# Australian Cotton Production Manual

## 2022

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# Foreword

By **Annabel Twine** (CottonInfo) &
**Brad Pfeffer** (CottonInfo)

Welcome to the 2022 *Australian Cotton Production Manual*. This manual is a key reference tool for best management practices in cotton, and is brought to you by the organisations responsible for cotton industry research, development and extension (RD&E): the Cotton Research and Development Corporation (CRDC) and CottonInfo.

CRDC invests in RD&E projects for the Australian cotton industry. A partnership between the Australian cotton industry and the Australian Government, CRDC exists to enhance the industry's performance.

CottonInfo is an initiative of industry partners CRDC, Cotton Australia, and Cotton Seed Distributors Ltd. CottonInfo is designed to connect you – cotton growers and consultants – with research, and provide you with information, where and when you need it. The CottonInfo team takes the research and development invested in by CRDC and turns it into practice information and knowledge, applicable to you and your farm.

CottonInfo integrates closely with the industry's best management practices program, *my*BMP, supported by Cotton Australia and CRDC. The *my*BMP program sets the industry's best practice performance criteria and provides a framework by which growers can participate in, and be accredited in, best practice.

This manual and its sister publication, the *Cotton Pest Management Guide,* are two of the key ways that CRDC and CottonInfo provide the latest in cotton industry RD&E to you each year.

The manual is developed by a team of industry researchers and experts, bringing you the latest information to help you make on-the-ground decisions for your crop and your farm.

The manual contains four sections, focused around the considerations and decisions that growers are faced with across the cotton growing season:

- **Planning:** The planning section of the manual covers the key considerations for growers – starting with the ideal climate for cotton growing, the availability of water and the resulting farming system of irrigated, semi-irrigated or dryland cotton. The section then looks at the other key determinants for cotton in the planning phase: the selection and preparation of fields; choosing the right variety; planning for nutrition and energy use efficiency; and laying the foundations for year-round integrated pest, weed and disease management.
- **In-season:** The in-season section of the manual focuses on the areas of particular relevance for growers once the crop is in the ground. Crop establishment, crop growth, efficient spray application and managing the crop for yield and fibre quality are the key chapters in this section, along with irrigation management, which showcases the new technologies in development or already in the field.
- **Harvest and post-harvest:** The harvest and post-harvest section of the manual looks at cotton during its final on-farm stage. This section includes chapters on preparing for harvest and harvest itself, including managing considerations relating to quality, and managing cotton stubble and residues post-harvest. It also looks at the off-farm process of ginning and classing, providing a beyond the farm gate perspective.
- **Business:** The business of cotton is complex. This section looks at the business components of cotton production including economics, marketing, finance, insurance, and the safety and management of the industry's human resources.

The manual is designed to help you increase your input efficiencies and improve your yield; help the industry proactively manage issues that affect all of us; and ensure our cotton remains of very high quality.

On behalf of the CRDC and CottonInfo teams, we hope you find this year's *Australian Cotton Production Manual* a valuable and informative reference.

Remember, the CottonInfo team of regional extension officers, technical leads and *my*BMP experts are standing by to assist you with all your cotton information needs. You can find our contact details at www.cottoninfo.com.au/contact-us.

You can also find further information on the topics covered in this manual (and the sister publication the *Cotton Pest Management Guide*) at the CottonInfo website (www.cottoninfo.com.au), and specific best practice information for your farm at the *my*BMP website (www.mybmp.com.au). You can find information on all of CRDC's investments online at the CRDC website (www.crdc.com.au).

Finally, on behalf of CRDC and CottonInfo, thank you to the team of authors, reviewers and contributors from across the cotton research community and wider industry for their invaluable assistance with this publication.

CRDC Cotton Research and Development Corporation | CottonInfo | *my*BMP


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# PLAN FOR GROWTH

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# The Australian cotton industry

By **Brad Pfeffer** (CottonInfo)

**Acknowledgements Dr Michael Bange (Cotton Seed Distributors) and Ruth Redfern (CRDC)**

Cotton is the most used textile fibre in the world, renowned for its versatility, breathability and strength. It has been grown throughout the world for thousands of years, with about 70 other countries currently growing cotton. It was first brought to Australia with the First Fleet in 1788. However, it was in the 1960s that Australian's modern cotton industry began to develop, largely in the Namoi Valley of NSW.

From small beginnings, Australia's cotton industry is now a valuable agricultural export commodity. Cotton is currently the major agricultural crop grown in many rural and remote regions of Queensland (Qld) and New South Wales (NSW). In recent years, the industry has expanded into northern Victoria (VIC), Western Australia and the Northern Territory.

Australian cotton aims to be the highest yielding, finest, cleanest and greenest cotton in the world. Globally, Australia is not a large cotton producer – only around 3% of the global crop is grown within Australia, by about 900 cotton growers on up to 1500 farms.

Australia is one of the largest exporters of cotton, with nearly 100% of the national crop exported, generating an average of $1.9 billion in export revenue annually. The majority of Australian cotton goes into high quality yarns for use in the woven and knitted apparel sector in the Asia Pacific. The industry continues to develop export relationships with new and emerging markets.

The industry generates significant wealth and provides an economic foundation to many regional and remote rural economies, employing more than 12,000 people across 152 communities.

A culture of innovation within the industry, supported by and embracing a well-organised research, development and extension (RD&E) framework, has been a major contributor to the industry's success. Improved practices driven by RD&E have reduced insecticide use by more than 97% and improved water-use efficiency by 48%.

The best cotton producers now achieve more than two bales of cotton per megalitre (ML) of water – almost double the industry average of just a decade ago. The industry is at the forefront of environmental management systems, and climate variability mitigation and adaptation.



The cotton industry continues to change practices to meet societal expectations. The introduction of the industry's best management practice program *my*BMP, the uptake of biotechnology to help reduce pesticide use, and the implementation of the industry's environmental assessment and resulting actions, are all examples of the cotton industry recognising the need for change, and working with the RD&E system to enact it.

In recent years, new cotton varieties, new farming technologies, and favourable weather and market conditions have facilitated an expansion in southern NSW cotton-growing regions, reaching as far south as northern Victoria. The industry is also developing cotton production practices for northern Australia, with the continuing expansion of both growing areas and support infrastructure.

## Growing cotton through best management practices

The Australian cotton industry has invested heavily in its best management practices program, *my*BMP. Vast amounts of industry experience and research underpin *my*BMP – from growers, researchers and industry bodies – making it a key online tool for growers in achieving best practice in growing cotton.

*my*BMP provides all cotton growers with a centralised location to access the industry's best practice standards, which are fully supported by scientific knowledge, resources and technical support. It provides growers with tools to:

- Improve on-farm production performance.
- Manage business risk.
- Maximise market advantages.
- Demonstrate sustainable natural resource management to the wider community.

**For more, visit the *my*BMP website: www.myBMP.com.au. Growers must register to access best management information. Tip – once registered, you can watch virtual tours of all the *my*BMP features from the Grower homepage. If at any time you have questions, or require support, call 1800cotton (1800 268 866) for phone support and training.**

***my*BMP is proudly supported by Cotton Australia and the Cotton Research and Development Corporation (CRDC).**

## Connecting growers with research

Australian cotton growers have been quick to embrace RD&E, with many of the industry's major achievements in water use efficiency and pesticide use reduction resulting from the application of research findings on farm.

Ensuring growers know about the research outcomes and information is the role of CottonInfo, a joint program delivered by cotton industry bodies Cotton Australia, the Cotton Research and Development Corporation and Cotton Seed Distributors.

CottonInfo is designed to help growers to improve their productivity and profitability via best practice (working with *my*BMP), and helping the industry become more responsive to emerging, or emergency, issues. The CottonInfo team of regional extension officers, technical leads and *my*BMP experts can provide you with the latest information, driven by research, on a range of cotton topics.

**www.cottoninfo.com.au**

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# Industry bodies and CottonInfo partners

## Cotton Australia: advocating for Australian cotton

Cotton Australia is the peak representative body for the Australian cotton growing industry. It determines and drives the industry's strategic direction, with a strong focus on R&D, promoting the value of the industry, reporting on its environmental credibility, and implementing policy objectives in consultation with its stakeholders.

Cotton Australia helps the Australian cotton industry to be world competitive, sustainable and valued by the community. It has roles in policy and grower representation, best management practices (through the delivery of the *my*BMP program), promotion and education, and biosecurity.

One of Cotton Australia's key roles is advocacy, helping to reduce the regulatory burden on growers and advance their interests at all levels. The organisation advocates extensively on a wide range of legislative and regulatory issues confronting growers and has a team of dedicated regional staff, providing support and advice to growers on the ground.

Cotton Australia also plays an important role in providing grower feedback on research priorities, and advocating for greater funding for rural R&D. Cotton Australia provides ongoing advice to the CRDC on research projects and where research dollars should be invested.

**www.cottonaustralia.com.au**

## CRDC: science underpinning the cotton industry's success

The Cotton Research and Development Corporation (CRDC) delivers outcomes in cotton research, development and extension (RD&E) for the Australian cotton industry. A partnership between the Commonwealth Government and the Australian cotton industry, CRDC exists to enhance the performance of the cotton industry through investment in, and delivery of, RD&E: helping to increase the productivity and profitability of growers.

CRDC's investment in RD&E is funded through an industry levy, with matching Commonwealth contributions. Over $408 million has been invested in over 3400 cotton RD&E projects by growers and the Government over the past 30 years – delivering real impact for growers. Impact assessments in core areas of CRDC investment – optimising water use efficiency and crop nutrition RD&E – show that CRDC has delivered return on investments to growers of $8.29 to $1 and $5.40 to $1 in these areas respectively. In addition, the impact assessment of one specific CRDC-supported project – Qld DAF's Central Queensland early planting research – found that the research delivered a return on investment to growers of $17.10 to $1.

The 2022–23 year marks the fifth year for CRDC under our 2018–23 Strategic RD&E Plan. CRDC's aim through this five-year Strategic Plan is to contribute to creating $2 billion in additional gross value of cotton production for the benefit of Australian cotton growers and the wider community. The plan has five key areas of focus: increasing productivity and profitability on Australian cotton farms; improving cotton farming sustainability and value chain competitiveness; building the adaptive capacity of the Australian cotton industry; strengthening partnerships and adoption; and driving RD&E impact.

Australian cotton growers and the Commonwealth Government will co-invest $18.6 million through CRDC into cotton RD&E during 2022–23, across approximately 300 projects and in collaboration with around 100 research partners.

**www.crdc.com.au**

## Cotton Seed Distributors Ltd: cotton seed for tomorrow's cotton crop

Cotton Seed Distributors Ltd (CSD) has been supplying quality cotton planting seed to the Australian cotton industry since 1967. CSD was formed through the vision of Australia's foundation cotton growers and remains committed to the success of today's industry.

CSD is a major investor in cotton breeding, research and development, having developed a long and successful partnership with the CSIRO Cotton Breeding Program. CSD's objective is to deliver elite varieties that are specifically bred and adapted to suit local growing conditions by delivering yield and quality outcomes to keep the Australian cotton industry at the premium end of the global fibre market.

On behalf of the industry, CSD takes an active role in the development and licensing of best-in-class biotechnology traits that add value to the overall performance of CSD varieties and to Australian growers.

CSD also conducts large scale replicated trials focused on new varieties, technologies and techniques to assess performance across diverse environmental conditions; and provides industry wide extension services focused on cotton production and agronomy via the CSD Extension and Development Agronomy team and CottonInfo joint venture, in partnership with CRDC and Cotton Australia.

**www.csd.net.au**

## The Australian cotton industry: working together

Collaboration is king in the Australian cotton industry, with many industry bodies, research organisations and individual researchers, consultants, agronomists and growers working together on joint programs and initiatives. It's a strength of the cotton industry. Key partners with CRDC and CottonInfo in the *Australian Cotton Production Manual* – as well as many other programs – are:

- Cotton growers and cotton communities (including Cotton Growers Associations).
- Cotton Australia.
- Cotton Seed Distributors.
- The rural research and development corporations.
- Cooperative Research Centres (CRCs).
- CSIRO.
- NSW Department of Primary Industries.
- Queensland Department of Agriculture and Fisheries.
- Commonwealth Department of Agriculture and Water Resources.
- Crop Consultants Australia.
- Universities.

# The cotton plant

By **Sandra Williams** (CSIRO) & **Michael Bange** (Cotton Seed Distributors)

## Dryland cotton…

- **Being perennial, cotton's priority is survival. So during periods of stress, cotton can drop fruit to preserve its resources for supporting the growth of existing leaves, branches, roots and older fruit.**
- **Cotton can often compensate after fruit loss as it can re-grow fruit over a long period compared to many other crops.**
- **The aim is to maximise the period of fruit production in the context of season length.**

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 metres in height, but grown commercially it rarely exceeds 1.6 m. Its tap root can reach depths of 1.8 m. Cotton in Australia is managed as an annual crop, so is sown, harvested and removed each year. Cotton fibre forms on developing seeds inside a protective capsule called a boll. When 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 – in uncultivated cotton, the fibre is just a by-product to aid in seed dispersal. When cotton is picked, the seed and the attached fibre are harvested, compressed into modules and transported to a gin where the seeds and contaminants (leaf and twigs) are separated from the fibre. The fibre is then compressed into 227 kg bales, classed according to fibre quality, and exported around the world to textile mills. By-products of the ginning process are cotton seed and oil, which are also valuable commodities.

## Perennial growth habits

In its native habitat as a perennial shrub, cotton can survive year after year. Therefore, in situations where the crop has inadequate resources (moisture, solar radiation, nutrients) it will drop or 'shed' some flowers or small bolls (also called fruit). This is a way to guarantee its survival by using the limited resources available to support its leaves, branches, roots and the remaining fruit. This is why extended periods of low solar radiation (cloudy weather), excessively hot weather, or limitations on root systems (soil compaction and water stress), particularly during flowering, can lower yields. But being a perennial, the cotton plant has an indeterminate growth habit. This means that the plant develops fruit over an extended period, so the plant can often compensate after stress (such as pest attack or physiological shedding), by continuing to grow and produce new fruit if time and conditions permit.

## Cotton development and day degrees

The development of a cotton plant is strongly influenced by temperature. This development can be predicted using seasonal temperature records and by calculating day degrees (DD). DD is the accumulation of heat units related to the daily maximum and minimum temperatures.

For many years, cotton grown in Australia used the DD formula as follows:

**DD = (Max temp - 12°C + min temp - 12°C) ÷ 2**

When minimum temperatures are less than 12°C, the DD formula is:

**DD = (Max temp - 12°C) ÷ 2**

This accumulation of DD has been calibrated with specific targets for a range of cotton development events (Table 1). The term 'cold shock' refers to when minimum temperature <11°C, and cotton development is delayed. The DD requirement for first square and first flower increases by 5.2 every time a cold shock occurs. This methodology works well when conditions are not extreme. Research has found that a function that has a base temperature of 15.6°C (instead of 12°C) and an optimum of 32°C can better predict crop stages when there are more extreme conditions. There is also no need to accommodate for cold shocks. This new approach to estimating crop development, also known as '15-32 system', is being delivered alongside the existing approach on the Cotton Seed Distributors website day degree calculator (www.csd.net.au/ddc, membership may be required, or Facts on Friday: "New Day Degree Calculator to Assist in Crop Development").

**TABLE 1: Cotton growth stages with target DD**

| Cotton development | Notes | Accumulated DD (base 12) after planting |
|---|---|---|
| Germination | Germination will start as a seed takes in (imbibes) moisture and temperatures are warm enough. | |
| Emergence | The two cotyledons (seed leaves) break the soil surface and unfold. | 80 |
| Vegetative growth | A cotton plant adds a new node every 42 DD or 2–4 days. This rate will slow as the crop approaches cut-out. | |
| First square | A square is a flower bud. The first square occurs on the first fruiting branch at approximately 5-7th nodal position above the cotyledons, about 4–6 weeks after emergence. Initiation of the first 'pinhead' square normally occurs when the true leaf on node 4–5 is unfurled, and signals the beginning of the reproductive phase. | 505 |
| First flower | The first square will develop into the first flower within 15–20 days (8–10 weeks after emergence). The cotton flower is white, with five petal flowers and normally opens first thing in the morning. The cotton plant is usually self-pollinating, and this occurs very shortly after the flower opens. Once fertilised the flower turns reddish purple and then desiccates as the boll begins to develop. | 777 |
| Flowering to max boll size | After the flower petals fall off, a fertilised boll (fruit) is visible. In 20–25 days this boll will reach its maximum boll size. After fertilisation, the boll begins to develop. The boll is divided into 3–5 segments called locks, which contain lint and 6–9 seeds. The number of locks is determined by the time a square has reached a 'pinhead' in size. | 1087* |
| Open boll | Under optimum conditions it takes about 50 days from flowering to having an open boll. | 1527* |

*Note that these are estimates for individual bolls and do not represent whole crop development.

For further information watch “Using Day Degrees in Cotton Production” on the CottonInfo Youtube channel www.youtube.com/cottoninfoaust.

As there are many applications of the use of the day degree function that uses the base temperature 12°C within the industry, it will take time to recalibrate these applications to the use of the new function (15-32). Continue to use applications that are tuned to the older function of base 12, as there are no concerns associated with their use or the data generated. The aim is to eventually apply the new function universally across the industry.

## Cotton growth

During cotton plant growth and development, two types of branches, vegetative (monopodial) and fruiting (sympodial) will arise. Having only one meristem (growing point), vegetative branches grow straight and look much like the main stem. Vegetative branches can also produce fruiting branches. The first fruiting branch will generally arise from nodes six or seven (position will depend on preceding temperature conditions and variety). With the potential to grow multiple meristems, this branch will grow in a zig-zag pattern and produce multiple fruiting positions. Figure 1 shows a fruiting branch that has formed above a main stem leaf. This branch has produced two fruiting structures along with their subtending leaves.

The pattern of development and growth of the plant is described in Figure 2, where the development of new fruit occurs at the top of the plant on new fruiting branches as well as along older fruiting branches. Maintaining vigorous vegetative growth before flowering is important as it is these leaves, branches and roots that will support and supply the future boll load. As a cotton plant develops, new leaves grow and expand, producing carbohydrates to allow additional growth of leaves and the developing roots. Once reproductive structures begin to develop, vegetative and root growth will normally slow down as the plant begins to supply resources to the developing fruit. When resources exceed the needs of the developing fruit, the rate of vegetative and reproductive growth continues.

**Fruit develops from a tiny flower bud or ‘square’ which continues to grow until it flowers. The flower desiccates after about 3 to 4 days, exposing a small green boll. This boll will continue to grow until it matures.** (Photo: Paul Grundy, Qld DAF)

**FIGURE 1: A developing fruiting branch and associated structures.** (Photo: Paul Grundy, Qld DAF)

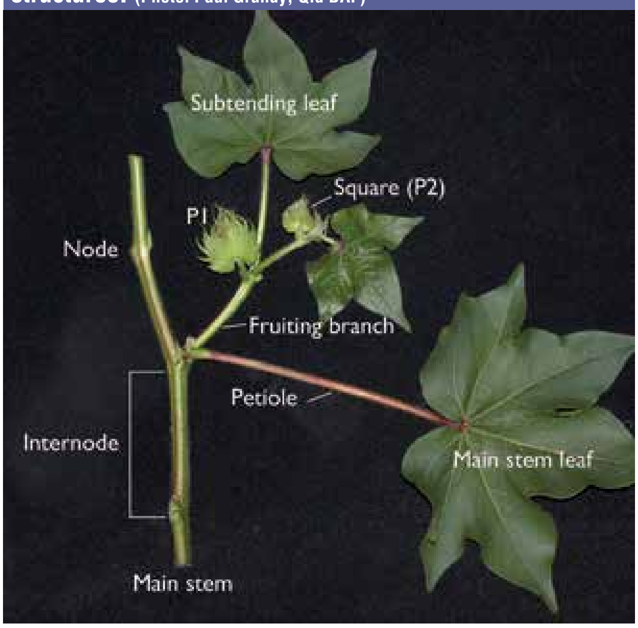
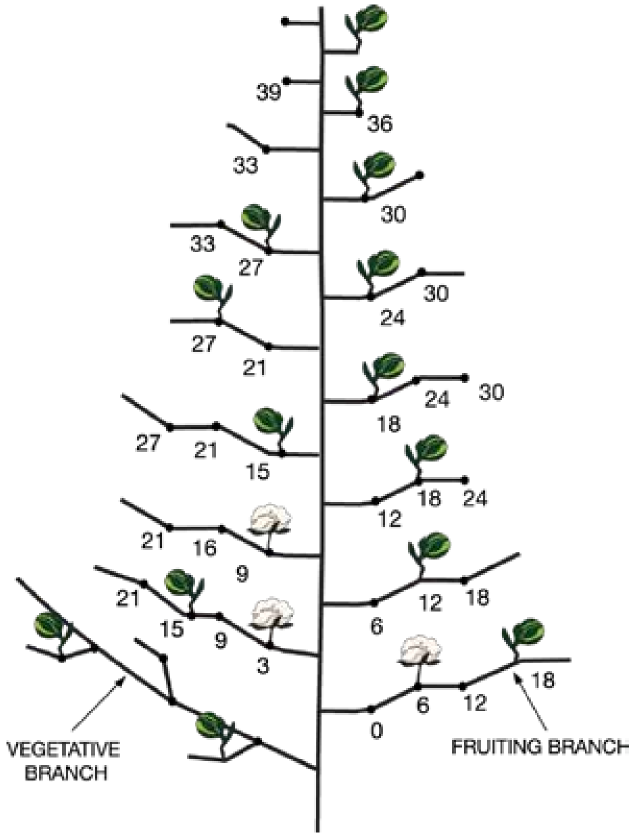



**FIGURE 2: Rate of development of fruiting sites on a cotton plant, adapted from Oosterhuis 1990. Numbers represent days from appearance of first square to the production of a new fruiting site.**

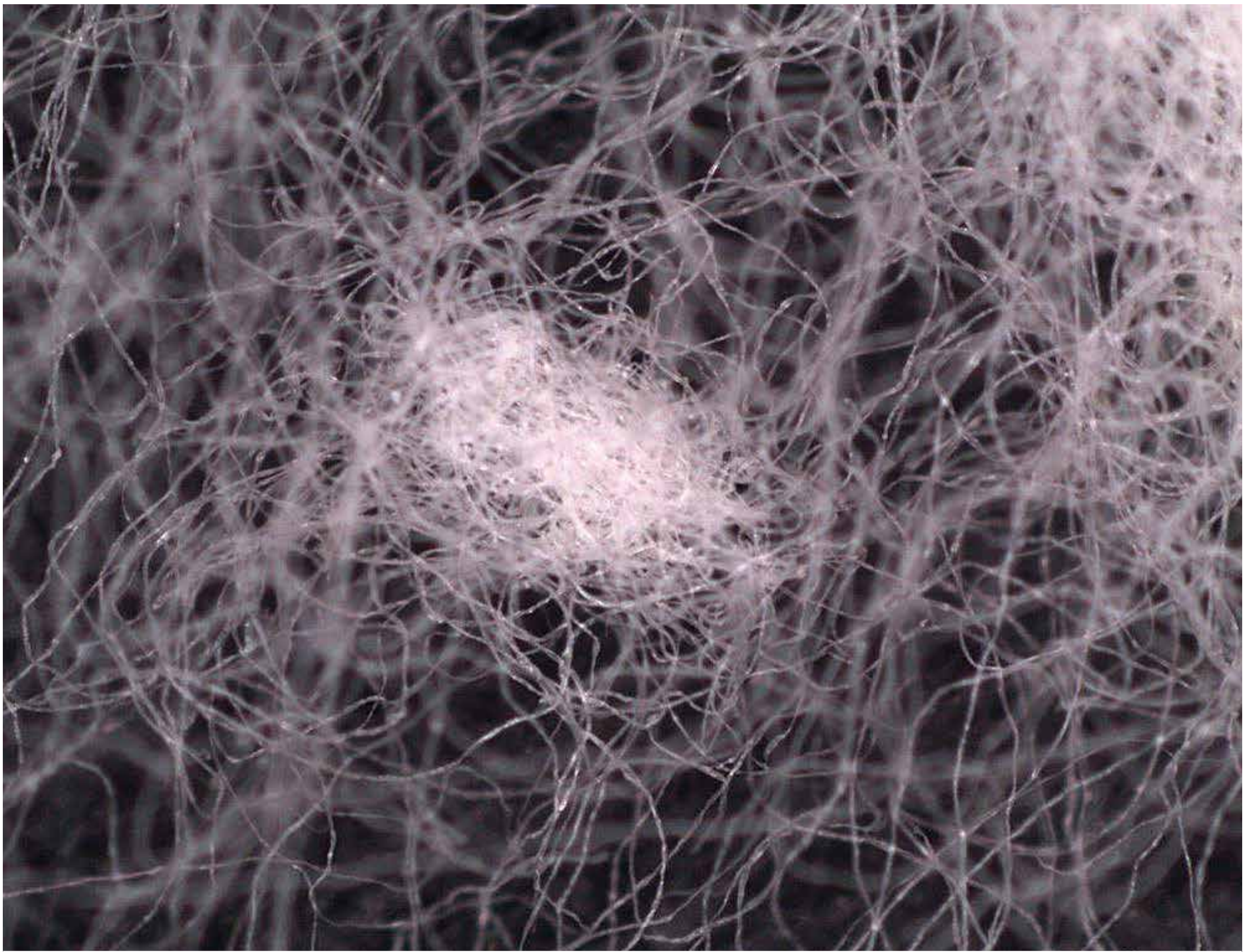



Good crop management aims to keep the reproductive and vegetative growth in balance for as long as the season allows, timing cut-out to maximise the number of mature fruit (bolls) at harvest. The more fruit that is produced before cut-out generally results in higher yields.

At cut-out the supply of carbohydrates, water and nutrients equals the amount needed by the developing bolls and new growth stops.

During crop growth certain growth parameters (such as node production and fruit retention) should be measured and recorded to help with management decisions for maximum yield. In some situations where there is plenty of water and nutrients, excessive vegetative growth can occur. Growth regulators such as mepiquat chloride can help manage this growth. Measuring vegetative growth rate (VGR) is an effective technique used to assist with these decisions. See the *Managing crop growth* chapter for further information.

