertiliser, particularly on heavy clay soils in wet years. Loss of available nitrogen can also occur via leaching in sandier soils and de-nitrification in clays, leading to early season deficiencies. If plant roots penetrate deeper during drier conditions on sandy soils, they may encounter leached bands of nitrogen, stimulating late season vegetative growth or reducing gin turnout.

Nitrogen application after sowing

Due to the risk of nitrogen loss early in the season, at least half the seasonal nitrogen fertiliser requirement should be applied after sowing.

Apply in-crop nitrogen fertiliser 25-50 days after sowing. Some flexibility may be required to respond to seasonal conditions, particularly on clay soils, and nitrogen fertiliser could be applied 5 days earlier or later if needed.

It is preferable to apply in-crop nitrogen prior to flowering (about 45 days after sowing). Only apply nitrogen later during flowering if the crop is showing deficiency symptoms or to capitalise on a positive seasonal forecast and very sunny weather.

Crops showing nitrogen deficiencies after flowering will rapidly reach cut-out, and any decision to fertilise must be implemented quickly. Nitrogen applications at or after cut-out will not be taken up by the plant and risk crop regrowth at a later time.

Splitting of nitrogen fertiliser application so the majority is applied between 25 and 50 days after sowing is the most efficient and effective way to apply nitrogen, and reduces the risk of fertiliser burn to seedlings on sandy soils. Flexibility is required in the method of application of in-crop nitrogen to reduce the risk of wet ground preventing machinery entering the field.

A small strip of cotton left without nitrogen fertiliser at planting can be used as an indicator for when in-crop nitrogen is required. Ensure any other required nutrients (e.g. as identified by a soil test) are applied across both the main paddock and indicator strip to prevent other deficiencies confusing the result.

Cotton without nitrogen fertiliser (left) showing nitrogen deficiency symptoms only 22 days after sowing compared to the fertilised area (right). This indicates that soil nitrogen is very low or not available to the crop. For this situation in-crop fertiliser will be required soon on the fertilised area. If the low soil nitrogen was not anticipated, the intended rate of in-crop nitrogen fertiliser should be increased.

This field has greater inherent fertility as the cotton to the left (that has not been fertilised with nitrogen) has only recently shown symptoms and is a similar size to the fertilised cotton to the right. In-crop nitrogen fertiliser is now required on the fertilised area.

Adjusting the budgeted in-crop nitrogen rate

Change the rate from the pre-sowing plan if:

- a significant proportion of the at-sowing nitrogen has been lost (e.g. prolonged above average rainfall after sowing sufficient to run water in the furrow).
- the crop is lacking vigour and is pale green (a symptom of nitrogen deficiency as distinct from the lime green striping of quick, vigorous growth seen on page 22).
- the pre-sowing fertiliser application has not been effective (e.g. incorrect depth or placement).
- a seasonal forecast for drier than average conditions during March to May means an increase in the yield potential of crops provided there is adequate N (see yield versus nitrogen uptake graph and table on page 39). Be aware that forecasts are only probabilities and cloudy weather may still occur.
- there is a need for a second in-crop application of nitrogen.

Discuss with your agronomist

Crop nutition:

- Pre-season soil testing
- Likely nitrogen recycling from crop residues
- Strategies and methods for applying fertiliser
- Fertiliser blends

Backed up water can be prevented by increasing the tail drain capacity and splitting the field to reduce furrow length.

Irrigation

General principles of cotton irrigation are covered in WATERpak. This section will focus on what is unique about irrigating cotton in the Burdekin.

Furrow irrigation using fluming is currently the most common method of delivering water to cotton in the Burdekin. Overhead (lateral move or centre pivot) or trickle tape methods are desirable on the well drained sandy loam, river levee and delta soils.

Key factors for irrigating Burdekin cotton:

- **The transition from wet to dry weather during flowering is critical.** Prolonged wet and overcast weather prior to flowering will suppress root exploration. Do not waste time cultivating if the crop needs irrigating as a flowering crop can experience severe water stress very rapidly and significant yield penalties will occur if irrigation is delayed. When fertiliser (e.g. N) is required, it should be applied as quickly as possible then immediately followed by irrigation water.
- **Irrigate most frequently during flowering.** Timely irrigation is most critical for crops flowering in February–March when evaporation rates and crop sensitivity to moisture stress are highest.
- **Budget for 4 ML/ha of irrigation water (furrow irrigation)* between March and late May.** Less than 2 ML/ha can be required in wetter than average years and as much as 8 ML/ha in the driest of seasons. Water will need to be available at relatively short notice in January and February if a dry spell occurs.
- **Irrigate before available soil water reduces to 50%.** The use of soil moisture monitoring equipment can be very helpful for measuring changes in soil moisture and predicting when irrigation water should be applied.
- **Aim to minimise waterlogging and nutrient loss.** Furrow irrigation run times should be no more than 10 hours on clay soils. Design field drainage to prevent backup from storm or irrigation water.

* the actual volume of water used will depend on field application efficiency and whether tail water is recycled. This example assumes a field application efficiency of 75% (i.e. 25% of the water applied to the field is unrecycled tail water).

WATERpak summary

The response of cotton to water (for more details see WATERpak):

- Cotton is most susceptible to water stress for a 50 day period (from first flower to about 10 days after cut-out). In southern Australia yield losses can be as high as 2.7% per day of stress during this period when fruit retention is high.
- Water stress is most likely when plant available soil water falls below 50%. The plant available soil water depends on rooting depth and soil type.
- Cotton is very sensitive to waterlogging due to poor drainage or over-irrigating. Research elsewhere has measured a yield reduction of 0.2 bales/ha per day of waterlogging during flowering — 10 days of waterlogging could reduce yield by 2 bales/ha.
- Impacts of waterlogging on young vegetative crops are not as severe as for flowering crops.
- Nitrogen uptake is linked to the amount of plant available soil water. Too wet or too dry will inhibit uptake.
- Cotton is relatively tolerant to water deficit early in growth. High levels of water and nutrient supply can induce excessive vegetative growth and suppress root growth.
- Compared to soybean, cotton is more tolerant of arid conditions.

Scheduling – How do I know when to irrigate cotton?

There has been no specific research to date to evaluate scheduling options for cotton grown in the Burdekin. The 'best bet' guidelines that follow are derived from existing cotton knowledge, other Burdekin experiments and experience from commercial fields. Note that:

- It is better to anticipate the need for irrigation than to react to crop water stress. Pre-order likely water requirements from Sunwater at least several days in advance.
- The methods used to predict when to irrigate are different for furrow and overhead/drip delivery systems.

A combination of plant visual symptoms, crop growth stage, measurement of available soil water and likely weather should be used to predict when irrigation is required.

Plant available soil water

Plant available water is the maximum volume of soil water that a plant can physically extract. A decision to irrigate can be made when soil water depletion in the root zone reaches about 50% of plant available moisture (the refill point).

Burdekin soils have different water availabilities - see the table on page 44 for the most common soil groups.

If the crop is at or near flowering and there has been a prolonged period of wet humid weather then assume the plant is 'soft' and root activity will be near the surface. IRRIGATION SHOULD BE APPLIED 5 TO 7 DAYS AFTER THE LAST RAINFALL EVENT.

The fraction of plant available water depleted between irrigations directly affects the balance between vegetative and boll growth of cotton, hence yield. Too frequent irrigation can stimulate leaves and stems, producing excessive growth that shades lower bolls and reduces harvesting efficiency. Overextending the time between irrigations can reduce yields by inducing moisture stress.

Soil water depletion can be measured by a capacitance or neutron probe. Measurements should be evaluated 3 to 5 days after irrigation or significant rainfall and the soil water extraction extrapolated to determine the date when depletion will reach the refill point and irrigation is required. Be sure to relate probe data to an estimate of root depth. Visual inspection of roots may reveal that a large proportion of lateral roots are near the surface indicating that a more frequent, short duration irrigation may be required.

In the absence of a soil water probe, the extraction of water can be estimated from evaporation rate, crop cover and rooting depth (see Appendix 8 for method of calculation).

Crop growth stage

The rate of water use is proportional to leaf area (ground cover) and evaporation rate. Burdekin crops reach 100% ground cover 50-70 days after sowing, (20-50 days earlier than southern crops) and therefore use more water earlier.

The impact of crop water stress will depend on the stage of growth. Cotton is most sensitive to water stress from first flower to about 10 days after cut-out. The period from sowing to early squaring (10 nodes or 25 DAS) is the least sensitive to water stress.

Weather forecast

Check the weather forecast for the dates that irrigation is intended. On clay soils, if rain is very likely, and temperatures are mild (≤30 °C) and humidity relatively high, consider delaying irrigation to reduce the risk of waterlogging. **Do not** delay irrigation if the crop is flowering and a dry period has followed a prolonged wet period or root growth is known to be impaired.

Plant visual symptoms

- **Mid-day wilting.** This is usually an early symptom of water stress. However, if the wilting occurs due to high evaporative demand rather than reduced soil water, immediate irrigation is unlikely to alleviate the symptoms.
- **Plant temperature.** If the top leaves feel warm when held in palm of the hand, the plant is likely to be water deficient.
- **Height above red stem.** Provided nutrition is adequate, red stem pigmentation can indicate plant moisture status. A vigorously growing plant is unlikely to require irrigation when there is greater than 10 cm of tender green stem above the red colouring. A rapid rise in red pigmentation up the main stem is a sign of moisture stress.

Mid-day wilt early in flowering. Plants can become water stressed very quickly if dry conditions follow prolonged wet periods. Prompt irrigation is essential to prevent yield loss particularly during flowering.


Red colouration of the main stem is an indicator of water stress; the closer to the top of the plant the greater the stress.

Key irrigation scheduling times using furrow irrigation

Crop establishment

Rainfall will determine the need for irrigation to establish the crop. **It is preferable to sow no more than 3 cm into a base of good soil moisture and then water up if needed**. Sowing deeper increases the risk of burying or waterlogging the seed if significant rain occurs between sowing and establishment, and has been a common cause of poor establishment in the Burdekin to date.

Cotton seed (blue) sown 3 cm deep onto a base of subsoil moisture. Rain or irrigation is required soon after sowing for good establishment.

In-crop irrigation

The timing of the first in-crop irrigation will vary greatly with seasonal conditions. In drier seasons the first irrigation could occur in January, but may not be required until mid March or later in wetter seasons. Cotton is relatively tolerant to water stress early in growth and subtle moisture stress can encourage root exploration. A cotton crop on a clay soil established by watering up with a full profile of soil water will not need irrigation for at least 3 weeks after emergence.

Cotton should be irrigated when it has extracted about 50% of plant available soil water (PAWC). The table below includes the PAWC for the most common soil groups in the Burdekin.

Avoid water stress during flowering. The transition from wet to dry weather is critical and irrigation must be prompt as plants are soft with a poorly developed root system.

Likely maximum rooting depth, plant available water content and within season furrow irrigation frequency for typical Burdekin soils.

Soil groups	Maximum Rooting depth (m)	Plant available water content (mm)	Likely irrigation frequency (days) - no rainfall	
			Feb – April	May – June
Cracking Clays	0.9	130	6 -10	10-14
Sodic and non sodic Duplex*	0.9	114	5-10	10-14
Gradational	0.9	87-112	5-10	8-14
Levee / loam**	1.0–1.7	100-150	5-8	9-16

Note: These figures assume no soil compaction or other limitations to root growth or water uptake (source: Donnollan 1991)
* only the deepest A horizons are considered suitable for cotton (see management options for soil types table on page 27).
** Rooting depth can vary significantly between seasons on these soils.

Timing the last irrigation

Plan the last irrigation to allow the crop sufficient time to begin natural senescence and the soil to dry without affecting yield or quality. A cotton crop can extract 75% of plant available water prior to picking without affecting yield or quality. This takes about 20 days for a soil with 100 mm of total plant available water and about 30 days for a soil with 150 mm of available water during May to July. If the soil has not been adequately dried there is a risk the crop will re-shoot before picking and require an additional defoliation.

When Nodes Above White Flower (NAWF) falls below 3-4 and is still falling a week later, plan the date of the final irrigation by recording this as the date of last effective flower:

- Using long term temperature averages, calculate 800 Day Degree (DDS) (Appendix 3) forward from last effective flower to give the predicted picking date. If a DDS cannot be calculated, estimate the days from last effective flower (e.g. if in April then assume 60-65 days to picking; if in May assume 70 days to picking).
- Depending on the plant available soil water, plan to apply the last irrigation when 75% of plant available water is extracted. For example, provided root development is not impaired final irrigation should occur 20 or 30 days prior to the picking date for soils with 100 mm and 150 mm plant available water respectively.

Overhead or tape delivery systems

Cotton will require more frequent irrigation of smaller water volumes when irrigated using these systems. The maximum volume of water that can be applied in one day by the system must be greater than the maximum daily evaporation. For more detailed information on the set up and management of these systems see WATERpak.

These systems will provide the most efficient application of water to cotton grown on well drained soils (levee, sandy-loams). They also permit fertigation hence more timely application of leachable nutrients such as nitrogen and sulphur.

Timing and volume of irrigation to be applied is best predicted by calculating the water used by the crop. This is done by accumulating the daily evaporation (calculated by evaporation pan) since the last irrigation and multiplying by a crop factor. Irrigation must occur before the calculated volume of water used by the crop exceeds the volume of water that can be applied in one day by the irrigation system. The method for calculating daily crop water use is shown in Appendix 8.

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 graphs on page 11 and page 18).

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.

This commercial crop experienced early season shedding but with effective management set a large top crop. Growth of additional fruiting branches to recoup early season shedding losses has resulted in tall plants, but this field yielded over 8.0 bales/ha during the cloudy year of 2010.

To date all high yielding crops in the Burdekin (>8 bales/ha) during wetter than average seasons with significant levels of early season shedding 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.

How can I tell if canopy growth and development is on track?

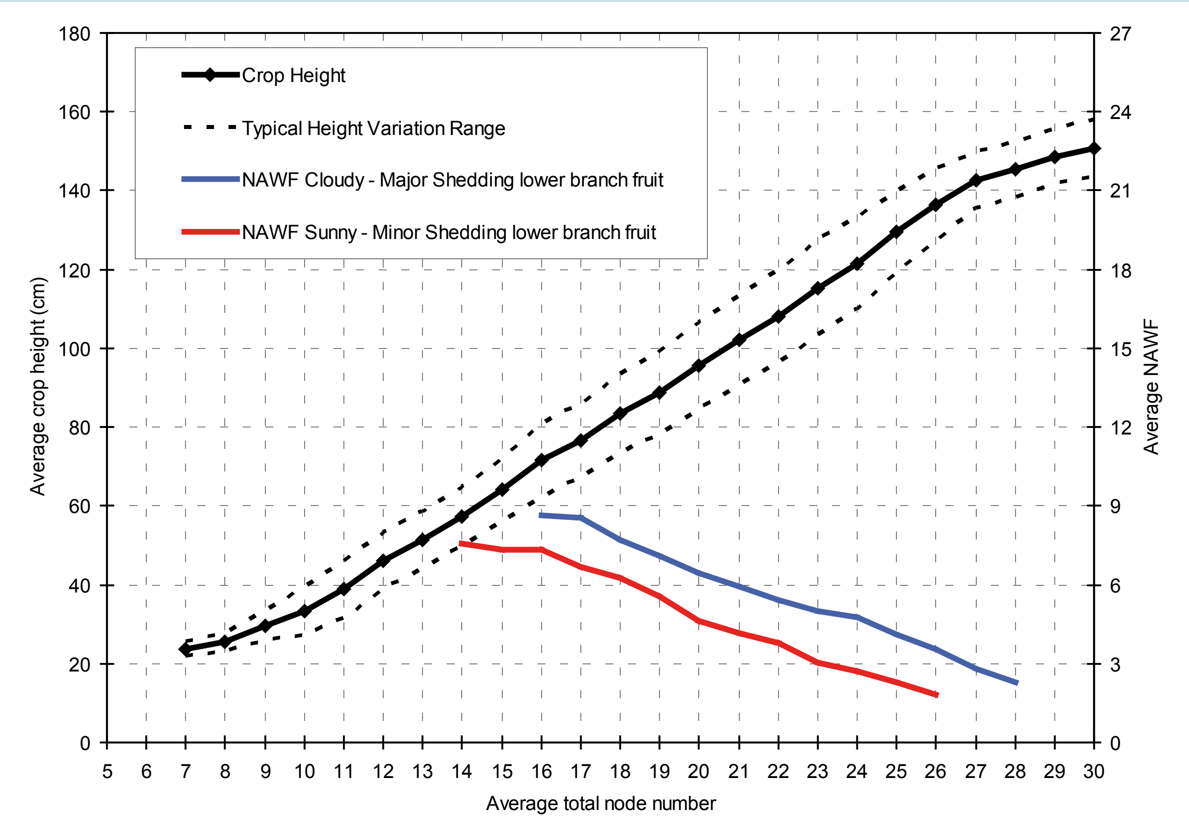
In southern climates, crop development can be accurately predicted with the use of day degree temperature models. Deviations from expected development can be detected early and remedial steps taken to encourage or curb the rate of canopy development.

The reliability of day degree based models in the Burdekin is questionable, particularly for wetter than average seasons and the inability to account for the disruption to boll setting caused by periods of cloudy weather and fruit shedding.

A prototype model created from multiple data sets gathered from high yielding cotton crops grown experimentally and commercially between 2008 and 2011 has been developed for the Burdekin to assist growers and advisors to determine whether or not a crop is growing at an acceptable rate from 6 nodes through until crop cut-out. This model tracks growth and development in terms of the crop height in relation to each main stem node (black line) and shows the range of acceptable and typical variation that might be expected between different crops and varieties (upper and lower dashed lines).

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 and P2 fruit from first 4 or more fruiting branches (blue line) and crops with minimal shedding of early boll positions (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 an early enough stage to take corrective action (e.g. increase irrigation frequency, avoid MC, or adjust the nitrogen program).