Approaching cut-out, bolls grow and become larger sinks for carbohydrates, water and nutrients, leaving less available for new growth. NAWF (nodes above white flower) is the number of nodes from the



**Growers need to consider the impact of management on fibre quality as well as yield. Image of a process nep (an entanglement of fibres which can affect finished fabric). Obtained by means of a Wild Makroskop M420 microscope equipped with a Leica DFC290 digital camera.** (Photo: CSIRO)

uppermost first position white flower to the terminal. This number will naturally decrease as the season progresses as growth slows from the terminal. As flowering progresses in a pattern up the plant, the NAWF will decrease. Cut-out occurs when NAWF approaches the top of the plant and flowering ceases (NAWF = four or five). More information on measuring NAWF and cut-out can be found in the *Preparing for Harvest* chapter. Just as flowering progresses in a pattern up the plant, so does the maturation and opening of bolls. Therefore, measuring the number of nodes from the uppermost first position cracked boll (NACB – nodes above cracked boll) to the terminal is an effective way to determine crop maturity. Crops are considered mature and ready for defoliation decisions if they have reached four or five NACB. More information on measuring NACB can be found in the *Preparing for Harvest* chapter.

## Cotton fibre biology

Cotton fibres begin their development as single cells that start to form on the unfertilised seeds, called ovules, just before flowering. Cotton fibre is almost pure cellulose, is non-allergenic, and has unique breathable characteristics that make it widely sought after to use in clothing, from undergarments to high-end fashion. Fibre development can be divided into four phases as outlined in Table 2.

**For more information, download FIBREpak from www.cottoninfo.com.au or www.mybmp.com.au**

**TABLE 2: Cotton fibre development**

| Fibre development | Notes |
|---|---|
| Initiation | Occurs just before and at flowering. The initiation of fibre cells on the seed coat can take up to three days. After the initial burst, a second set of fibre cells are initiated, which develop into the fuzz left behind on the seed after ginning. |
| Elongation | This is the rapid expansion and growth of the fibre cell's primary wall (partially controlled by internal water/turgor pressure). During this time the plant is sensitive to stress (water, nutrition and cool temperatures). Final fibre length is determined both by the length of this period and rate of fibre elongation. |
| Secondary wall thickening or fibre thickening | Is the formation of the secondary wall where cellulose (a product of photosynthesis) is laid down in layers inside the fibre cell's primary wall. The amount of cellulose deposited is affected by photosynthesis. Due to fluctuations in photosynthesis daily, fibre growth rings are formed. They consist of two cellulose layers: a thicker layer that is formed during the day and a more porous layer that is laid down at night. |
| Maturation | This is where the fibre cells dry out and the fibre becomes a twisted ribbon-like structure. Mature fibre is easily detached from the fuzzy seed. |

# New growers' checklist

By **Cotton Australia**

New growers should have a thorough understanding of their responsibilities before making the decision to grow cotton. There is no single recipe for producing a profitable and sustainable cotton crop, but to be successful you must approach cotton production with long-term planning and commitment.

The Australian cotton industry operates in an extremely cohesive and cooperative environment, where a number of industry organisations exist specifically to support growers, from research extension to agronomy, community relations and advocacy. You will also find that your fellow cotton growers are prepared to willingly share their experiences and offer invaluable advice.

## Some questions for first time cotton growers

- **How committed are you to cotton?**
  To be successful you must apply good planning, thoroughness, timeliness and careful management to all your business and cotton production practices.
- **Who will harvest your crop?**
  Cotton picking machinery is expensive. Most new growers employ picking contractors to harvest the crop, but in good seasons, contractors can be in short supply.
- **Have you planned for cotton?**
  Among the critical factors in growing cotton are: fitting cotton into your crop rotation program, sound weed management, good soil management, integrated pest management strategies and effective stubble management after harvest. Review relevant chapters in this manual to help plan and inform your decisions.
- **How much of your time does cotton require?**
  Cotton is a relatively complex crop to grow, requiring specific agronomic knowledge and some farming techniques that you may not have used before. A cotton crop will require timely and constant attention from planting to picking through to post crop management.
- **How do you feel about using chemicals?**
  The cotton industry takes the stewardship of chemical usage very seriously. The industry has reduced its use of synthetic insecticides by 97% since 1992 thanks to Integrated Pest Management (IPM) techniques. You must be prepared to apply the industry's Best Management Practices for pesticide use, including using an IPM strategy and following the industry's resistance management plans.
- **Will you grow dryland/or irrigated cotton?**
  **Have you done a water budget?**
  In the planning process, decisions about cropping and what area to sow can be made seasonally. Develop a water budget, based on expected water availability and likely crop requirements. Irrigators should also consider whether their system is adequate for timely and efficient irrigations, and can also meet peak water demand. If you are considering dryland cotton, it is important to ensure that your soil's Plant Available Water Capacity (PAWC) and starting profile is sufficient and climate risks are considered.
- **How do you feel about complying with GM cotton regulations?**
  Growing a genetically modified cotton means that you must sign a contract with the owner of the technology. All commercial GM cotton technologies in Australia require compliance with resistance management plans that form part of the licence conditions. You should be aware of all the requirements of the resistance management plans and crop management plans for the respective products. Refer to the *IPM and Resistance* chapter.
- **Have you talked to your neighbours?**
  It is your responsibility to ensure chemical drift is minimised on your farm and does not occur outside your property boundaries. Cotton is highly susceptible to phenoxy herbicides such as 2,4-D. The core best management practice for safe and responsible pesticide use is to develop a pesticide application management plan (PAMP) and establish good communication to help ensure risks around pesticide application are managed. Letting your neighbours, local resellers, spray contractors and aerial operators know that you have cotton can help minimise risk, particularly in new or isolated areas. Don't forget apiarists as neighbours. New growers are also encouraged to use SataCrop (satacrop.com.au) – a digital tool for mapping fields and crop types, so other farmers and spray contractors can be informed of the location of potentially sensitive neighbouring crops. BeeConnected can help identify nearby location of hives and facilitate communication between spray applicators and beekeepers (www.beeconnected.org.au). Refer to the *Effective spray application* chapter for more information.
- **How will you finance your crop and manage risks?**
  Cotton has high growing costs. Financing the crop is a major consideration, and it is recommended that you speak to a financial advisor. Hail presents a significant risk to summer crop production including cotton. It is important to discuss insurance coverage with an experienced specialist. Refer to the *Insurance* chapter.
- **Who will buy your cotton?**
  Cotton has unique marketing parameters based around fibre quality. Discuss premium and discount sheets as well as price with an experienced cotton merchant/marketer. For a list of Australian merchants, please see www.austcottonshippers.com.au
- **Is your current machinery adequate to grow cotton?**
  Can you adapt your existing machinery? Or will you need to engage the services of contractors? Minimise machinery acquisitions until you are sure about your long-term commitment to cotton growing.
- **Have you contacted a consultant?**
  Seek the services of a cotton consultant early for management advice and crop planning, particularly if you have limited cotton agronomy experience. Speak to experienced local cotton farmers for advice on the selection of a reputable consultant, your local Cotton Grower Association is a good place to start or for more information, contact Crop Consultants Australia at www.cropconsultants.com.au
- **Have you contacted a spraying contractor?**
  Unless you plan to do all of your own spraying you should discuss your requirements with an aerial and/or ground rig operator before the season commences. Ensure you use a reputable and accredited spray contractor with adequate insurance coverage.
- **Have you contacted a farm inputs supplier?**
  You will need to source suppliers for farm inputs such as seed, fertiliser, herbicides, insecticides, growth regulants, defoliants and a licence to grow GM cotton (Technology User Agreement (TUA)).
- **How will you stay up to date?**
  The industry has a large number of resources to support cotton growers and it is important to stay informed on emerging issues and best practice.

**Refer to the Australian cotton industry organisations on pages 4 to 6.**

# Planning

Chapter 3 sponsored by – VICCHEM The Right Chemistry

# Climate for cotton growing

By **Jon Welsh** (CottonInfo/Ag Econ)

## What's new…

- **Seasonal streamflow forecasts offer a new form of decision support and help with water management by assessing the likelihood of catchment in-flow or water harvesting opportunities.**
- **Statistical modelling is combined with outputs from General Circulation Models to predict future streamflow which can help cropping strategies, water market planning, managing drought and future allocation of water.**
- **Streamflow forecasts are offered in almost all cotton catchments and forecasts include historical skill and a probability distribution three months ahead.**

Ideal conditions for cotton are sunny warm days with maximum temperatures between 27–32°C with overnight minimums of 16–20°C. Daytime temperatures greater than 32°C put stresses on the plant, which has to transpire more water to keep cool. Night temperatures above 22°C will begin to increase respiration processes while temperatures below 11°C (cold shock) or above 36°C (hot shock) will result in a shock to the plant that temporarily arrests development. Extended periods of low solar radiation (cloudy weather), too much or too little rain/water and excessively hot weather, particularly during flowering can impact on yields.

## Best practice…

- **Best practice climate risk management is to survey credible General Circulation Models (GCMs) to identify consensus and trends. Alignment of these outputs can improve confidence when making critical on-farm investment decisions. Review model performance against observations to gauge usefulness.**
- **In neutral ENSO and Indian Ocean conditions consider using statistical models such as analogue years, SOI Phase seasonal outlook and check historical probabilities using www.climateapp.net.au. Neutral ENSO does not necessarily mean average and in these years local rainfall variability tends to increase.**
- **Stay in touch with CottonInfo's Moisture Manager: A monthly summary of indicators, multi-week and seasonal rainfall and temperature guidance and features commentary from leading domestic and international research agencies.**

## Planning

Assessing the climate risk for a coming season can help with decision making, particularly with regards to managing inputs. There is a range of information available to growers on the status of El-Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM).

### El Niño-Southern oscillation index (ENSO)

ENSO refers to the sea surface temperature anomaly in the tropical Pacific Ocean. A strongly positive Niño 3.4 index is associated with El Niño (historically dry) events and a strongly negative index is associated with La Niña (historically wet) events. The Southern Oscillation Index (SOI) is an air pressure measurement calculated between Tahiti and Darwin. The SOI represents a 30-day average of a broad belt of air pressure in the Pacific Region. When the SOI is positive (La Niña), mean sea level air pressure is lower, and conditions are historically more favourable for rain.

### Indian Ocean Dipole (IOD)

The IOD is a sea surface temperature Index in the Indian Ocean. This is a secondary moisture source during the winter and spring seasons in Eastern Australia and represents the distribution of the warm ocean currents in the Indian Ocean. A negative Indian Ocean value is favourable for moisture supply and cooler spring conditions.

### Southern Annular Mode (SAM)

The SAM is a measurement of the mean sea level pressure around latitudes in Antarctica. This measurement is the difference or "gradient" of the air pressure patterns that can affect daily variations in eastern Australian rainfall and temperatures. Fluctuations in the SAM account for a similar variation for that of ENSO in agricultural areas of eastern Australia during winter and spring extending into summer in some regions. The key feature of the SAM is its influence on easterly moisture circulation patterns from

**TABLE 1:** Tips for planting.

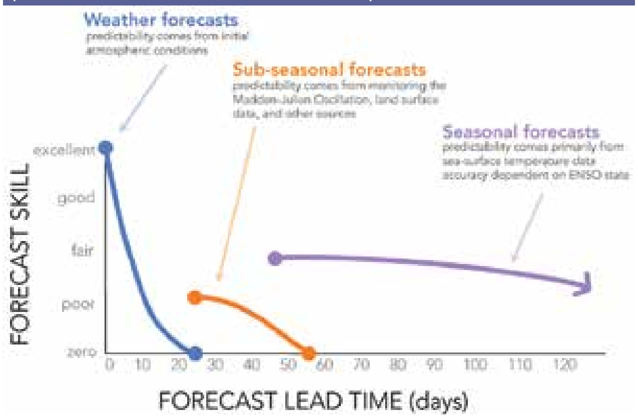
| Recommendation | Rationale |
|---|---|
| What ENSO "phase" are we in? | GCMs are more accurate in defined La Niña/El Niño events. ENSO "neutral" does not mean average and variability will increase. Proceed with caution during neutral ENSO years. |
| Which mode of variability is the Indian Ocean Dipole (IOD) in? | The IOD commences its life cycle in May and matures in October/November. A positive IOD will reduce moisture during planting in central and southern areas; conversely a negative IOD can improve planting conditions. |
| Always survey more than just the BOM seasonal outlook and weather models | It is good risk management practice to glean information from other research agencies. Any trends towards wet/dry can give us more confidence. |
| Seasonal predictions for rainfall most useful in winter/ spring seasons | The primary ingredient for a GCM's prediction is ENSO. Other tropical and local influences determine monsoonal rainfall during our summer and autumn season which have lower predictability. |
| In growing season, monitor the path of the MJO as it moves around the globe | An active MJO phase can disrupt normally stable, fine weather patterns. In recent years rain has been aligned with early growing season rainfall and a 7–14 delayed onset of rainfall in January and February. |
| Heat wave advice from the BOM site | Heat wave predictions are improving. Go to www.bom.gov.au and search 'heat wave' which takes you to the forecast. This can aid in irrigation management decisions. |

the Tasman Sea into eastern Australia, where a positive anomaly allows moisture to feed into inland trough and frontal systems producing rain events. A positive SAM will direct moist, convective air from the Tasman Sea and Coral Sea into frontal activity. The record rainfall received over the Australian continent in 2010 was attributed largely to the sustained positive influence of the SAM on rain bearing moisture circulation patterns. A negative SAM has also been found to reduce the number of cold fronts that originate from the Southern Ocean resulting in a dry, stable westerly air pressure pattern.

## The Madden Julian Oscillation (MJO)

The MJO is a tropical disturbance that propagates eastward around the global tropics with a cycle in the order of 30–60 days. The MJO has wide ranging impacts on the patterns of tropical and extratropical precipitation, atmospheric circulation, and surface temperature around the global tropics and subtropics. The MJO is often variable, with periods of moderate-to-strong activity followed by periods of little or no activity. The MJO affects the Australian continent from November to April. Although studies have shown the MJO has a stronger connection with rainfall in more northern cotton areas, a passing MJO can also unsettle often stable circulation patterns and lead to a change in southern growing areas. With climate scientists anticipating tropical influences to shift further south in future, the MJO may have even more impact through central-eastern Australia.

**FIGURE 1: Forecasting skill for three different types of weather and climate models.**
**(Source: International Research Institute, 2015)**




## Using General Circulation Models (GCMs) for planning

Most GCMs display information in the form of dynamic computer-generated colour charts or models, so it is useful to identify accuracy and inputs of these models. Three categories of model predictions exist:

- **Weather outlooks.** A 0–10 day prediction, normally run on 12 hourly intervals.
- **Multi-week (or sub-seasonal) predictions.** This category is currently the focus for many global research agencies. Outputs are generally refreshed through an 8–28 day period and offer another form of guidance on rainfall and temperature. These are generally run weekly or twice weekly.
- **Seasonal outlooks** display rainfall and temperature guidance for the following three months. These models are refreshed by research agencies usually once a month. Accuracy levels are highest in winter and spring. Statistical and ensemble predictions also compliment model outputs. Moisture Manager surveys all model outputs and hindcast performance at critical periods throughout the year. Some tips for using seasonal GCMs for planning ahead for your next crop are shown in Table 1. Figure 1 shows the skill of these individual models and their derived inputs. The accuracy of seasonal forecasts is improving and may add value to planning and budgeting decisions in farming businesses.

## Water balance and streamflow predictions

GCMs not only assist with weather and climate forecasts. They can also help us understand water balance across the landscape, which can help assess the likelihood of dam in-flow, water run-off and subsequent harvesting opportunities. All streamflow forecasts contain uncertainty due to several factors. This information is provided using probabilistic forecasts and historical assessments of forecast skill and help irrigators improve their water management and decision-making capability. Figure 2 provides an example of an output for inflow into the Hume Dam catchment in southern NSW. There are menu options for a range of cotton growing locations with tabs including historical skill throughout the year for the chosen location. To

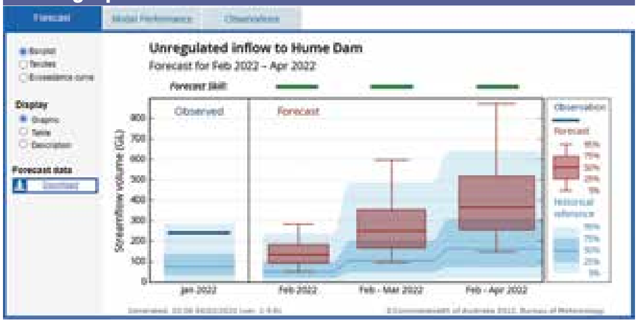
**TABLE 2: Southern Annual Mode – Correlation strength with rainfall in cotton growing areas.**

| | Cotton production cycle | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boll fill | | Harvest | | Fallow | | | | Planting | | First flower | Boll fill |
| **Region** | **Jan/Feb** | **Feb/Mar** | **Mar/Apr** | **Apr/May** | **May/Jun** | **Jun/Jul** | **Jul/Aug** | **Aug/Sept** | **Sept/Oct** | **Oct/Nov** | **Nov/Dec** | **Dec/Jan** |
| Emerald | | | | | | | | | High | | | |
| Dalby | | | | | | | | | Medium | High | Medium | |
| St George | | Medium | | | | | | | | Medium | | V.High |
| Boggabilla | | | | | | | | Medium | | Medium | | |
| Moree | | | | | Medium | | Medium | | V. High | | | |
| Wee Waa | | | | | Medium | | Medium | | | V.High | | Medium |
| Caroona | | | | | | | High | Medium | | High | | |
| Trangie | Medium | | | | | | | Medium | | High | High | Medium |
| Hillston | | | | | | | | | Medium | | High | Medium |
| Hay | | | | | | | | | High | Medium | Medium | Medium |
| Swan Hill | Medium | | | | | | | | Medium | | Medium | |

Correlations shown are calculated at the 95% confidence interval. SAM correlations are positive with rainfall (i.e. A positive SAM anomaly has a positive effect on rainfall).
Source: CottonInfo, BOM, CSIRO 2014.

access streamflow forecasts and to learn more about this decision support, go to www.bom.gov.au/water/ssf/index.shtml

**FIGURE 2:** Seasonal streamflow forecasts can aid water budgeting decisions pre-season and mid-season to manage precious water resources.




## In-season tactics

The dynamic nature of the Australian monsoon season makes planning in-season particularly challenging and forecasts on long lead times can be of limited use. A climate risk management plan may consist of surveying two or three weather models on an 8–16 day lead, heat wave forecasts and the status of the MJO. Studies have shown that ENSO has little effect on rainfall in cotton areas after December. The IOD matures in November each year and has little to no influence after then.

# Risk analysis using statistical modelling

In years when Pacific and Indian Oceans are neutral, GCMs may offer little in terms of risk management; no clear output for wetter or drier conditions, or model skill is low. In these years, statistical models can be valuable in determining likely outcomes when planning a winter or summer crop. One useful source of climate statistical analysis for your local area that can aid in decision making is ClimateApp.

- **CliMate:** Download the iPhone app or go to www.climateapp.net.au. Choose a weather station closest to you and run analysis: How Often? How's the Season? or How Likely? A range of probabilities show likelihood of rainfall and temperature at a given location.

# In-season climate risk management – growing season

## Planting

The SAM is a key driver of planting rainfall in spring throughout all cotton areas. In neutral ENSO years we need to monitor the phases of the SAM together with seasonal forecasting models and shorter term (0–10 day) tools from the Bureau of Meteorology and other international agencies. In neutral years the SAM can dominate moisture circulation patterns that can often determine the success or failure of forecast rain events. In contrast, the SAM will often follow suit should a La Niña or El Niño event occur. Scientists confirm the SAM is the dominant mode of climate variability in the Eastern Australian spring. The co-efficient of variation of the SAM with rainfall in cotton has variable strength across cotton growing regions. Table 2 shows when the SAM affects each region and the connection with rainfall.

## First flower/boll fill/harvest

Into the growing season, the climate drivers of our climate systems are beginning to change to a more dynamic system influenced by local

**TABLE 3:** Tips for in-crop.

| Recommendation | Rationale |
|---|---|
| Survey seasonal temperature outlooks | These are useful for determining likely evaporation rates and crop water demand. The first port of call for moisture risk analysis. Temperature forecasts will identify changes from the mean, which require preparation on the farm to schedule irrigations. |
| Check BOM extreme heat model regularly | Four-day heat waves can be a game changer to any crop. The BOM heat model will pick up heat cells out to 10 days. |
| What is the MJO* doing? | The MJO is a broad trough of low pressure. When active, it can trigger a rain event. See 'Moisture Manager' for regular updates. |
| Survey three multi-week rainfall models | Multi-week models forecast out to 16–21 days. These will be variable on long lead times. Models bringing rain tend to align at about 10 days out. |
| Survey short term rain models | When multi-week models predict a rain event, short term models such as the BOM WATL site and other GFS** sites need to align. Surveying three top models for consensus is a must a week away from a promising rain event. |

*MJO is the Madden-Julian Oscillation. **GFS is the Global Forecast System.

sea surface temperatures, upper air disturbances and tropical convective moisture. Except for Central Queensland, the effects of El Niño Southern Oscillation will be reduced at the onset of summer and the usefulness of longer term seasonal (three monthly) rainfall models for planning will become limited. When scheduling irrigation and fertiliser applications there are some information tools and general principles available to aid crop management. Table 3 shows some suggested practices.

**Useful information:**

**Moisture Manager is an information-rich, user-friendly and up-to-date weather and climate service essential for farming businesses looking for an edge in climate risk management. Moisture Manager is delivered by CottonInfo.**

**To sign up for the Moisture Manager (and other CottonInfo communications) visit www.cottoninfo.com.au/subscribe, and follow us on twitter @CottonInfoAust. Visit www.cottoninfo.com.au/climate**

**CliMate allows you to interrogate climate records to ask questions relating to rainfall, temperature, radiation, and variables such as heat sums, soil water and soil nitrate as well as El Niño Southern Oscillation status. www.climateapp.net.au**

**The Bureau of Meteorology is Australia's national weather, climate and water agency, providing regular climate forecasts, warnings, monitoring and advice – www.bom.gov.au**

# Dryland cotton

By **Michael Bange** (Cotton Seed Distributors)

This chapter presents information to assist in establishing differences in yield potential, reliability and risks for dryland cotton between row configurations and regions. Extensive field research has been used including the OZCOT crop simulation model and historical climate records. Improvements in variety performance and technology traits have simplified the process of growing dryland cotton, making cotton a more reliable and consistent performer within the rotational mix.

## Risk and potential

Dryland cotton growers don't need to take uncalculated risks. History can serve as our guide to the risks and benefits of different cropping strategies. Crop simulation models are powerful and can help inform your decision-making.. CSIRO at Narrabri has used long-term climatic records (1957 onwards from the Bureau of Meteorology) and the OZCOT crop simulation model originally developed by Brian Hearn, CSIRO, to study the prospects for dryland cotton production in different regions. The OZCOT crop simulation model uses historical weather data, basic soil parameters (such as plant available soil water), and defined management options to give estimates of potential crop yields. The model has been comprehensively tested across both commercial dryland (including skip rows) and irrigated crops throughout the industry.

The intent behind skip row configurations is to slowly provide available soil water to the planted rows, allowing continued growth during dry periods. In practice, the benefits are:

- A reduced risk of negative effects of water stress on fibre quality.
- Reduced yield variability.
- Better economic returns due to production costs being reduced more than the yield relative to solid planted cotton.

### Best practice...

- **Soils with a greater plant available soil water holding capacity reduce risks associated with dryland production. As with all dryland crop production, full profiles also significantly reduce year-to-year variation in yields.**
- **The optimal sowing window in most regions is 15th October to 15th November.**
- **Skip row configurations reduce the downside risk in years with low rainfall.**
- **Double skip is more suitable for soils with lower plant available water holding capacity.**
- **Average fibre length is improved with skip configurations compared with solid.**
- **Seasonal climate outlooks such as the El Niño-Southern Oscillation (ENSO) phenomenon should also be considered as these can lead to differences in potential yield and associated risk.**
- **Be aware of average rainfall and variability between October and April in your region.**
- **Be aware of the ability of crops to access moisture in skip rows. Some soil types will limit root growth.**

## Rainfall

The main consideration for dryland production and a source of variability across regions is rainfall. Regions differ greatly in the average total amount of rainfall as well as the variability between and within seasons. Generally, the risk of less rainfall between the months of October and April is greater in the southern cotton growing areas (Table 1). The traditional dryland cotton growing areas have higher average rainfall during these months, coupled with higher rainfall during the December through March period when flowering and boll filling occur. Refer to the *Climate for cotton growing* chapter for more information.

## Predicting dryland cotton yield potential

The information in this chapter uses the OZCOT crop simulation model developed by CSIRO. Some assumptions used in this study were: Cracking clay soils storing 200 mm or 250 mm of plant available soil moisture in a 1.5 m profile; a full profile at sowing; Bollgard variety; crops sown on the 30th October; row spacing set at 1 m; established population of seven plants per metre of row; nitrogen non-limiting; historical climate data from 1957 onwards. The model simulates potential yield. It does not account for the affects of insect pests, diseases, weeds, management failures, and soil nutrient limitations other than N. The model also does not simulate the effects of climate and management on fibre quality, which is another important consideration when growing dryland cotton.

### Sowing opportunities

The risk of failing to obtain a sowing opportunity was assessed for three 30-day periods starting from the 15th of September. A sowing opportunity was defined in terms of adequate soil moisture and temperature and there was no account for Bollgard planting window restrictions. A sowing opportunity was considered to occur when there was:

- 25 mm (1") of water in top 100 mm (4") soil.
- 18°C mean temperature for three consecutive days.

The Darling Downs, Moree and Gunnedah were found to have a slightly lower risk of failing to sow for the 90-day period starting 15th September for dryland cotton production than for most other areas especially for the period 15th October to 15th December (Table 2). Refer to the *Climate for*

**TABLE 1: Average rainfall for cotton producing regions between the months of October and April as well as between December and March.** (Source: Australian Rainman)

| Region | Rainfall October to April (mm) | Rainfall December to March (mm) |
|---|---|---|
| Hillston | 212 | 121 |
| Narromine | 303 | 183 |
| Warren | 310 | 194 |
| Gunnedah | 407 | 253 |
| Coonamble | 326 | 205 |
| Wee Waa | 391 | 251 |
| Bellata | 409 | 263 |
| Moree | 396 | 258 |
| Croppa Ck | 404 | 265 |
| Goondiwindi | 426 | 281 |
| Dalby | 488 | 319 |
| Biloela | 534 | 373 |
| Emerald | 489 | 356 |

**TABLE 2: Probability of failing to sow based on the sowing opportunity for different periods starting 15th September.**

| Region | Probability of failing to sow (%) | | | |
|---|---|---|---|---|
| | 15th Sep to 15th Oct | 15th Oct to 15th Nov | 15th Nov to 15th Dec | Overall 15th Sep to 15th Dec |
| Gunnedah | 43 | 15 | 14 | 24 |
| Wee Waa | 49 | 18 | 25 | 31 |
| Bellata | 55 | 21 | 13 | 30 |
| Moree | 42 | 16 | 18 | 25 |
| Croppa Creek | 36 | 18 | 17 | 30 |
| Goondiwindi | 39 | 17 | 24 | 27 |
| Dalby | 52 | 10 | 10 | 25 |
| Biloela | 52 | 18 | 10 | 27 |
| Emerald | 50 | 33 | 17 | 33 |

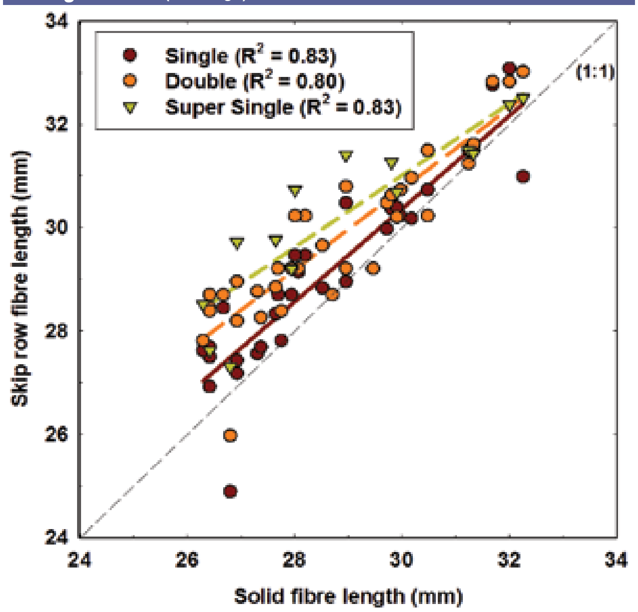
*cotton growing* chapter for more information on assessing the climate risk for the coming season.

## Dryland regional yield potential and row configuration

Several field studies have been conducted to compare the relative yield of skip row configurations compared with solid 1 m plant configurations. They generally show that when yields of solid configurations are high, skip row configurations have a penalty; but when yields of solid configurations are low the difference in yield between skip rows and solid configurations are small. There are also significant fibre quality advantages attained from skip row configurations (see Figure 1).

The expansion of dryland cotton into new areas and the need for greater flexibility in farm equipment has meant that a greater range of row configurations have been considered. Two configurations that are now being used are alternate row (1 in 1 out, 80 inch [2 m]) and super single (1 in, 2 out). The analyses presented here do not explicitly use the OZCOT crop simulation model to predict yield potential for these two row configurations as the model has not been validated for these situations. However, the responses presented in Figure 2 can be used to convert the double skip yields to the equivalent alternate row and super single yields. It can be seen from these graphs that, in general, yields for the alternate row configurations are similar or slightly better across all double skip yield potentials. For super single, yields are greater for this configuration when double skip yield potential is less than 1.98 bales/ha.

**FIGURE 1: Fibre length of various skip row configurations compared with solid row configuration in dryland cotton systems. As points approach the 1:1 line, fibre length of the skip configurations equals that of the solid configuration.** (M. Bange). Note that this data is not simulated data.




In Tables 3 to 5 the average potential yield from three different row configurations (solid, single and double) is presented on a regional basis along with the associated 'Probability of exceedance' values. Probability of exceedance is used to indicate yield variability that exists with different seasonal climatic conditions experienced in each region. For example, an 80% probability of exceedance means that there is an 80% chance of at least achieving the yield presented for that region. Generally, across all regions, yields were improved with single skip and overall yield variability was reduced. Yield was also lower and more variable for solid. Mean yield across most regions was slightly less for double skip compared with single skip, but there were more chances (i.e. higher 80% and lower 20% probability of exceedance) of attaining better yields with double skip in soil with a lower plant available water holding content (200 mm vs 250 mm).

**FIGURE 2: illustrates the relationship of lint yield of alternate row and super single skip row configurations to double skip row configurations. Also shown is the 1:1 line (dotted). Where values are on the 1:1 line they are equal. Note that this data is not simulated data.**

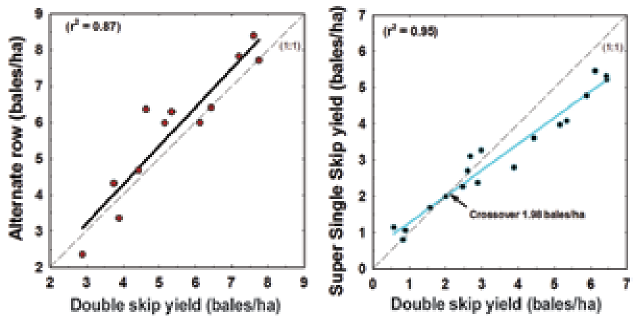
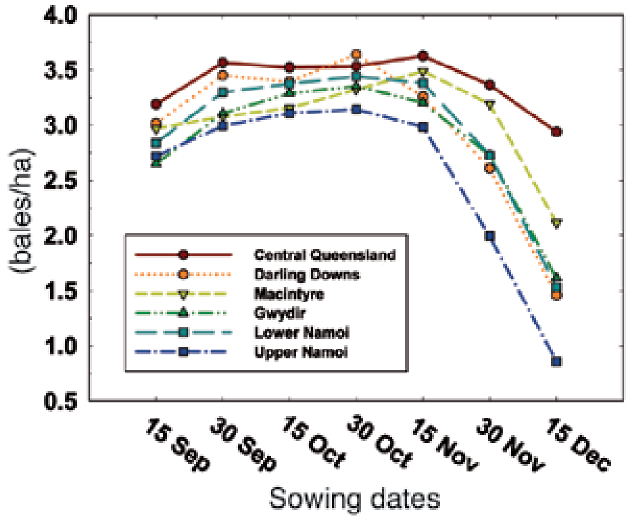



**TABLE 3: OZCOT predictions, solid row configuration – effects of two plant available soil water holding capacities on potential yield (bales/ha) and variability of yields, expressed in terms of probability of exceeding. Soil profiles are full at sowing.**

| Region | 200 mm Plant Available Soil Water | | | 250 mm Plant Available Soil Water | | |
|---|---|---|---|---|---|---|
| | Mean | 80% | 20% | Mean | 80% | 20% |
| Gunnedah | 3.1 | 1.9 | 4.6 | 3.9 | 2.5 | 5.5 |
| Wee Waa | 3.3 | 2.0 | 4.8 | 4.0 | 2.7 | 5.7 |
| Bellata | 3.4 | 2.2 | 4.7 | 4.1 | 2.8 | 5.4 |
| Moree | 3.1 | 2.0 | 4.4 | 3.8 | 2.7 | 5.3 |
| Croppa Ck | 3.4 | 2.1 | 4.9 | 4.1 | 2.8 | 5.5 |
| Goondiwindi | 3.3 | 1.9 | 4.7 | 3.9 | 2.5 | 5.4 |
| Dalby | 3.4 | 2.0 | 4.7 | 4.1 | 2.8 | 5.2 |
| Biloela | 3.4 | 2.5 | 4.5 | 4.3 | 3.2 | 5.5 |
| Emerald | 3.5 | 2.4 | 4.4 | 4.2 | 3.1 | 5.2 |

**FIGURE 3: Change in expected mean crop yield with sowing date. Yields have been predicted using a single skip configuration and plant available water holding capacity of 200 mm.**




## Time of sowing

The length of sowing windows in dryland crops is often longer than for irrigated crops as the length of growing season is less for dryland cotton. Refer also to the *Crop establishment* chapter for more information on sowing time. While there is a trend for yields to slightly increase until late October planting, the optimum sowing time for most regions based on mean yields was from 15th October to the 15th November. In all regions mean yields of crops grown in single skip configuration were less when crops were sown early before the 30th September (Figure 3). The latest sowing date where there was no substantial penalty to average yield was the 15th November for all regions with the exception of the Darling Downs, where yield reduced after the 30th October. Later sowings within this window can give the crop more time to capture rainfall when the crop needs it most. Sowing times outside this window not only reduce mean yield but also increase potential yield variability. Further analysis of the simulated outcomes also highlighted higher average yields were attained with solid configurations in most locations with the later sowings (post 15th November). This is probably a result of the shortened season length where crops in skip row situations do not have the time to access the moisture located in the skip. Finally, you should consider the timing of crop maturity, which may be influenced by sowing, as rainfall at harvest can affect lint quality considerably.

## Conclusion

These analyses act only as a general guide to the potential yield and risks of dryland production for different regions. The outcomes and interpretation may change depending on several field specific factors. These include soil water holding capacity, starting soil moisture and costs. The most benefit comes from simulating a growers' specific conditions using their own soil type and costs. Further comments on management and financial considerations of dryland cotton and different row configurations in dryland cotton production are included in this manual. The use of Bollgard varieties has helped to reduce some of the risks associated with growing cotton, but dryland cotton still presents a relatively large risk. Crop simulation models such as OZCOT, combined with climate risk tools (Chapter 3) provide useful tools to help evaluate the risk.

## Other dryland cotton considerations

Further management information for dryland cotton can be found throughout this manual including:

- If you haven't grown cotton previously or recently, review the *New growers' checklist* Chapter 2.
- Dryland production systems require varieties that yield well in water limited situations – refer to Chapter 7.
- Cotton can be a useful rotation option in many dryland cropping systems. Refer to Chapter 6 for rotation and previous crop history considerations.
- Seasonal climate forecasts may offer opportunities to adjust crop management in light of probable weather trends. Responses can include modification to row configurations or fertiliser rates. Crop models can also be linked to climate data to assess potential risks with different forecasts. Refer to *Climate for cotton growing* chapter for more information.
- An integrated approach to insect, weed and disease management is important in ensuring cotton remains profitable. While biotechnology provides many benefits to the industry, it is important that the stewardship responsibilities (such as requirements for pupae busting) are understood; see Chapter 11 for insecticide and Bt stewardship, and Chapter 12 for herbicide stewardship.

**TABLE 4: OZCOT predictions, single skip row configuration – effects of two plant available soil water holding capacities on potential yield (bales/ha) and variability of yields, expressed in terms of probability of exceeding.**

| Region | 200 mm Plant Available Soil Water | | | 250 mm Plant Available Soil Water | | |
|---|---|---|---|---|---|---|
| | Mean | 80% | 20% | Mean | 80% | 20% |
| Gunnedah | 3.3 | 2.4 | 4.3 | 3.8 | 3.0 | 4.8 |
| Wee Waa | 3.4 | 2.4 | 4.4 | 4.2 | 3.2 | 5.0 |
| Bellata | 3.6 | 2.6 | 4.8 | 4.3 | 3.4 | 5.0 |
| Moree | 3.3 | 2.2 | 4.4 | 4.0 | 3.0 | 5.0 |
| Croppa Ck | 3.6 | 2.4 | 4.8 | 4.4 | 3.2 | 5.5 |
| Goondiwindi | 3.4 | 2.4 | 4.3 | 4.1 | 3.4 | 4.9 |
| Dalby | 3.6 | 2.5 | 4.4 | 3.9 | 3.1 | 4.6 |
| Biloela | 3.5 | 2.7 | 4.0 | 3.9 | 3.0 | 4.6 |
| Emerald | 3.5 | 2.5 | 4.5 | 4.3 | 3.1 | 5.2 |

**TABLE 5: OZCOT predictions, double skip row configuration – effects of two plant available soil water holding capacities on potential yield (bales/ha) and variability of yields, expressed in terms of probability of exceeding.**

| Region | 200 mm Plant Available Soil Water | | | 250 mm Plant Available Soil Water | | |
|---|---|---|---|---|---|---|
| | Mean | 80% | 20% | Mean | 80% | 20% |
| Gunnedah | 3.2 | 2.5 | 4.0 | 4.0 | 2.9 | 4.9 |
| Wee Waa | 3.4 | 2.3 | 4.6 | 4.2 | 2.7 | 5.2 |
| Bellata | 3.6 | 2.6 | 4.6 | 4.3 | 3.1 | 5.4 |
| Moree | 3.3 | 2.4 | 4.3 | 3.4 | 2.5 | 4.2 |
| Croppa Ck | 3.3 | 2.3 | 4.5 | 4.3 | 3.1 | 5.9 |
| Goondiwindi | 3.4 | 2.3 | 4.3 | 3.6 | 2.8 | 4.3 |
| Dalby | 3.2 | 2.2 | 4.0 | 4.0 | 2.7 | 5.2 |
| Biloela | 3.4 | 2.6 | 4.0 | 4.2 | 3.3 | 5.1 |
| Emerald | 3.4 | 2.4 | 4.2 | 4.1 | 3.1 | 5.2 |

- Full destruction of current crop residues and ongoing maintenance to remove any remaining 'ratoon'/stub cotton and volunteer cotton is important for pest and disease management, however can represent a significant cost in dryland cotton. Refer to Chapter 23.
- For an example of a dryland cotton gross margin refer to CottonInfo's gross margin budgets: www.cottoninfo.com.au/publications/australian-cotton-industry-gross-margin-budgets

**Useful resources:**

**Bange M.P., Carberry P.S., Marshall J., and Milroy S.P. (2005) Row configuration as a tool for managing rain–fed cotton systems: Review and simulation analysis.**

**Australian Journal of Experimental Agriculture 45(1): 65–77.**

**A summary of climate indicators can be found in the monthly CottonInfo newsletter update or receive the updates automatically by registering at www.cottoninfo.com.au**

**Bange, M.P., Caton, J., Hodgson, D., Brodrick, R., Kelly, D., Eveleigh, R., Marshall, J., Quinn, J. (2012). Expanded row configuration options for Australian dryland cotton. In: Proceeding of the 16th Australian Agronomy Conference, 14-18 October 2012, Armidale, New South Wales.**

**Milroy, S.P., Bange, M.P., and Hearn, A.B. (2004). Row configuration in dryland cotton systems: modification of the OZCOT simulation model. Field Crops Research 82:1-16.**

**Row spacing in dryland cotton: www.youtube.com/cottoninfoaust**

McGREGOR GOURLAY

# KNOWLEDGE INNOVATION PRODUCTIVITY RESULTS

*Pioneering the way in Eastern Dryland Cotton*
*"Wallangra Station", NSW.*

# Irrigation system choices & water budgets

Contributing authors: **Louise Gall** (Gwydir Valley Irrigators Association), **Janelle Montgomery** (CottonInfo), **Graham Harris** (Qld DAF), **Ben Crawley** (NSW DPI)

Water is a production input and the goal of good water management is to optimise production per megalitre of water. This is measured as water use efficiency (WUE) or water productivity.

## Water budget

Preparation of a water budget at the beginning of each season enables you to estimate how much cotton can be grown with the available irrigation water, stored soil water and forecast rainfall. To prepare a water budget you need to know:
1) Seasonal crop water requirements;
2) The climate and its variability; and,
3) The available water supply.

**Seasonal crop water requirements:** Estimating crop water requirements (crop evapotranspiration or ETc) is crucial for planning the planted area, crop mix and irrigation management. Table 1 shows the water requirements of a range of crops.

Daily crop evapotranspiration (ETc) is the water transpired by a crop and evaporation from the soil/crop surface in a day – expressed as mm/day. It is calculated by multiplying daily potential evapotranspiration (ETo) by a crop coefficient (Kc). Daily ETo is a function of radiation, air temperature, humidity and wind speed. Kc is a function of crop growth stage and soil surface moisture conditions. The total seasonal ETc is an accumulation of the daily crop ETc over the whole season – 1 ML/ha is equivalent to 100 mm depth on a hectare. Total seasonal ETc varies from crop to crop and year to year but will usually be within the range provided in Table 1.

### Best practice…

- **Plant available water capacity (PAWC) is the amount of water held in the soil between field capacity (full point) and permanent wilting point. Irrigation scheduling decisions should take place when soil moisture is between field capacity and refill point, known as the readily available water (RAW) (see Figure 1).**
- **A water budget for the farm can help inform planting decisions and optimise production per megalitre of water.**
- **Information is recorded each season to improve whole farm irrigation decisions including water volumes, water quality, PAWC and water use indices.**
- **Using standard indices and available tools to determine and benchmark water use efficiency over time will help identify opportunities to improve water use efficiency.**

### Water use efficiency…

**Water use efficiency is a generic term that describes the optimisation of production per megalite of water. The two most useful water use indices are:**

- **Irrigation water use index (IWUI) relates total production to irrigation water applied. This is a measure of irrigation management that does not account for rainfall or stored soil moisture and is therefore only useful for comparing between nearby fields or farms in the same season. It should not be used to compare where there may have been differences in rainfall received. Care should be taken to reference it as irrigation water use to avoid misunderstanding. IWUI can be applied at either a field or a farm scale.**
- **Gross production water use index (GPWUI) is the best water use index for comparing bales per megalitre between farms, regions and seasons. GPWUI relates total production (bales) with total water used, including irrigation, effective rainfall and used soil moisture. Measuring soil moisture use is difficult, but can be estimated. Rainfall is effective if it contributes stored soil water in the crop root zone (refer to WATERpak p6 for more details). GPWUI can be calculated at a field or farm scale.**

The daily ETc varies throughout the season in response to weather conditions, crop stage (canopy size) and soil water availability as shown in Figure 2. Typically, peak leaf area and maximum daily water use coincide approximately three to five weeks after first flower. Factors such as salinity, poor nutrition, soil compaction and pests or disease can reduce ETc and crop yield potential (WATERpak 2.1 p141).

**Useful resources:**

**WaterSched Professional – can calculate the theoretical daily and seasonal water use of a range of crops – https://waterschedpro.net.au/**

**IrriSAT – remote sensing determines site specific crop coefficients, providing local evapotranspiration (ETc) or daily crop water use – https://irrisat-cloud.appspot.com**

**GoSat – combines local weather data and forecasts with satellite imagery and analytics using CSIRO algorithms to forecast crop water use on a day-by-day basis – https://www.goannaag.com.au/gofield**

**Daily reference evapotranspiration derived from automatic weather station records and satellite measurements is available from the Bureau of Meteorology – http://www.bom.gov.au/watl/eto/**

Once you understand the potential water use of your crop, it can be adjusted for expected seasonal conditions. This requires knowledge of regional temperatures, median rainfall, the probability of above or below median effective rainfall and the impact of rainfall distribution on irrigation, dam supplies or extraction limits. To plan appropriately, investigate rainfall records as well as historic and current climatic patterns to help predict what sort of season to expect. Refer to Chapter 3. The Bureau of Meteorology (www.bom.gov.au/climate) or Australian CliMate (www.climateapp.net.au)

**FIGURE 1:** Plant Available Water Capacity.
(Source: WATERpak p149)

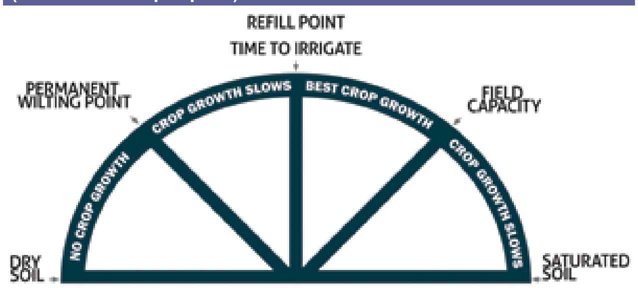


**TABLE 1: Water requirements of crops.** (Source: WATERpak Table 2.1.2)

| Crop | Crop evapotranspiration requirement[1] (mm) | Peak daily water use (mm/day) | | | Critical Irrigation Periods |
|---|---|---|---|---|---|
| | | $ET_0$ = 6 mm | $ET_0$ = 8 mm | $ET_0$ = 10 mm | |
| Barley** | 350 to 500 | 6.9 | 9.2 | | Shot – blade to late flowering |
| Chickpeas** | 350 to 500 | 6.0 | 8.0 | | 4 to 5 weeks after flowering |
| Cotton*** | 650 to 770 | 6.9–7.2 | 9.2–9.6 | 11.5–12 | Peak flowering and early boll development |
| Maize* | 600 to 850 | 7.2 | 9.6 | 12 | Tasselling through seed fill |
| Lucerne for hay** | 750 to 1500 | 6.9 | 9.2 | 12 | From one week after cutting to flowering |
| Navy beans** | 300 to 450 | 6.9 | 9.2 | 11.5 | Flowering |
| Peanut** | 500 to 700 | 9.2 | 9.2 | 11.5 | Flowering and pegging to pod maturity |
| Sorghum* | 450 to 850 | 6.0–6.6 | 8.0–8.8 | 10–11 | Boot to dough stage |
| Soybeans** | 500 to 775 | 6.9 | 9.2 | 11.5 | Flowering to leaf drop |
| Sunflower* | 600 to 800 | 6.9 | 9.2 | 11.5 | Once bud is visible, start of flowering and just after petal drop |
| Wheat** | 350 to 500 | 6.9 | 9.2 | | Boot stage and flowering until soft dough stage |

1. The crop evapotranspiration (ETc) is the demand that must be met by in-season rainfall, irrigation and stored soil water at planting. $ET_0$ = Evapotranspiration.
Sources: *Pacific Seeds 2006/07 Cropping yearbook. **Graham Harris, DPI&F, pers.comm. ***WATERpak 2001.

provide information on climate and seasonal progress and can be used to complement local farm data.

Finally, an understanding of available water supply includes soil water levels, irrigation water allocations, rainfall runoff, total storage capacity and ability to trade water. Review available water supply and consider what area to plant and how much to irrigate. The maximum area of crop that can be irrigated is determined by crop water requirements, the irrigation system capacity and efficiency, water availability and factors specific to the location, farm and grower.

## Calculating the area to irrigate

Area = Irrigation water available/annual crop irrigation water requirement × irrigation system efficiency.

### For example:

*A cotton crop might require about 800 mm (8 ML/ha) of water. Median rainfall during the season for this location is 350 mm (3.5 ML/ha), This means in a median year the crop irrigation water requirement is 4.5ML/ha.*

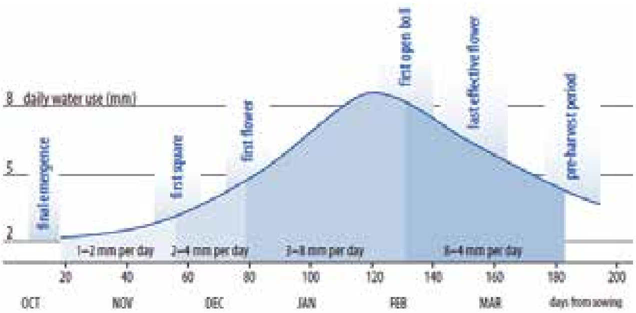
*At planting, the grower has 300 ML in storage and 700 ML of available allocation, totalling 1000ML. The grower estimates that another 500 ML will be harvested during the season. This means there is approximately 1500ML of irrigation water available:*

*Whole Farm Efficiency: 64%, i.e. 36% of irrigation water lost through deep drainage, in-field leaching and evaporation and seepage from on-farm storages and channels.*

*Area = 1500 ÷ 4.5 × 0.64 = 213 ha*

Studies undertaken to consider the area to dedicate to irrigated cotton production have found that at least 5–6 ML/ha of water supply is required in most regions. Irrigation water applied was found to range from 5.37 to

**FIGURE 2: Nominal seasonal Daily Water Use (mm/day) for cotton production.** (Source: WATERpak Figure 2.1.3)




8.9 ML/ha and was significantly influenced by rainfall received and the efficiency of irrigation systems. Refer to WATERpak Ch 3.3 and Table 3.3.1, pg 265.

**Useful resources:**

**CottonInfo: Preparing a Water Budget – www.cottoninfo.com.au/publications/water-preparing-water-budget**

**WATERpak Chapter 3.3 Water use efficiency, benchmarking and water budgeting, pp 18–21 – www.cottoninfo.com.au/publications/waterpak**

# Irrigation with limited water

Under normal water availability scenarios, most farms will fully irrigate. This means irrigation water is applied to completely meet evapotranspiration (ETc) or crop water demand over and above rainfall and soil water, with the aim of maximising yield. However, when water supply is limited, there are several management options available for growers:

- Fully irrigate a reduced area.
- Deficit irrigate a larger crop area (Chapter 16).
- Include different crops that require less irrigation.
- Partial irrigation of different row configurations.

Deficit irrigation occurs when less irrigation water is applied than that required to fully satisfy ETc. In this case, water stress occurs at some time(s) during the growing season. Irrigation applications should be timed to the most yield sensitive growth periods (peak flowering and boll fill). Canopy temperature sensors (CTS) used in combination with soil moisture probes in the GoField Plus range will help growers schedule limited irrigations to avoid water stress during peak flowering and boll fill (https://www.goannaag.com.au/). Different crops have different seasonal ETc requirements and thus crop choice, maturity length and planting time can be used to adjust to limited water.

If, when calculating the area of irrigated cotton, the irrigation water supply is pushed below 5–6 ML/ha, then partially-irrigated skip row may be an option (WATERpak pg 266). Skip row cotton provides an alternative to increase the area of cotton which can be grown, allowing an upside in production if conditions improve and less downside in potential fibre quality discounts if the season deteriorates.

## Impact of row configuration on yield, input costs and fibre quality

Cotton's vigorous tap root allows for extensive exploration of the soil profile for moisture and nutrients. This characteristic has led to the use of wide row configurations that increase the total amount of soil moisture available to the plants, allowing the crop to hold on for longer during dry periods. There are a range of different configurations being used by growers across the cotton industry in semi-irrigated situations. These include single skip, 1.5 m and 2 m (60 and 80 inch), double skip, super single, one in one out, as well as some non-uniform configurations (Figure 3). The positive and negative features of each configuration, including the relative water use efficiencies, depend on the individual differences in soil type and soil moisture, environment, cropping history, machinery, water availability and other factors. The row configuration chosen in combination with the seasonal conditions experienced will influence the likelihood of fibre quality discounts. Refer to Chapter 4 (*Dryland*).