The prototype canopy growth model for the Burdekin, showing the relationship between crop height, node number and NAWF for high yielding crops grown in the Burdekin between 2008 and 2011. This tool shows the mean height of these crops per development node and the typical variance that might be expected. Two relationships are given for NAWF. The red line represents the likely relationship between NAWF and crop node number for crops that have a high retention and minimum shedding of lower branch bolls. The blue line represents the same relationship but for crops where shedding has been extensive on 4 or more lower fruiting branches (loss of P1 and possibly P2 fruit).

Full page versions of both the high retention and high shedding NAWF comparisions for this Burdekin Growth Model (BGM) have been provided at the back of this publication for you to copy and use.

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

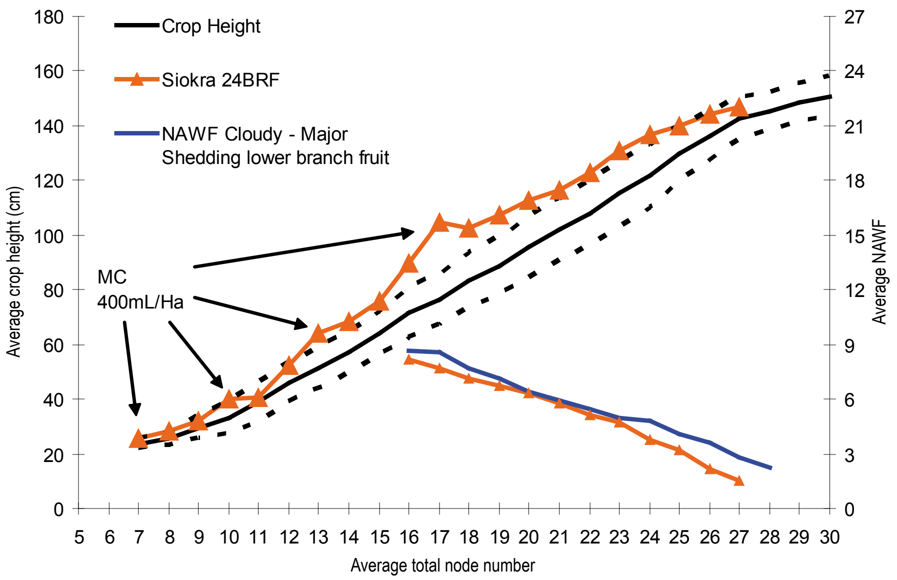
Too much nitrogen applied early, particularly on light sandy soil types when combined with monsoonal weather, can cause excessive growth and a tendency to shed fruit. Free-draining light soils tend to allow vigorous early and mid-season growth compared to more restrictive Barratta clay soils or sodic duplexes. Extended cloudy wet weather can exacerbate the situation due to fruit shedding, high humidity and night temperatures that allow greater leaf and inter-node expansion. Crops will compensate for low radiation by growing larger leaves and compete for light by growing taller, a relationship made worse by densities of more than 6-7 plants per metre of row.

Reduce the potential for excessive growth by avoiding high rates of nitrogen fertiliser at planting and not sowing more than 7 seeds per metre.

Even with appropriate sowing and fertiliser rates, growth can still become excessive, particularly during periods of monsoonal wet weather. The BGM can be used to help determine if the balance of crop growth has tipped towards excessive vegetative expansion instead of fruiting sites and boll development, and whether corrective action should be taken (such as applying a growth

Various scenarios when using the Burdekin growth model (BGM).

NAWF	Crop height: Below	Crop height: At trend	Crop height: Above
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 causes of low vigour (e.g nutrition or soil moisture). Has the weather changed from wet to dry suddenly?	Unless the crop is at the late stages of flowering the crop may be at risk of premature cut-out. A 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 manage growth, bearing in mind length of season remaining.	NAWF 2 or more below: MC not recommended. NAWF less than 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.
At 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 pattern of growth 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 and keep assessing development.
Above	This is an unlikely scenario. Extraordinary 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.



An example of the use of the BGM using Siokra 24BRF. Crop height, node number, and nodes above white flower were measured over a season, and management decisions made based on the variation on growth predicted by the model. Arrows indicate when MC applications were made.

Sicot 71BRF with no MC (left) and highest MC rate treatment (2800 mL/ha) (right). The reduction in crop size (biomass) and boll numbers is clearly evident and reflects yield and segmented picking results. See Appendix 9 for more details of these experiments.

regulant or subtly decreasing the frequency of irrigation). The manipulation of irrigation frequency to moderate growth that works well in the Ord River Irrigation area is typically difficult to achieve due to unpredictable rainfall during the monsoon season in the Burdekin. The application of mepiquat chloride (MC) is therefore particularly useful for curbing a trend of excessive growth during such conditions.

Crop height above the typical variance (upper dotted line) on the BGM or within the variance limit but showing a rapidly emerging trend away from the mean for recent data points might indicate that growth is excessive or becoming so. The type of corrective action will then depend on the NAWF trend (see scenario table). If NAWF is following the recommended line (red or blue), but crop height is excessive, an application of MC or more restrictive irrigation may be warranted. If NAWF is below trend (by 2 or more nodes) then be aware that future vigour may already be declining and that an MC application may hasten this process and cause premature cut-out if insufficient bolls have been retained.

Using MC to manage 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 a 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.**

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 required to compensate for earlier shedding losses. Note the reduction in the number of P2 fruit number and the reduced size of these bolls. cv Sicot 74BRF 2011.

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 Sicot 74BRF 2011.

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.

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.

Local research has demonstrated that methods for successfully scheduling MC applications in a tropical climate are different to those used elsewhere. High rates of MC through either single or cumulative applications under tropical conditions can reduce crop yield potential due to decreased production of outer canopy fruiting sites. The decision to treat with MC should consider plant height, retention, node number, and flowering progression (NAWF). Do not apply MC if the crop is stressed by waterlogging, has insufficient access to nitrogen, or cannot be irrigated at typical soil moisture refill trigger points.

Discuss with your agronomist

Managing excessive growth:
- Recent weather and likely outlook
- Is MC the best option?
- Possible alteration of soil moisture or crop nutrition management
- Levels of boll retention
- Consider ation of any insect or weed management issues if appllying MC

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.

Discuss with your agronomist

Progress to cut-out:

- Recent weather, likely outlook, and how much time remains until the end of April
- Average boll counts per metre row
- Potential usage of MC
- Irrigation scheduling

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 on page 47) 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**.

DISCUSS WITH YOUR AGRONOMIST

CROPS LACKING VIGOUR:

- Recent weather and likely outlook
- Monitoring crop vigour prior to flowering
- Boll retention and rate of NAWF decline
- Crop development stage and likely nitrogen status
- Irrigation scheduling

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

This crop has experienced premature cut-out. Flowers can be seen near the top of the crop from the field edges (top), and the plants have stopped growing after only setting 2-3 bolls each (bottom).

Pre-plant nitrogen placed at depth (20-25 cm) was unable to be accessed by the shallow root system, and a combination of the heavy clay soil, excessive field length, and poor drainage prevented timely remedial action to correct the resulting deficiency.

Insect management

A pest management strategy should view pest problems in a holistic sense by considering the environment, the pest, its natural enemies, and its relationship with the crop. Pest levels on any one day are related to larger cycles within the environment and every action taken by crop managers is likely to have future consequences. Integrated Pest Management (IPM) seeks to manage pests in a sustainable way that goes beyond a simple 'sample, spray and pray' approach. Insect management tools may include use of pest-tolerant, genetically modified cotton varieties, selective insecticides, attractive trap crops, encouragement of natural pest enemies for biological control, and removal of ratoon or volunteer cotton plants during fallow periods to limit 'green bridges' for pests between cropping cycles. Pests extend beyond individual fields and by acting collectively, growers can strategically disadvantage some pest populations on an area-wide scale.

Detailed information is published by the cotton industry annually in the Cotton Pest Management Guide and available to growers by surface mail or via web access. This publication is updated each season with latest information on pest management tools and technical data generated by the industry's research and development sector.

Key pest control considerations

- Only grow transgenic cotton varieties such as Bollgard II®.
- Minimise insecticide inputs. Use only when necessary as indicated by pest abundance and damage thresholds. Take into consideration population trend and presence of beneficial insects as well as crop stage when making control decisions.
- Avoid early-season insect control sprays prior to flowering. Early squares are often lost to weather-related shedding, and higher mean rainfall poses a much greater run-off risk for pesticides to potentially enter a water course.
- Ensure that correct identification of pests is made. There are many insects that are beneficial that can be confused with pests.
- Monitor regularly for insects (at least twice per week). Your agronomist can do this for you.
- Select insecticides based on IPM compatibility. Give preference to narrow-spectrum products and avoid broad spectrum organophosphate and pyrethroid products.
- Use ground rig spraying wherever possible for better placement accuracy and to reduce the risk of drift.
- Strictly adhere to the protocols and recommendations of the Bt Resistance Management Plan (RMP). This strategy is updated each year to reflect scientific advances and/or changes in pest resistance levels.

Insect pests of cotton in the Burdekin region. Occasional/possible pests are referred to in more detail in Appendix 4.

Pest	Susceptible crop stage	Other comments
Principal pests		
Green vegetable bug (*Nezara viridula*)	First flower to 60% open bolls	Often appear at the end of wet season as surrounding weeds dry out.
Red banded shield bug (*Piezodorus oceanicus*)	First flower to 60% open bolls	As above.
Cluster caterpillar (*Spodoptera litura*)	First flower to cut-out	Often active during wet season and until May.
Aphids (*Aphis gossypii* & *Myzus persicae*)	First flower to defoliation	Often active at the end of wet season with green peach aphids becoming more prevalent late autumn.
Mealybug (*Phenacoccus solenopsis*)	All season	More common in back-to-back cotton fields or in weedy pre-plant fields.
Redshouldered leaf beetle (*Monolepta australis*)	Squaring to cut-out	Very common during wet season. Often appear after rainfall. Damage is highly visual and can appear more extensive than it actually is.
Occasional/possible future pests		
Helicoverpa spp.	First flower to cut out	Particular attention should be paid during the transition from wet season to dry as Bt expression can temporarily decline as plants adjust to sunnier weather.
Silverleaf whitefly (*Bemisia tabaci*)	First flower to 60% open bolls	Often more common April onwards as surrounding weeds dry off.
Mirids (*Creontiades* spp.)	Squaring to cut out	Have been very uncommon in Burdekin.
Pale cotton stainer (*Dysdercus sidae*)	First flower to 60% open bolls	Have been uncommon. Typically seen from late April onwards.
Spider mites (*Tetrancychus* spp.)	First flower to 60% open bolls	Generally seen during the first month of dry weather.
Cotton harlequin bug (*Tectocoris diophthalmus*)	First flower to 60% open bolls	Often observed on field edges. Has a slow reproductive rate and therefore rarely a pest of concern.

Insect pests

Cotton is attractive to a range of insect pests, but with the use of transgenic varieties only a few are likely to be economically damaging. Many of the insects found in cotton crops are either harmless or beneficial (they either feed upon or parasite pests). An important part of IPM is to correctly identify crop insects and encourage the presence of beneficial insects to reduce pest abundance and the need to apply insecticides.

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 infest a crop and reach threshold levels within a few days**. Bugs can rapidly fly in from the surrounding environment.
- **Peak cotton attractiveness coincides with the pest's local migration patterns**. 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 when surrounding weed hosts dry off or as weeds are destroyed in the process of preparing fallow fields to plant sugarcane.
- **The threshold for green vegetable bugs (GVB) 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 (see page 63), 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 to GVB, 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. 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 products that provide good efficacy, such as clothianidin, carbaryl and pyrethroids, are all broad spectrum and can lead to flaring of secondary pests.
- **Both the nymph and adult stages of these pests are damaging** to the crop.

Sample crops with a beat sheet as soon as flowering commences and ensure that timely insecticide treatments are made when control thresholds are exceeded. As insecticide choices are limited, aim to minimise secondary impacts by considering what else may be controlled (or flared) with different products.

Green vegetable bug (GVB).

Redbanded shield bug.

Discuss with your agronomist

Stink bug management:

- Most recent pest counts and potential differences between fields
- Presence of other pests and time remaining to end of season (and whether or not this influences insecticide choice)
- Crop maturity and susceptibility to damage
- Withholding periods for insecticide options

Cluster caterpillar

Spodoptera litura is a common pest of Burdekin cotton crops, encountered from 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) can cause 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 may be sufficient to warrant control.

***Spodoperta* egg cluster (left) and larva (right).**

DISCUSS WITH YOUR AGRONOMIST

SPODOPTERA MANAGEMENT:

- Caterpillar counts and observed levels of flower or boll damage
- What are the softest control options available?

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. 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 organophosphates) 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 sap they excrete a sugary substance called honeydew. In cotton, feeding damage from severe aphid infestations can cause leaf distortion and reduced photosynthesis, and 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 viral disease cotton bunchy top (see Appendix 5), 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 honeydew 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.

Cotton aphid colony. Photo by Lewis Wilson, CSIRO.

Sticky leaf caused by aphid-produced honeydew (left) and non-affected leaf (right). Photo by Lewis Wilson, CSIRO.

Beneficial insects that prey on aphid populations. Clockwise from top left: ladybird larva, hoverfly larva and a parasitised aphid in amongst live aphids. Photos by Hugh Brier, DAFF (top) and Lewis Wilson, CSIRO (bottom).

Discuss with your agronomist

Aphid management:

- Rate of infestation, location, and whether numbers are increasing or decreasing
- Are natural enemies also present (e.g. ladybirds, lacewings, parasitoids and hoverflies)?
- Crop maturity and the risk to canopy development or exposed cotton lint
- Presence of other pests such as silverleaf whitefly or mites and whether this influences insecticide choice
- Potential for insecticide failure – have there been resistance problems locally in other crops?

Mealybugs

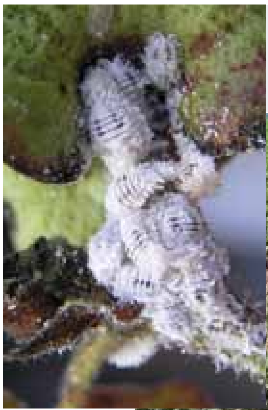
The solenopsis mealybug, *Phenacoccus solenopsis* is an exotic pest first encountered in Australian cotton crops both in the Burdekin and the central Highlands during 2009. This pest has been responsible for major economic losses in cotton in Pakistan and India. It is not known how this pest entered 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 2009/10 Central Highland crops.

As a new pest, little is known about its impact on cotton or appropriate control measures and thresholds. Solenopsis mealybug 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 usually occur first in field margins (particularly beside weedy areas) but can 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 will often 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 precursor to a more severe outbreak. A future threshold may therefore consider not only the presence or absence of this pest but its rate of change and population characteristics.

At the time of writing there were no registered insecticide control options for solenopsis mealybug and research is currently underway. To date, the most effective control methods have been on-farm hygiene and avoidance of broad spectrum insecticides to allow the unimpeded activity of various natural enemies that can have a significant impact. Remove all cotton volunteers and ratoon plants in fields used for annual cotton production to minimise population carry-over between cotton seasons. Control alternate broadleaf weed hosts common in the Burdekin such as black pigweed and vines.

A wide variety of predators of solenopsis mealybug provide effective biological control in cotton crops, including lacewings, lady birds and endemic cockroaches (no parasitoids have yet been observed). Take care when monitoring as some of these predators' larval stages are well camouflaged (e.g. lacewings and *Cryptolaemus montrouzieri* ladybirds). Natural enemy presence can often signal the beginning of a decline in mealybug numbers provided that predator activity is not disrupted by broad-spectrum insecticide usage. Hence this pest can complicate spray decisions for the control of shield bugs.



A plant badly infested with mealybug (left) and a 'hot spot' within a Burdekin cotton field (below).

Lacewing egg, larvae and adult. The larvae has camouflaged itself to look like mealybug.

Pupae (left) and adult (right) of three banded ladybird *Harmonia octomaculata*. Photo by Melina Miles, DAFF.

***Cryptolaemus montrouzieri* ladybird larvae feeding on mealybugs. Photo by Zara Hall, DAFF.**

Mealybug management:

- Level of outbreak and rate of increase
- Are natural enemies present and are they providing effective control?
- Latest research and control options

Discuss with your agronomist

Redshouldered leaf beetles

The adult stage of redshouldered leaf beetles, *Monolepta australis* can be a pest of cotton in some seasons. Swarms of beetles migrate into a crop (usually overnight) and can severely defoliate patches of plants. These hot spots tend to look more extensive than they actually are as the damage creates a stark 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 and the higher proportion of field edge means a greater percentage of overall area may be affected.

Redshouldered leaf beetle.

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

Leaf damage caused by redshouldered leaf beetle (patches often occur near field margins).

Redshouldered leaf beetle management:

- Actual infestation levels - what percentage of crop area is affected?
- Control options related to other pest activity

Discuss with your agronomist

Weed management

A successful weed management program for cotton aims to:

- prevent yield loss from weed competition
- remove alternate hosts of pests or diseases
- prevent lint contamination at harvest
- reduce the weed seed bank over time (reducing future weed issues)
- achieve these aims with minimal inputs.

In addition, the program must:

- manage species shift (avoid build up of any weeds advantaged by management actions)
- prevent the build-up of resistant weeds (especially glyphosate-resistant weeds)
- ensure no detrimental off-site effects.

While these aims are common to all cotton-growing areas, weed management in the Burdekin region has additional challenges, relating to:

- **avoiding residual herbicides** due to the high probability of excessive early-season rains, relatively light soil types, the region's proximity to environmentally sensitive receiving water bodies, and the ease with which chemicals can leach into the shallow underlying aquifer
- **very rapid growth rate of weeds**, with multiple germinations, and multiple generations possible in a season, potentially creating high selection pressure
- **system complexity**, i.e. a range of potential rotation crops with short turn-around times.

Effective weed management in Burdekin cotton crops has been achieved with a combination of good pre-crop management, appropriate crop agronomy, sensible use of glyphosate in-crop, and the use of inter-row cultivation or other options if weeds escape the application of herbicides. Central to this weed management program has been the use of cotton varieties including Roundup Ready Flex® technology, (tolerant to glyphosate, a group M herbicide) to control early season weeds in-crop. These varieties are particularly well suited for cotton used as a sugarcane rotation crop where a high number of grass and sedge weeds are likely.