In some cases, inherent characteristics such as soil type and location may mean there is minimal advantage in adopting skip row practices. When considering skip row plantings, it is important to consider the following:

**Single Skip** has the lowest risk of losing yield when conditions are favourable. It will, however, also use its moisture profile the quickest. Having a plant row 50 cm one side and one metre skip to the other, single skip will enjoy some benefits of 'partial root zone drying.' It is best suited to heavier soil types with high plant available water capacity (PAWC) and more irrigation water availability.

**Double Skip** provides more insurance against lower yields when compared to single skip, especially when conditions are less favourable. Having a plant row 50 cm one side and a 1.5 m skip row to the other, double skip provides the benefits of 'partial root zone drying' which toughens the plant. It is best suited to drier profiles and hotter environments. Vigorous growth and fruiting from vegetative branches taking advantage of extra light in the skip may cause difficulty at picking.

**Super Single (one-in-two-out)** has been grown in semi-irrigated situations. The widely spaced plant rows 3 m apart means the yield and potential upside in a good season is severely limited. However, it may be an option when there is a full soil moisture profile at planting and where there is a high chance of severe water limitation during flowering and boll fill due to minimal irrigation water resources or forecast rainfall. Super single allows growers to minimise growing costs as well as limit the likelihood of fibre quality discounts.

**One-in-one-out (1.5 or 2 metres)** cotton is shown in Figure 3. Experience has shown yield potential is similar to or slightly higher than double skip, but it may be more prone to fibre quality discounts because it

**FIGURE 3:** Row configuration guide.
(Source: CSD Getting the most out of skip row irrigated cotton)

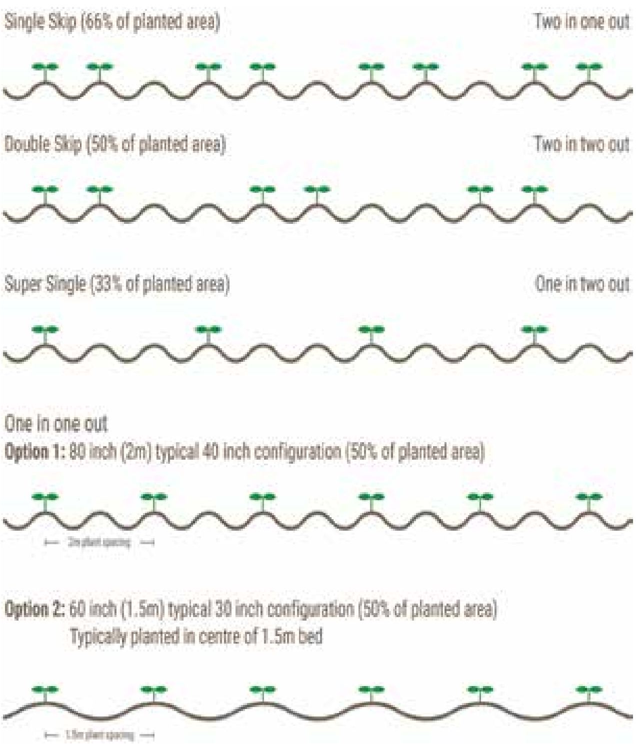
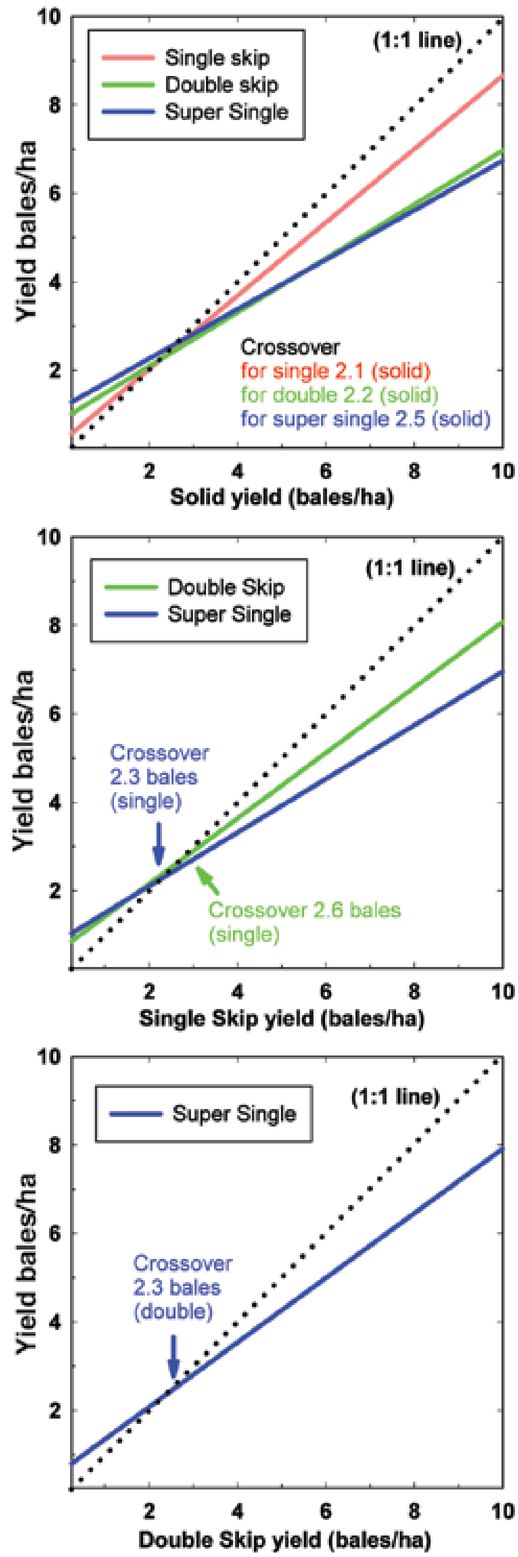



**FIGURE 4:** Average yield comparison.
(Compiled by M. Bange 2012)



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does not have the advantage of mild early stress. A more uniform growth habit can reduce lodging; allow better spray penetration and defoliation when compared to double skip. If irrigation water becomes available both 1.5 or 2 m plantings can be irrigated to increase yield potential.

Variable row spacings have been tried, but the non-uniform nature of these plantings can lead to variable maturity which can be difficult to manage. Consistent spacing across the field will deliver more uniform plant growth. Figure 4 provides a comparison of the average yields of various row configurations. Responses are generated from long-term and controlled comparisons. The crossover point refers to the average yield potential at which there is no further improvement in the yield of a particular configuration compared to the configuration stated on the bottom of each graph. For example, in the middle graph, the average yield potential at which single skip outperforms double skip is 2.6 bales/ha.

As shown in Figure 4, skip row cotton limits yield potential compared to solid plant stands, but when water is limited skip row plantings will deliver greater surety in yield and increase the potential to achieve base grade fibre quality. Skip row cotton will provide savings for variable input costs of seed, insecticides, defoliants and picking, which in combination with yield and quality can often lead to a better risk/return proposition. A lower yielding wider row cotton crop can at times give a better gross margin than a higher yielding crop on a narrower configuration. Gross margin is not just a function of the yield produced, but a combination of yield, quality and input costs associated with the row configuration chosen.

**Useful resources:**

**CottonInfo Webinars: What does it take to yield well with limited water – www.youtube.com/CottonInfoAust**

**Canopy Temperature Sensors**

**SIP2 Podcast – https://smarterirrigation.com.au/plant-based-sensing-optimising-irrigation-timing-in-limited-water/**

**GVIA – www.gvia.org.au/community-and-industry-initiatives/irrigation-efficiency/optimised-irrigation-row-comparison/**

**CottonInfo Irrigation toolbox series – https://www.cottoninfo.com.au/publications/ irrigation-toolbox-series-overview**

## Water use efficiency, irrigation system efficiencies and water accounting

Irrigators are constantly striving to maximise the productivity of every drop of water. Measuring and monitoring the efficiency of irrigation across fields and the farm as a whole is important to identify potential areas for improvement. Water use efficiency is a generic term that encompasses a number of performance indicators including water use indices and irrigation system efficiencies.

Irrigation system efficiencies compare water output to a water input at different points of the irrigation system of the farm as a whole, and are expressed as a percentage. The three most widely used system efficiencies as detailed in WATERpak pp11–12 are:

- **Application efficiency:** Relates to the amount of water supplied to the field and the amount of water available to the crop. There are a range of flow meters available to measure water received at the field for both surface and overhead systems. In fully irrigated furrow fields irrigation usually aims to fill the soil moisture deficit as shown in Table 2. In recent years with new field designs, a significant number of fields now practice tailwater recycling, this has the potential to increase field application efficiency (Table 2). To calculate the volumetric efficiency of the tailwater return system it is important to consider the tailwater leaving the field and the distribution losses before reuse. Losses including runoff, drainage and evaporation will influence the amount of water available to the crop but are difficult to measure.
- **Field canal/conduit efficiency:** Assesses the on-farm distribution system and relates water received at the field inlet to the water received at the farm gate and accounts for losses in storages and channels. Storage meters are available to complement meters used to measure water sourced from rivers, bores or overland flow. The same methodology of comparing water input to water output can be applied to the individual

**Choosing the appropriate row spacing and monitoring soil moisture will improve the efficiency of fully or semi-irrigated cotton.**
**(Photo: Lou Gall GVIA)**

components of the on-farm distribution system (such as individual storages or channels) and is discussed further in WATERpak Chapter 1.6.

- **Whole farm efficiency:** Combines application and field canal efficiencies. Estimating whole farm irrigation efficiency is complex, involving an understanding of the irrigation water availability to crop needs for each irrigation, on each field on the farm. Collating information on several fields and incorporating tail water recycling further complicates the efficiency measure.

Water accounting which tracks irrigation water and estimates the proportion actually used by the crop across the whole farm, does provide an estimate of farm irrigation efficiency. A detailed example can be found in WATERpak p13 table 1.2.2. The 'Benchmarking water productivity of Australian irrigated cotton' project has used gross production water use index (GPWUI) and whole farm irrigation efficiency (WFIE) in their analysis of the industry's irrigation performance. The equation used to calculate WFIE in the project is as follows:
*WFIE = (crop water use – effective rain – soil moisture)/irrigation water used on farm*

The 2019 'Benchmarking water productivity of Australian irrigated cotton' report found that whole farm irrigation efficiency (WFIE) had improved from 70% in 2006–07 and 2008–09 to 81% in 2017–18 (Figure 5). The project found that much of this can be attributed to reduced losses in storages. Critically, however, any comparisons between seasons must consider rainfall. More detail is available in the NSW DPI Primefact. (www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/1185288/Benchmarking-Water-Productivity-of-Australian-Cotton.pdf)

A simple first step to understand water use across your farm is to develop a water account showing water inputs, crop water use and the key WUE indices of IWUE and GPWUI. There are software packages such as WaterTrack which can assist with this. Consultants like Aquatech Consulting can help put together a whole farm water balance and can then advise on the type of works and cost to reduce losses.

**Useful resources:**

**CottonInfo factsheets:**

**- Irrigation benchmarking**

**- Calculating water use indices to benchmark water use efficiency: www.cottoninfo.com.au/water-management**

**Silo Climate Data: https://legacy.longpaddock.qld.gov.au/silo/**

**BOM: www.bom.gov.au/watl/eto/about.shtml#introduction**

**WaterTrack: www.watertrack.com.au/**

**Storage Seepage and Evaporation: https://eprints.usq.edu.au/23245/**

**WATERpak 1.2 Water use efficiency benchmarking and water budgeting pg 4.**

**www.cottoninfo.com.au/publications/waterpak**

**Water Productivity: https://www.dpi.nsw.gov.au/agriculture/irrigation/irrigation/irrigation-primefacts/benchmarking-water-productivity-of-australian-cottonprimefact**

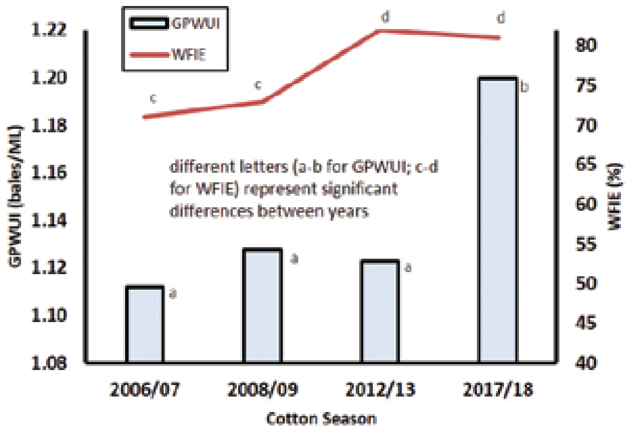
**GoannaAg: www.goannaag.com.au/**

# Irrigation systems

The four most used cotton irrigation systems are the two surface irrigation systems; siphon and bankless channel or siphon-less, and the two pressurised systems; overhead irrigation (centre pivots and lateral moves) and surface or sub-surface drip. These systems have been compared in the grower-led Keytah System Comparison project at Moree, NSW, since 2009. The comparison provides a commercial assessment of the yield and water use efficiency of these four irrigation systems as measured using the standard Gross Production Water Use Index (GPWUI) as shown in Figure 6.

GPWUI includes soil moisture, rainfall, irrigation water and yield which makes it the most useful indicator for long-term comparisons of performance between seasons, regions and farms as it accounts for climatic variation between seasons and all sources of water. The research has found that performance is influenced more by season than by system selection. Seasonal variation in yield was 3.4 bales/ha, but there was only 0.06 bales/ha variation between systems (not including new 2021 development W567). GPWUI variation between seasons was 0.43 bales/ML compared to 0.09 bales/ML between systems. Importantly, optimising existing systems may be the most appropriate change to make to improve irrigation performance on your farm.

**FIGURE 5: Gross Production Water Use Index (GPWUI) and Whole Farm Irrigation Efficiency (WFIE) productivity trends 2006–2018. Different letters represent significant differences in analysis of variance.**




## Siphon irrigation

Siphon irrigation is the primary system used by the Australian cotton industry, but labour resourcing is forcing some growers to look to alternatives. Typically, 60 to 80% of the water applied to the field is used by the crop, the remainder is recycled as tailwater runoff or lost to deep drainage (more significant in lighter red soils).

Siphon irrigation is continually improving. Work conducted by Gillies (2012) and Montgomery and Wigginton (2007) measured application efficiencies as high as 90% for individual irrigation events, but there is significant variation between farms and between fields. Small management changes and an understanding of soil infiltration properties can help optimise siphon irrigation and significantly increase water use efficiency. Lighter soils tend to have a high final infiltration rate, while heavy clay soils typically have a lower final infiltration rate. Flow rates from traditional siphons are influenced by siphon placement, furrow entry conditions, and supply head height. Flow through siphons increases as head increases and decreases as head decreases. Many growers are working to optimise siphon irrigation using siphon flow meters, water advance sensors, channel level sensors or systems such as SISCOweb to ensure profiles are effectively wet and deep drainage minimised. The understanding of application uniformity has improved, and use of irrigation scheduling and electromagnetic surveys has increased.

## Automation with small pipe through bank (PTB) or smart-siphons

The challenges of labour resourcing and timely irrigation management are driving efforts in automated siphon irrigation. Automation has the potential to more precisely target irrigation to crop demand, improve application uniformity and distribution, avoid stress caused by waterlogging or delayed irrigation.

Small PTBs are where permanent 75–90 mm pipes are installed through the head ditch. Each pipe is placed at a consistent level through the head ditch which ensures even flow rates through the pipes for specific head heights. There are three basic forms all of which still require rotobucks:

- **Standard SPTB:** The head ditch is split into sections, with each section filled from the supply channel by a gate fitted with automation.
- **Double head ditch SPTB:** Water is delivered from the main head ditch via a single outlet into a second head ditch split into sections. The second head ditch is fitted with SPTB as at "Waverley", Wee Waa.
- **Smart siphon:** SPTB are fitted with rotating elbows which are remotely controlled on or off in gangs of up to 150 siphons as installed at "Keytah", Moree.

All the SPTB options reduce the labour requirements and have the potential to be fully automated. Utilisation of channel level sensors, water advance sensors, and soil moisture monitors will further aid in achieving improved water use efficiency.

**Useful resources:**

**CottonInfo: Knowledge of furrow irrigation infiltration characteristics is key p13 Irrigation and N tour booklet – FINAL.pdf (cottoninfo.com.au)**

**Surface irrigation – Key factors to consider when improving furrow WATER: Evaluating furrow irrigation performance I CottonInfo WATER: Calculating water use indices to benchmark water use efficiency I CottonInfo**

**CottonInfo YouTube: Optimising furrow irrigation with SISCOweb – https://youtu.be/-saHo7ZdQhY**

**Moving to an autonomous irrigation system and Automated small pipe irrigation system – https://youtu.be/bmItNZYXkMA**

**Siphon placement – https://youtu.be/wswKV4kSzn8**

**WATERpak: Ch 5.2 Developing a surface irrigation system pg 355.**

**Ch 5.3 Surface irrigation performance and operation pg 365.**

**www.cottoninfo.com.au/publications/waterpak**

**Keytah System Comparison – www.gvia.org.au/community-and-industry-initiatives/irrigation-efficiency/keytah-system-comparison/**

**More Profit per Drop – https://moreprofitperdrop.wordpress.com/?s=bullamon+plains**

**CRDC: Gillies, M. 2012. "Benchmarking furrow irrigation", The Australian Cotton Water Story, Cotton Catchment Communities CRC – www.crdc.com.au/publications/australian-cotton-water-story**

**Gwydir Valley Irrigators Association Inc – Keytah System Comparison – gvia.org.au**

**Ch 5 Precision Agriculture: Technology and Economic Perspectives – https://static1.squarespace.com/static/59af474b197aea0fbfcf6be1/t/5bfcb59370a6ad6baf50896e/1543288629910/Precision+Ag+Technology_Springer+Dec+2017.pdf**

**Smarter Irrigation for Profit 2 – https://smarterirrigation.com.au/malcolm-gillies-and-joseph-foley-from-usq-talk-about-sisco-at-the-gvia-field-day/ https://smarterirrigation.com.au/automated-broad-acre-irrigation-with-small-pipe-through-bank-sptb/**

## Bankless channel or siphon-less irrigation

Bankless channel or siphon-less irrigation systems are designed to address labour resourcing, energy use and the reuse of tailwater. Generally, the field is split into bays and watered at a high flow rate. All furrows in a bay are irrigated at once without siphons or rotobucks. The most basic siphon-less systems principally remove the need for siphons and aim to minimise soil movement in the transition from siphon to siphon-less. There are different approaches being implemented, some with tail water reuse design and others that use existing tail drains and still pump tailwater. The continuous reuse of tail water in adjacent bays can potentially improve application efficiency, reduce water loss from channels, and reduce pumping costs. The removal of rotobucks will reduce labour and enhance efficiency of cultivation. There are many different designs. Growers should discuss their specific needs with an irrigation designer to ensure that the design chosen fits with management requirements, soil type and slope.

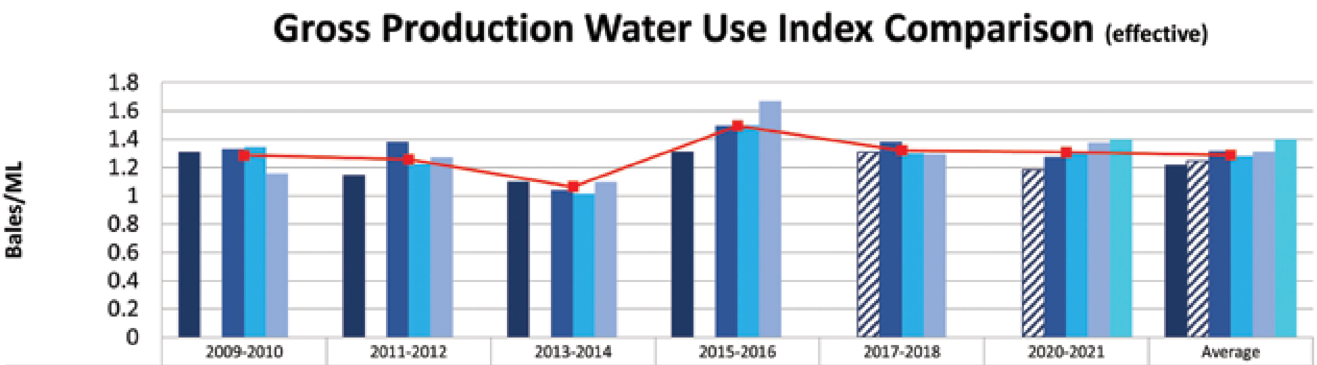
### Considerations for system choice

- **Slope:** If field slope is steeper than 0.3%, (1:333) a siphon system must be used.
- **Flowrate:** A supply rate of at least 24 ML/day is required.
- **Soil characteristics:** Soil with a very slow infiltration rate will limit choices.
- **Topsoil:** Minimise topsoil movement.

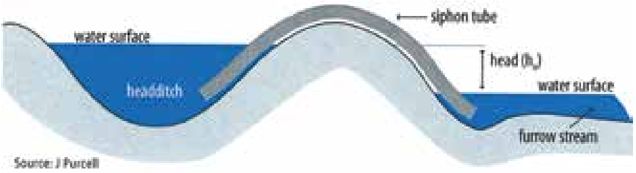
### Some of the common designs are:

- **Large PTB:** Hand siphons are replaced by a large diameter gated pipe. The rotobuck area is excavated to create a distribution basin for the water to level out and enter all furrows. A 250 mm diameter pipe will supply 12 furrows, while a 750 mm pipe can supply 100 furrows. A large rotobuck is placed between each pipe outlet.
- **GL bays**: The furrow direction is rotated 90 degrees. The new head ditch is below ground, looking exactly like a tail drain. The head ditch fills and water enters the furrows. A check bank runs through the field to the tail drain, with the tail water backed up by bay outlets. There is a 200 mm drop between each section, allowing head ditch water and tail water to cascade from bay to bay. GL Bays design was developed by Glenn Lyons, GL Irrigation Pty Ltd. (Thank you Glenn Lyons for providing this information.)

**FIGURE 6:** Keytah system comparison GPWUI summary




| | 2009-2010 | 2011-2012 | 2013-2014 | 2015-2016 | 2017-2018 | 2020-2021 | Average |
|---|---|---|---|---|---|---|---|
| Siphon | 1.311528853 | 1.146410968 | 1.1018934 | 1.312808442 | | | 1.218160416 |
| Smart Siphon | | | | | 1.308494488 | 1.184403654 | 1.246449071 |
| Lateral | 1.33205435 | 1.382419592 | 1.041476581 | 1.495110087 | 1.380410184 | 1.275520137 | 1.317831822 |
| Drip | 1.346320977 | 1.223956235 | 1.016774259 | 1.498783298 | 1.300161585 | 1.305067787 | 1.281844023 |
| Bankless | 1.158732077 | 1.272085183 | 1.098994364 | 1.671525806 | 1.2936638 | 1.376813999 | 1.311969205 |
| W567 Bankless | | | | | | 1.400674534 | 1.400674534 |
| Average | 1.287159064 | 1.256217995 | 1.064784651 | 1.494556908 | 1.320682514 | 1.308496022 | 1.288649526 |




**Siphon placement is important to improve uniformity of application and irrigation efficiency.** (Drawing Jim Purcell)

- **Rollover bays:** This can be flat bays with rollover banks or furrows across bays with rollover banks. The existing field or series of fields are cut up into level bays. Each level bay has a furrow length of 400 m and width of 500 m. This 20 ha pond is filled with water from each end until the water meets in the middle. The tail water and new supply water is then drained into the next bay which is 150 mm lower.
- **Siphon-less with tail water backup:** Hand siphons are replaced with a large PTB or single rubber door type bay outlet. The rotobuck area is excavated to create a distribution basin for the water to level out and enter all furrows. The rotobuck /check bank continues through the field to the module pad. A rubber door type bay outlet holds tail water in the section, so it backs up the dry furrows.

**Useful resources:**

**Siphon Irrigation Field Day 2019: www.cottoninfo.com.au/publications/irrigationsiphon-less-irrigation-field-day-booklet**

**www.gvia.org.au/community-and-industry-initiatives/industry-partnerships/siphon-less-irrigation/**

**CottonInfo: Going bankless a grower's perspective: www.youtube.com/cottoninfoaust**

**WATERpak Chapter 5.4 Bankless Channel Irrigation Systems page 388 www.cottoninfo.com.au/publications/waterpak**

**CottonInfo Bankless channels – Turkey Lagoon case study: www.cottoninfo.com.au/water-management**

**More Profit per Drop: Bankless Channels – Bullamon Plains case study and video: https://moreprofitperdrop.wordpress.com/?s=bullamon+plains**

**Consultants and designers**

**Aquatech Consulting: www.aquatechconsulting.com.au/**

**SMK Consultants: www.smk.com.au/**

**PCTAg: http://pct-ag.com/packages-pricing/**

**Tahlee Consulting Services: E: bernie@tahlee.com.au**

**GL Water Services: E: glennlyons@bigpond.com**

**Peter Leeson Pty Ltd: E: peter@peterleeson.com.au**

**NJC Irrigation solutions: E: admin@njcis.com.au**

## Overhead irrigation, centre pivots and lateral moves

Overhead irrigation is a 'just in time' irrigation system. It uses a whole of system management approach and requires different management in terms of agronomy, irrigation schedules and application volumes. Overhead irrigation has the potential to produce very good yield and water use efficiency. However, it is essential that overhead systems are installed with the capacity to meet the peak crop demands and that system performance is monitored to ensure uniform application. Staff will need training, and service technicians must be readily available to manage in-season breakdowns and to ensure that the system is maintained at optimal performance.

Overhead systems remove the need for rotobucks and do not require furrow or bed development, reducing land preparation and increasing suitability to other crop options. However, they have higher operating energy costs, higher capital set up costs and higher service and maintenance requirements compared with surface irrigation options. Savings of up to 30% have been found where overhead machines have replaced surface irrigation, however these savings can be offset by higher energy and capital costs and must be balanced with water reliability. Water savings depend on the performance of the existing irrigation system, soil type and the seasonal conditions. A well performing surface system can be as efficient as an overhead irrigation system. Optimisation of an existing system should be considered before investing in an alternative system.

### Critical considerations:

- Ensure the overhead system has managed system capacity to meet peak crop water demand.
- Overhead system performance must be checked at commissioning and regularly after installation.
- Overhead systems should be operated at optimal pressure to avoid unnecessarily high running costs.

**Useful resources:**

**CottonInfo: Smith P., et al (2014) "A Review of Centre Pivot and Lateral Move irrigation installations in the Australian cotton industry", NSW Department of Primary Industries: www.cottoninfo.com.au/water-management**

**WATERpak Chapter 5.5 Centre Pivot and Lateral Move Systems pg 392. www.cottoninfo.com.au/publications/waterpak**

**IAL Centre Pivot & Lateral Move Irrigation Course: www.irrigationaustralia.com.au/training**

**More Profit per Drop: Qld DAF Growers Guide to Centre Pivots and Lateral Moves: https://moreprofitperdrop.wordpress.com**

## Surface and sub-surface drip irrigation

Surface and sub-surface drip irrigation (SDI) is a low pressure, low volume system involving the application of water through emitters with a discharge designed to meet the crop evapotranspiration demand. Sub-surface drip tape is laid permanently and has been documented to last for 10–15 years. Surface drip is laid just below the soil surface. Recently available systems include gravity fed designs and fully modular low-pressure systems. Both use tape that is removed and recycled on a seasonal basis (tape costs approximately $1,000/ha annually).

Drip systems can provide very good irrigation efficiencies but do require different management in terms of agronomy, irrigation schedules and application volumes compared to surface irrigation. To ensure that drip irrigated cotton systems provide improvements in labour, yield and water use efficiency, care should be taken to warrant that the system has the appropriate pumping and filter capacity to meet peak crop water requirements.

**TABLE 2: Application Efficiency**

| | Irrigation completely fills soil profile | Irrigation completely fills soil profile and recycles tailwater |
|---|---|---|
| Soil moisture deficit before irrigation (mm) | 70 | 70 |
| Soil moisture deficit after irrigation (mm) | 0 | 0 |
| Water delivered to rootzone (mm) | 70 - 0 = 70 | |
| Total water applied (mm) 1.2 ML/ha = 120 mm | 120 | 120 |
| Tailwater available for reuse (mm) | | 25 |
| Net water applied | | 120 - 25 = 95 |
| Application Efficiency (Ea) | 70/120 = 58.3% | 70/95 = 73.7% |

Adapted from WATERpak p11

A system setup with limited capacity will struggle to yield and hence achieve the desired GPWUI targets. Where permanent drip systems are being installed it is important that there is reliability in water supply from year to year to justify the significant capital investment. Where water reliability is low the disposable surface drip options may be more suitable. It is critical that best management practices in design, installation, management and maintenance of drip irrigation systems are followed – if not, then profitable investment in these systems is unattainable.

**Useful resources:**

**Raine, S.R., Foley, J.P. and Henkel, C.R. (2000). Drip irrigation in the Australian cotton industry: a scoping study. NCEA Publication 179757/2. USQ, Toowoomba: www.insidecotton.com**

**More Profit per Drop website has a range of articles discussing SDI: https://moreprofitperdrop.wordpress.com/2012/04/10/growers-guide-to-centre-pivotsand-lateral-moves-released/**

**WATERpak Chapter 5.6 Drip Irrigation: Design, installation and management Table 2 www.cottoninfo.com.au/publications/waterpak**

**WaterQuip: www.waterquipmoree.com.au/**

**Drip gravity Micro irrigation https://ndrip.com/ Netafim Modnet https://www.netafim.com.au/**

### System changes

Before replacing an existing irrigation system with an alternate design, it is important to assess the performance and optimisation of the existing system, to be sure that changing is warranted. A well-designed irrigation system should:

- Maximise the amount of water placed into the crop root zone from water pumped.
- Distribute the water uniformly across the field.
- Be capable of meeting peak crop water use.
- Be suitable for your soil type, topography, mean seasonal rainfall and irrigation water reliability
- Have minimal energy and labour inputs.

**TABLE 3: Guide to irrigation system costs** (adapted from IAL: Peter Smith, Sapphire Irrigation Consulting)

| Irrigation type | Capital costs $/ha | Irrigation efficiency (% approx.) | Expected life (years) | Labour requirement | Electricity costs per kWh ($) | | Diesel costs per litre ($) | |
|---|---|---|---|---|---|---|---|---|
| Energy price ($) | | | | | 0.20 | 0.30 | 1.30 | 1.60 |
| Siphon* | 4500–6000 | 50–80 | 25+ | High | 8.82 | 13.23 | 15.36 | 18.91 |
| Lateral move** | 3000–7000 | 80 | 15+ | Low | 26.46 | 39.68 | 46.08 | 56.72 |
| Centre pivot*** | 3500–7000 | 80 | 15+ | Low | 52.91 | 79.37 | 92.17 | 113.44 |
| Subsurface drip | 7000–9000 | 85 | 15+ | Low | 44.09 | 66.14 | 76.81 | 94.53 |

* Siphon capital costs includes land prep, surveying, earth works, furrow installation and infrastructure.
** Lateral move with gravity fed channel - 1.5 times length of LM run.
***Centre Pivot with pump motor and main - 1.5 times CP length.
Prices are indications and the table should be used as a guide only.
Capital costs per ha is a common range not including unusual extremes.
Irrigation efficiency is an estimate of typical, practical overall system efficiency with good management attained over several years with good maintenance. It is not peak possible efficiencies.
Labour requirements are estimates to properly operate and maintain a system.
Assumed pump efficiency = 70%
Derating factors: Electric 14%, diesel 20%.
Assumed fuel consumption = 220 g/kWh = 0.26 L/kWh.

**TABLE 4: Grower-led Keytah systems comparison estimated costing**

| Irrigation type | Capital set up ($/ha) | Annual operating costs ($/ha/annum) | Comments |
|---|---|---|---|
| Siphon | $1,500 | $150 - $175 | Capital set up includes land preparation and minimal supply infrastructure<br>Siphon irrigation was the most consistent yielding system regardless of seasonal conditions<br>GPWUI were comparable to other systems.<br>Siphons have low operating energy, maintenance and capital setup cost. |
| Small pipe through bank (automated smart siphons) | $1,500 plus $800 - $1,100 | $65 | Setup costs for automation of existing siphon fields will be influenced by the approach chosen, field dimensions and the row configuration 30 inch vs 40 inch (0.75 m vs 1 m).<br>Permanent small pipe through bank will address labour resourcing, improve application uniformity and help optimise siphon irrigation. |
| Bankless | $1,500 - $2,500 (land preparation) plus $1,200 (infrastructure and automation) | $20–$25 | Costs for land preparation will vary depending on the amount of soil being moved. Infrastructure cost vary depending on equipment being installed<br>Low operating costs are attributed to minimal labour and energy cost.<br>The Keytah system comparison trial found that the bankless channel system produced yield and GPWUI comparable to the other three systems under review. |
| Lateral move | $4,000 - $6,000 | $260 | The lateral move has consistently produced high yield and GPWUI throughout the trial.<br>Operating energy, maintenance and capital setup costs are more than for surface irrigation systems.<br>Overhead irrigation requires completely different management in terms of agronomy, irrigation schedules and application volumes compared to surface irrigation. |
| Drip | $9,000 | $275 - $1,275 | System setup will impact on yield potential.<br>Drip systems have high operating energy, maintenance and capital setup costs compared to other systems.<br>Where surface tape is used annual replacement cost is approx. $1,000/ha<br>Overhead irrigation requires completely different management in terms of agronomy, irrigation schedules and application volumes compared to surface irrigation. |


Siphon-less irrigation may be suitable. Discuss your needs with a designer, (Photo: Andrew McKay CottonInfo)

Table 3 provides a comparison between irrigation systems. This information may assist in planning and design. A breakdown of capital (set-up) and annual operating costs from the grower-led Keytah systems comparison trial is presented in Table 4. A 'with' and 'without' scenario analysis with support from a suitably qualified agribusiness financial advisor is a robust method to assess the economic and financial performance of investment in an alternative system. The 'with' and 'without' approach involves four steps:

1. Prepare a whole farm profit analysis for the current farming system ('without' scenario) and one with the alternate system ('with' scenario).
2. Undertake a financial analysis over the life of the investment for the 'with' and 'without' scenarios.
3. Complete an economic analysis to compare the internal rate of return and the net present values for the 'with' and 'without' scenarios.
4. Perform a marginal analysis to calculate the marginal return and payback period for the investment.

When considering moving to a siphon-less design such as Large PTB, GL Bays, rollover bays, or siphon-less with tail water backup, it is important to discuss your requirements with a designer. Some rules to remember are:

- **Slope:** If field slope is steeper than 0.300%, (1:333) a siphon system must be used.
- **Flowrate:** A supply rate of at least 24 ML/day is required.
- **Soil characteristics and variability:** Soil with a very slow infiltration rate or significantly different soil types will impact design.
- **Topsoil:** Minimise topsoil movement.
- **Automation:** Choose gate and pipe infrastructure which has the potential to be automated now or into the future.

When considering investing in overhead or drip systems ensure that you:

- Conduct a 'with or without' financial assessment.
- Determine the system capacity needed to satisfy peak crop demand.
- Ensure operating pressure is minimised while still allowing optimum system performance. Energy costs are an increasing component of operating costs and may affect the financial viability of these systems.
- Expect to invest significant time in planning, training and set up. It will take several years to maximise the performance of an overhead or drip system.
- Check the performance of systems after installation and at regular intervals.
- Get good advice on the financial, management and tax implications of such a large investment.
- Consider the reliability of your irrigation water and the implications for seasons when water is not available.
- Obtain a 'site specific' system design tailored to match the environment (soil characteristics, topography) and management requirements.

## System advantages and disadvantages

The decision on which system is right for you will be driven by soil, climate, management requirements and the availability of the resources of water and labour. Each of the systems covered in this chapter has a range of advantages and disadvantages as detailed in Table 5. Growers should consider which aspects are most important for their operations and use this to guide their system decisions. The Keytah system comparison project is a partnership between the Gwydir Valley Irrigators Association (GVIA) and Sundown Pastoral Company. It has been possible through funding from the CRDC and the Federal Government Rural R&D for Profit program.

**TABLE 5: System advantages and disadvantages**

| System | Advantages | Disadvantages |
|---|---|---|
| Traditional siphon | Lower capital set up costs. | High labour requirements. |
| | Dominant system that can produce high yields and GPWUI if optimised. | |
| Automated siphon | Reduced labour requirements to traditional siphons. | Increased cost compared to traditional siphon. |
| | More uniform application and improved efficiency. | Positioning roto-bucks in line with pipes through banks. |
| | Potential for remote control or automation. | |
| Bankless channel and siphon-less | Reduced labour and potential for automation. | Not suitable for paddocks with varying soil types. |
| | Improved machinery efficiency – no need for rotobucks or driving through ditches during spraying and picking. | Need suitable slopes and can require significant removal of topsoil in some locations. |
| | Limited maintenance – tail drains are graded every 2–3 years. | Installation costs can involve significant earth work. |
| | Potential to re-use tailwater and improve water use efficiency. | Structures can be costly. |
| | | Less understanding of the water use efficiency of these systems. |
| Overhead irrigation | Potential for improved yield and water use efficiency (GPWUI). | High capital set up costs. |
| | Potential for increased rainfall infiltration. | Just in time irrigation system requires skilled labour for servicing and breakdown management. |
| | Reduced potential for runoff and deep drainage. | High energy costs to pressurise water. |
| | Flexibility to fit a broad range of crops. | |
| | Improved machinery efficiency. | |
| | Potential to improve fertiliser use efficiency. | |
| Surface or Sub-surface Drip | Potential for improved water use efficiency. | High capital set up costs. Surface tape requires annual replacement. |
| | Potential to control runoff and minimise deep drainage. | Just in time irrigation system requires skilled labour for servicing and breakdown management. |
| | Potential to increase rainfall infiltration and reduce soil surface evaporation. | High energy costs to pressurise water. |
| | Enhanced fertiliser efficiency. | Additional care required with cultivation. |

Overhead irrigation, such as centre pivots or laterals, has higher establishment costs but potential for improved yield and water use efficiency.

## Best practice…

- Evaluate full potential performance of existing system before changing to alternative systems. Performance is impacted more by seasonal conditions than by system.
- When assessing an alternative investment consider yield and prices risk, the extent of water savings and reliability of water supply, likely impact of changing energy costs, and availability of labour.
- Identify site specific constraints of existing infrastructure and design accordingly.
- Full potential of overhead and drip systems is only possible if installed with the capacity to meet peak crop demand and regular audits are conducted to ensure uniformity of application.
- When evaluating irrigation systems, Gross Production Water Use Index (GPWUI) is the best water use index for comparing bales between farms, regions and seasons. This relates total production (bales) to the total amount of water used, from all sources including irrigation water, effective rainfall and soil moisture.
- Successful integration of a new system will require a change in mindset and practices.

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# Field selection and cover crops

**Acknowledgements: Hayden Petty (Summit Ag), Steve Buster (RivCott/Summit Ag), Susan Maas (CRDC), Michael Braunack (CSIRO), John Bennett (USQ), David Lawrence (Qld DAF), Paul Grundy (Qld DAF/CottonInfo), Allan Williams (CRDC) and Oliver Knox (UNE/CottonInfo).**

## Cotton soils

There are several considerations when determining if a soil is suitable for cotton. Crops are more likely to produce high yields when their roots can grow freely in well-structured soils. Good structure will also enable water infiltration and internal drainage to occur throughout the season and quickly re-establish aeration after irrigation and/or rainfall. Structure will also influence the plant available water capacity (PAWC), which needs to be sufficiently large to meet the moisture requirements of the crop. For example, soils that have a high PAWC, such as clay-rich alluvials and deep black earths, allow a longer interval between furrow irrigations. Similarly, under dryland conditions, starting out with a full profile in these soil types can delay the onset of moisture stress in crops.

The alluvial soil types, black earths and the better structured grey and brown clays, with their extensive cracking, provide favourable conditions for vigorous root growth. In contrast, soil types with dense, sodic subsoils have poor profile permeability (the ability of water to move through the soil), and hence limit root development. Structural damage due to excessive traffic or tillage at high moisture content is likely to create large platy clods that restrict permeability.

### Best practice…

- **Conduct soil sampling to determine your soil's physical and chemical properties.**
- **Crop growth will be easier to manage in a field with a uniform soil type. Variable rate technology may overcome some of the issues where fields are not uniform.**
- **Prevent or minimise erosion in susceptible areas and establish a monitoring plan to track progress.**
- **Rotation crop planning should consider issues such as weeds, previous herbicide use, insects, disease, water use, soil health trends, and soil structural issues.**
- **Crop rotations and fallow can be an important part of an integrated weed management system, providing the opportunity to use different groups of herbicides, as well as incorporating other measures such as strategic cultivation and crop competition. Refer to the *Integrated Weed Management* chapter for more information.**
- **One of the difficulties with the use of alternative herbicides is that residual properties may be toxic on following crops. Keep good records and always check the label for plant back periods. Consider the following two crops you may plant when planning rotations as some residual herbicides have very long (>18 months) plant back periods.**

## Surveying soil variability

Money spent on a soil survey before development is usually repaid several times over because of the potential management problems that it highlights. When planning a new cotton development, soil mapping can inform irrigation design so that each field or management unit can have a uniform soil condition and slope (as much as possible). In fields already developed for irrigation, variability problems may exist or develop to the point that the field must be redeveloped.

Soil surveys should be made before redesigning. Increasingly, precision agriculture is improving the ability of farmers to monitor and manage variability within their fields. Before re-developing land, be sure to consider other crop types and bay configurations that may be more efficient or easy to switch between crop types. For example, a bankless channel design can be used for both row cropping and rice rotations. Refer to the previous chapter for information on irrigation layouts.

Simple outputs from machinery GPS that indicate deviation in the slope and plane of the field can provide information on how water might be draining or holding in areas. A detailed understanding of the physical and chemical structure of the soil at known areas of a field can also provide additional perspective to spatially collected data. Overlayed with other information such as yield maps, this information can inform variable rate application and/or a decision to re-design a field. Refer to Chapter 10.

**Further information on mapping slopes and soil types across the farm can be found in the Natural Assets module in *my*BMP.**

## Land forming

One way to ensure good surface drainage and reduce waterlogging is through developing an appropriate slope and field length in combination with furrows and hills/beds. Land forming using laser grading usually is needed to provide the required slope across all parts of a field, particularly under irrigation. Land forming of cotton fields can create soil problems, particularly the exposure and spreading of unstable subsoil. This subsoil may have inadequate organic matter, be sodic, depleted of mycorrhiza, have a high pH and could be saline

Depending upon the depth of cuts required, some farmers have found it preferable to stockpile the original topsoil, landform the subsoil, and then replace the topsoil. Care needs to be taken to not exacerbate any further compaction problems by trafficking wet subsoil in this situation as the

### Dryland cotton…

- **Soil compaction can significantly reduce cotton yields by restricting root growth, which reduces water and nutrient uptake. Trafficking wet fields should be avoided – use the crop to dry soil down to well below plastic limit before harvest.**
- **Growers should dry the soil down to the major rooting depth to minimise compaction if not using controlled traffic farming (CTF). If using CTF then some compaction is good as it allows traffic by machinery when the rest of the field is 'above' the safe moisture level.**
- **In higher rainfall systems, cotton is often considered a 'pillar' crop, that underpins the profitability of both irrigated and dryland farming systems. As such, it is vital to consider the previous crop history and crop choices for their impacts on soil water accumulation, weeds, insects, diseases, and soil structure and soil health.**

**FIGURE 1: Symptoms of soil compaction can include roots terminating in a swollen 'nub', or showing an abrupt directional change. Often root damage occurs at a uniform depth.**

ability to remediate deep soil will be limited. If subsoil is exposed to the surface under laser levelling conditions both physical/chemical constraints need to be managed to limit any yield reduction. Refer to the *Nutrition* chapter for information on how to manage soil nutrient constraints.

## Soil compaction and controlled traffic farming (CTF)

The loss of soil structure due to compaction can significantly reduce cotton yields by restricting root growth, which in turn reduces water and nutrient uptake. Figure 1 provides an example of compaction symptoms. Some compaction is an inevitable consequence of machinery use throughout the season and can remain from previous seasons. Where the soil is wetter than the plastic limit, which is the point when the soil goes from breaking in a brittle manner to one where it performs more like plasticine, the change in soil strength and risk of compaction from equipment is greatest. In high clay soils this will be close to permanent wilting point, which means growers should dry the soil down to minimise compaction if not using controlled traffic farming (CTF).

If using CTF then some compaction is good as it allows traffic by machinery when the rest of the field is 'above' the safe moisture level. Ideally, trafficking wet fields should be avoided, using the crop to dry soil down to well below plastic limit prior to harvest, although compaction cannot always be avoided. Modern cotton pickers are heavy (upwards of 36 tonnes) with a much greater potential to cause soil compaction compared to the previous basket picker systems (a little over 20 tonnes). A CRDC-supported study to assess the impacts of the round bale picker on the farming system found that for the six cotton fields studied, there was significant soil compaction beneath all wheels. All sites had some change in subsoil porosity down to 0.8 m, with significant compaction observed to this depth on more than 50% of soils.

A dry harvest provides the widest range of options for preparation and improvement of cracking clay soils (provided that heavy rain does not follow soon afterwards). Clay soils may be cultivated when dry, but non-swelling soils containing higher amounts of loam or sand can be damaged if cultivated when too dry as the soil structure is more easily broken down. CTF is the most efficient way of dealing with the compaction problem by constraining traffic to defined tracks through the field. Ideally farmers should be working towards a CTF system and all field operations need to be considered with that in mind as the consequences of compaction can be seen in fields for a long time.

Soils may take years to recover from structural damage. Remediation of compacted soil often requires a combination of strategies such as using a series of rotation crops to dry and crack the soil and/or deep tillage. The greatest effect of remediation of compacted clay soils is where there is a number of wetting and drying cycles from various rotation crops.

**Useful resources:**

**NEC1301 Final Report: 'An impact assessment framework for harvesting technologies in cotton' available on request from CRDC**

**SOILpak – www.cottoninfo.com.au/publications/soilpak**

## Rotations, cover crops and previous crop history

Rotation crops can be used as a tool within the farming system to maximise the advantages and minimise the disadvantages at a field and whole-of-farm basis. This is because previous crop history and crop choices can impact cotton by affecting soil water accumulation in dryland systems, irrigation efficiencies, weed, insect and disease pressures, soil structure and soil health.

Recent research and on-farm monitoring have shown that large productive crops and systems with short fallows are best to maintain soil organic matter levels and support more biological activity. This is a challenge in dryland systems where long fallows are used to build soil moisture, especially following cotton or other crops such as chickpea that provide little ground cover. Cover crops may help minimise soil erosion following low stubble crops, and also help maintain soil organic matter and biological activity.

Recent collaborative research with DAF Queensland, DPI NSW, CSIRO and with support from GRDC and CRDC showed that cover crops can help increase net water storage across the fallow and early crop growth in situations that have limited ground cover. In dryland systems, there were dramatic yield results for the subsequent cotton and wheat crops, attributed in part to more even crop establishment and greater water extraction. In a trial conducted during dry conditions, improving ground cover allowed the opportunity to plant a crop, while the bare plots were too dry.

Trials in Southern NSW have also been conducted to see if cover cropping through the winter fallow can improve infiltration and PAWC of red brown earth soil under furrow irrigation. Findings from a "rotation by cover cropping" trial saw yield improvements over the "standard long fallow treatment" by continuously cropping and adding biomass to the soil through cover cropping. Termination of cover crops needs to occur before excessive moisture uptake occurs.

Research has found that spraying cereals out before Zadoks growth stage Z39 produced enough biomass to increase water infiltration but did not dry the profile down too much to cause poor establishment of the cotton crop. In dryland grain situations, grazing of cover crops during extreme drought conditions was also a profitable option. Long-term field experiments have also looked at management impacts on key beneficial microbial communities in cotton farming systems. Legumes in rotation had a significant positive effect on N mineralisation and microbial diversity and activity; whereas continuous cotton systems resulted in lower non-symbiotic N-fixing bacteria and N2 fixation, and overall reduced microbial activities.

However, many legumes are disease hosts for cotton pathogens, so these benefits need to be weighed against the potential to increase cotton disease risk. Crop rotations and fallow can be an important part of an

integrated weed management system, providing the opportunity to use different groups of herbicides, as well as incorporate other measures such as strategic cultivation and crop competition. Refer to the *Integrated Weed Management* chapter for more information.

One of the difficulties with the use of alternative herbicides is that residual properties may be toxic on following crops. Keep good records and always check the label for plant back periods. Consider the following two crops you may plant when planning rotations as some residual herbicides have very long (>18 months) plant back periods. Farm management software can be useful to keep track of herbicide usage and plant back periods.

Rotations and fallows can also be an important consideration in disease management because they affect the survival and reproduction of plant pathogens, as well as the biology and quality of the soil. Using rotation crops that are not hosts will usually help in preventing the amount of pathogen in the soil from increasing. Crop residues should be managed based on best practice for the diseases present, and be aware that some crop residues may also have an allelopathic effect on cotton. Disease risks are generally higher in back-to-back cotton fields. Refer to the *Integrated Disease Management* chapter for more information.

In conclusion, choosing a suitable soil type for cotton production prior to field development and planting is an important decision that underpins the whole production system. However, how we then manage those soils can also have a significant effect on the cotton yields achieved and the sustainability of the system into the future. The Cotton Rotation Crop Comparison Chart (*Disease management* Chapter 13), provides a comprehensive matrix of the different rotation crops available and their positive and negative impacts.

**Research findings suggest cover cropping on poorly structured red brown earth soils can improve water infiltration and PAWC.**

**Useful resources:**

**Refer to the Cotton Rotation Crop Comparison Chart in Chapter 13.**

**SOILpak – www.cottoninfo.com.au/publications/soilpak**

***my*BMP – www.mybmp.com.au**

**WATERpak – www.cottoninfo.com.au/publications/waterpak**

**GRDC cover crop update – https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/03/cover-crops-can-boost-soil-water-storage-and-crop-yields**

**Dan Hayllor and family have modified all their machinery (including their CP690) to 4m wheel centres to reduce compaction. To listen to Dan talk about this in a CottonInfo podcast, scan the QR code (above).**

Chapter 7 sponsored by – CSD Cotton Seed Distributors

# Selecting the seed

By **Sam Lee** (Cotton Seed Distributors)

## What's new…

- Sicot 606B3F commercially released for the 2021–22 season.
- V and F rank data updated for several varieties.

There is a wide range of cotton varieties that can be grown in Australia. Varieties are generally selected based on yield, quality and disease resistance characteristics; however, other traits such as determinacy, leaf shape and season length may also be important. Several varieties containing Bollgard 3 technology are currently available for planting in 2022 (see Table 1); including the newest variety – Sicot 606B3F. This is a shorter season variety, which continued to be extensively trialled across the industry throughout the 2021–22 season. Cotton Seed Distributors also offers two varieties containing the Roundup Ready Flex trait (no Bollgard) and two straight conventional cotton varieties. The full range of cotton varieties available are outlined at www.csd.net.au.

## Yield

In irrigated production systems, yield is the primary selection characteristic. Some varieties are widely adapted and can perform in a range of environments. Sicot 714B3F is derived from the Sicot 71 family. This variety has demonstrated exceptional yield performance in a wide range of environments and is also the best choice for growers in regions with shorter seasons. Sicot 746B3F and Sicot 748B3F perform well in full season environments. They have similar yield, quality and disease tolerance; but Sicot 748B3F is more vigorous than Sicot 746B3F. Sicot 748B3F should be selected for fields that generally produce shorter cotton – such as fields with a history of soil constraints or if full seasonal water cannot be guaranteed – due to its fibre quality.

Dryland production systems require varieties that yield well in water limited situations. The best dryland varieties are generally very indeterminate and have robust fibre characteristics. Sicot 748B3F is generally the preferred variety for central and western dryland environments while Sicot 714B3F is more suited to short season dryland environments or late planting. Sicot 714B3F is also a medium density seed variety, which can be a helpful attribute for establishing seedlings under more marginal conditions.

The relative performance of cotton varieties can be compared online at www.csd.net.au using the variety comparison tool. The latest variety guide is also available online and should be consulted to assist in selection. The final yield of any variety is the product of its yield potential, limited by the environment. It is worth your time to select the best performing variety for your farm. In fact, different fields on your farm may require different varieties to achieve the highest yields. Historically, cotton growers are quick to adopt new varieties. Cotton varieties bred in Australia have demonstrated a 1.8%

## Best practice…

- In addition to yield potential, consider quality traits and disease ranking when selecting a variety.
- If accessing biotechnology traits, contact a Technology Service Provider (TSP) to learn more about requirements and stewardship.