Cotton varieties containing Liberty Link® technology (tolerant to glufosinate, a group N herbicide), may also be useful, although they have not yet been commercially tested in the Burdekin. Glufosinate is very effective on many broad-leaf weeds, but compared to glyphosate, is relatively weak against grasses, and is not suitable for use in fields with a history of heavy grass weed densities. The use of varieties containing the Liberty Link® technology in biannual rotation with varieties with Roundup Ready Flex® technology would enable these herbicide groups to be rotated, reducing the risk of weeds developing resistance, and assisting in the control of herbicide-tolerant cotton seedling volunteers.

Pre-crop weed management

Following sugarcane

Weed density can be very high, as limited opportunities exist to reduce the seed bank in a ratooned sugarcane production system. This high weed pressure is a major reason for growers choosing a cotton rotation in these fields. Establish cotton beds after sugarcane ploughout and pre-irrigate to germinate weed seeds brought to the surface by cultivation and allow control with non-glyphosate products prior to sowing cotton. Herbicides such as Spray Seed®, a mixture of paraquat and diquat (herbicide Group L), are ideal for controlling small weeds in this situation. Care should be taken to ensure the herbicides have no plant-back issues for cotton. Avoid phenoxy type herbicide (Group I) applications within 2-3 weeks of sowing cotton, as the residues from these products can cause considerable damage to emerging cotton seedlings.

Following a grain crop

In rotation with grains such as mungbeans and maize, ensure weeds are managed in all the cropping phases and during any fallow periods, ideally using herbicides with different modes of action in each phase.

The adoption of minimum tillage practices in a cotton-grains rotation may also provide weed control benefits, as the lack of cultivation avoids bringing buried weed seeds to the surface where they can germinate. Burdekin fields that have regularly been cultivated prior to and after planting often have higher weed densities. Also, some weeds will not readily germinate from the soil surface and their germination is assisted by cultivation.

In-crop weed management

Weeds have an explosive ability to establish and grow during the wet season. Both glyphosate and glufosinate herbicides can be used very effectively to control weeds early- to mid-season with their respective transgenic trait varieties. Roundup Ready® herbicide, used over the top of Roundup Ready Flex® varieties, has given excellent control of a broad suite of grass and broad-leaf weed species. This product has proven robust and user-friendly during the wet season. Good efficacy has been achieved with ground and aerial applications, provided rainfall does not occur within 2-3 hours of application. The environmental conditions and 'softness' of weeds that germinate during the wet season allow for very rapid uptake of the applied herbicide, ensuring a rapid and effective kill.

Grasses will germinate rapidly after rainfall in cotton crops, potentially leading to a rapid explosion of weed numbers. The seedbank for grasses and sedges is often very high within the Burdekin due to the historical monoculture sugarcane production systems, thus the problem needs regular monitoring and management. Photo by Graham Charles, NSW DPI.

Be on the alert for weed survivors of a glyphosate application. Resistance is most likely to occur in the following grasses:

- Awnless barnyard grass (*Echinochloa colona*)
- Liverseed grass (*Urochloa panichoides*)
- Johnson grass (*Sorghum halepense*)
- Sweet summer grass (*Brachiaria eruciformis*).

Also look out for possible resistance in amaranths (*Amaranthus* spp.) and fleabanes (*Conyza* spp.). Feathertop Rhodes grass (*Chloris virgata*), while not considered to be glyphosate resistant, is very difficult to manage in a glyphosate-focused system, and is rapidly becoming a problem in many fields from Emerald to Moree.

If fields begin to become dominated by any of these species (or if even small numbers of Feathertop Rhodes are present), give serious consideration to adjusting either your weed management program, or future rotations (e.g. return field to sugarcane).

Feather top Rhodes grass has spread rapidly throughout eastern Australia's cropping regions and is a difficult to control weed. Whilst not common in the Burdekin be on the lookout for this weed. Photo by Graham Charles, NSW DPI.

To reduce the risk of glyphosate resistance developing and to comply with the requirements of the Monsanto Roundup Ready Flex® Crop Management Plan, it is essential to control any weeds that survive a Roundup Ready® herbicide application with an alternative (non-glyphosate) weed management tactic before they set seed. In the Burdekin, this is most easily done by using inter-row cultivation in some 7–14 days after the glyphosate application provided that care is taken not to disturb crop root systems more than is necessary. This 'double-knock' backup strategy may not be possible in the wet conditions which often occur early in the season, but should be used for weed escapes when conditions suit later in the season.

If early season grass weeds are a problem, consider using a Group A herbicide applied 7–10 days after glyphosate. While regular use of a Group A herbicide is not recommended, using a double-knock and following with an inter-row cultivation as soon as practical should extend the useful life of the Group A herbicides, providing a valuable fall-back strategy.

Cotton development and weed management

Cotton seedlings are susceptible to competition from rapidly growing weeds. Good weed control is important during the establishment phase to ensure that crops can achieve their potential.

All weed management inputs should occur prior to canopy closure. Most weeds that emerge after this stage will be shaded and out-competed by the cotton. Weeds commonly encountered in the Burdekin are shown below.

More detail on all aspects of integrated weed management in cotton is contained in WEEDpak (available online from www.cottoncrc.org.au).

Weed management:

- Recent weather and likely outlook
- Seasonal usage of glyphosate to ensure overall allocations available according to the technology user agreement conditions are not exceeded
- Weed species
- Potential to combine herbicide applications with growth regulants or insecticides

Discuss with your agronomist

Common weeds associated with cotton production in the Burdekin.

Weed	Species	Comments
Nutgrass	*Cyperus* spp.	Can be managed with repeated applications of glyphosate.
Black pigweed	*Trianthema portulacastrum*	Very susceptible to glyphosate under Burdekin wet season conditions.
Billygoat weed	*Ageratum conyzoides*	
Awnless barnyard grass	*Echinochloa colona*	At high risk of developing resistance to glyphosate.
Green amaranth	*Amaranthus viridis*	At risk of developing resistance to glyphosate.
Ground cherry	*Physalis* spp.	
Pigweed	*Portulaca oleracea*	Relatively tolerant of glyphosate.
Sesbania	*Sesbania cannabina*	Small plants are susceptible to glyphosate.
Bellvine	*Ipomea plebeia*	Small plants are susceptible to glyphosate.

Examples of commonly used herbicides and their groupings within the Burdekin farming system.

Herbicide group	Examples of active ingredients	Examples of Trade Names	Typical use and weeds controlled	Maximum plant back for cotton
A	Haloxyfop & Fluazifop	Verdict 520® & Fusilade®	Post-emergent control grasses.	None.
B	Trifloxysulfuron & Halosulfuron	Envoke® & Sempra®	Some broad leaf weeds.	Check label on group B as very long plant backs can apply.
C	Bromoxynil, Fluometuron & Prometryn	Bromicide®, Cotoran® & Gesagard®	Pre- and post-emergent control grasses and some broad leaf weeds. Cotoran® and Gesagard® can be applied as directed sprays in cotton.	Check label on group C.
D	Pendimethalin & Trifluralin	Stomp® & Treflanv®	Pre-emergent control grasses and some broad leaf weeds.	None.
F	Norfluazon	Zoliar®	Fallow-preplanting control grasses, nut grass and broad leaves.	Refer label.
G	Flumioxazin & Oxyfluorfen	Pledge® & Goal®	Pre- & post-emergent control grasses and some broad leaf weeds. See label.	Refer label.
I	2,4-D amine, Dicamba, Fluroxpyr & MCPA	Amine®, Banvel®, Starane® & MCPA®	Post-emergent control broad leaf weeds and cotton.	21-60 days – CHECK LABEL.
K	s-Metolachlor	Dual Gold®	Pre-emergent control grasses and some broad leaf weeds.	
L	Diquat & Paraquat	Reglone® & Gramoxone®	Post-emergent control grasses and broad leaf weeds.	None.
M	Glyphosate	Roundup Ready®	Post-emergent control grasses and broad leaf weeds, applied over the top in varieties including Roundup Ready Flex® technology.	None.
N	Glufosinate	Liberty® or Basta®	Post-emergent control broad leaf weeds and some control of grasses. applied over the top in varieties including Liberty Link® technology.	None.

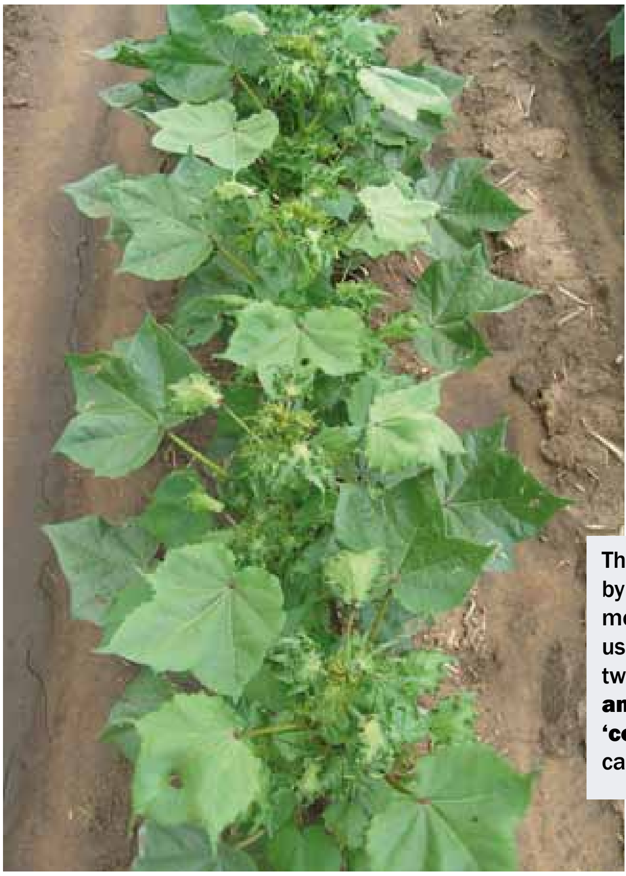
Herbicide damage

Cotton is a robust, perennial crop which is difficult to kill with herbicides once it is established. However, cotton can be very easily damaged from a yield potential perspective by many of the broad-leaf herbicides routinely used on other crops. Cotton is particularly sensitive to the phenoxy and other Group I herbicides (such as 2,4-D), with very small amounts of these herbicides capable of causing severe damage to the crop. Cotton is most sensitive to these herbicides during the 8–16 node stages of crop growth.

In order to reduce the risk of herbicide damage:

- Allow for plant-back periods from herbicides applied to previous crops. Remember to check the label.
- Ensure spray rigs are thoroughly decontaminated before using on cotton, especially if they have been used to control broad-leaf weeds in an alternative crop.
- Ensure neighbours are aware of spray-drift issues for cotton and its sensitivity to the Group I herbicides.
- Ensure herbicide applications to cotton don't drift onto neighbouring crops.

Detailed information of herbicide damage is available in the *Herbicide Damage Guide for Cotton*, which is part of WEEDpak.



This phenoxy herbicide-damaged cotton was caused by a simple mistake where a measuring jug used to measure out 50 ml of Starane® (fluroxpyr) was then used to measure out MC for a subsequent spray job two weeks later. **Always take care to decontaminate and label specific measuring equipment as 'cotton only' to avoid cross-contamination.** In this case a dirty jug contaminated an entire cotton field.

Roundup Ready® herbicide is very effective at dissolving traces of phenoxy herbicides from spray application equipment, resulting in a contaminated spray mix. As this product is used early season, spray equipment MUST be properly decontaminated before the season begins. **Roundup Ready® herbicide and poorly decontaminated spray equipment are not a forgiving combination.**

Decontamination of application equipment

The ability to accurately apply herbicides, growth regulators and insecticides to cotton in a timely manner is critical for successful cotton production. Whether using an on-farm boom spray or a contractor, it is essential that appropriate precautions are taken to decontaminate application equipment from previous residues.

As sugarcane is the dominant crop within the Burdekin region, it is highly likely that spray equipment will have previously been used to apply hormone herbicides such as 2,4-D or MCPA. Since only trace amounts of these compounds can have significant impact on cotton plants, it is crucial that equipment is decontaminated properly. This significant issue can be easily underestimated by contractors and first time growers. During the 2008 and 2009 seasons approximately 17% of the 1400 ha grown was badly affected by hormone herbicides derived from poorly decontaminated on-farm or contractor equipment. Carefully ensure that any measuring jugs and chemical handling and/or mixing equipment are also free from contamination. Note the basic decontamination process suggested here is a guide only — check product information for specific requirements.

Basic decontamination process:

1. Always follow label recommendations for use and post-application cleaning guidelines.
2. Do not let spray solution stand in a boom or tank. Clean immediately after spraying by running clean water through the tank, spraylines and nozzles as a first flush.
3. After flushing partially fill the tank again and run clean water through the tank, lines and nozzles for at least 10 minutes.
4. Remove filters and clean with appropriate detergent (see table below) using a soft brush as necessary.
5. Partially fill spray tank with water and add appropriate cleaning agent. Follow the table below for methods and standing times.
6. Finally, flush all items with clean water.

Importance of neighbourhood communication

It is essential to talk to your neighbours, particularly those within 1-2 kilometres, about your intention to grow cotton. Unlike drier southern production regions, the Burdekin rarely experiences long distance drift and sugar cane crops adjacent to cotton can be sprayed with phenoxy herbicides as long as attention is paid to field conditions. The prevailing wind often blows from the south east during the morning before changing towards a northerly sea-breeze in the afternoon. Depending on crop placement, there is often potential to take advantage of these daily patterns and ensure that any local drift is likely to fall away from the cotton crop.

Recommended decontamination practices for various pesticides

Chemical type	Cleaning agent(s) per 100L water	Instructions
General cleaning	250 g powdered laundry detergent.	Flush sprayer with fresh water. Thoroughly agitate and flush cleaning mixture through system. Drain, and then rinse clean with water.
Hormone type herbicides - water soluable formulations (e.g. 2,4-D amine or MCPA)	500 g washing soda.	Half fill spray tank, thoroughly agitate and then flush through some solution and let stand for a minimum of 2 hours but preferably overnight.
Hormone type herbicides - oil soluable formulations (e.g. 2,4-D ester)	4 L of kerosene + 500 g washing soda + 125 g powdered detergent.	Drain, flush and rinse twice with clean water.
Diuron, Dual®, Triatrazines, Velpar®	Clean water.	Flush sprayer with fresh water. Thoroughly agitate and flush cleaning mixture through system. Drain, and then rinse clean with water.
Sulfonylureas (Brushoff®, Ally®, Glean®)	350 ml household chlorine bleach (35 g/L available chlorine). **Never mix bleach and ammonia**.	Rinse sprayer after herbicide use with water and drain. Then agitate chlorine solution through system, let stand for a minimum of 2 hours. Drain then flush system with two lots of clean water. Clean nozzles, screens and strainers with chlorine solution separately.
Insecticides and fungicides	250 g powdered laundry detergent.	Thoroughly agitate and flush through system. Drain, and then rinse clean with water
OP and Carbamate insecticides	1 L household ammonia + 125 g powdered detergent. **Never mix bleach and ammonia**.	Thoroughly agitate. Flush through a small amount through the sprayer and leave overnight. Drain, and rinse clean with at least two washings of water
Broadstrike®, Lontrel®, Verdict® & Fusilade®	500mL of liquid washing detergent (e.g. OMO®).	Flush the system, then quarter fill the tank with water and add the detergent. Start pump and recirculate for at least 15 minutes. Drain and flush with fresh water.
Glyphosate	Clean water.	Rinse thoroughly several times with clean water.

After cleaning and decontamination of the main system, remember to check all filters, screens and nozzles. Replace or service any faulty parts after decontamination is completed. Source: SPRAYpak – Cotton Growers Spray Appplication Handbook 2nd Edition.

Diseases

No major diseases other than *Alternaria* leaf spot have been reported on cotton growing in northern Australia. For disease to occur, three conditions must be met; both the microorganism responsible and a susceptible host must be present, and environmental conditions must fall within a certain range for the pathogen to germinate, grow and develop.

The following summarises cotton pathogens known to occur in the Burdekin, and other potential disease threats that may affect the development of a future cotton industry in the region.

Alternaria leaf spot

Alternaria leaf spot (*Alternaria macrospora* and/or *alternata*) is the most prevalent and serious disease of cotton in northern Australia. Disease severity can be high, particularly in cooler wet years and where potassium may be limiting.

Symptoms begin with small brown necrotic lesions, 1-2 mm diameter, surrounded by a purple halo. The lesions may extend up to 2-3 cm in diameter in some cases with the impact more severe on okra leaf types, where a lesion on the mid-rib can cause leaf necrosis for the remainder of the leaf blade below the lesion. A marked yellow halo surrounding the necrotic lesion is common on mature leaves. Under suitable conditions, the fungus will sporulate and take on a black sooty appearance. As the disease progresses the tissue at the centre of old lesions will turn grey, dry and may crack and fall out giving a 'shot hole' appearance. Premature defoliation and senescence of the lower plant canopy is the most noticeable symptom of *Alternaria* leaf spot. However in northern Australia, *Alternaria* leaf spot is also common in the upper canopy.

Advanced symptoms of *Alternaria* leaf spot. The disease is more common in the upper canopy in northern Australian crops. Photo by Mike Bell, DAFF.

There is limited information regarding control of *Alternaria* leaf spot on cotton, probably because it has not been a major disease in established cotton growing areas. At present there are no fungicides registered for the control of *Alternaria* on cotton in Australia. Potassium deficiency can exacerbate the severity of *Alternaria* leaf spot.

Boll rots

Boll rot is a generic term referring to a number of diseases whereby bacteria and fungi cause damage to bolls, lint and seed.

Many species of microorganisms, mostly fungi, have been implicated as causes of boll rots. Many are opportunistic wound pathogens that cause rots following insect damage or other wounds to bolls. Others are secondary invaders of already-diseased tissue. However a few are described as primary pathogens, and are capable of entering intact bolls directly or through natural openings.

Boll rot caused by *Alternaria macrospora* begins as small spots with dark margins. The spots enlarge and eventually may affect the whole boll.