## Dryland cotton…

- Select varieties likely to achieve the best possible establishment under your dryland farming conditions.
- Select varieties which have a good fibre quality package.
- Select varieties which are suitable to the season length in your area and consider if a more indeterminate variety may provide opportunity to take advantage of late rainfall events.
- Select varieties which have a proven dryland yield potential in your area.
- Select a combination of varieties if necessary for different conditions within your farming operation and the time of planting.

**TABLE 1:** Summary of varieties containing Bollgard 3.

| | Sicot 714B3F | Sicot 746B3F | Sicot 748B3F | Sicot 754B3F | Sicot 606B3F | Sicot 707B3F |
|---|---|---|---|---|---|---|
| Climate suitability | Cool/central | Central/hot | Central/hot | Central/hot | Cool/central | Cool |
| Production | Irrigated, dryland | Irrigated | Irrigated, dryland | Irrigated | Irrigated | Irrigated |
| Maturity | Full | Full | Full | Full | Med/full | Med/full |
| Growth habit | Compact | Compact | Moderate | Vigorous | Compact | Compact |
| Boll size | Med/large | Med/large | Med/large | Med/large | Med/large | Med/large |
| Seed density | Normal | Low density | Low density | Low density | Low density | Normal |
| Relative gin turnout | 42.0 | 45.0 | 44.0 | 43.0 | 42.6 | 42.0 |
| Relative length | 1.20 | 1.21 | 1.23 | 1.24 | 1.19 | 1.19 |
| Relative strength | 30.0 | 30.0 | 31.0 | 31.0 | 31.9 | 30.0 |
| Relative micronaire | 4.4 | 4.5 | 4.5 | 4.5 | 4.0 (based on limited data) | 4.6 |
| Bacterial blight | Immune | Immune | Immune | Immune | Immune | Immune |
| V rank | 112 (standard) | 102 (41) | 103 (39) | 99(27) | 115 (19) | 106 (18) |
| F rank | 128 (9) | 132 (7) | 132 (7) | 152(6) | 13 (1) | 116 (2) |
| Seed size (average seeds/kg) | 9770 | 11430 | 11295 | 12050 | 11365 | 9410 |

Please visit www.csd.net.au for the most up to date figures, as they may change from season to season.

increase in average yield per year, so newly released varieties are often the best choice.

## Quality

Our fibre quality is regarded as some of the best in the world. Breeding has improved fibre characteristics, with fibre length and strength increasing significantly in recent years. Micronaire values vary from year to year and are influenced by the environment, but breeding has helped keep micronaire values in the premium range for most growers. Lack of contamination also makes Australian cotton attractive to spinners.

Some varieties such as Sicot 754B3F have exceptional fibre characteristics and may achieve additional premiums. Pima cotton has the best fibre quality and commands a higher price for lint, however no varieties are currently commercially available in Australia. There is an inverse relationship between yield and most fibre quality traits but through careful selection, breeders have been able to get high yielding varieties with good fibre quality. Some fibre quality traits are more important in particular environments. In the hotter regions, selecting varieties with lower relative micronaire may assist in minimising discounts and achieving premiums. In dryland situations, selecting varieties with the best fibre length will reduce the chance of length discounts. Variety selection can also impact on grades. Careful defoliation and ginning will limit any grade loss.

## Disease

Breeding has provided the main method of managing our major diseases such as Bacterial Blight, Verticillium and Fusarium wilt. The industry has developed a ranking system (F rank for Fusarium and V rank for Verticillium) to allow growers to compare the disease resistance of varieties. A standard ranking scheme has been developed which indicates the resistance performance of commercially available cotton varieties as a percentage of industry nominated benchmark varieties (with the number of trial comparisons used to determine the number reported in brackets). The best commercial varieties available currently have an F rank of 152 and a V rank of 115. Breeding aims to improve the disease resistance over time and new varieties generally have improved F rank.

Breeding varieties with higher V ranks is slow and difficult. CSIRO breeders are working hard to develop better Verticillium tolerance. By selecting varieties with the highest disease resistance in fields with significant disease pressure, yields will likely be maximised. In the case of Fusarium and Verticillium, selecting the most resistant varieties can help to reduce the inoculum in the soil, thereby reducing its impact on subsequent crops. The latest disease rankings are available in the CSD Variety Guide and online at www.csd.net.au. Refer to the *Integrated Disease Management* chapter for more information.

## Okra leaf shape

There is one conventional (contains no biotechnology traits) variety with okra leaf shape that is commercially available and breeding with the trait is continuing.

## Biotechnology

There are two broad classes of cotton biotechnology traits which are approved and available in Australian cotton varieties, providing either insect protection, herbicide tolerance or in varieties which are stacked with a combination of both traits. Bollgard 3 technology has replaced Bollgard II. Bollgard 3 controls a range of lepidopteran pests including the *Helicoverpa* spp. and produces three insecticidal proteins: Cry1Ac; Cry2Ab; and, Vip3A.

One of the key benefits of Bollgard 3 is the significant reduction in insecticide use which has allowed an increased adoption of integrated pest management (IPM) principles, as well as providing growers with a consistent platform to manage insect control costs. Bollgard 3 reduces, but does not eliminate, the continued threat insect resistance poses to the Australian cotton industry. Continued vigilance and adherence to the approved resistance management plan is essential.

Roundup Ready Flex technology confers full season tolerance to glyphosate herbicides. The ability to use registered glyphosate herbicide in-crop to control a wide range of weeds allows growers to design weed control programs that can target individual fields and specific weed problems. The technology has reduced the reliance on pre-emergent herbicides and has allowed growers to more effectively use minimum tillage techniques and reduce manual weed chipping costs. Development of the next generation of stacked herbicide traits is underway. When selecting a variety, the presence of a trait is indicated in the name of the variety.

- B3F = Bollgard 3 stacked with Roundup Ready Flex.
- RRF = Roundup Ready Flex (no Bollgard).

To access cotton seed, growers must sign a grower agreement with Cotton Seed Distributors (CSD) and a Technology User Agreement (TUA) with Bayer if the seed contains biotechnology traits (see below).

## Accessing biotechnology traits

The access to the various traits is governed by the major technology companies who develop and commercialise the technology via an annual license called a TUA. The TUA forms the basis of the relationship between the grower and the technology company. The primary purpose of the TUA is to clearly define the terms and conditions associated with use of the technology each season.

It includes the prices, payment and risk management options for the technology and other matters. It also includes stewardship requirements specific to a technology. There is a requirement to undertake training from the trait provider prior to accessing the technology. In practicality, the licensing process is managed by Technology Service Providers (TSPs) on behalf of the technology companies. TSPs are primarily well-known local and national retailers of crop protection products and cotton planting seed. Growers should direct initial enquiries about accessing biotechnology to their local TSP.

All cotton biotechnology traits commercialised in Australia are supported by an appropriate stewardship program which forms part of the annual TUA between technology owners and growers. The stewardship programs are a product of collaboration between the cotton industry and the developers of the technologies with an aim of supporting their long-term sustainable use. This is important to ensure the traits continue to provide value to growers and more importantly provide a basis for the introduction of new novel traits. Refer to the *Integrated Pest Management and Resistance Management* chapter for more information.

**Further information can be found at www.bollgard3.com.au**

# CONTACT YOUR LOCAL CSD EXTENSION AND DEVELOPMENT AGRONOMIST TODAY TO DISCUSS YOUR GROWING OPTIONS

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EXTENSION & MARKETING DEVELOPMENT LEAD
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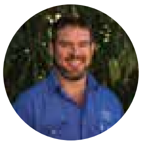

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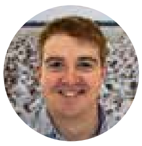

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# Nutrition

By **Jon Baird** (NSW DPI & CottonInfo)

**Acknowledgement: John Smith (AgriFutures), Chris Dowling (Back Paddock), Ben Macdonald (CSIRO) and Graeme Schwenke (NSW DPI), Brendan Griffiths (UNE), Jon Welsh (CottonInfo/AgEcon), Oliver Knox (CottonInfo/UNE), Wendy Quayle (Deakin University)**

## What's new…

- **Splitting fertiliser application will reduce nitrogen loss and improve yields, but don't apply fertiliser late in the growing season (plant cut-out) as this promotes vegetative growth, increased disease and reduced yield potential.**
- **Phosphorus improved cotton yield when applied pre-season and mixed thoroughly within the profile. Yields were further improved when nitrogen was applied with similar timing to the phosphorus.**
- **Irrigation management will influence nitrogen availability. Applying smaller but more frequent irrigations increases in-crop mineralisation activity, further increasing plant available N from organic sources.**

Nutrient efficiency is a crucial management consideration as ensuring the crop has adequate nutrition is critical to maximising yield. With fertiliser application being one of the highest variable costs in irrigated cotton, long-term farm management and fertiliser strategies should build and maintain adequate soil nutrient levels for continued high production levels. Maintaining a balance between crop removal and soil supply sustains lint yield and quality of cotton, maximising nutrient efficiency. Balanced nutrition also prevents the development of nutrient deficiencies and reduces risk of adverse off-site consequences of over-application. Cotton nutrition should be planned with consideration of other management practices such as:

- Crop rotation.
- Stubble management.
- Tillage practices.
- Use of legumes, manures and composts.
- Soil chemistry (salinity, sodicity) that may limit root development and exploration.
- Water availability (irrigation deficits or starting soil moisture levels in rain grown production).
- Soil physical condition.

## Best practice…

- **Monitor nutrient levels in your soils during the cropping rotation to ensure nutrition strategies are not leading to a decline in soil fertility or excessive nutrient loading.**
- **Fertilise fields on their own merit, based on yield expectation, native soil fertility and ease of irrigation management.**
- **In-crop monitoring allows adjustments to fertiliser inputs based on seasonal conditions and expectations.**
- **Making the most of nutritional inputs relies on good irrigation, disease and weed management. Nutrition is one part of a complex system.**

### Nutrient supply

The supply of nutrients for a cotton crop is dependent on residual nutrient reserves in the soil from a previous crop, in-crop mineralisation of nutrients from soil organic matter, and the application of nutrients in the form of synthetic fertilisers or organic compounds. As part of crop management, routine soil analysis can indicate the fertility level in your soil at that point in time. The ideal time of the year to soil sample is the cooler months of July and August, when soil microbial activity is less than in the warmer months. Once soil nutrient levels have been measured and seasonal nutrient tactics developed, fertiliser requirements for your crop can be accurately calculated. Seasonal nutrient tactics take into consideration historical and expected yield, cropping history, cropping system and nutrient losses, crop use efficiencies, plant nutrient recovery and uptake, and soil condition and characteristics.

There is considerable variability in the supply of nutrients from the soil both across a farm and within a field. The use of yield maps, land-forming cut and fill maps or soil surveying equipment, such as electromagnetic surveys (EM surveys), can be used to guide fertiliser inputs within fields. An important aspect for budgeting the crop's nutrient supply is that for most nutrients more than 50% is taken up during the flowering period (see Table 2). This has two major implications: first, you need to ensure adequate nutrition is available in the soil by the start of flowering because plant uptake increases dramatically during this period and deficiency can occur quickly; second, late application of most nutrients has little impact on plant fruiting development and yield.

## Nitrogen

Cotton sources most of its N as nitrate-N from the mineralisation of soil organic matter and residual soil mineral N. Mineralisation is a biological process within the soil that results in the release of nutrients in a form that is available for crop uptake. Typically, around two thirds of the crop's N needs come from soil N while the remaining needs come from N fertiliser. Uptake of the soil N is much more efficient than the uptake of fertiliser N. A farming system that incorporates legumes and cover crops increases soil carbon, soil mineral N and lint yield. The plant requires nitrogen to initiate the growth and maintenance of key amino acids and proteins which are the building blocks of plant cell development. Most of the plant's nitrogen use is sourced from the soil through root absorption of nitrate, ammonium and/organic N. Nitrogen is transported throughout the cotton plant via the transpiration vessels, with the final placement dependant on the nitrogen demand.

Although N fertiliser is the minor source in most cropping seasons, N application is critical to maximising production where soil sources cannot match crop demand. Fertiliser N ends up as nitrate-N in the soil where it can be taken up by the plant, remain in the soil, or be potentially lost to the atmosphere. Not matching application to crop demand means more N will be left in the soil where it will be at greater risk of loss from the system through leaching, runoff and denitrification (Figure 1). Irrigation management can also influence the amount of nitrogen, both soil and fertiliser N, that is lost from the system.

Growers are recommended to follow BMP irrigation management as water flow rate, flow time and the amount of water applied to the field can cause excessive N loss from the system. The cotton plant uses N throughout the entire growing season, with the greatest requirement during the flowering stage (Figure 2). Insufficient nitrogen supply during this period will reduce yield. However, excess nitrogen can also have significant detrimental impacts on cotton. Rank vegetative growth, boll

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**TABLE 1: Nutrient removal at various yield levels in bales/ha. The green shaded area represents macronutrients, yellow shaded area represents micronutrients (note a change in units of measurement).**

| Yield | N | P | K | S | Ca | Mg | Na | B | Cu | Zn | Fe | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| b/ha | kg/ha | | | | | | | g/ha | | | | |
| 4 | 33 | 11 | 12 | 4 | 2 | 7 | 0.13 | 8 | 11 | 56 | 91 | 18 |
| 5 | 50 | 13 | 17 | 5 | 3 | 8 | 0.14 | 18 | 13 | 64 | 99 | 24 |
| 6 | 65 | 15 | 22 | 6 | 3 | 9 | 0.15 | 28 | 15 | 73 | 109 | 30 |
| 7 | 81 | 17 | 26 | 7 | 4 | 11 | 0.15 | 36 | 18 | 85 | 122 | 36 |
| 8 | 95 | 19 | 30 | 8 | 5 | 12 | 0.16 | 43 | 20 | 97 | 138 | 42 |
| 9 | 109 | 21 | 33 | 9 | 5 | 13 | 0.17 | 49 | 22 | 112 | 156 | 48 |
| 10 | 123 | 23 | 36 | 10 | 6 | 14 | 0.18 | 55 | 24 | 128 | 176 | 54 |
| 11 | 136 | 25 | 39 | 11 | 6 | 15 | 0.18 | 59 | 26 | 145 | 199 | 60 |
| 12 | 148 | 27 | 41 | 12 | 6 | 16 | 0.19 | 62 | 28 | 164 | 224 | 66 |
| 13 | 160 | 29 | 43 | 13 | 7 | 18 | 0.2 | 65 | 30 | 185 | 252 | 72 |
| 14 | 171 | 31 | 45 | 14 | 7 | 19 | 0.2 | 66 | 32 | 207 | 283 | 78 |
| 15 | 182 | 33 | 46 | 15 | 7 | 20 | 0.21 | 67 | 34 | 231 | 316 | 84 |
| 16 | 192 | 35 | 47 | 17 | 7 | 21 | 0.22 | 66 | 36 | 257 | 352 | 90 |
| 17 | 201 | 37 | 48 | 18 | 8 | 22 | 0.22 | 65 | 38 | 284 | 390 | 96 |
| 18 | 210 | 39 | 48 | 19 | 8 | 24 | 0.23 | 62 | 41 | 312 | 431 | 101 |
| 19 | 219 | 41 | 48 | 20 | 8 | 25 | 0.24 | 59 | 43 | 343 | 474 | 107 |

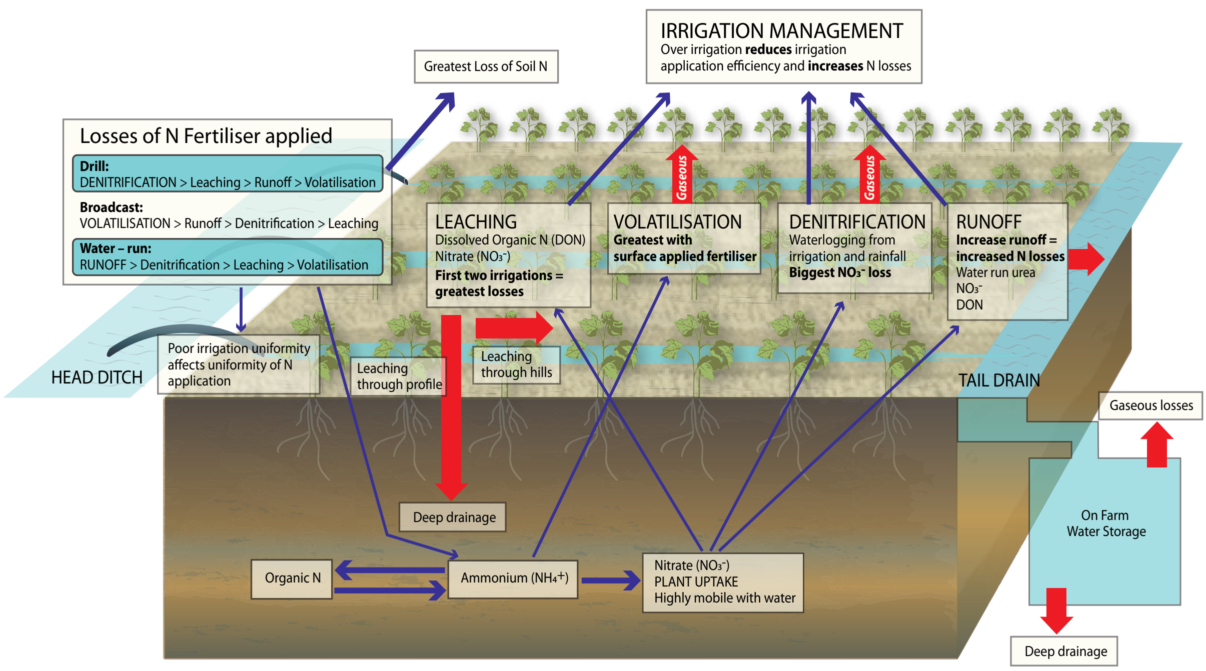
Source: Rochester (2014) final report.
P removal is reduced in the new small seeded varieties to between 1.5–2.0 kg/ha/yield compared to the 2.2–2.8 used in this table (Mike Bell and Brendan Griffiths).

shedding, delayed full boll load and crop maturity, small fruit, increased disease problems such as Fusarium wilt, Verticillium wilt and boll rots, difficulties in defoliating, harvesting problems and reduced fibre quality are all problems associated with over-fertilising with N. All these impacts have considerable economic costs and result in reduced profitability through lower yields, quality downgrades, increased production costs, higher fertiliser costs and reduced N efficiencies. Matching N supply to crop N requirements requires close monitoring and management because N availability is affected by a range of physical, chemical and biological processes that occur in the soil. These processes are influenced by climatic conditions such as temperature and rainfall intensity. Irrigation deficits and incidence of waterlogging also affect the amount of nitrogen taken up by the plant, retained in the soil or lost to the environment (Figure 1). Therefore, the key to maximising the return from N inputs is in applying the right fertiliser, at the right rate, at the right time, in the right place.

## Right fertiliser

There are different chemical or physical forms of fertiliser that can be used to supply N to cotton, such as manures and composts, granular fertilisers, anhydrous ammonia (gas), and liquid fertilisers. Anhydrous ammonia (82% N) and urea (46% N) are the two major N fertilisers used in the cotton industry. The fertiliser chosen may be limited by the capacity to obtain, store, and apply it. Composts and manures need to be spread and incorporated, while anhydrous ammonia (gas) needs to be applied at a depth of at least 15 cm by trained staff using specialised equipment to reduce the possibility of excessive losses through ammonia volatilisation.

**FIGURE 1: Nitrogen and irrigation cycle highlighting the major loss pathways of N.**



Urea is the most versatile N product to manage as it can be applied using a range of different application methods and times. Although urea is more stable than most N products, if broadcast on the soil surface it should be timed with a rain or irrigation event and/or incorporated quickly after application to reduce the risk of ammonia volatilisation losses.

## Right rate

In developing a fertiliser program, it is important to consider the following strategies and integrate them according to your own farm's needs:

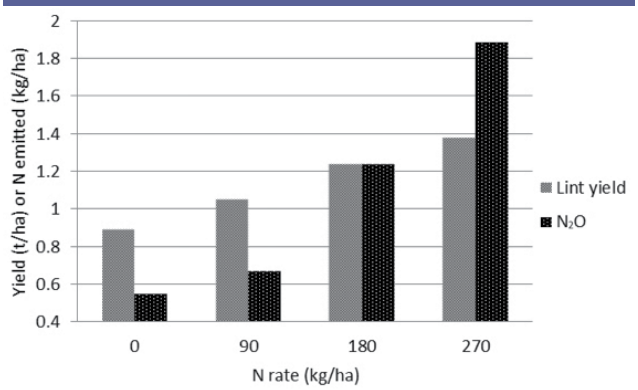
- Determine soil nutrient status using pre-season soil sampling (ideally to a depth of 60–90 cm for N).
- Calculate expected crop nutrient requirement taking into consideration expected yield, in-crop mineralisation, cropping history, cropping system, nutrient losses, crop N uptake efficiencies from the soil and fertiliser N, and soil condition and characteristics.
- Develop a fertiliser use plan that is best suited to your farming system and environment.

The fertiliser rate will depend on the type of fertiliser being used, when it is being applied and how much of each nutrient is required. The composition of the fertiliser (percentage of each nutrient in the fertiliser) will dictate just how much of the product needs to be applied to meet the crop requirement. If all the fertiliser is being applied upfront, an adjustment must be made to consider losses and inefficiencies. On the other hand, if a starter fertiliser is being used at planting with later in-crop applications, the rate of fertiliser must be adjusted for each application. The rate is determined by soil analysis in the winter prior to planting the crop and can be modified by leaf and petiole analyses performed in-crop.

- Monitor the crop through petiole (early season) and leaf analysis (flowering to defoliation) to determine if the crop has sufficient or inadequate nutrient levels (plant tissue testing is discussed in more detail later in this chapter).
- Develop a long-term management program that maintains or improves soil health by replacing the expected level of nutrient removal (Table 1) and conducting one comprehensive deep soil test during the cropping rotation.

Industry research measuring nitrous oxide emissions from applied fertiliser has enabled a better understanding of the relationship between rates of applied nitrogen and losses to the atmosphere. Nitrous oxide production (representing denitrification N losses) increased exponentially as the rate of applied N increased beyond crop uptake capacity in a wheat/cotton rotation field experiment conducted on the Darling Downs. Figure 2 shows the relationship between lint yield and nitrous oxide emissions in response to variable nitrogen application rates. The same relationship has also been shown at Narrabri, Moree and Gunnedah.

**FIGURE 2: Cumulative nitrous oxide ($N_2O$) emissions and lint yield in response to N application on cotton at Kingsthorpe (Qld) on heavy black clay in 2010–11. (Source: Scheer, et al 2013)**




## Right time

The timing of fertiliser application is determined by the production system, soil condition and type of fertiliser being used. Importantly, N fertiliser timing should provide the plant with sufficient N sources at critical plant N uptake periods (Figure 3). Recent research showed that in high-yielding cotton systems, the timing of N fertiliser influenced lint yield (Figure 4).

### Key points when applying N –

Prior to planting:

- Apply in winter when soils are cool to reduce the risk period for substantial losses through denitrification and leaching due to heavy rainfall events.
- Allow sufficient time (three weeks) between application into moist soil and planting to prevent seedling damage (especially with anhydrous ammonia fertiliser).
- Apply N at the correct depth and position to prevent unnecessary losses and seedling damage.
- Composts and manures need to be spread and incorporated prior to planting. N from recycled organic material may not be available to the crop established in the year of application.

In-crop:

- Split application of N fertiliser allows for rate adjustments as the season progresses which may improve the return on the fertiliser inputs, thereby improving efficiency. However, the timing of split application is critical and rain (wet soil) may impact the ability to apply fertiliser in-crop on time, increasing the risk of crops being nutrient deficient during high demand periods (e.g. flowering).
- Applying N too late can favour diseases such as Verticillium wilt and boll rots (see *Disease* chapter), may delay maturity, and affect defoliation.
- Anhydrous ammonia (gas) fertiliser cannot be applied too close to planting as seedling damage may occur from ammonia burn, (this can also be a problem with urea, especially where placement is close to the seed row).

## Right place

Most fertilisers (other than foliar) are applied to the soil, pre-plant, at depth (preferably 300 mm) and off the plant line. If possible, offset the

**FIGURE 3: The pattern of plant N uptake and water use for an irrigated cotton crop. (Source: Chris Dowling, Back Paddock)**

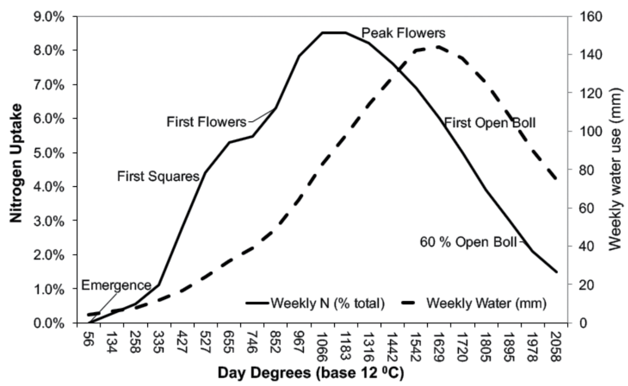


**TABLE 2: Maximum nutrient uptake rate and timing of nutrients in whole crop.**

| | Maximum uptake rate (per day) | Percentage taken up during flowering |
|---|---|---|
| Nitrogen | 2.1 | 55 |
| Phosphorus | 0.7 | 75 |
| Potassium | 3.2 | 61 |
| Sulphur | 0.8 | 63 |
| Calcium | 2.6 | 55 |
| Magnesium | 0.7 | 61 |
| Iron | 24.0 | 46 |
| Manganese | 6.5 | 49 |
| Boron | 6.5 | 60 |
| Copper | 0.9 | 61 |
| Zinc | 3.7 | 73 |

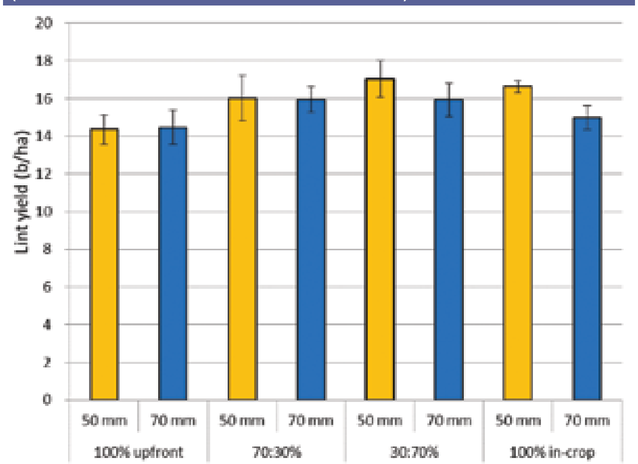
application inside the plant line on the irrigated furrow side. This will reduce leaching into the alternate furrow plus increase N saturation of the plant line. Applying fertilisers too close to the plant line may cause seedling damage due to the salt or toxicity effects. Anhydrous ammonia should be applied deeper than 15 cm to reduce losses to the atmosphere through ammonia volatilisation.