Bolls infected by *Phytophthora* appear dark brown to black, sometimes with areas of white mould on the surface.

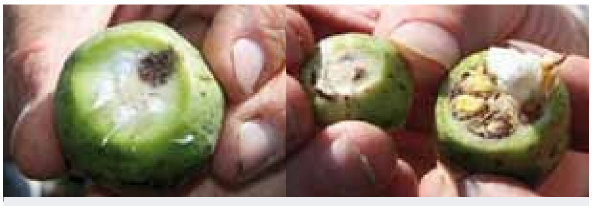
In later stages of development of *Lasiosiplodia* boll rot, bolls become covered with a sooty black layer of fungal filaments and spores.

The distinctive feature of *Sclerotinia* boll rot is the production of black fungal structures (2 to 10 mm diameter) within and/or on the surface of the rotted bolls. A white cottony fungal growth may be present and the branch adjacent to the boll may also be affected.

The majority of the damage in Australia can be attributed to: *Alternaria macrospora*, *Fusarium* spp., *Lasiodiplodia threobromae*, *Phytophthora* spp., and *Sclerotinia* spp.

Rhizopus sp. and *Botrytis* sp. produce profuse grey fungal growth over bolls that have been damaged by insect attack.

The first record of cotton boll rots caused by the fungal pathogen *Nematospora coryli* were made in the Burdekin during 2010. This pathogen is unique in that it is always transmitted by sap-sucking Heteropteran insects. This fungus causes several serious diseases of cotton including seed rot, internal boll rot (stigmatomycosis) and tight lock. In the USA fibre losses of 40-60% have been reported. Insect control is the best way to prevent infection, although improved cultivar resistance may be possible. This was the first record of *Nematospora coryli* on cotton in Australia.



Nematospora coryli **has caused boll rot and internal boll rot (stigmatomycosis). Photo Lynda Smith, DAFF.**

Conditions favouring boll rot

The primary factor controlling the prevalence of boll rot is moisture. Micro-organisms capable of producing boll rot can be found in most cotton fields. Persistent moisture and/or relative humidity predispose a crop to a range of boll rot organisms, and can be further aggravated by a dense canopy that restricts air flow and drying potential.

Control measures

The chosen Burdekin planting window minimises the incidence of boll rots. During boll maturation from late April-June, field conditions are likely to be drier and cooler and therefore far less conducive to outbreaks of boll rots.

Field selection is important as poorly drained soil will retain more water and have higher relative humidity. Over-irrigation from boll opening onwards will also increase within-canopy humidity and potential level of disease incidence. Certain varietal characteristics (such as okra leaves) can reduce boll rot due to improved sunlight penetration.

Lower within-row plant density improves air movement and drying, reducing relative humidity within the canopy. Balanced nitrogen fertilisation can supply the developing crop's needs without promoting excessive vegetation. Vigilant insect checks and prompt response to outbreaks to diminish injury will reduce subsequent boll rot.

Other potential disease threats

The table below summarises disease threats to cotton in the Burdekin. For more information see Appendix 5.

Potential disease threats to cotton production in the Burdekin.

Type of infection	Disease(s)	Comments
Seedlings	*Rhizoctonia solani* (AG 4)	Use fungicide treated seed and good hygiene. Unlikely to cause significant seedling mortality at sowing due to high field temperatures.
	Pythium spp.	As above.
	Fusarium spp.	As above.
	Anthracnose caused by *Colletotrichum* sp.	As above.
Stem and root	Fusarium wilt – *Fusarium oxysporum*	Prevent entry to the Burdekin on seed and crop residue, or soil-contaminated people or machinery.
	Verticullium wilt – *Verticillium dahliae*	As above but not seed-borne.
	Charcoal rot – *Macrophomina phaseolina*	Avoid early season inter-row cultivation as following rainfall can encourage disease incidence.
Foliar	Tropical cotton rust – *Phakopsora gossypii*	May require resistance varieties or fungicide somewhere in the future.
	Cotton Bunchy Top	Viral disease spread by aphids.

Biosecurity disease risks

Due to the Burdekin's northern location and closer proximity to South-East Asia, the region may have an increased likelihood that any incursion of an exotic disease could be first observed in the tropics before more southerly production regions. Growers and consultants should keep an eye out for unusual diseases and pests within commercial crops and report these to the Exotic Plant Pest Hotline on 1800 084 881. You will be forwarded onto an experienced person who will be able to ask you questions about what you have seen and arrange for a sample to be collected. Do not send samples without first contacting a biosecurity officer as this may risk further spreading an exotic pest or disease.

If you do find a suspected exotic plant pest, the following precautions should be taken to contain the pest and protect other parts of your farm:

- Call the exotic pest hotline 1800 084 881.
- Do not touch, move, or transport affected plant material.
- Wash hands clothes and footwear that have been in contact with affected plant material.
- Mark the location of the pest detection and limit access to the area.
- Restrict operations in the area while waiting for the identification of the suspected exotic pest.

Two diseases that are currently not in Australia but are deemed to represent a high risk to the Australian cotton industry are covered below. Both of these diseases are present in parts of Asia.

Cotton Leaf Curl Disease

Cotton leaf curl disease (CLCuD) caused by the Begomo group of viruses is currently NOT present in Australia, however these viruses are prevalent throughout India, Pakistan and parts of SE Asia, and silverleaf whitefly (the vector that transfers this disease) is common throughout Queensland. With begomoviruses present in nearby countries, potential exists for a future outbreak of cotton leaf curl disease to occur in Australia.

Affected plants have readily identifiable symptoms that if observed should be reported immediately to local biosecurity authorities. This disease causes upward cupping of the leaves together with the thickening of leaf veins. A classic symptom is the emergence of leaf-like structures (enations) from the leaf veins in some cotton varieties affected by CLCuD.

Characteristics of cotton leaf curl disease are leaf enations and vein thickening (left), and cupping of the leaves (right). Photos taken in Pakistan by Cherie Gambley, DAFF.

Blue disease showing stunting and downward cupping of leaves (left) and typical pattern of disease occurrence (right) with affected plants amongst normal plants. Photos taken in Brazil by Murray Sharman, DAFF.

Cotton Leaf Roll Dwarf Virus (CLRDV) or blue disease

Commonly known as blue disease, CLRDV is currently NOT present in Australia, however these viruses are prevalent throughout Africa, Asia and the Americas, and given the wide-spread abundance of cotton aphid vectors (*Aphis gossypii*) the potential entry and spread throughout all cotton growing regions in Australia is of concern.

CLRDV remains within the insect for at least a few weeks, and is deposited into other plants when the insect feeds again. The disease is often seen as small patches of plants, often just on a single row. Single infected plants may be overlooked if overgrown by nearby healthy plants.

Leaves affected by CLRDV tend to be smaller, thicker, more brittle and leathery than healthy leaves and have an intense green colour with yellow veins. Reddening of stem petioles and leaf veins can occur in some infections. Leaf edges tend to roll downwards and under and plants become stunted due to a shortening of the branch internodes. Plants produce many branches, sometimes giving a bunchy zig-zag stem habit. Symptoms are more obvious in plants infected at an early age and stunting is more pronounced. Infected plants also produce smaller bolls and boll shed may occur. A recently reported atypical strain of the virus has less plant stunting and more leaf reddening but it is difficult to distinguish the strains based on symptoms alone.

There are no known hosts of blue disease outside cotton. Plants showing CLRDV-like symptoms should be reported immediately to local biosecurity authorities.

Disease management:

- Disease incidence
- Any unusual plant symptoms or pests
- Contact the Exotic Plant Pest Hotline on 1800 084 881 if you are unsure

Discuss with your agronomist

Wet season runoff and best practice

Minimising agrochemical and fertiliser losses

As with many agricultural industries, pesticides and fertilisers are essential components of high-yielding viable cotton production systems. However, the many insecticide inputs required for conventional cotton production make it both unreliable and uneconomic in tropical Australia, as demonstrated by the failure of the cotton industry in the Ord River Irrigation Area (ORIA) during the 1970s. Conventional cotton production is not recommended for the Burdekin.

The advent of transgenic cotton varieties that incorporate insect and herbicide tolerant traits have enabled significant reductions in pesticide use. However, the Burdekin planting window (just prior to the wet season) still poses a high risk for potential pesticide and nutrient losses, as runoff volumes are generally too large to be contained on-farm. This increased risk was considered when developing the agronomic practices in this guide.

To minimise wet season losses and related impacts, identify all early season crop inputs that can be reduced or avoided without compromising later yield potential. The majority of pesticides and fertilisers are not required until just before flowering onwards — a period that coincides with rapidly decreasing rainfall.

1. If a pesticide is required, give preference to products with the least environmental impact.
2. Limit initial nutrient application to only what is required for early crop development.

Pesticides

The use of Roundup Ready Flex® and potentially new Liberty Link® varieties eliminates the need for pre-plant soil-applied herbicides that have been commonly detected as contaminants in other Burdekin farm runoff studies (Davis et al., 2008). Glyphosate and glufosinate have low non-target toxicity and minimal residual impact, and can be used with a higher degree of safety during the monsoon season.

Insecticide usage on Burdekin cotton crops will be low due to the use of Bollgard II® transgenic varieties.

When insecticides are required **avoid products that have significant environmental hazard risks such as organophosphates and synthetic pyrethroids** as there are many other more target-specific, lower environmental impact options now available. Cotton generally becomes susceptible to insect attack at the onset of sunnier weather in March when bolls begin to form, therefore reducing the likelihood of pesticides entering run-off water. Best practice aims to limit the use of insecticides to the drier period of the season from March to May. A schedule of possible pesticides and likely usage periods is given in the table below.

Pesticide monitoring of field runoff water during the 2009 and 2010 seasons demonstrated that early season avoidance of insecticides and selection of narrow spectrum products was effective at minimising losses.

Summary of the main pesticides that may be 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
Herbicides		
Glyphosate	Grass & broadleaf weed control	Dec-May
Glufosinate	Broadleaf weeds and some grasses	Dec-May
Insecticides		
Diafenthiuron	Whitefly, spider mite or aphid species	April- May
Carbaryl	*Nezara viridula* (green vegetable bug)	March-May
Clothianidin	*N. viridula*	March-May
Fipronil	*Creontiades dilutes* (mirids)	March April
Synthetic pyrethroids	*N. viridula*	March-May
Indoxacarb	Caterpillar pests	February-April

Fertilisers

The loss of nitrogen from agricultural fields is a significant concern for all cropping in the Burdekin region, not only from a farm productivity viewpoint but also for the effects on down-stream water bodies as the area is close to sensitive wetland and marine receiving environments. Runoff water sampling from cotton grown on both heavy clay and sandy loam soil types has conclusively demonstrated that nitrogen applied early in the season is easily lost during wet season downpours, regardless of the form of fertiliser applied or its placement (in or on the planting bed).

Large pre-plant applications of nitrogen are not recommended and are likely to be ineffective in wet years. Instead, use a low pre-plant application rate (see page 39), followed by side-dressing at the end of the wet season (onset of flowering). Application rates need to consider the interim contribution from mineralising crop stubble during the wet season. Crop trimming (see page 35) can assist by lengthening or delaying the pre-flowering period to at least 60 days or more after sowing.

The significant potential for nitrogen losses during the wet season means that strategies to avoid these losses will be pivotal to the future success and acceptance of a Burdekin cotton industry from both environmental and cost of production viewpoints.

Large pre-plant applications of nitrogen for wet season cotton are likely to be lost. This is both uneconomic and environmentally unacceptable.

Soil erosion management

The potential for soil erosion is an important consideration for wet season cotton production, particularly on loam soils.

The planting window recommended for cotton in the Burdekin may not allow a long period for establishment prior to wet weather, creating significant potential for soil erosion due to a lack of soil cover and root system development, particularly on sandy loam soils.

A minimum tillage approach is recommended in the Burdekin where either a cover crop is established and then sprayed out with herbicide at cotton planting or the stubble of the previous grain crop is retained. Allowing time for the establishment of a cover crop such as millet or mungbeans prior to cotton is recommended for fields being rotated out of sugarcane for a summer fallow. These fields will often be cultivated multiple times after several years of sugarcane production to reduce any harvesting compaction and allow laser levelling practices to be completed. The establishment of cover crops on these fields several months prior to planting cotton allows time for the reworked beds to consolidate, and for cane roots and stools to break down.

Standing stubble from previous cover crops helps stabilise the soil surface and provides an organic source of slow release nitrogen early in the life of a cotton crop, reducing the need for bag fertiliser at planting.

Collecting samples from irrigation water as part of field runoff studies.

Crop management considerations — late season operations

Defoliation

Defoliation is the process by which a cotton crop is treated with a combination of harvest aid chemicals that remove the leaves and hasten the opening of bolls in preparation for machine picking. Hormone defoliants such as thidiazuron, when applied to cotton crops, increase the ethylene concentration within the leaves which in turn triggers a layer of cells at the base of the leaf petiole to die. This results in the abscission of the entire leaf complete with petiole. If done correctly the leaf will drop from the plant before it actually dies. Boll openers/ conditioners such as ethephon specifically enhance ethylene production which leads to the quicker splitting and opening of mature green bolls.

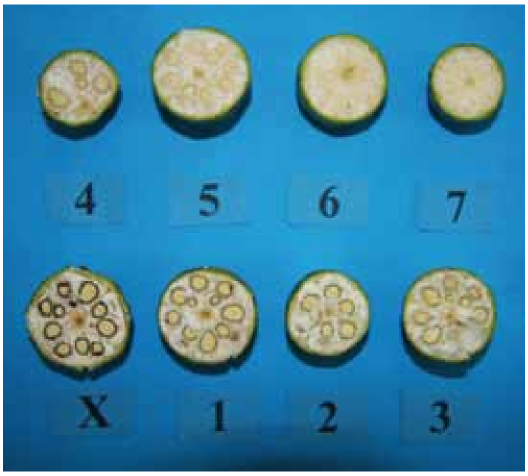
The effectiveness of defoliation chemicals depends on

- using appropriate combinations and rates of defoliant and boll openers
- timing their application appropriately to crop maturity
- taking into account likely temperatures post-application.

Defoliation in the Burdekin varies from other regions as the weather is cool but still humid, and **correctly assessing crop maturity is essential to avoid slow defoliation** and more than two applications of defoliant chemicals.

In fields with a compensatory top crop, the age difference between bolls spread over the top 8-10 nodes can be greater than initial impressions may suggest. To assess physiological maturity, locate the last cracked boll that is on the first branch position from the top of the plant. Then count up 4 nodes from the branch with the cracked boll. Any first position fruit above this level (i.e. 5 nodes or above the upper-most cracked boll) will still be immature and difficult to open under cool humid conditions. **A general rule of thumb is that when a crop is close to being ready for defoliation wait a few more days before applying defoliant products**. Often okra leaf varieties such as Siokra 24BRF can be defoliated with one pass if a little more time is allowed before applying defoliant

When the crop reaches 4 nodes above cracked boll (NACB), the top boll will have reached 'effective' maturity, where fibre development on all bolls is complete and defoliation can occur without risk of reducing yield and quality. The diagram opposite explains some issues associated with measuring NACB.



It is easy to over-estimate crop maturity, particularly on Burdekin crops with a large 'top crop'. A typical Sicot 74BRF plant in the field appears to have open bolls nearly to the top (right), but on closer inspection shows seven branches separating the last pickable boll from the last cracked boll. When cut in half from the last cracked boll to the top boll (above) it is apparent that positions 5, 6 and 7 are still immature and therefore the crop is not ready to defoliate. As conditions may be cool in May and June these positions may be 3-5 days apart.

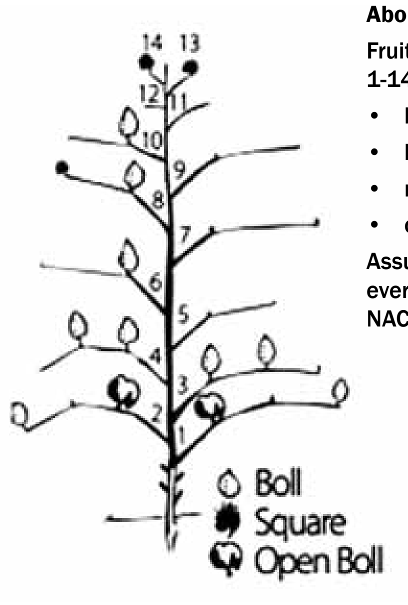
How far up the plant do you measure?

When using NACB for timing of and defoliation, determine how many nodes from the cracked boll to the last boll that you intend to harvest. On the diagram the last harvestable boll is on FB10, therefore ignore FB 11-14.

Do you count nodes without fruit on them?

YES. All nodes between the cracked boll and last harvestable boll should be included. The maturity of the boll is dependent on its age.

It takes the same length of time for a boll to mature properly regardless of the presence of other bolls on neighbouring nodes or positions. On the diagram, nodes 5, 7 and 9 have no fruit, but must still be included in the NACB measurement.



About this diagram:

Fruiting branches (FB) are numbered 1-14

- **highest cracked boll is on FB2**
- **last harvestable boll is on FB10**
- **nodes 9, 7 and 5 have no fruit**
- **current NACB value is 8.**

Assuming the bolls open at one node every 3-5 days, the crop will reach 4 NACB in 12-20 days time.

What defoliants should be used?

Generally thidiazuron-only based products (e.g. Drop®, Reveal®) are sufficient for defoliation even under cool conditions. Defoliation mixes whereby diuron is manually added may cause leaves to dessicate and 'freeze' onto the plant resulting in poorly defoliated cotton and later discounts for leaf contamination. The few quality discounts for commercially produced cotton from the Burdekin have been mainly due to leaf contamination relating to poor defoliation and leaf freezing where diuron has been separately added to thidiazuron products.

Using higher rates (1-2 L/ha) of ethephon (e.g. Prep®) with the first defoliation pass may improve boll opening and leaf drop under cool conditions as opposed to the leaf conditioning approach used further south which relies on minimal ethephon in the first application followed by a larger rate for the second pass.

Defoliation can generally be completed in the Burdekin within 10-20 days depending on temperatures.