Soil condition will affect these losses with the escape from dry soils occurring due to air spaces within the soils, while losses from wet soils occur back through the application furrow. Other fertilisers (P, K, Zn etc.) can be broadcast and then incorporated thoroughly within the soil profile to maximise contact between the roots and fertiliser. Research into P and K application indicates the preference for application even before the previous crop within the rotation due to the lack of mobility of these nutrients within the soil.

The amounts of nutrients that can be applied to the foliage is limited and the benefit short term. Foliar fertilisers can be used to help meet crop nutrient requirements when a nutrient has been identified as being deficient, and the quantity of nutrient required is small. Foliar is not suitable for the application of large amounts of nitrogen due to logistical challenges and the high demand for this nutrient.

*Right fertiliser, at the right rate, at the right time, in the right place* is important for the supply of all nutrients. It is of particular importance for N fertiliser application because of the potential for loss of N from the system

**FIGURE 4: The influence N fertiliser timing on lint yield at Myall Vale (NSW) – 2017/18.**
**(Source: Baird – 2018 Australian Cotton Conference)**




(Figure 1) and must be considered within your system when preparing an N management plan. These include:

- **Denitrification –** This is the most important loss of nitrate-N in irrigated cotton systems and can easily lead to losses of greater than 50% of the N, especially where excessive rates are used to achieve yield targets, or where poor layout dictates long irrigations which that results in extended waterlogging. Denitrification is a biological process that occurs under low oxygen conditions, such as during waterlogging, where nitrate N is converted into nitrogen gases and lost to the atmosphere. One of these gases is nitrous oxide, a greenhouse gas that is accumulating in the atmosphere and is contributing to ozone depletion.
- **Leaching and runoff –** Irrigation water can cause the excessive leaching of nitrogen from the planting hill, either out through the tailwater or below the root zone. Optimising irrigation management can reduce the amount of tailwater, decreasing the loss of nitrogen from the field. When fertigation is applied (i.e. water-run urea) it is recommended that the fertiliser is applied directly into the head ditch or as close to the field as possible to reduce potential gaseous losses.
- **Ammonia volatilisation –** This commonly occurs in two scenarios; firstly when solid urea is applied to the soil surface and not incorporated properly or promptly. The risk of loss via this pathway is greater where plant residues retained on the soil surface prevent the granules from contacting the soil; and, where soils contain low clay contents; soils are wet and drying; conditions are hot and windy. Free lime (calcium carbonate) present in the soil can accelerate ammonia volatilisation where ammonia sulphate fertiliser is used. Secondly, when ammonia products (e.g. anhydrous ammonia) are applied through water-run methods. Temperature, wind, row length, irrigation run time and placement of the applicator will all impact the rate of volatilisation that occurs when applying N by water-run. This method of application is not recommended in Australian cotton systems.
- **Removal of seed cotton –** Most of the crop N removed from the system is found in the cotton seed and can be significant, particularly in high yielding crops. Long-term budgeting should consider seed N removal after cotton harvest.

## Nitrogen Fertiliser Use Efficiency (NFUE)

NFUE is a simple measure that enables growers to gauge how well they are using the fertiliser N that they apply.

$$\text{NFUE} = \frac{\textit{lint produced (kg/ha)}}{\textit{N fertiliser applied (kg N/ha)}}$$

The current industry benchmark suggests that growers should be growing 13–18 kg lint/kg of fertiliser N applied. For many, this would seem very high and unattainable. However, initially the focus should be on improving the NFUE that you currently have and trying to answer the question of why one paddock may be better than another. The key to improving NFUE is in realising that N is only one factor that determines the final yield. Addressing the other constraints to yield in your crops can improve NFUE, while remembering that the seasonal growth will have one of the biggest impacts on NFUE. The goal is to establish a long-term improvement in NFUE.

Seasonal conditions may cause single seasons of low NFUE but if long-term NFUE is below 10 and lint yield is below par for the area and soil type, then it is highly likely there are issues within the production system that simple application of more N or changing of product form, placement or timing are not going to fix. Until the yield limiting issues are identified and overcome, the yield target within those fields should be adjusted to ensure the N application is reduced accordingly. In irrigated cotton, irrigation management is a key to maximising N efficiencies. In heavy clay and dispersive soils, the period of waterlogging following irrigation can be as much as four times longer than the irrigation time in well-designed irrigation layouts, resulting in significant denitrification every time the crop is irrigated. Extended watering times also often increase deep drainage of water and N.

## Phosphorus

The aim of phosphorus (P) application to crops should be to replace the P removed in crop products, thereby at least maintaining the same level of P within soils for long-term sustainability. High-yielding cotton crops typically take up 18 to 43 kg/ha P and remove between 14 and 28 kg/ha P in the seed cotton, equivalent to approximately 1.7 to 2 kg P/bale. P plays an important role in the energy transfer process in the plant's cells, and is used in plant genetic processes and regulation of plant metabolism. P is essential for early plant growth, as P deficiency causes reduced seedling vigour; poor plant establishment and root development; and delayed fruiting and maturity. Plants deficient in P will appear stunted with red/purplish colour. P is highly immobile in the soil, meaning that it predominantly stays where it is applied. This makes the application of P fertiliser challenging in cotton crops. This is because cotton roots do not congregate in areas of high P concentration like fibrous root systems of cereal plants and are not particularly good at finding bands of P in the soil. The aim with fertiliser P application should be to treat the largest volume of soil possible and to be available throughout the soil profile where plant roots are active. Treating a large area maximises the fertiliser interception in the soil by the plant roots.

Generally, only about 20–30% of the P applied as fertiliser is used by the crop in the year of application, with the remaining P requirement coming from other sources in the soil, to which fertiliser application in previous years has contributed. Low rates of P can be applied with the seed (up to 9 kg P/ha or 40 kg/ ha MAP, 1 m row spacing) where there is good seedbed moisture. There is some risk with this due to the production of ammonia and salinity during the breakdown of MAP (DAP should not be applied with the seed) that may affect germination and seedling establishment. Side-dressing of P fertiliser between sowing and squaring may not be as effective as applying P before planting. Soil P is available to the crop via several pools and interactions. It is important to understand the pools and interactions to understand how the soil test methods relate to them. There are three soil test measurements of P that are important to understand for P budgeting:

The 'labile' or 'sorbed P' (fast release) is the pool delivering P into the soil solution, as the plants draw solution P from the soil. This pool is most strongly correlated to the Colwell measurement test.

There are also slower release pools of P in the soil. It is these that generally hold the compounds formed in cotton growing soils from prior fertiliser application, e.g. calcium phosphate. It is this pool that delivers P into the fast release pool, and is most likely to be depleted over time. **This pool is measured using the BSES soil P test, in the surface 0–10 cm, and the sub-surface depth of 10–30 cm.**

The Phosphorus Buffering Index (PBI) provides an indication of the likelihood of applied fertiliser P being tied up. The higher the number the more likely the fertiliser P will be tied up: <140=low; 140–280=moderate; >280=high. Most cotton soils are in the low to moderate PBI which increases P placement and timing options. Measuring both the labile and slow release pools of P is important in tracking soil P fertility. The Colwell P test may remain relatively constant over time, indicating a sufficient level of P input. However, the slow release pool may be supplying some of the P to the labile pool which may be resulting in the decline of the background slow release pool of P. By the time the decline in the background P becomes deficient (decreasing Colwell P test) it will be more difficult and expensive to restore background levels of P in the soil. Use soil testing in conjunction with plant tissue testing (critical level around 0.33%) as well as nil and high fertiliser P application strips in fields to determine if P is limiting and whether responses to applied P are being achieved.

Arbuscular Mycorrhiza fungi (AMF previously known as VAM), found in the soil, have an association with cotton and assist in accumulating and making P available to the plants by significantly increasing the soil area occupied by the root system and its capacity to take up water and nutrients, especially P. Low AMF populations can increase the risk of P related problems where:

- Soil P is low/marginal.
- There have been prolonged periods with no growing plants (crops/ weeds).
- Frequent and significant soil disturbance occurs across multiple wetting and drying cycles.

## Potassium

Potassium (K) is a mobile nutrient within the plant and has a role in energy transfer, osmotic regulation (maintaining turgor), protein synthesis and nitrogen metabolism. Adequate K nutrition has been linked to reducing the incidence or severity of plant diseases and improving yield and fibre quality. There are several forms of K found in the soil that are available to the plant. These include K in the soil solution freely available, exchangeable K held on clay particles and/organic matter and non-exchangeable K held in and on clay particles and not readily available to plants. While most soils have large amounts of K, only a small proportion (less than 2%) is available to plants.

Potassium is absorbed as the K+ ion from the soil solution. Its uptake is affected by competition with the other cations in the soil solution, including $NH4^{+}$, $Na^{+}$, $Mg^{++}$ and $Ca^{++}$. Other soil factors that affect K uptake include cation exchange capacity (CEC) and soil structure. As CEC rises, the soil solution K concentration typically falls due to selective adsorption of K onto exchange sites on the clay surface, with the rate of K supply to the plant reduced. Sodic or poorly structured soils allow K in the soil solution to diffuse less efficiently towards the depleted zones around cotton roots, also reducing the ability of the soil to meet crop K demand. Premature senescence is a potassium-related disorder that can occur in cotton regardless of the supply of K from the soil. Other nutrients, including phosphorus, have been found to be deficient in affected plants, although not to the same extent as K. The disorder is chiefly caused by the plant's inability to meet nutrient demand due to a high boll load. Premature senescence can be compounded by stresses such as waterlogging, cool, cloudy weather or soil compaction which interfere with the plant's ability to take up K, reducing the plant's capability to meet crop demand especially during the period of peak demand between flowering and boll fill. Deficiencies at this time will have detrimental effects on lint yield and fibre quality. There is also evidence of an association with Alternaria infection, although both can occur independently. When deficiencies are experienced later in the season, as the developing boll load is a strong and competitive sink for available K, the youngest mature leaf at the top of the canopy is often the first to show symptoms. Treatment of K related to early senescence is rarely effective after the appearance of symptoms. Increasing soil K supply, and foliar application of K to the crop canopy in the weeks preceding the critical growth period and a triggering weather event have been the most effective strategy to reduce the incidence and effect of senescence.

## Other essential nutrients

**Zinc:** Zinc (Zn) is essential in small amounts for enzymes and plant hormones. Deficiencies may affect yield, maturity and fibre quality, and can be seen in the leaves as interveinal chlorosis, cupping and possible bronzing, stunting. Zinc is best applied to the soil as a broadcast and worked in with cultivation. Zn can also be successfully applied to crops as a foliar spray; it can alleviate symptoms and supply sufficient zinc to meet crop needs. Zinc sulphate is the most effective and inexpensive form of Zn to apply to the soil or to the crop as a foliar spray but is very restricted in its compatibility for mixing with early season crop protection products.

**Iron:** Iron (Fe) is an essential nutrient required in very small amounts for chlorophyll synthesis and some enzymes. Deficiency symptoms include interveinal chlorosis of the young growth and yellowing of the leaves.

Although plentiful in the soil, most of this iron is unavailable to plants. Availability is greatly affected by high concentrations of cations, particularly manganese. Applications of P and Zn fertiliser can also reduce iron uptake. Waterlogging can lead to deficiencies in alkaline soils, although these are generally short-lived and should be managed via foliar application for most cotton soils.

Other essential nutrients such as copper, boron, calcium, magnesium, sulphur, manganese and molybdenum have specific roles in meeting the nutritional needs of a cotton crop. They are required in small amounts and deficiencies are rare.

## Organic amendments

The application of an amendment – such as chicken litter or feedlot waste – onto cotton soils is increasing within Australia's cotton growing regions where delivery costs are economically viable. The advantage of organic amendments is the balanced availability of a range of nutrients and a significant amount of organic matter. Chicken litter can provide relatively large amounts of N, P and Zn to the cropping system, reducing the amount of inorganic fertilisers needed as well as improving overall soil health. A three-year study in southern NSW found that when poultry litter was applied at 16 $m^3$/ha, the cotton system required a reduction of 80 kg N/ha and 35 kg P/ha in applied synthetic fertilisers while increasing yield by 1.3 bales/ha. When sourcing organic waste for on-farm use, growers should seek independent analysis to guide them on application rates and nutrient budgets due to variations in these products.

**For more information the following resources and tools are available at:**
**www.cottoninfo.com.au and www.mybmp.com.au**
**NUTRIpak, FIBREpak, SOILpak**
**Vetch Fact Sheet**
**Nutrients removed in harvested seed-cotton**
**Nutrilogic**
**Australian Soil Fertility Manual (2006) Graham Price (Ed).**
**Fertiliser Industry Federation of Australia.**
**CottonInfo Nutrition video playlist www.youtube.com/cottoninfoaust**

# Monitor your soil

It is important to monitor your soil because farming practices impact the soil chemical and physical properties. Conduct comprehensive cropping soil tests in increments of 30 cm down to depths of 60–90 cm before the next cotton crop, which will have the highest nutrient requirement in a rotation. If cropping back to back cotton this would be best done once every three to four years.

Due to inherent soil variability within fields, soil samples must be representative of differences within the fields. Fertiliser manufacturers and suppliers have sampling protocols based on field size or soil type variability within fields. In irrigated cotton fields, differences in soil N levels have been identified between head ditch and tail drain ends of the field and should be considered separately for the determination of crop N budgets. The soil samples need to be sent for analysis as soon as possible after sampling. If samples are likely to sit for even a few days they are best stored in a fridge to minimise the soil biological activity that is occurring in the sample.

Monitoring can then identify constraints and prevent the development of any further issues within the production system. This can be particularly important in the subsoil layers that impact on nutrient and water availability in the later stages of crop development. Problems associated with subsoil constraints include compaction, soil dispersion (sodicity), high or low pH, salinity, nutrient toxicities, and waterlogging. These problems can result in poor seedling emergence, poor plant growth, loss of bolls and poor boll set, reduced yields, erosion, increased land management costs and other management issues.

## Soil organic matter

### Importance of soil organic matter

Soil organic matter influences all three aspects of soil fertility:

- Biological: Supplies nutrients for plant growth and provides energy and nutrients for soil micro-organisms.
- Physical: Stabilises soil structure and promotes soil aggregation, improves soil water storage and infiltration.
- Chemical: Increases soil cation exchange capacity, buffers soil pH, reduces effects of salinity and sodicity, and is a store of plant essential nutrients.

Soil organic matter is a key source of the N mineralised during the cropping season. The amount of N mineralised can be roughly calculated in the following ways:

Summer fallow mineralisation:
N mineralisation (kg N/ha) =
0.15 x Organic C (%) (0–30 cm depth) x Fallow period rainfall (mm)

In-season mineralisation can be calculated through two equations:
1) Net N mineralisation =

$$\left(\begin{matrix} Soil \\ organic\ C \\ (\%) \end{matrix}\right) \times \left(\frac{1}{\frac{soil}{C{:}N\ ratio}}\right)^{a} \times \left(\begin{matrix} Soil\ bulk \\ density \\ (mg/m^3) \end{matrix}\right) \times \left(\frac{\%\ of\ N\ that\ mineralises}{100}\right)^{b} \times 10{,}000$$

Note: a. soil C:N ratio normally 10–12:1
b. 3–5% of N normally mineralises

2) N mineralisation using soil %N directly =

$$\frac{\%N}{100}\ x\ (soil\ bulk\ density)\ x\ \left(\frac{\%\ of\ N\ that\ mineralises}{100}\right) x\ 10{,}000$$

Note: using the measured %N can be more accurate at estimating mineralised N than the C:N ratio.

## Organic matter losses

Organic matter is quickly depleted under continuous cropping if soils are not managed carefully. Soil organic matter losses are accelerated by frequent cultivation, excessive nitrogen fertiliser application, erosion of topsoil, crop stubble removal (silage, hay or burning), and high soil temperatures (bare fallow in summer).

## Managing soil organic matter

Soil organic matter levels in many cotton fields have declined significantly since the fields were developed, and tend to be lower than nearby unirrigated fields of a similar soil type. Arresting the decline and rebuilding soil organic matter should be an important consideration to ensure soils remain fertile. This means balancing the decomposition of organic materials with the addition of organic matter (crop residues and other organic materials) and/or reducing the loss of carbon from the soil. Inputs of organic materials include:

- Retaining stubble.
- Growing cover crops and green manure crops.
- Alternative crop rotations.
- Composts.
- Animal manures.
- Bio-solids.

Losses can be reduced by changing management practices:

- Reduce tillage operations.
- Employ controlled traffic and use permanent bed systems.
- Stop burning or baling crop residues.

It may be difficult to achieve this balance in every cotton production system due to soil type, environmental conditions, and agronomic constraints. Some of these practices have conflicting impacts. For example, retaining crop stubble on the surface reduces build-up of Fusarium inoculum, increases soil water infiltration and soil water storage, reduces soil erosion and protects the soil, but a significant amount of carbon is lost to the atmosphere as carbon dioxide ($CO_2$) as soil organic matter decomposes. In contrast, a targeted tillage operation to incorporate stubble and control pupae can increase soil carbon. Cultivation causes the loss of soil moisture and exposes the soil to erosion.

Most of a crop's nutrient requirements are met from the recycling of soil organic matter and the nutrients released during the decomposition of this material. Inorganic fertilisers are required when the soil is unable to meet a crop's nutrient demand and are critical in optimising production. Manures and composts can be an important source of organic matter for soils as well as a valuable supply of nutrients. However, there is a time lag between the application of these materials and when nutrients become available to the crop because the nutrients are released slowly to the soil through biological processes. In irrigated cotton systems, the decline in soil organic carbon levels can be reduced or stabilised with changes to conventional cropping systems. By eliminating deep tillage, soil structure can be maintained and by incorporating stubble, good soil health is promoted. Other management practices, including reducing fallow periods and optimising water and nutrient applications, can also be important.

# Sodic soils

Many of the soils used for cotton production in Australia are sodic or strongly sodic below a depth of 0.5 m. Sodicity reduces root growth and water and nutrient uptake. Ground water used for irrigation can cause sodicity problems, particularly when the water contains high sodium levels relative to calcium (see the *Sustainable cotton landscapes* chapter).

The level of sodicity can be quantified by determining the exchangeable sodium percentage during a soil test. Table 3 provides a guide to the broad classification of sodicity within Australian soils.

As soil sodicity increases there are several detrimental effects on the soil's physical properties that influence plant growth and yield potential. Soil dispersion increases in sodic soils, resulting in reductions in the infiltration rate of the soil, the hydraulic conductivity of the soil, and the plant available water capacity of the soil. So, in sodic soils, water is not able to get into the soil as fast, cannot travel within the profile as well and there is less ability to store water for plant growth. These soils become increasingly hard-setting and have greater susceptibility to waterlogging. There is only a narrow band of ideal conditions for plant growth between the soil being too wet and then becoming too dry with a physical barrier of hard soil for root penetration. Sodic soil can be ameliorated by applying calcium to displace the sodium from the clay surfaces. The best form of calcium to use is determined by the pH of the soil. If the soil is alkaline, gypsum will give the best results while if the soil is acid, lime should be used. In this case, lime also has the added benefit of raising the pH of the soil. Sodicity at depth  is difficult and expensive to manage because of the limited penetration of surface applied and incorporated ameliorants.

**TABLE 3: Sodicity classification for Australian soils – classification definition.**

| Classification | Definition |
|---|---|
| Non sodic | ESP <6 |
| Low sodic | ESP 6–10 |
| Moderately sodic | ESP 10–15 |
| Highly sodic | ESP >15 |

The addition of organic matter to soil helps to reduce the effects of soil sodicity. Organic matter helps hold the soil aggregates together, stabilises soil chemistry, reduces dispersion and improves soil structure. It is difficult to get sufficient organic matter deeper into the soil. Management of paddocks with sodicity at depth (>60 cm) should be done by adjusting inputs to better match the reduced yield expectations in combination with careful planning of rotation crops.

# Saline soil

Salinity and sodicity are separate issues. A soil can be saline without being sodic, or it can be both sodic and saline. A saline soil is one with excess salts in the soil solution (Table 4). Soil solution is the liquid in soils held between the soil aggregates. When the concentration of salts in the soil solution exceeds that found in the plant roots, water flows from the roots back into the soil. In this situation, the plant is unable to meet its water demands even though the soil is moist. Salinity occurs as a result of ground water rising to within 2 m of the soil surface, or by irrigating with saline water, or by applying salts via fertilisers. Refer to the *Sustainable cotton landscapes* chapter for further information about assessing suitability of water quality for irrigation. Salinity is measured by testing the soil solution's electrical conductivity (EC).

**Source: "Salinity and sodicity – what's the difference?" By David McKenzie *The Australian Cottongrower* Feb-Mar 2003.**

# Compaction

Soil compaction is characterised by a reduction in airspace and increase in soil density and strength restricting root growth, reducing the availability of nutrients and water to the cotton plant. It can also increase denitrification, further reducing the availability of nitrogen. Some compaction is an inevitable consequence of using heavy machinery on soils, but by

**TABLE 4: Saline soil classes based on different soil textures.** (Adapted from, Diagnosis and management of soil salinity, NSW DPI)

| Class of soil salinity | ECse (dS/m) | EC1:5 (dS/m) | |
|---|---|---|---|
| | | Clay loam | Clay |
| Low | <2 | 0.29 | 0.40 |
| Moderately low | 2–4 | 0.57 | 0.80 |
| Moderate | 4–8 | 0.86 | 1.20 |
| Moderately high | >8 | 1.14 | 1.60 |

implementing good management practices, minimum tillage systems and guidance systems, the impact can be minimised or localised. Restoration of compacted areas can be difficult and expensive when it occurs at depth. Machinery operations on wet soil will exacerbate the problem.

**For more information the following resources and tools are available at:**
**www.cottoninfo.com.au and www.mybmp.com.au**
**WATERpak**
**NUTRIpak**
**SOILpak**
**CottonInfo soils video playlist www.youtube.com/cottoninfoaust**

# Monitor your plants

Often, nutrient deficiencies are not identified until symptoms appear, by which time some yield reduction will have occurred despite remedial fertiliser application. Plant analyses can provide information about the nutritional status of a crop and indicate the potential for nutrient deficiencies which, if identified early enough, could be rectified by applying the appropriate fertiliser with little or no impact on the crop. There are two types of plant analysis for cotton – petiole and leaf.

**Petiole analysis** is ideal for monitoring nitrate-N and potassium concentrations through to early flowering. Petiole tests have been calibrated for nitrate and potassium, but are not recommended for other nutrients. Three samplings approximately 10 days apart (600, 750 and 900 day degrees) are required to give a good indication of the rate of change in the nitrogen and potassium in the petioles.

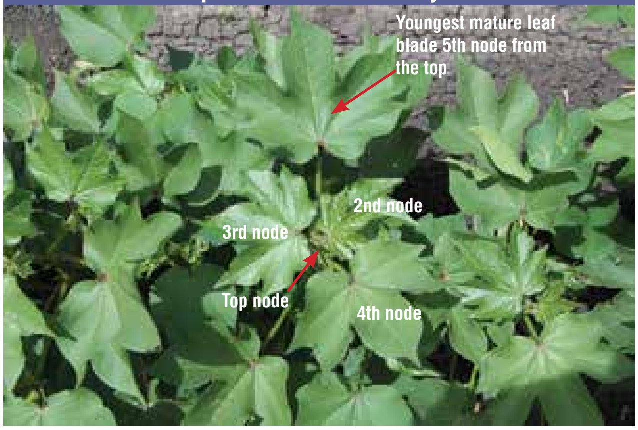
**Leaf analysis** can be used to monitor all nutrients including micronutrients. Sampling leaf tissue twice (at flowering and cut-out) produces the most useful information. Follow sampling directions carefully as results are only as good as the sample provided.

Tips for leaf blade and petiole sampling:

- Ensure samples are taken at a similar soil moisture and time of day and record stage of growth (day degrees).
- Do not sample when the crop is stressed (especially during waterlogging or cloudy weather).
- Sample at least 50 petioles or 50 leaf blades from the youngest mature leaf, normally the fourth or fifth unfolded leaf from the top of the plant (refer to Figure 5).
- Immediately remove leaf blades from the petiole.
- Collect samples with clean, dry hands or clean gloves, to avoid contamination with sweat or sunscreen.
- Loosely pack samples in a paper bag. Immediately store in a cool place (refrigerator or cooled esky) and transport to laboratory as soon as possible.

NutriLOGIC can be used to assess both petiole analysis (early crop nutrient monitoring) and leaf analysis (flowering to defoliation crop nutrient monitoring) and help decisions on additional N fertiliser requirements.

**FIGURE 5: Identification of youngest mature leaf blade used for leaf and petiole nutrition analysis.**




Reduced, minimal or zero tillage practices, crop rotations, cover crops, legumes, composts, stubble incorporation, manures and controlled traffic are just some of the management practices which can be introduced into a cropping system that can have beneficial impacts on soil health and soil fertility as well as reduce costs and improve productivity.