Key Issues for defoliating Burdekin crops:

- Aim to have soil moisture at close to refill by defoliation. Severely water-stressed crops can be difficult to defoliate whereas too much soil moisture may lead to soil compaction during picking.
- If boll openers/conditioners are applied before the crop is mature, a number of top bolls might be lost due to shedding.
- Only use boll openers and defoliants when the bolls are mature. You cannot speed up the physiological maturing of developing fibres with defoliants, and forcing immature bolls to open can result in lint quality issues due to undeveloped fibres.
- Check the 7 day temperature outlook and determine the likely concentration of thidiazuron to be applied to the crop. Cooler temperatures generally necessitate a higher application rate. **Refer to product label**.
- Ensure before starting defoliation that the cotton will be able to be picked within 2-3 weeks. Delays in picking beyond 3 weeks have an increased risk of the cotton plant regrowing new leaves that may require further treatments with defoliants and additional production expense.
- Do not add diuron to thidiazuron as a tank mix. This mix is not registered and has a high risk of causing leaves to 'freeze' on the plants with the resulting stuck dead leaves potentially contaminating the lint at picking. If conditions are particularly cool and diuron may be advantageous, be sure to use a commercially blended diuron/thidiazuron product.

Defoliation:

- The level of boll maturity
- Likely forecast temperature and rainfall outlook
- Rates and proportions of different defoliant chemicals
- Irrigation scheduling leading up to defoliation

Discuss with your agronomist

Harvesting

Picking can commence when the last top bolls have opened and at least 95% of the crop's leaves have fallen. It is not unusual for some green leaf to remain on the very bottom inner canopy section, but all of the outer and upper canopy should be shed.

Prior to planting, secure the services of a picking contractor who will be able to pick and form the cotton into either traditional large rectangle sized modules or the more recent round modules. While either method is suitable, consider the most cost-effective option for the likely transport options available at the time. Freight rates can vary considerably depending on the type of modules used, the availability of southern-bound transport, and the type of semi-trailer decks available.

Consider where modules will be built and/or placed as it is likely that modules may remain on farm for some weeks after picking. Ensure they are located in accessible areas (with appropriate road access) that are not likely to interfere with adjacent field operations or be subject to field water runoff from irrigation or rainfall. While modules are able to withstand rainfall, they will readily act as a 'wick' and absorb standing water resulting in significant downgrading or even total loss.

In the Burdekin's humid climate it is critical to ensure that daily picking does not commence until the morning dew has completely evaporated. Often this will not occur until at least 9:00 a.m. during mid-winter. Picking cotton that is excessively moist can cause self combustion of modules, additional ginning costs if lint drying is required, and also affect the quality of the lint post-picking. Evening dew forms relatively quickly and picking after sunset should be avoided. The picking window is therefore only 7-9 hours per day. It is important to monitor these field conditions, particularly when using contracted picking teams who may want to maximise the number of picking hours per day.

It is normal that a small percentage of lint will remain on the cotton plants after picking (see photo). Unlike other harvesting methods where the plant is cut and removed, a picker uses specialised finger-like tools called spindles which catch the lint as the bush passes through the picking head. Any bolls that are tight locked or immature are likely to be only half picked during a single pass. The remaining lint is often fluffed or 'tagged' out, and quite visible post-picking, however as the losses are generally less than 3%, a second pick is not viable.

Picking cotton on a 30 inch row spacing.

Carefully consider the type of module that will best suit your transport options.

It is normal for a small amount of lint to be left behind after picking. The remainder of the unpicked crop can be seen to the left of the photo.

End of season crop destruction

After picking, the remaining cotton bushes must be destroyed as soon as practically possible. This can be achieved through:

- root pulling/cutting and mulching using a purpose built power take off driven implement.
- mulching and cultivation.
- mulching and treatment of any regrowth cotton with appropriate herbicide.

The most optimal method will depend on the equipment available and what type of crop will follow (e.g. grains or sugarcane).

For sugarcane, an effective method is to mulch the cotton plants down to near ground level after picking (with or without root cutting), direct drill cane billets into the existing beds and treat cotton bush regrowth with broadleaf herbicides as part of standard weed management program. The establishing sugarcane crop will rapidly smother any surviving cotton plants.

For other crops, a mechanical method that either pulls the roots or cuts the mainstem at or below ground level is highly recommended, as cotton is difficult to control with herbicides in short term grain rotations. When root cutting cotton, ensure that the stub will not regrow by severing the main-stem below where the cotyledons were attached.

Controlling ratoon cotton or seedlings between seasons is an essential part of effective pest management. Allowing plants to grow between season creates a 'green bridge' for a number of insects pests. It allows resistant sucking pests to survive on farm between seasons and can expose Bt toxins to pests in the environment, potentially accelerating the development of resistance to these toxins in Bollgard II® transgenic varieties on which tropical cotton production depends.

Discuss with your agronomist

End of season crop destruction:

- Following crop rotation options
- Appropriate mechanical and herbicide cotton destruction methods

Picked cotton crop is ready for end of season destruction.

In this field, the picked cotton plants have been root cut and mulched, and the permanent beds planted to maize.

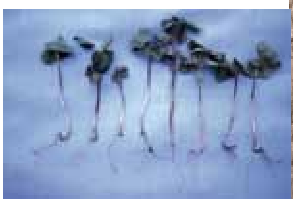
Trouble shooting

Questions to consider or discuss with your agronomist to diagnose the cause of a crop problem.*

Crop establishment problems

If the crop is showing no or patchy emergence after 4 days, or seedlings do not appear healthy, examine the field by digging up and closely examining the seeds/seedlings. Factors that may influence establishment include:

- **Seed viability.**
  Is the seed new season? If leftover from last season, has it been stored in a cool dry place?
- **Planting depth.**
  Was the seed sown too deep? Depths greater than 2-3 cm can be a problem on hard setting loam soils, particularly if rainfall has occurred between planting and emergence. Are plants struggling to push through with a swollen hypercotyl?
- **Smearing in seed furrow.**
  Did the planter compact the seeding furrow by smearing the soil?



- **Field toxicities.**
  Was the fertiliser placed too close to the seed line resulting in burn? Is there a residual herbicide causing establishment problems?

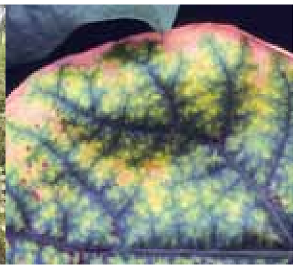
- **Planting rate.**
  Was the planting rate set correctly? Did the planter have a blockage? Was the drive wheel slipping?
- **Soil conditions.**
  Was the seed placed into sufficient moisture? If sown dry and watered up did the moisture reach the seedline or has the planting bed collapsed and buried the seed even deeper? If light rain occurred post-planting, did the seed germinate and then die before full watering up could take place?
- **Establishment pathogens.**
  Was a propriety seed coat treatment used? Is there evidence of diseased root tips or on the seedling stem near ground level?
- **Waterlogging.**
  Has rainfall or poor drainage drowned the seeds or seedlings? Dead seeds will smell rotten when recovered and squeezed.
- **Insect damage.**
  Was an insecticide seed dressing used? Are soil dwelling insects present in the field (e.g. crickets or wireworms) or do the seedlings show signs of chewing damage (e.g. chewed tops or cutting of main stem at ground level)?
- **Inability to throw off seed coat.**
  Was the seed sown too shallow, preventing removal of the seed coat by the surrounding soil as the seedling emerged?

Canopy disorders

Monitor canopy health throughout the season. Symptoms you may encounter and possible causes include:

- **Distortion of new growth.**
  Has the crop been affected by phenoxy herbicide drift or spray rig contamination? If Roundup Ready® was recently applied was all application equipment (boom, tanks and measuring jugs) clean of previous residues? Is there a symptom gradient across the field that may indicate a pattern of drift matching a recent spray application direction of travel? New foliage distortion with a finger-like appearance may indicate phenoxy herbicide damage, whereas leaves subtly 'cupped' upwards could indicate a zinc deficiency. WEEDpak and NUTRIpack have photographs of herbicide damage and nutrient deficiency symptoms.
- **Leaf scalding.**
  Has the crop been sprayed recently? Was a foliar fertiliser used or is there a possibility of chemical contamination? Has the damage appeared quickly and in large patches and are red shouldered leaf beetles present? Is the scalding more lesion-like, which might indicate *Alternaria* leaf blight?

- **Yellowing of leaves.**
  Where is the yellowing most pronounced? Yellowing that is more obvious at the bottom may indicate nitrogen deficiency whilst yellowing at the top may be due to herbicide contamination. General yellowing may be nitrogen or sulphur deficiency (see NUTRIpak for symptoms). Is available soil nitrogen adequate? What was the fertiliser program for the crop and how much rain has occurred? Have the roots reached the placed fertiliser? If symptoms are patchy or in rows was there a problem with fertiliser application?
- **Darkening of leaves to red/purplish colour.**
  Where in the canopy are symptoms most visible? Acute reddening between the leaf veins in the lower canopy combined with light green new leaves might indicate a phosphorous deficiency (below left) . Pronounced symptoms in the upper canopy and a marked increase in *Alternaria* leaf blight prevalence post cut-out could indicate potassium deficiency (below right), or simply be the impact of cool weather and crop decline leading up to maturity. Check soil test results and see NUTRIpak for symptoms.

- **Flowers are becoming obvious at the top of the crop.**
  If it is March or early April this may indicate an advanced case of premature cut-out. Check to see if a sufficient number of bolls have been set. If it is mid to late April and the crop has set an acceptable boll load this is indicative of crop cut-out and part of the natural progression to maturity. Discuss fruit counts with your agronomist.
- **Speckly yellowing of the leaves in places or large patches.**
  Both mites and jassids can cause these symptoms in mid season cotton. Ask your agronomist to check for insect presence.

- **Yellow spots on the outer canopy leaves.**
  These have occurred during hot weather combined with showery rain on most plants within the field, and may be due to a condition called sunspots which occurs when light rain combined with high radiation temporarily disrupts the chlorophyll in the leaves. This symptom generally goes away after several days.

- **Scalded patches on the leaves (particularly the edges).**
  This can occur after extended periods of cloudy weather are followed by intensive sunlight. Often this symptom in the Burdekin is confined to a cohort of the same leaves across each plant (e.g. main stems leaves off certain nodes).

Root system disorders

Root systems can develop problems even if the canopy appears to be flourishing. Check root system development by carefully uprooting several representative plants from each field weekly up until flowering.

- **Poor tap root development.**
  Has it been very wet since emergence? Waterlogging may have encouraged lateral root expansion instead. A kinked tap root may indicate a hard pan. A damaged tap root may also be an indication of fertiliser burn.
- **Death of the lower section of tap root.**
  This might indicate waterlogging and lower root system suffocation. Were planting beds consolidated before planting or have they since settled? Was fertiliser placed under the seed line? Is the soil type a sodic duplex with a hostile subsoil?
- **Majority of root system is growing sideways.**
  This is common if conditions have been wet. Roots will explore the upper section of the bed or hill and avoid lower waterlogged zones.

*Images have been sourced from the Cotton Symptoms Guide (2012)

Appendix 1. Common terms and acronyms

Adventitious boll. A boll which forms in an axil on the stem, not on a fruiting branch.

Beat sheet. A 1.5×2 m sheet of canvas (generally yellow) placed over a furrow and adjacent row that acts as a capture surface for insects when a metre stick is used to 'beat' the crop towards the sheet. Used for sampling a range of insects.

Biomass. The total dry weight of a plant or its parts.

Boll. Cotton fruit capsule that contains the cotton lint and seed. Forms immediately after the flower petals have fallen.

Boll filling. The process of seed and lint development. Begins at flower fertilisation and ceases shortly before the boll cracks and opens.

Bollgard II®. A trademark of Monsanto Ltd. Cotton containing both the Cry 1Ac and Cry 2Ab genes from *Bacillus thuringiensis*.

Bt. An abbreviation taken from the bacterium *Bacillus thuringiensis* from which genes that allow the expression of the Cry 1Ac and Cry 2Ab toxins were derived.

Cotyledons. Seed leaves that appear as a symmetrical pair of leaves at seedling emergence.

Cut-out. The date when the last effective bolls are formed. Cut-out is generally recognised when the number of nodes above white flower falls below four.

Days after sowing (DAS). The number of days elapsed since sowing.

Defoliation. The application of harvest aid chemicals that accelerate the opening of last bolls and removal of leaves to a crop that has reached final maturity.

Day degree (DD). Heat accumulation calculated progressively during the season to monitor a crop's progress. Daily sums are used to predict date of growth stages of cotton crops (see Appendix 3). The total sum or accumulation of day degrees is referred to as DDS or DDA.

Denitrification. A microbially-facilitated process whereby nitrates are lost from soil due to their conversion to gaseous nitrogen oxide products. Generally occurs after deep placement of nitrogen fertiliser followed by wet conditions.

Emergence. The two cotyledons (seed leaves) break through the soil surface and unfold.

Field application efficiency. The percentage of water applied to a field during an irrigation that stays on/in the field.

First flower. The date at which there is on average one open flower per metre of row.

First square. The date when the leaf adjacent to the first square has unfolded on 50% of plants.

First true leaf. The first leaf developed by a seedling with the appearance and arrangement of a normal cotton leaf.

Fruiting branches. Usually arise from 6 or more main stem nodes above the soil surface and often above several vegetative branches. These branches have several nodes, each with a square and a subtending leaf. Fruiting branches have a zig-zag growth habit.

Fruiting site. The position on a plant where a fruit (square or boll) is formed. The site has either a fruit or an abscission scar where a potential fruit was shed.

Fruit position. The location of a boll on the fruiting branch. The first position (P1) is closest to the main stem (if present, or there may only be an abscission scar where the boll once was), with sequential bolls numbered outwards (P2, P3 etc).

Germination. As soon as a cotton seed touches moist soil, it will take in (imbibe) moisture and the development process from seed to plant begins.

High volume instrument (HVI). An instrument that is able to quickly and accurately determine the fibre properties of a large volume of cotton.

Horizons. Layers of soil types identified from the surface down. Root systems are often limited to the A horizon, as many soils have B horizons unsuitable for crop growth.

Imbibe. The process of a seed absorbing moisture from the soil.

Insecticide resistance. A pest develops resistance to an insecticide due to repeated usage. This may lead to poor control or insecticide failure.

Integrated Pest Management (IPM). Pest control based on the integrated use of a range of strategies to reduce pest numbers in a crop. The aim is cost effective pest management, reduced selection for resistance in pesticides and reduced risk of off-farm contamination.

Insect Resistance Management Strategy (IRMS). A guideline on what chemicals should be used to control certain pests and at what stage of the season. These are published annually in the *Cotton Pest Management Guide*.

Irrigation water use index. The lint produced per megalitre of irrigation water used.

Lateral branch. See vegetative branch.

Liberty Link®. Glufosinate-tolerant plants registered by Bayer.

Management unit. An area of a farm that is managed in the same way (e.g. a singular field, variety, or planting date).

Maturity. Crop maturity occurs when all bolls have completed fibre development.

Mepiquat chloride (MC). A chemical used to manage canopy development in cotton crops.

Micronaire. Measurement of specific surface area based on the pressure difference obtained when air is passed through a plug of cotton filters. This reflects fineness and maturity.

Module. Field-picked cotton is compacted into large rectangular or round modules for storage and transport to a gin.

Natural enemies. Predators and parasitoids of insect pests.

Node. The junction between leaves or branches and the main stem. The internode is the space on the main stem between successive leaves or branches. Nodes on the dominant stem are known as main stem nodes, and are usually numbered upwards starting from the first node produced after the cotyledons.

Nodes above cracked boll (NACB). Describes the number of nodes between the very top of the plant and the nearest underlying branch with a boll in the first position (closest to the main stem) that has begun to split and open. Used to assess crop maturity and determine when to start defoliation.

Nodes above white flower (NAWF). The number of nodes above the topmost white flower in first position (P1). Usually the average of 5 plants at a sample point.

Okra leaf type. Cotton varieties that have deeply lobed leaves similar to the okra plant.

P1, P2 etc. Fruiting position along a fruiting branch. P1 is the fruiting position closest to the main stem. A fruiting branch may have up to 6 fruiting positions.

Pan evaporation. Evaporation as measured by the depth of water lost from the open surface of a standard evaporimeter. A useful tool for calculating watering schedules.

Peak flowering. The period of crop development where the plant has the highest numbers of flowers opening per day.

Pix. Common name for mepiquat chloride cotton growth regulator.

Phase. The development stage of cotton relative to susceptibility to insect attack:

Phase 1	Germination to 1st flower.
Phase 2	1st flower to cut-out.
Phase 3	Cut-out to harvest.

Plant stand. The number of established cotton plants per metre of row.

Planting window. Specified calendar period during which cotton may be sown.

Pre-irrigation. When a field is irrigated prior to planting a crop.

Ratoon plant. A cotton plant that has regrown from a remaining rootstock after a crop has been harvested and destroyed.

Refuge crop. An approved crop planted as a component of a Bollgard II® resistance management plan to ensure production of *Helicoverpa* moths which have not been exposed to Bt transgenes and hence are likely to be fully susceptible.

Resistance management plan (RMP). The annual strategy devised on a regional basis to manage insect resistance to Bt cotton technologies.

Retention. The percentage of fruiting sites that contain fruit (squares or bolls). Often expressed as P1 retention (percentage of 1st position fruiting sites where fruit survive), or total retention (percentage of fruit survival on all fruiting sites).

Roundup Ready®. Glyphosate-tolerant plants containing the cp4 epsps gene by Monsanto.

Side-dressing. Post sowing in-crop application of fertiliser.

Sodicity. A measure of exchangeable sodium in relation to other exchangeable cations. A sodic soil contains enough sodium to interfere with plant growth processes.

Soft approach. The strategy of selecting the least disruptive insecticide option for pest control. 'Soft option' insecticides are generally target-specific and have minimal effects on other species.

Square. Cotton flower buds. First seen as a triangle of bracts.

Subbing up. The process whereby irrigation infiltrates the planting bed.

Tipping. The loss of the terminal growing point. Causes the plant to develop multiple vegetative branches.

Technology Service Provider (TSP). The local agent licensed to act on behalf of the transgenic technology owner. The TSP arranges grower contracts and monitors compliance.

Technology User Agreement (TUA). The contract that a grower enters into with a transgenic trait supplier (Monsanto or Bayer) that allows the growing of transgenic cotton varieties.

Terminal. The uppermost growing point on the main stem. Also present on the vegetative branches.

Trap crop. A patch of chickpeas sown to be attractive to any *Helicoverpa* moths that may have emerged from a nearby Bollgard® cotton crop. Once the cotton crop is harvested the trap crop is cultivated, destroying any progeny of emerging moths. Trap cropping is part of the Bt resistance management plan.

Vegetative branch. These branches (also know as laterals) most frequently emerge from the main stem nodes below the fruiting branches (in nodes 2–6). Vegetative branches may produce their own fruiting branches that give rise to pickable bolls.

Volunteer plant. Different to a ratoon plant, volunteers arise from spilt cotton seeds, typically from dropped seed cotton during harvesting.

Water-up. Irrigation immediately following planting, if pre-irrigation has not been practised.

Water use efficiency (WUE). A general measurement of the efficiency with which available water is used to produce a crop. Includes measures of the efficiency of supply, application, and conversion of water to cotton lint.

Common acronyms

Acronyms used in the cotton industry.

ACRI Australian Cotton Research Institute Narrabri

AWM Area Wide Management

CCA Crop Consultants Australia Inc.

CGA Cotton Growers Association

CA Cotton Australia

CRDC Cotton Research & Development Corporation

Cotton CRC Cotton Catchment Communities Cooperative Research Centre

CSD Cotton Seed Distributors

CSIRO Commonwealth Scientific & Industrial Research Organisation

DAFF Department of Agriculture, Fisheries and Forestry Queensland

DAS Days After Sowing

DD Day Degree

EC Electrical Conductivity

ESP Exchangeable Sodium Percentage

GPS Global Positioning System

GVB Green Vegetable Bug

HVI High Volume Instrument

ICAC International Cotton Advisory Committee

IPM Integrated Pest Management

IRMS Insecticide Resistance Management Strategy

IWM Integrated Weed Management

MC Mepiquat Chloride

NACB Nodes Above Cracked Boll

NAWF Nodes Above White Flower

PAWC Plant Available Water Content

RMP Resistance Management Plan

SLW Silverleaf Whitefly

TIMS Transgenic & Insect Management Strategy (Committee)

TSP Technology Service Provider

TUA Technology User Agreement

VGR Vegetative Growth Rate

WUE Water Use Efficiency

Appendix 2. Useful weather forcast sites

When using weather forecast information, carefully read all associated disclaimers and note how often the site updates, as forecasts can change rapidly. Some weather predictions are based on automatic computer modelling only and are not verified before publishing.

Australian Bureau of Meterology

A range of forecasts and latest observations can be found from the home page (www.bom.gov.au).

Some current specific links include

- Ayr daily weather observations and long term averages (www.bom.gov.au/climate/dwo/IDCJDW4005.latest.shtml).
- SOI graphs and climate outlooks (www.bom.gov.au/climate/).

COLA and IGES

14 Day Precipitation and Temperature outlooks for Australia and New Zealand (wxmaps.org/pix/prec7.html and wxmaps.org/pix/temp7.html).

OzForecast

Enter your location details for a 7 day weather outlook, predicted rainfalls, current observations and weather radar (ozforecast.com.au).

WeatherZone

General weather information and weather discussion forum (www.weatherzone.com.au).

Wetterzentrale

A German site that provides a 6-hourly precipitation outlook over the next 9 days (www.wetterzentrale.de/pics/ausavnpanel4.html).

Appendix 3. Accumulated sum day degrees

The calculation of accumulated day degrees (DDS) provides an easy and reliable, although approximate, means of following crop development and predicting key events. Day degree calculations should be used as a guide only. See Constable and Shaw (1988) for more details on day degree calculation.

From four nodes to early flowering (17 nodes) there is a constant 60 DDS for appearance of each successive node, which is similar for most varieties. Day degrees can be calculated using the following formula:

DD = [(max-12)+(min-12)]/2

Where:
DD = day degrees for that day
Max = maximum temperature for that day (°C)
Min = minimum temperature for that day (°C)
(note: if <12, then a value of zero is used)

Day degrees for a growing season should be calculated and summed from the planting date.

Degree days have been found to have a varied correlation with development in the Burdekin climate and therefore may not always accurately predict growth and development. This is due to complicating factors such as shedding and high night temperatures which may alter the relationship between accumulated DD and actual crop development. The table below shows the relationship between accumulated DD and crop development stages as recorded for Burdekin crops between 2007 and 2011 together with standard deviation, contrasted against data recorded for cotton in the Ord River Irrigation Area (ORIA) and temperate Australia (e.g. Narrabri). This data shows the variation between observed crop development stages and accumulated DD for the Burdekin.

Accumulated Day Degrees (DDS) recorded for Burdekin crops between 2007 and 2011 within the planting date/climate study experiments, together with recorded DDS for the ORIA and temperate Australian crops.

Growth stage	Burdekin	ORIA	Temperate Australia
First square	463 (±40)	546 (±40)	505
First flower	807 (±55)	888 (±50)	777
First open boll	1603 (±108)	1783 (±75)	1537
60% open olls	2053 (±149)	2040 (±120)	2060
Crop maturity	2243 (±185)	2200 (±120)	

Appendix 4. Potential minor insect pests

Insect pests that have the potential to cause minor damage in Burdekin cotton crops include:

- *Helicoverpa* spp.
- Silver leaf whitefly (*Bemisia tabaci*)
- Mirids (*Creontiades* spp.)
- Cotton harlequin bug (*Tectocoris diophthalmus*)
- Spider mites (*Tetrancychus* spp.)
- Pale cotton stainer (*Dysdercus sidae*)

Helicoverpa spp.

Bt cotton effectively controls most lepidopterous pests including *Helicoverpa* and has greatly reduced the need for insecticide control. However, regular monitoring (twice per week from flowering onwards) for this pest is still important as Bollgard II® crops can have temporary 'dips' in the level of toxin expression, particularly during sudden changes to field conditions (e.g. from wet to dry). If these dips coincide with a *Helicoverpa* egg lay, potential exists for caterpillar escapes and crop damage. It is normal for eggs and very small larvae to be present in Bollgard II® fields as the newly hatched caterpillars need to feed on the cotton to receive a lethal dose. However, control may be warranted if larger larvae (5 mm or larger) are found. Detailed economic thresholds and recommended control options for *Helicoverpa* larvae can be found in the Cotton Pest Management Guide (published annually).

A late instar *Helicoverpa* larvae in non-Bollgard II® refuge cotton.

Silverleaf whitefly (*Bemisia tabaci* B-biotype)

Silverleaf whitefly (SLW) are a common and major pest of horticultural crops and cotton throughout the world. SLW is a major pest for Burdekin cucurbit growers but control has been rarely required in cotton, possibly due to climatic conditions after sowing and the local farming system combined with the success of SLW natural enemies in cotton fields. SLW prefer dry hot conditions, and wet season conditions during the first months of production are generally unfavourable for the build up of this pest. As conditions dry out in autumn, lower daily temperatures slow the rate of SLW development and cool winter temperatures near maturity (when open bolls make the crop susceptible to honeydew contamination) further decrease the risk of reaching the economic pest threshold. The introduced wasp parasitoid *Eretmocerus hayati* has also generally been very active in the Burdekin.

Detailed sampling strategies, economic thresholds and recommended control options for silverleaf whitefly are published annually in the Cotton Pest Management Guide.

Silverleaf whitefly adults (left) and nymph stage (right). Photos by Richard Lloyd, DAFF.

Green mirids (*Creontiades dilutus*)

Mirids are a common pest of cotton within Australia's temperate growing regions. However, this pest has been rare in the Burdekin since cotton trials began in 2007. Mirids can affect a crop from the seedling stage onwards, attacking the growing terminal, squares and young bolls. A sucking pest, mirids damage plant structures whilst feeding, leaving no obvious physical chewing damage. Infestation occurs when the winged adult stage migrates into crops. Both adults and nymphs are easily sampled using a beat sheet. Mirids can damage squares (causing them to flare and shed), and bolls, causing shedding or damage that affects opening. Bolls older than 25 days are generally not susceptible to mirid damage.

Detailed sampling strategies, economic thresholds and recommended control options for mirids are published annually in the Cotton Pest Management Guide.

Green mirid adult (left) and nymph stages (right). Photos by Moazzem Khan, DAFF.

Spider mites (*Tetrancychus* spp.)

In southern regions, two spotted spider mite, *Tetrancychus urticae*, is the primary mite pest species. Since Burdekin trials began in 2007 this pest has been largely absent but its relative the red bean spider mite *Tetrancychus ludeni* has been frequently observed at very low levels in a single or series of hot spots within a crop where the leaves may redden or yellow. In the case of *T. ludeni* the mites are readily visible to the naked eye on the undersides of affected leaves. This species is unlikely to cause economic damage to cotton crops and mites generally are not likely to be a common pest in the Burdekin climate. A wide range of beneficial insects and predatory mite species will attack spider mites.

Detailed sampling strategies, economic thresholds and recommended control options for mites are published annually in the Cotton Pest Management Guide.

Two spotted mite (left) and bean mite (right) in cotton. Bean mite is more common in the Burdekin. Photos Lewis Wilson, CSIRO.

Cotton harlequin bug (*Tectocoris diophthalmus*)

This large brightly coloured pest is often observed in very low densities on field margins in Burdekin cotton crops. Female harlequin bugs characteristically lay their egg rafts on a stem or petiole of the outer canopy and ‘guard’ them until hatching. This pest is unlikely to ever reach economically damaging levels in commercial scale fields due to their slow reproductive rate.

A female cotton harlequin bug guarding an egg raft in cotton. Photo by Jim Wark, Cotton CRC.

Pale cotton stainer (*Dysdercus sidae*)

Pale cotton stainers are an infrequent pest of cotton but were observed in considerable numbers late season in 2009. Similar to mirids, adults migrate into crops and breed. Stainers feed on bolls and cause abortion of the developing seed and potential entry point in the boll wall for boll rot. Unlike green vegetable bugs and green mirids this pest will feed on bolls of all ages, even those close to maturity. Damage to older bolls may introduce diseases that affect lint colour and boll opening, and may reduce seed germination. Thresholds for this infrequent pest are currently under development.

Cotton stainer nymph (top) and adult (bottom). Photos by Lewis Wilson, CSIRO.

Appendix 5. Potential diseases of tropical cotton

Seedling diseases

Possible causes of seedling disease include *Rhizoctonia solani* (AG4), *Pythium* spp., *Fusarium* spp., and anthracnose caused by *Colletotrichum* sp. Only *Colletotrichum* sp. has been recorded on cotton in northern Australia. None of these pathogens are likely to affect seedling cotton in the Burdekin due to very warm conditions during the planting window.

Symptoms

- Seed decay.
- Seedling death before emergence.
- Stunted and chlorotic seedling.

Control

- Use seed treated with recommended fungicides.
- Farm hygiene (destroy all residues and volunteers from previous cotton crops).
- Use resistant varieties if available.

Stem and root diseases

No major diseases of roots and stems have been reported in northern Australia. However, diseases with the potential to cause yield loss include:

Fusarium wilt

Fusarium wilt caused by *Fusarium oxysporum* f.sp. *vasinfectum* (Fov) is an important disease of cotton crops in eastern Australia. Once established in a field it is virtually impossible to eradicate. No incidence of fusarium wilt has been reported in northern Australian cotton.

Symptoms

- Dull or wilting leaves.
- Plants may die from the top down.
- Plants become stunted.

Control

Importation of fuzzy seed from southern regions poses a significant threat for the introduction and spread of Fov in northern Australia.

- Keep farms free of Fov. Follow the 'Come Clean – Go Clean' principles when shifting vehicles and equipment on and off farm. Particular caution should be exercised where picking contractors are utilised from southern regions.
- Use fungicide and Bion® treated seed for planting.
- Use resistant cultivars (e.g. varieties with a higher F-rank - see CSD website for details).

Verticillium wilt

Verticillium wilt caused by *Verticullium dahliae* is another important disease of cotton not confirmed in northern Australian cotton. This disease is more prevalent in cooler temperate regions and is only likely to present problems during the cooler months of May and June by which time most Burdekin cotton crops are nearing maturity and therefore have reduced susceptibility.

Symptoms

- Young plants remain stunted.
- Leaves become mottled, yellowing between the veins and leaf margins.
- Plants may die, or remain stunted as they recover during warmer weather.
- Vascular browning discolouration occurs and may be evident in stems and petioles.
- Plants may defoliate during cold weather.

Control

Verticillium wilt is augmented by excessive use of nitrogen and/or a potassium deficiency, so balanced use of fertiliser is important to manage this disease.

- Practice good farm hygiene (Come Clean – Go Clean).
- Use resistant cotton cultivars (e.g. varieties with a higher V-rank - see CSD website for details).
- Rotate cotton with non-host crops, such as grains or sugarcane.

Charcoal rot

Charcoal rot caused by *Macrophomina phaseolina* is a common disease of cotton, particularly in tropical areas. The disease has been recorded on cotton in Katherine and the ORIA, but is considered to be of minor consequence.

Symptoms

- Wilting of plants followed by chlorosis and death.
- Grey or ashy lesions may be seen on the stem when broken.
- Small black specks (sclerotia) can be seen on the affected area.

Control

- Use treated seed for planting.
- Avoid seeding during very high temperatures.
- Avoid inter-row cultivating if subsequent waterlogging is likely.

Foliar diseases

Tropical cotton rust

Tropical cotton rust caused by *Phakopsora gossypii* was first reported in Darwin, the Northern Territory, in 1973 and is common on naturalised cotton at Mataranka, Darwin and Katherine. No tropical cotton rust has been reported on cultivated cotton in northern Australia, but it could be a future threat.

Symptoms

- Small (1-3 mm) pustules develop on the underside of leaves. The pustules may be pink-brown or yellow-brown and may become whitish or ashy with a powdery centre.
- Numerous small spots develop on older leaves.
- Spots are purple with a red brown centre on the upper side of the leaf and brown and powdery underneath.
- Infection appears more severe during the drier months of the year.

Bacterial blight or angular leaf spot

Bacterial blight caused by *Xanthomonas axonopis* pv *malvacearum* was reported on cotton in Northern Australia during the 1960s but has not been reported during more recent research phases during the 1990s and 2000s. Resistant varieties may explain the more recent absence of this disease.

Symptoms

- Symptoms may be observed on leaves, bolls, bracts or stems as water-soaked, dark green angular spots on the leaves.
- Small round water-soaked spots may become brown to black on the bolls and bracts.

Control

- Use treated seed at planting.
- Grow resistant varieties (all current varieties are resistant to this disease).
- Destroy previous cotton crop residues.
- Practice good on-farm hygiene.

Cotton Bunchy Top (CBT)

Viral disease of cotton spread by cotton aphid (*Aphis gossypii*) that reduces the yield of affected plants. Severity of disease impact is relative to the crop stage that infection occurs.

Symptoms

- Infected plants are stunted with small leaves, short internodes and petioles and small fruit.
- Some leaves on infected plant will show characteristic 'mottling' symptoms (see below).

Control

- Use treated seed at planting.
- Destroy previous cotton crop residues, especially cotton volunteers and ratoons.
- Monitor aphid populations, examine plants in aphid infested areas for signs of CBT disease and control aphids if necessary.

CBT symptoms: stunted plants (top) and leaf mottling (bottom). Photos by Cherie Gambley, DAFF.

Appendix 6. Planting date and climate interaction research summary

Experiments were conducted at the Ayr Research Station from 2007 to 2012. The site had an alluvial silty maidavaile soil to a depth of 600-700 mm overlaying fine sand. Cotton was sown at either early December, late December, or early January (see Table 1 for actual dates). The variation in sowing times was to gain a more comprehensive spread of measurements for crop response to monsoon conditions (e.g. various growth stages would be exposed to monsoon weather simultaneously).

'Upland' *G hirsutum* L. cultivars were sown during the study (Table 2). The varieties were chosen to represent a range of growth habit, leaf shape and maturity profiles when grown in temperate regions:

- Sicala 60BRF – medium height and maturity, normal leaf shape, large bolls.
- Sicot 70BRF - medium height and maturity, normal leaf, smaller bolls.
- Siokra 24BRF - tall, indeterminate mid to late maturing, okra leaf, large bolls.
- Sicot 80BRF/Sicot 74BRF - indeterminate late maturing, normal leaf, medium bolls.

(Sicot 80BRF was superseded and replaced by Sicot 74BRF after season 1).

A plant population of 5-6 plants per metre row was established on 76 cm spaced rows (6.6-8 plants/m^2) each season, using a configuration of 2 rows per bed with irrigation furrows between beds. Furrow irrigation was used for seasons 1 to 3 and trickle tape irrigation was used for seasons 4 and 5.

Seed cotton was machine harvested with a spindle picker from each experiment plot.

Table 1. Sowing dates for the 5 years of the study.

Season 1	Season 2	Season 3	Season 4	Season 5
3 Dec 2007	1 Dec 2008	1 Dec 2009	-	-
19 Dec 2007	18 Dec 2008	19 Dec 2009	18 Dec 2010	20 Dec 2011
7 Jan 2008	7 Jan 2009	7 Jan 2010	7 Jan 2011	7 Jan 2012

Table 2. Varieties planted at each sowing date for the 5 years of the study.

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

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 rainfall totals for the January–February period exceeded all prior records since 1951. 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 exceeded all previous totals since 1951 (Figure 1A).

Solar radiation levels deviated considerably from the long term average during the five seasons. Seasons 1 and 2 had low radiation levels during January and February associated with wet weather. However March and April (autumn) were sunny with above average radiation. Radiation levels for season 3 were generally below the mean by 10-20% for the period spanning January to April whilst season 4 was sunny conditions during January and February but cloudy for March. Season 5 was unique with radiation levels close to the long term mean for each month except March which was characterised by very cloudy wet weather resulting in the lowest monthly measurement of radiation recorded during the entire 5 study period for December–May (Figure 1B).

Maximum temperatures were close to the long term mean for each season, particularly for the period of March to June which coincided with the setting and filling of bolls. The exception was cooler than average conditions in January and February during season 2 which again reflected high rainfall and cloudy conditions at the time. Minimum temperatures were significantly below the mean for seasons 3 and 4 during the period from April to June (Figure 1C). The number of nights that recorded minima <12°C were significantly higher during season 4 (32) compared with seasons 1 (10), 2 (12), and 3 (15).

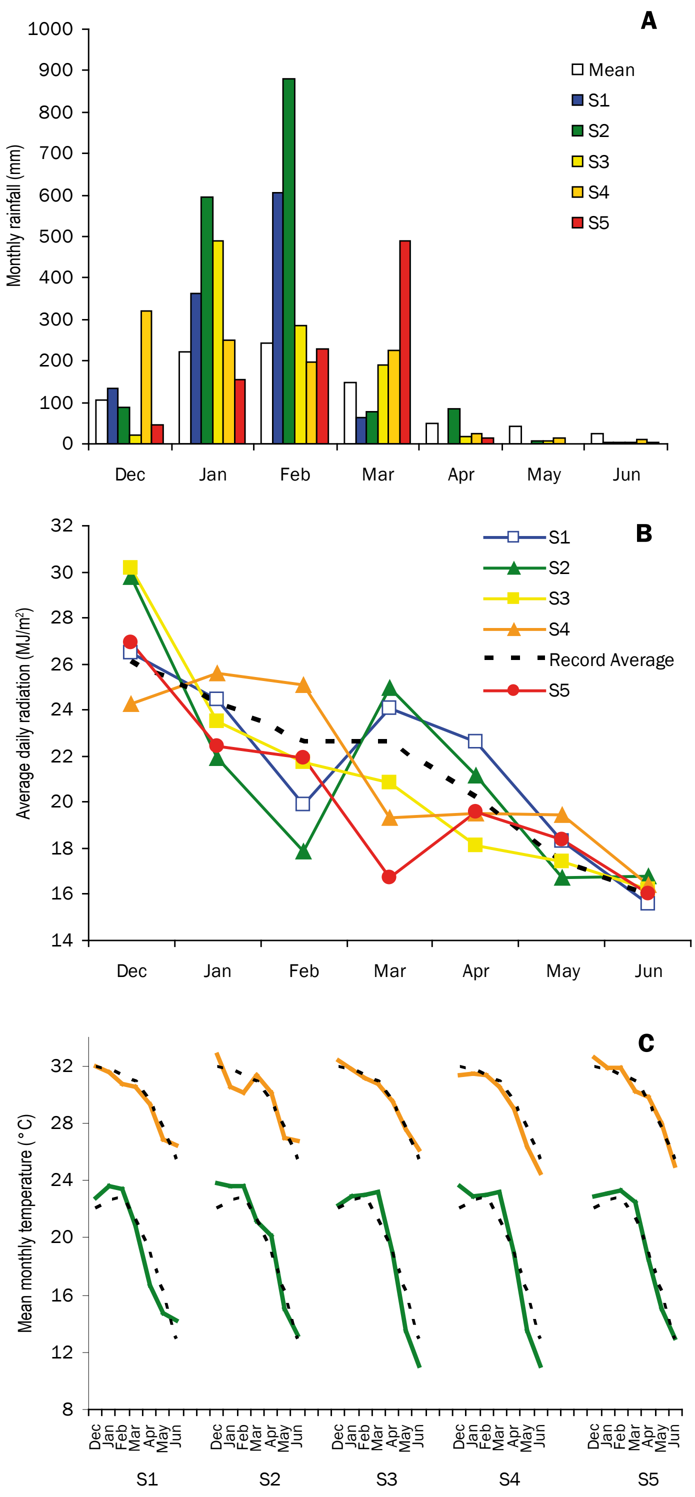


Figure 1. Climatic records for the five seasons: (A) monthly rainfall, (B) average daily solar radiation, and (C) average monthly maximum and minimum temperature for each month of crop growth, and the long term mean (dotted line).

Lint yields

Machine-picked yields ranged from 5.43 to 12.77 bales/ha during the first 4 seasons (season 5 was incomplete at time of writing), depending on cultivar and time of sowing. A comparison of mean lint yields (all cultivars combined) showed that the sowings on 19 December and 7 January in the season 1 and 7 January in season 2 had high lint production (Figure 2). The remaining planting seasons had lint yields that were significantly lower (Figure 2).

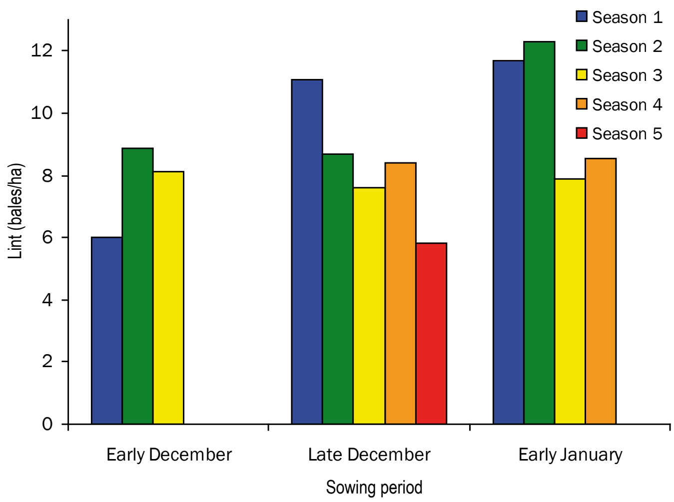


Figure 2. Lint yield for each production season and sowing date presented as a mean for all cultivars. High yields for the January sowings co-incided with sunny conditions throughout autumn.

Differences in observed in yield can be attributed to climatic limitations after the commencement of flowering. The high yield plantings of seasons 1 and 2 occurred where sunny conditions returned soon after the commencement of flowering. For seasons 3-5 all plantings were subject to periods of cloudy weather during flowering reducing overall yield potential. Conditions in March are particularly important for yield potential for cotton planted between December 20 and January 20. Although incomplete at the time of writing crop response measurements during season 5 continue to support this premise. Season 5 had average radiation levels throughout December to May with the exception of March which was very cloudy and wet. This weather significantly reduced the yield of the December sowing (Figure 2) and the potential yield for the January sowing (estimated from plant biomass sampling to be in the vicinity of 6.5-7.5 bales/ha as field was yet to be picked as this guide went to print) again suggesting reduced yield potential from cloudy weather in March.

Yield components

A key finding from the climate study was the influence of cloudy weather on crop canopy yield partitioning. The contribution of lower fruiting branches to overall yield was reduced when the commencement of flowering coincided with extended wet weather and cloudy conditions. This was due to shedding and reduced boll size. If flowering commenced during sunny conditions, yield (number and size of bolls) were partitioned more evenly throughout the canopy. The contribution of fruiting sites on the upper and outer canopy bolls is therefore critical when lower bolls have been lost due to monsoon conditions during early flowering. Therefore, management tactics must be geared towards encouraging rapid compensation after periods of cloudy weather.

Early January sowing provided significant yield advantages in seasons 1 & 2 and no disadvantage in seasons 3 & 4 whilst biomass data (still incomplete at writing) indicate a potential advantage for season 5. This was generally due to the onset of flowering for this sowing period occurring in very late February or early March (depending on lower branch shedding), which better coincides with the likely decline of the summer monsoon season (Figure 3).

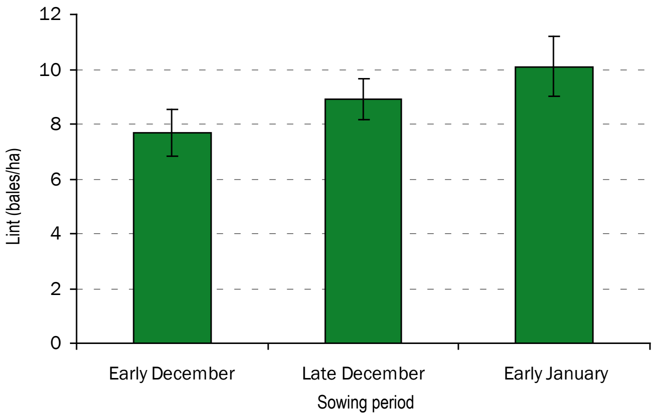


Figure 3. Lint yield presented as an overall mean of seasons and varieties from 2008–2011. January sowing has achieved the highest aggregate yield for this period.

The data gathered between 2008 and 2012 (Figures 2 & 3) as well as commercial crop yield data (Figure 4) suggest that that 7-8 bales per hectare is attainable for seasons with periods of cloudy weather in March and April (e.g. 2010, 2011 & 2012) on coarse textured soils and January sowing. The high yields recorded during 2008 and 2009 (Figure 4) are very difficult to achieve when autumn is characterised by below average radiation, a limitation that supplants most other field factors. Crop management tactics (advocated throughout NORpak) that capitalise on the cotton plants' ability for compensation when periods of sunny weather occur is critically important to maximising yield in cloudy years.

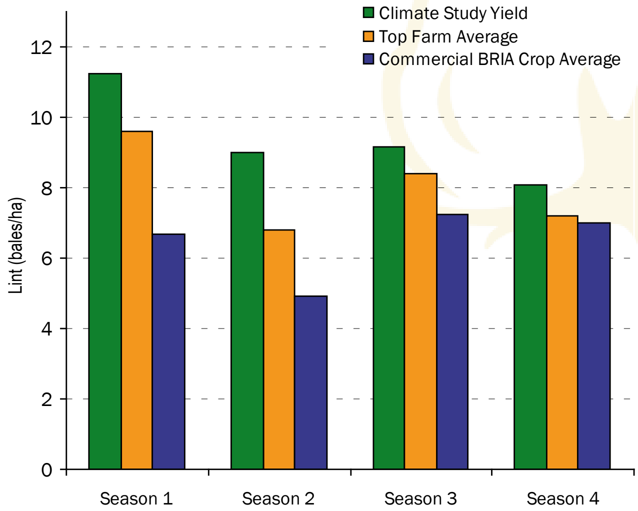


Figure 4 Yields from the climate experiment, top commercial farm average and Burdekin valley average (all farms) for 2008-2011. The yield presented from the climate study is the aggregate yield across cultivars for the planting date that represents the window in which the majority of the commercial crops were sown (e.g. all commercial crops in 2008 and 2009 were sown between 20-30 December hence the yield from the December 20 plantings in seasons 1 & 2 are used for comparison).

19 December (top) and 7 January (bottom) sown cotton from season 1. Flowering of the December-sown cotton coincided with 2-3 weeks of cloudy wet weather. These plants shed bottom bolls and grew a compensatory top crop. The January-sown cotton had sunny conditions from first flower, so retained bottom fruit and is consequently shorter in height. Despite appearances, the final yields for these two plantings were very similar (11.4-11.7 bales/ha).

Appendix 7. Trimming research summary

Several replicated experiments were conducted between 2009 and 2011 to investigate whether pruning the terminal sections from vegetative 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 350-400 DDA or 17-21 days under Burdekin conditions. 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 and that the response was the same between 7 nodes and 15-16 nodes (first flower). Despite the delay in flowering, crop trimming was found to not affect final crop maturity.

Trimming greater than 3-4 nodes from the plants was not detrimental to subsequent regrowth, but significantly delayed final crop maturity in some cases (Table 1).

Experiments were conducted at the Ayr Research Station (2009 and 2010) and commercial cotton fields near the township of Clare (2001). The Clare site had a river levee sandy soil and the cotton was sown on one metre spaced hills.

Trimming was conducted in the plots for all experiments utilising a petrol-driven hedge trimmer with a 500 mm cutter bar mounted on a mobile steel frame with wheels. This frame allowed trimming height to be accurately set and controlled, providing a neat cut.

Results for flowering, maturity and yield for each experiment are given below.

Table 1. Trimming results from 2009 trimming experiment (sown 4 December 2008).

Growth Stage	Severity of trimming	DAS to flowering	DAS to 80% open bolls	Bales per hectare *
Control	No trimming	44	165	9.2a
7 Nodes	Trim off 3 nodes from top	61	164	9.3a
7 Nodes	Trim off all nodes leaving only cotyledons	62	163	7.5b
11 Nodes	Trim off 3 nodes from top	61	164	9.4a
11 Nodes	Trim off all nodes to the first fruiting branch (remove 5-6 nodes)	64	163	9.5a
First Flower (16 Nodes)	Trim off 3 nodes from top	65	163	9.7a
First Flower (16 Nodes)	Trim off nodes leaving 3-4 fruiting branches from top (remove 5-6 nodes)	67	168	9.3a
First Flower (16 Nodes)	Trim off all nodes down to the first fruiting branch (remove 5-6 nodes)	72	177	9.4a

Table 2. Trimming results from 2010 trimming experiments (sown 20 December 2009).

Experiment	Growth stage when trimmed	Severity of trimming	DAS to flowering	DAS to 80% open bolls	Bales per hectare (kg)*
Siokra 24BRF	7 Nodes	Trim off 3 nodes from top	62	151	8.1 a
	11 Nodes	Trim off 3 nodes from top	61	151	8.4 a
	First Flower (16 Nodes)	Trim off 3 nodes from top	65	154	7.9 a
	Control	No trimming	44	151	8.2 a
Sicala 60BRF	7 Nodes	Trim off 3 nodes from top	63	147	8.4 a
	11 Nodes	Trim off 3 nodes from top	62	147	8.6 a
	First Flower (16 Nodes)	Trim off 3 nodes from top	66	151	8.6 a
	Control	No trimming	46	147	8.4 a

Table 3. Trimming results from 2011 trimming experiments (sown 14 January 2011).

Experiment	Growth stage when trimmed	Severity of trimming	DAS to flowering	DAS to 80% open bolls	Bales per hectare (kg)*
Siokra 24BRF	7 Nodes	Trim off 3 nodes from top	63	177	8.3 a
	11 Nodes	Trim off 3 nodes from top	62	177	8.7 a
	First Flower (16 Nodes)	Trim off 3 nodes from top	65	177	8.7 a
	Control	No trimming	43	172	9.8 b
Sicot 74BRF	7 Nodes	Trim off 3 nodes from top	64	182	8.3 a
	11 Nodes	Trim off 3 nodes from top	64	182	8.5 a
	First Flower (16 Nodes)	Trim off 3 nodes from top	66	184	8.9 a
	Control	No trimming	45	177	9.1 a

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

Appendix 8. Calculating daily crop water use using potential evaporation and crop factor

The irrigation water required is the sum of the calculated evapotranspiration using an evaporation pan or calculated from daily weather data. For more detail on this method of calculation or alternative methods see WATERpak.

Measured by evaporation pan:

Daily water use = PE*CFpan

PE = daily pan evaporation

CFpan = pan crop factor

Calculated evapotranspiration:

Daily water use = ETo*CF

ETo = daily potential evapotranspiration calculated from daily weather data or downloaded from a weather station or from a web site e.g. Bureau of Meteorology.

CF = evapotranspiration crop factor

Time of growth stages and crop factors for Burdekin cotton

Growth stage	Days	CFpan	CF
Sowing to 7 nodes	27	0.3	0.4
7 nodes to 1st flower	18	0.53	0.7
1st flower to cut out fruit retention <60%	50-60	0.75	1.0
1st flower to cut out fruit retention >60%	32-45	0.83	1.1
Cut-out to max. bolls	15-20	0.75	1.0
> max. bolls	25-30	0.53	0.7

Appendix 9. MC experiments 2010/2011

Replicated experiments were established to compare increasing dosages of MC (pix) on cotton growth and yield potential during 2010 and 2011 season. The experiments were conducted on Sicala 60BRF, Siokra 24BRF, Sicot 74BRF and Sicot 71BRF.

MC was applied to each treatment at approximately 2 week intervals which coincided with development nodes 5, 10, 15, 20 and 25. Doses of 200, 400 and 800 ml/ha were used singularly or in repeated dosages to arrive at the total applied dosages ranging from no MC to 2800 ml/ha (see tables). The MC treatments were applied with a calibrated boom equipped with 4 x 02 flat fan air-inducted nozzles that delivered 80L/ha spray volume.

Measurements were taken of total crop height, number of nodes and nodes above white flower at weekly intervals until flowers reached 2-3 nodes from the terminal. Weekly hand picking was conducted to determine crop maturity for each treatment within each experiment. Segmented hand picking was used to determine within canopy yield partitioning of different treatments just prior to machine picking. Sub-samples of seed cotton were taken from the machine-picked lint to determine lint turnout and fibre quality parameters.

Results

Final crop height was significantly reduced with increasing dosages of MC across all varieties and experiments. The total number of nodes had a marginally declining response with increasing dosages of MC tested.

Crop yield and lint turnout (%) was virtually non-responsive to MC over the treatment range used in 2010 whereas yield and turnout declined significantly with increasing doses of MC, particularly for Sicot 71BRF and Sicot 74BRF in 2011.

Time to crop maturity increased marginally with increasing dosages of MC, although in a practical sense treatment differences were within 7 days. There was no evidence for MC decreasing the time until crop maturity.

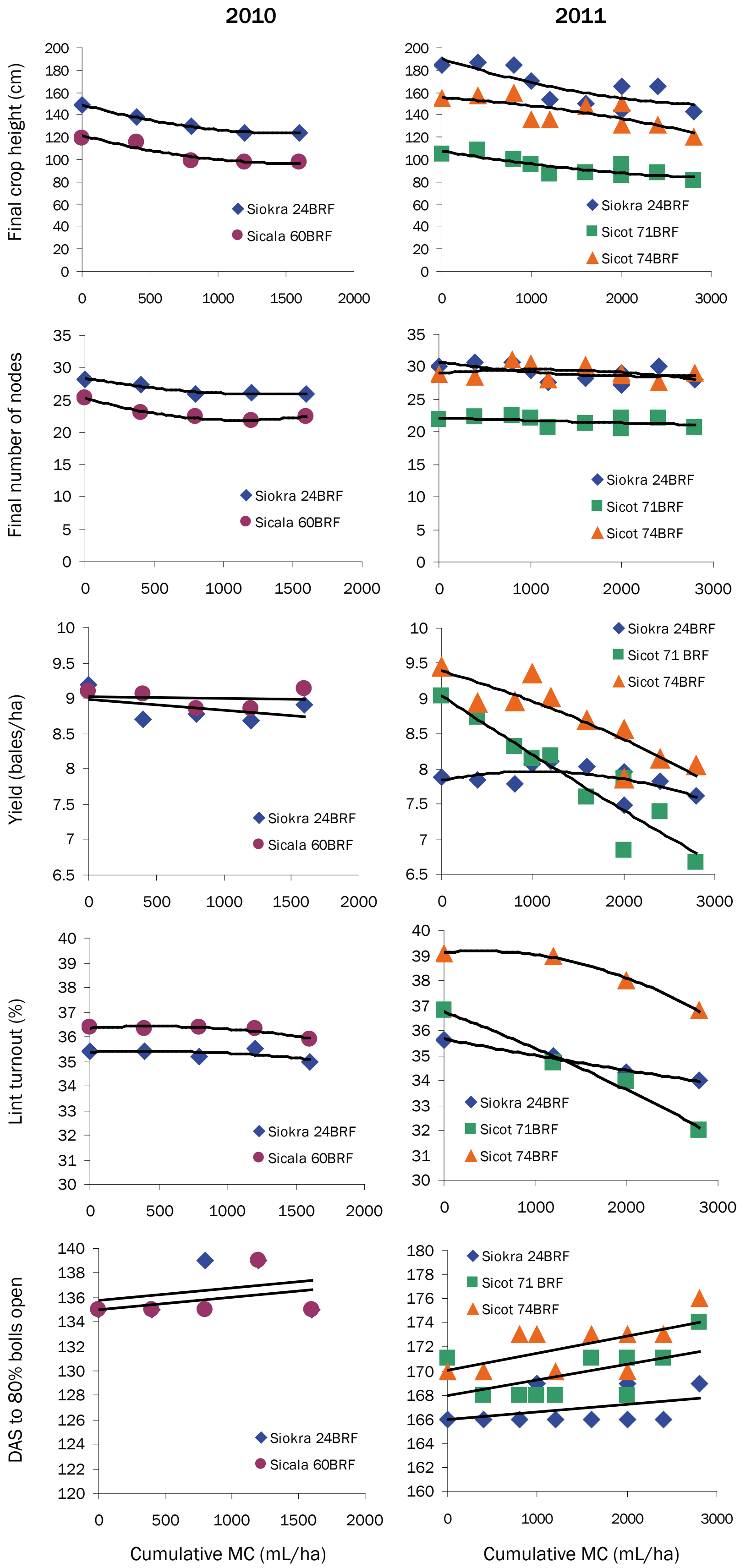
Segmented picking results suggest that the reduction in yield observed in the 2011 experiments was due to a reduction in fruiting sites and changes to boll partitioning within the crop canopy at the higher dosages. These reductions are evident visually in the photo on page 88, which shows a control plot beside a 2800 mL treatment plot for Sicot 71BRF.

Treatment structure applied to Sicala 60BRF and Siokra 24BRF 2010.

Treatment	Nodes 5-6	Nodes 9-10	Nodes 14-15 (FF)	Nodes 19-20	Total applied (mL/ha)
1	0	0	0	0	0
2	400	0	0	0	400
3	400	400	0	0	800
4	400	400	400	0	1200
5	400	400	400	400	1600

Treatment structure applied to Siokra 24BRF, Sicot 74BRF and Sicot 71BRF 2011.

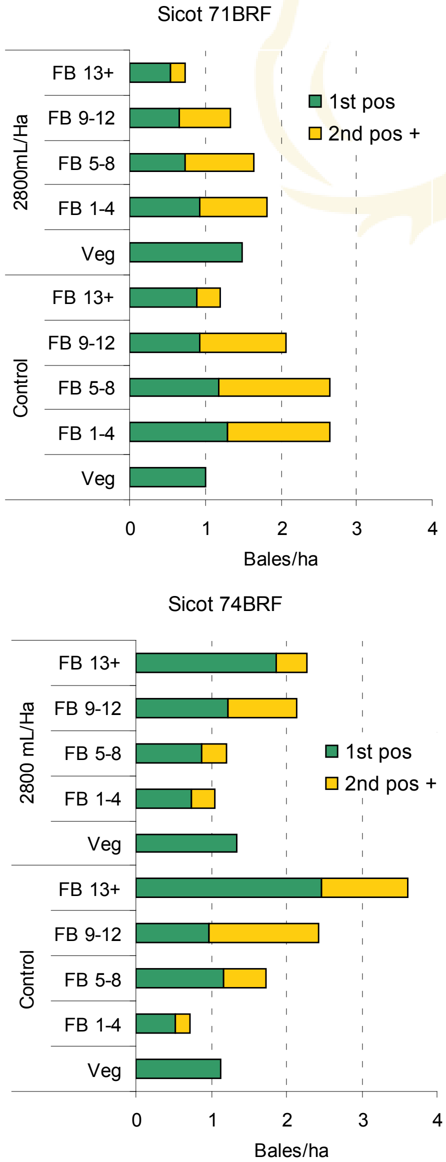
Treatment	Node 5	Node 10	Node 15	Node 20	Node 25	Total applied (mL/ha)
1	0	0	0	0	0	0
2	400	0	0	0	0	400
3	400	400	0	0	0	800
4	400	400	400	0	0	1200
5	400	400	400	400	400	2000
6	200	200	200	200	200	1000
7	800	800	0	0	0	1600
8	0	800	800	400	400	2400
9	800	800	400	0	0	2000
10	400	800	800	400	400	2800



Response to to increasing quantities of applied MC:

Left: **Sicala 60BRF and Siokra 24BRF (2010)**
Right: **Siokra 24BRF, Sicot 71BRF and Sicot 74BRF (2011)**

- **(a) final crop height (cm)**
- **(b) final number of crop nodes**
- **(c) crop yield (bales/ha)**
- **(d) lint turnout (%)**
- **(e) total days from planting until 80% of bolls are open.**



Segmented picking results for the control and 2800 mL/ha MC treatment for Sicot 71BRF and Sicot 74BRF in 2011.

Control plot Sicot 71BRF (left) and highest MC rate treatment (2800 mL/ha) (right). The reduction in crop size (biomass) and boll numbers is clearly evident and reflects yield and segmented picking results.

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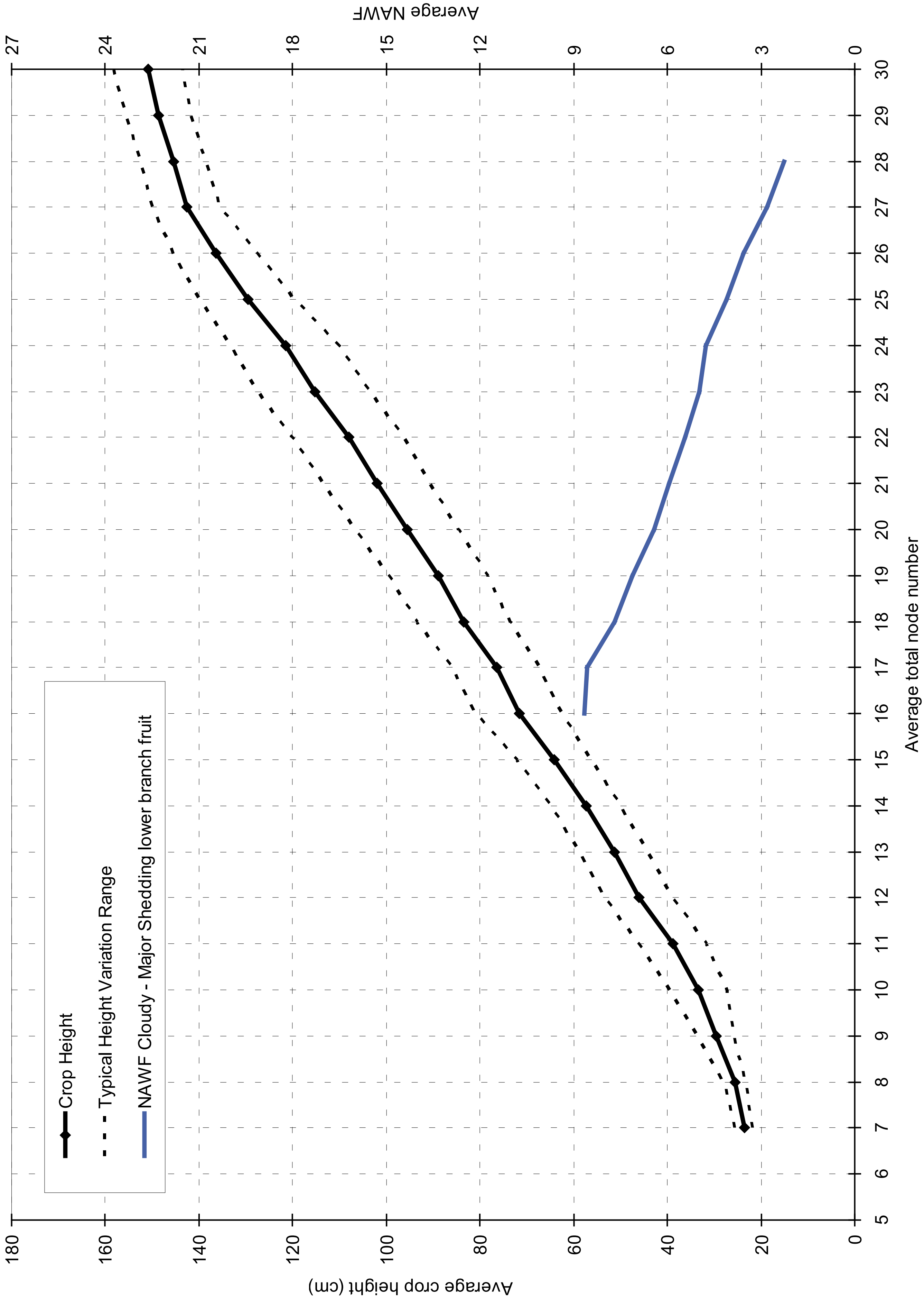
BGM for MAJOR shedding of lower branch fruit



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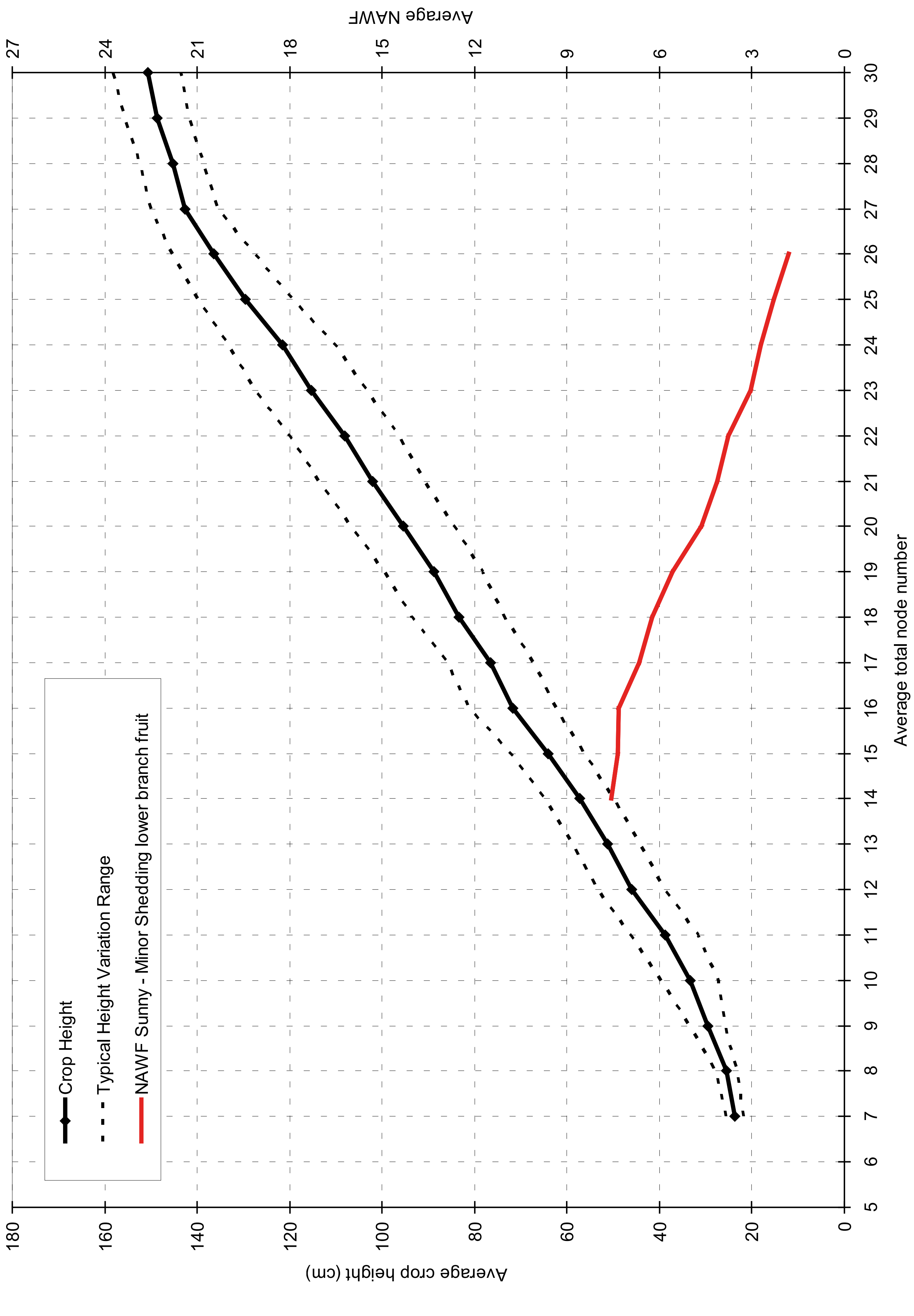

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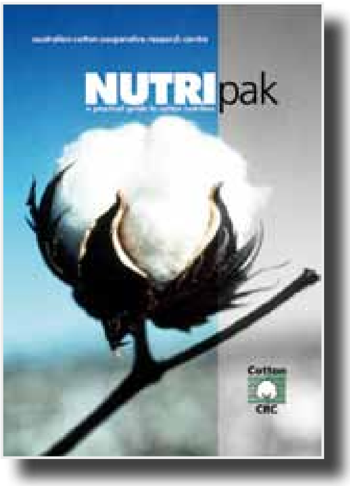

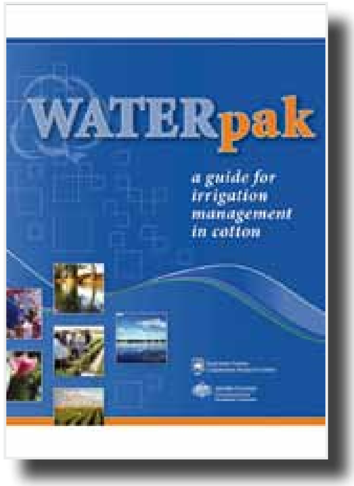

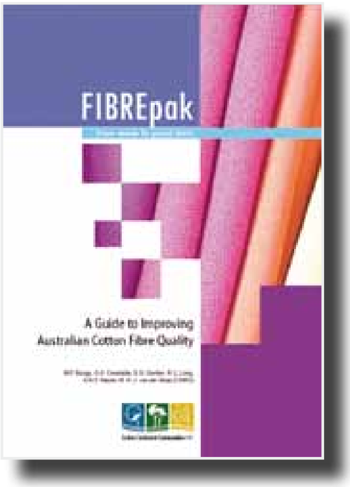

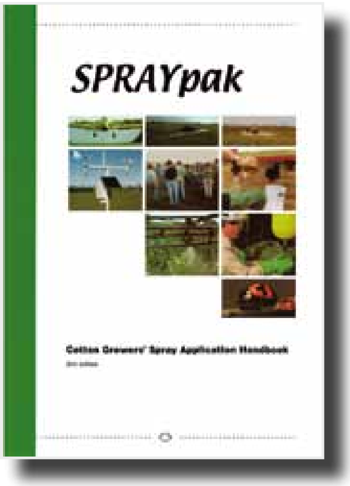

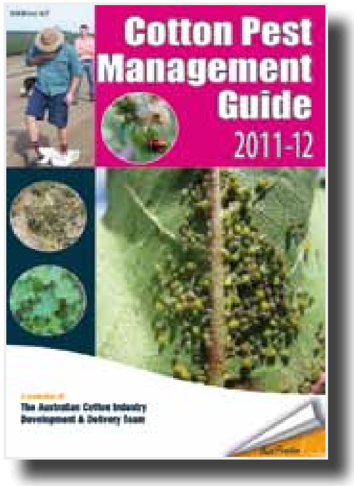

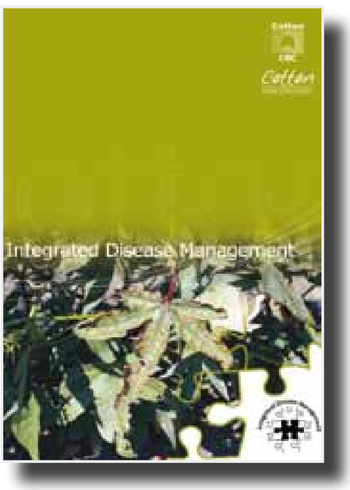

NORpak

This book has been written for those who would like to know more about growing cotton in the Burdekin. It has drawn on local knowledge and experience, much of it hard won by pioneering growers who have been testing new generation transgenic cotton since 2004, and provides agronomic advice derived from an ongoing research program focussed on aspects that set the Burdekin apart from other cotton production regions in Australia.

Cotton has the potential to be a high value crop rotation option for sugarcane. It is an exciting, but challenging crop to grow and this book highlights the things to consider before attempting Burdekin cotton production and details crop management tactics to increase the likelihood of success.