**For more information the following resources and tools are available at:**
**www.cottoninfo.com.au and www.mybmp.com.au**
**NutriPAK**
**SoilPAK**
**NutriLOGIC**
**Cotton Symptoms Guide**
**CottonInfo webinar: Monitoring trace elements in cotton**
**www.youtube.com/cottoninfoaust**

## Take home messages

- **Be realistic about your potential yield.** Trust your soil and tissue tests and apply your nitrogen (N) accordingly. How you do this will depend on your system and local conditions, but do pre-cotton soil tests to generate an N budget for your crop, then follow the crop's progress using petiole and leaf testing. Use post-crop soil N tests and harvest results to construct an N balance for your crop. If there is lots of N unaccounted for then it has been lost to the environment, so reconsider your approach.
- **Long-term NFUE below 10 in crops with below average lint yields for the area indicates soil constraints that simply applying more N won't fix.** Greater consideration of soil conditions and irrigation strategy is required with inputs adjusted accordingly. If yields are meeting expectations and NFUE is low, then excess fertiliser N is being applied, so use a reduced rate.
- **Maintaining soil N fertility is important.** Incorporation of legumes, cover cropping and maintaining soil organic matter are key components in being able to do this.
- **There are several pools of phosphorus in the soil.** It is important to understand these and the soil test methods that relate to them. The 'labile' or fast release pool of P is the pool delivering P into the soil solution that the plants draw from. This pool is most strongly correlated to the Colwell P soil test. There are also slower release pools of P in the soil and you measure this pool using the BSES soil P test. It is critical to at least replace what the plants are removing each year. As P is relatively immobile in the soil, and cotton seems to have difficulty locating bands of P, it is important when you apply P fertilisers to treat the largest volume of soil possible, to ensure maximum root interception, and to some depth if practical.
- **Promoting your soil biology with cover crops and rotations can help to buffer any N in your system and reduce losses.** There is more soil biology under rotations and cover crop systems than fallows and this increased biomass can sequester N, preventing losses and allowing it to be recycled into the crop over a season. Remember the soil is providing about two thirds of your crop N, so you need enough soil biology there to do this effectively.
- **A cover crop's roots allow for better water infiltration, provide more continuity of carbon to feed your soil biology and protect your topsoil from the ravages of heavy rain and wind.**
- **15 bale/ha crops are not just about high N rates.** They are also a product of the rest of the crop's diet, the soil conditions and optimising water availability and adaptation to the seasonal conditions. Minimising plant stress is the key to growing higher yielding crops. Yield reduction from waterlogging can be 12 kg lint per hectare per hour that it is waterlogged.
- **Storing N in your soil and irrigation water is going to lead to losses.** Try to match the N in the soil to meet the crop's demands and if you are recirculating or water-running N then use it quickly and add the N near to the crop. Once N is in the soil or water it is converted to nitrate and from there it can be lost. When denitrification occurs, small amounts of nitrous oxide, a greenhouse warming gas, are emitted into the atmosphere, as well as large amounts of nitrogen gas. There are always likely to be some losses, but management can help reduce them. When finishing the crop, foliar N application may be an alternative to water-run urea to avoid large losses of N in hot conditions.
- **Grab your copy of NUTRIpak and SOILpak and learn more about soil processes that affect your crop and how to manage them.** As (the late) Dr Ian Rochester would have said: "Stop treating your soil like dirt." Consider your soil, your rotation, the use of cover crops, review and improve your nutrient management.

**FIGURE 6:** Two examples of nitrogen deficiency in cotton fields. Maintaining soil N fertility is important, as is being realistic about your potential yield.

## Nutrition in a dryland cropping system

As with irrigated cotton, nutrition is paramount for healthy cotton grown in dryland conditions. The level of nutritional demand will not just depend on yield expectations but also on the biomass potential, which at the end of the day is related to available water. Growers need to be mindful of the stored moisture in the profile at sowing and the potential for in-crop rainfall when evaluating nutritional budgets. It is important growers start preparing for their dryland cotton in previous crops as long-term cropping systems will impact nutrient and soil water availability. In dryland crops both the quantity and the location of nutrients in the soil profile, relative to soil moisture, are important for nutrient use efficiency.

Key points to consider for dryland nutrition management:

- Ensure your cropping system is adequate for growing dryland cotton – good ground cover, good soil structure and high soil water availability.
- Monitor the soil nutrient availability. Soil sample in early winter months, so if fertilising is required it can be done earlier to reduce the impacts on soil structure.
- Build soil fertility during rotation crops. Cotton frequently responds more strongly to improved soil fertility than freshly applied fertiliser.
- Drill/incorporate applied N into the soil to reduce ammonia volatilisation.
- Adjust the application N rate for the expected yield and plant biomass. The plant may require more N early due to ideal growing conditions which leads to larger pre-flowering biomass. This could mine the soil of available N and water, causing potential reduction in production of fruiting structures later in the season.
- Choose the product, N form and application method of N carefully. Some combinations of product, N form and application method will have high potential losses, especially in a dryland cropping system.
- Where crop N requirement has been applied pre-sowing and a significant waterlogging event occurs pre-flowering, take steps to assess soil N availability and re-establish N supply related to new yield potential.
- Severe weather events can hinder the availability of nutrients through waterlogging and elongated soil saturation. Foliar fertilisers may be required when conditions hinder plant growth, especially early in the growing season.
- For nutrients other than N, early application of fertiliser is recommend to improve availability within the profile. Application rates should align with crop removal (refer to Table 1 for correlating nutrient removal rates to yield).

Planning for dryland cotton, including its nutritional requirements, starts well in advance of planting. Consideration for nutritional requirements should begin during earlier crops in the rotation.

# Case study:

## Soil health helps flood bounce-back

By **Brad Pfeffer** (CottonInfo)

Brendan Griffiths's cotton crop had a challenging start for the 2021–22 season.

Conditions were good at planting in mid-October and the crop established nicely. Then in November, the Macintyre River had a major flood and most of the crop went underwater for a few days.

Brendan farms not far from Goondiwindi and is growing about 220 hectares of 748B3F this season. Four days after the flood subsided at Griffiths Agriculture he received another 105 mm of rain in about three hours, which put large parts of the farm underwater again.

Despite these tough conditions with a very wet November – plus plenty of cool and cloudy weather – the crop recovered to the point that the November setback was barely noticeable by about mid-January, which was when the CottonInfo team visited Brendan.

He credits one of the factors in helping the crop to recover from the flooding and waterlogging as his approach to maintaining and building soil health.

"We have a strong focus on soil structure, root development and maintaining the soil structure and integrity," he said. "I think this has helped us recover from that flood event.

One of the strategies that has helped this year has been the move from two metre beds into single metre hills, which has helped from a drainage perspective.

He said the 2 m bed system had helped retain moisture in drier years, but these beds could also stay a bit wet when fully irrigating. Budgeting 10 ML/ha for the crop each year, he may end up needing eight in-crop irrigations, which means getting the water off is just as important as getting it on.

Rotations are also important. Coming out of the drought into the 2201/22 season, his cotton country was planted into ground that had a long fallow of wheat, mungbeans, wheat, mungbeans and then the cotton.

"That was driven by water availability, not by choice," he explained. "In saying that, we still had half of the 2021–22 crop into country that had wheat in 2020."

He also has a strong focus on controlled traffic and digital soil mapping to identify elevation issues and the best location for moisture probes.

This season, with the wetter conditions, some plans had to be adapted as the season went on. For instance, some in-crop herbicide applications were done by air, and in-crop fertiliser application was broadcast, then worked in with a cultivator and followed with an irrigation.

"We had planned to side dress and water-run some urea, but we were concerned about the weather. As it turned out, it was the right decision for the conditions. You have to accommodate the season that you are dealing with," he said.


**Sally Poole and Brendan Griffiths checking this year's crop on January 20.**

# Energy use efficiency

By **Jon Welsh** (CottonInfo/Ag Econ), **Janine Powell** (Ag Econ) & **Phil Szabo** (Taylored Engineering Solutions & Research)

Energy inputs are becoming increasingly scrutinised by policy makers and can also be a considerable cost to primary producers, and this is particularly true for cotton. Fuel, oil and electricity costs totalled $555/ha in 2020, second only behind crop nutrition ($664/ha) as the highest-cost line item in an irrigated cotton gross margin (Boyce, 2020). Irrigated cotton growers can reduce energy costs in any of three ways: reducing demand through saving water; improving energy efficiency of machines/ pumps; and substituting traditional grid or liquid fuels with renewable energy sources. Improving energy efficiency also makes significant reductions in greenhouse gas (GHG) emissions. Reducing GHGs is important in maintaining the environmental credentials of the Australian cotton industry, helping our product access export markets for sustainable cotton. To understand the range, costs and contributions of energy use to cotton production, a number of steps can be taken to ensure best management practice.

## Monitor to manage

Measuring high energy use elements across a cotton farm with fuel and water flow rate indicators, pressure gauges, tachometers and hour meters helps identify focus areas for greater efficiency, such as $/ML, $/ha or energy use per bale. Best management practice of farm energy inputs includes:

- For all pumps, measure diesel and electricity use: $/ML/m head. This is an easy first step to benchmark a pump against industry findings (refer to Best practice box for benchmarks).

### Best practice…

- **Water use efficiency is also energy use efficiency: water savings equate to avoided energy costs.**
- **Test your pump energy usage against industry benchmarks; an efficient pump will lift one ML of water one metre and use 0.96 litres of diesel or 4 kw hrs of electricity.**
- **Revisit your pump duty point and engine speed. Farm staff can inadvertently move engine throttle, leading to drastic alterations in energy use.**
- **Centre pivot and groundwater irrigators – consider hybrid diesel/grid/solar feasibility for your pump site. Incorporating renewable energy into irrigation can halve pumping costs in some situations.**
- **Automation technology and remote pump monitoring can also save energy and farm labour costs when installing a new system.**
- **Monitor tractor engine speed when undergoing heavy tillage. Throttling back and gearing up can reducing in-field fuel costs by 20%.**

- Review your electricity bills and meter readings to ensure readings are correct and tariffs are appropriate for your farm situation. It's a good idea for demand tariff customers to tender usage via an electricity broker.
- Adding a variable speed drive or improving power factor correction (PFC) (located on your electricity invoice) can also achieve energy savings and high investment returns.
- When purchasing liquid fuels, consider a buying strategy and period of demand (to manage seasonal fluctuations), storage life of fuel and fuel quality.
- Using heat wave prediction service to prepare the farm for high energy demands (maintaining inventory, servicing diesel motors).

## Water management to reduce energy costs

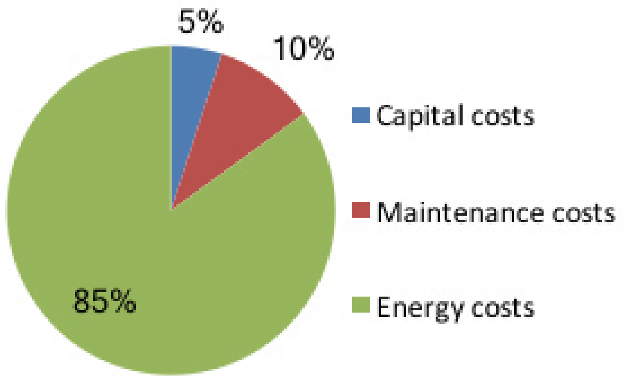
Reducing or optimising the amount of water pumped around the farm can substantially lower demand and energy costs. The CottonInfo website has resources with the latest research and knowledge on water use and management range from collection through to field distribution (e.g. WATERPak). Measuring volumes of inputs (fuel, labour) against outputs (water quantity, bales produced) is the key to making improvements and achieving best management practice. Some key tips are:

- Use tools to schedule irrigations and monitor soil moisture levels.
- Estimate your soil's capacity to hold and store water for your fields and soil types. Be aware of deep drainage and the exponential losses that can occur beneath the soil from saturation.
- Regularly monitor and maintain storages and channels for leaks and seepage. 20% of water use losses can be attributed to these areas. An EM survey and clay lining can remediate leaking channels. Consider structural improvements to reduce evaporation such as splitting irrigation storage into cells or raising dam walls.
- Maximise crop yields by testing and understanding bore water quality and any potential limitations.
- Measure pumping costs of bores – an efficient pump will lift one ML of water one metre and use 0.96 litres of diesel or 4 kWh of electricity.

## Auditing a pump site

Pump stations are generally overlooked when it's time to upgrade farm machinery or equipment. Cotton growers tend to spend more time in the farm ute or tractor, which are upgraded every three to five years, while the pump station continues to operate alone on the riverbank or in the field with little attention. For over a decade there has been a significant investment in research to identify where energy is consumed on-farm and how to improve our energy efficiency. From this research, it has been determined that

**FIGURE 1:** The lifetime cost of an irrigation system. (Source: McMullin, 2016)



irrigated cotton farms consume about 45% of their on-farm energy through pump stations. For groundwater irrigators this can be as high as 75%. Pump stations are a long-term significant investment; not only have they become expensive to operate, but they need to operate effectively or your crop is at risk. Areas to consider when investing in a pump station include the capital costs, maintenance costs and energy costs.

Figure 1 illustrates the weighting for each category with most costs accrued in energy through the project life. Investing in capital and maintenance cost can improve energy efficiency. Pulling out a Perkins engine from the old harvester and connecting to a pump found at last week's clearing sale might have a cheap up-front capital outlay and move the water that you need. But as a result, there is now a significant increase to ongoing maintenance and fuel costs. New, efficient systems can potentially save up to 50% in variable costs and considerable labour when designed and installed correctly. Industry research of over 198 irrigated cotton farms developed an energy auditing process for pump stations. The study also found a single pump make and model is used to pump up to 60% of the water volume in the industry, providing valuable data on energy efficiency and system design flaws. A qualified engineer or consultant conducting a pump energy audit normally follows a systematic approach to benchmark pump performance. The results from an audit highlight the pump station's combined efficiency (pump, motor and drive train), individual pump and motor efficiency and determine pumping cost ($/ML and $/ML/metre head). From this information, it is possible to develop a maintenance and management plan and recommendations for future upgrades to improve energy efficiency. In some cases, it is also possible to increase water flow rate.

In a management plan, knowing what speed to operate the pump for best efficiency and maximum water flow rate gives options to meet the tasks required, whether it be flood harvest, irrigation or numerous others. Observations from previously conducted pump audits has resulted in several findings. Many engines and electric motors have been oversized for the task required of the pump. This can lead to low loads and higher fuel consumption as the engine is not operating at optimum temperatures. High pipeline water velocities increase the total dynamic head across the pump, which results in the pump working more and consuming more energy. Water velocities should be below 2 m/s.

To maintain water flow rate and reduce velocities it is necessary to increase the pipe diameter. This becomes critical on the suction side; if the suction head (pressure) is too high, cavitation can occur. This will reduce performance and increase energy costs while also causing significant damage to the pump itself, requiring regular impeller replacements if left unchecked. Ingesting cotton trash can reduce pump performance by 20%. Ingesting cotton trash also causes severe vibrations in the pump, which risks further damage to equipment (Refer to Figure 2). Air entrainment of 2% by volume reduces pump performance by 20%. Many growers have seen whirlpools or vortices near the pump inlet, which is one way for air entrainment to occur. A corrosion hole approximately the size of a five-cent coin in the suction pipe can cause a significant reduction in pump performance. Poor sump designs such as being too small or not in deep enough water will decrease pump performance.

Water velocities in a sump should be kept below 0.3 m/s. Keeping in mind that one cubic meter of water weighs one ton, this requires significant energy to change the water direction. Pump station setup is critical. Many pump stations have excessive pipe networks, or the pump station is located in a poor position. The older style mechanical engines, while reliable, do consume more fuel than the more modern electronically-controlled diesel engines. Check with your industry pump consultant for government subsidies available for pump assessments. Measuring your pump station performance gives you the ability to manage your pump station and reduce operating costs.

**FIGURE 2: Cotton trash can reduce pump performance by up to 30%.** (Photo: Phil Szabo)

**FIGURE 3: An industry first installation of a 55 kw submersible pump driven by combined 100KW solar and 110 kVA diesel generator at the Gill family's "Waterloo" Narromine, NSW.** (Photo: Jon Welsh)

## Tractors and energy use

The field preparation and post-harvest phase of cotton production are when all heavy tillage tractor operations occur. These are energy intensive practices that require optimisation and can account for 20% of total energy consumed on an irrigated cotton farm. The practice of monitoring or examining individual tractor operations can yield significant energy savings. Check ripping depth and groundspeed by reducing engine speed and gearing up; fuel consumption can be reduced by 7 litres per hour (168 hp tractor). Fuel consumption can be further reduced by 10% with a small (25 mm) decrease in ripping depth.

Deep ripping does not always provide an economic solution in some soil types. Experts have observed that farmers in Australia tend to overballast their tractors. Setting up ballasts correctly on your tractors can optimise fuel consumption, reduce wear and service costs and reduce soil compaction. For information on how to ensure your tractor is correctly ballasted and wheel slip is reduced for maximum traction and fuel efficiency visit www.aginnovators.org.au

## Incorporating renewable energy into irrigation

Cotton's agronomic requirement for high solar exposure means it is geographically well placed to take advantage of solar photovoltaic (PV) energy as an alternative source of generation. Recent improvements in drive technology have enabled a combination of energy sources to operate irrigation pumping systems. Solar PV technology (both grid power and diesel generation) pumping systems have been installed successfully within the cotton industry. However, some points to note when considering alternative energy sources and irrigation pump feasibility are:

- Satisfactory commercial payback occurs on solar-only irrigation projects where water extraction rates are high and a water storage dam is nearby to maximise available solar pumping hours through the year. These generally occur in shallow to medium depth groundwater irrigation bores.
- Matching solar powered irrigation pumping with sporadic or seasonal demand (e.g. capturing overland flow) of surface water has proven challenging with analysis showing standalone PV investments are on the low-end of commercially acceptable returns.
- Hybrid systems allow a pricing hedge of different energy sources and can reduce the reliance on fossil fuels and grid power. Figure 3 shows a hybrid diesel/solar bore in operation in the Macquarie Valley pumping 5 ML/day. At dawn and dusk, DC current from PV is mixed with AC current from the generator to ensure consistent voltage supply to the irrigation pump.
- A new pumping system can offer considerable labour savings through remote monitoring and precise measurement of water resources, pump performance and pumping inputs.
- Installation returns of PV hybrid systems have shown acceptable project payback where an earthen storage can be utilised or year-round or out-of-season generation can be utilised. This may occur through pumping into storage in cooler months, operating grain drying equipment or (potentially) charging electric vehicles/machinery and replacing fossil fuels.

**Further information:**

**www.cottoninfo.com.au/energy-use-efficiency**

**www.mybmp.com.au (Energy and Input Efficiency)**

**www.qff.org.au/projects/energy-savers/**

**www.farm-equipment.com/articles/18076-how-to-properly-ballast-atractor-increase-traction-reduce-fuel**

**CottonInfo video: Integrating alternative energy solutions into irrigation farms**
**www.youtube.com/cottoninfoaust**

**Solar PV systems offer potential for the cotton industry. A range of factors should be considered when incorporating renewable energy into irrigation.** (Picture: Ruth Redfern)

# Digital agriculture – what is it?

**Acknowledgements: Meredith Conaty (CRDC), Jane Trindall (Innovation consultant), Anthony Rudd (i-Ag), Andrew Skinner (Integrity Systems Company), Leanne Wiseman (Griffith University), Michael Bange (Cotton Seed Distributors), Nicole McDonald (University of Central Queensland), Joseph Foley (University of Southern Queensland) and Claire Welsh (CSIRO).**

Digital agriculture is a broad term that refers to digital and data-based technologies that can be adopted within farms and along agricultural supply chains. It has been estimated that harnessing the full value of digital agriculture could add over $20 billion to the annual gross value of production (GVP) of the entire Australian agricultural sector. In the cotton industry, we have already seen the potential for digital agriculture to assist with farm practices such as irrigation scheduling and automation, crop monitoring and sensing, and variable rate input application. In this chapter, we examine some of the first steps for adopting digital agriculture technologies and some of the benefits it could offer.

## Getting your office set up

The adoption of digital agriculture technologies is strongly linked with the farm office. Streamlining the office environment can help ensure smooth integration with new technologies and platforms. Simple steps to improve your office include:

- Move away from paper record keeping and manual processes to digital forms and workflows where possible.
- Seek advice from an IT provider or hardware reseller.
- Know the capabilities of your existing hardware, software and internet, including processing power, connection speed and bandwidth allowances.
- Automate office processes for routine maintenance like software updates, file sorting, hard drive management and data backup.
- Install quality cyber security and virus protection software and be careful how you store and control sensitive information such as usernames and passwords. Consider two-factor authentication.

### Best practice...

- **A digital strategy will help you get your business ready to adopt digital technology.**
- **Get your office set up right and prioritise moving away from paper record keeping and manual processes.**
- **Match your communications to your needs now and in the future. Understand what data can be transmitted and for how far, for each option. Seek support if you need it.**
- **Access available training to build the digital literacy of you and your staff.**
- **Enter data contracts with care.**
- **Ask lots of questions. Be curious about the trialling and validation of agtech products.**
- **Visit the NFF website to see the NFF “Farm data code” which is intended to inform the policies of service providers who manage data on behalf of farmers. It helps farmers evaluate the policies of those providers.**

- Evaluate data storage options. Relying on a computer's hard drive is high risk for data loss or corruption. While external hard drive or USB devices reduce the risk, they can be lost, fail or become corrupted. Where internet services allow, web-based data hub server storage is an easy and safe way to store files, and access rights can be allocated to agronomic partners for sharing of information.

## Choose the right communications technologies

One of the key challenges has been choosing which communications technologies to install or use on farms to connect devices. To evaluate an option:

- Understand the type, size and amount of data that you generate on your farm now and in the future.
- Evaluate the strengths and weaknesses of each system in communicating your data needs.
- Assess the service support available.

Examples include:

### Radio

- Taggle equipment is a relatively inexpensive and innovative low power radio system which sends simple data from sensors to a gateway and onto the Taggle servers over a mobile phone network to display information on a webpage. The range is 15 to 20 km.
- WiSA uses radio signals between the sensor nodes and a base station, which is cabled to an on-farm computer operating the WiSA software. Webpage connection via mobile or landline allows remote control through that computer.

### LoRaWAN

- The open source LoRaWAN communications protocols can be used at different levels, from a basic one-way data output from a sensor node to a LoRaWAN gateway connected to a server and the web, up to fully blown control signals between the system to actuate gates and valves. The range is 10 to 15 km and data rates are low.
- Goanna equipment transmits over a LoRaWAN system from sensor nodes to a gateway, through a mobile phone network out to their servers and their webpage.

### WiFi

- ‘Waverley’, an irrigated property at Wee Waa, uses Rubicon equipment with a zigbee-type communication protocol – an older shorter range (2 to 4 km) two-way comms protocol that transmits data across from sensor node to sensor node to return to the gateway, or direct from outermost sensor node to the gateway. The gateway is connected to Rubicon servers via the mobile network, for grower web-view on their webpage on a connected device. This system is two-way for control, with data output from nodes to gateway, and control signals back to actuate irrigation gates. This enables growers Steve Carolan and Andrew Greste to remotely control the automated irrigation gates from their mobile phone or office computer.
- The Dosec Design EnviroHub is a unit being used at ‘Keytah’, Moree, and can be equipped with different telemetry options to transmit from sensor nodes to the hub, before it then sends data via mobile network. This system is also two-way to enable remote control over irrigation gates.
- Directional WiFi antennas and cheap domestic WiFi units can transmit data from field sensors to gateways that are connected to landline or optical fibre networks.

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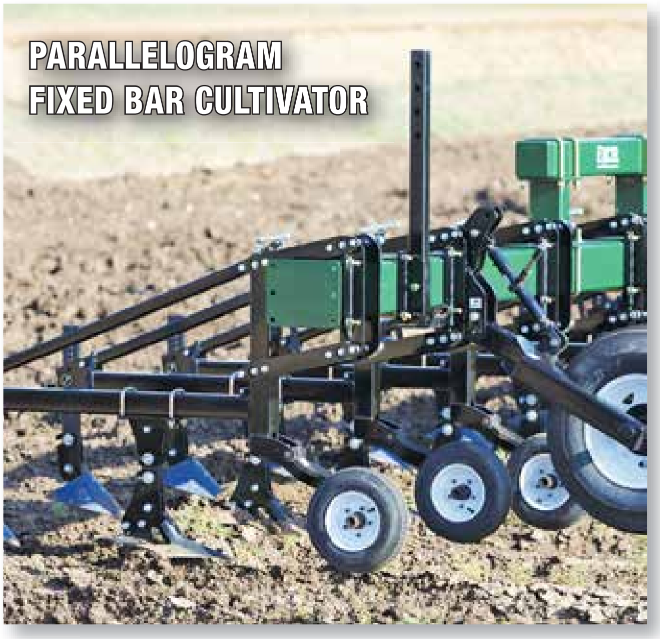


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St George grower Lucas Wuersching checks over irrigation equipment being used to automate a bankless channel (tailwater backwater) system, with a range of on-farm sensors connected over a LoRaWAN network on the farm. To listen to a podcast with Lucas and Craig Saunders discussing the system, scan the QR code (below).

### Mobile/cellular

- Narrow Band Internet of Things (NB-IoT) and Cat-M1 devices operate through the existing mobile network, on a lower frequency than phones, with low data transmission rates of simple data over 1.4 times the mobile range, and have a three to five year battery life.
- 3G/4G/5G based loggers and control systems are used commonly in the industry and can collect sensor data and handle control signals where there is mobile phone coverage. Private on-farm cell towers can provide on-farm mobile coverage and are connected back to optical fibre networks through directional microwave links.

### Satellite

- Pivotel, SatVUE and Myriota offer simple devices to transmit sensor data to webpages via cheap satellite connections.

### Choose the best internet option

- Location – what is the best option for my location?
- Connection speed – many factors can affect your connection speed.
- Reliability and support – use a well-known reputable internet provider.
- Data plans – costs can vary depending on the type, size and speed of connection. Going over your monthly data allowance can be costly so always overestimate your usage.

**For detailed information see the Accelerating Precision to Decision Agriculture Data communications report www.crdc.com.au/precision-to-decision**

## What data do I have? And how is it being used?

The data that you store on your farm machinery, computer, in the cloud and on other digital devices that you use to operate your business is an asset and should be managed in the same way you manage other business items such as your accounts. One important consideration is the ability to move data in and out of the tools and software system. There are several questions you should be asking when choosing software to use in your business, including software on machinery, associated with sensors, and on your computers.

- Can I export or share the data? Is it compatible with other systems that I already have or might want in the future? Does it allow me to import data that I already have?
- If the answer is yes, then the format of the data becomes important. You should prioritise standard and open formats such as the Adapt standard1 that is becoming reasonably well supported. Other considerations would be – What format does the software export or share data in? Will this be compatible with other software vendors going forward? (CSV and JSON are common.)
- Check how complete the data being exported from any software is and what standards are being used, if any. Many software systems will only export a subset of the data you have saved, meaning that its value can be reduced over time.
- Finally, the last question to consider is: how large is the import/export of my data likely to be? This is important, especially for cloud-based products as large data sets may be difficult to upload/download due to connectivity and bandwidth concerns. The ability to back up your data off-site is important.

There are services to assist you automate the collection and analysis of your data across various sensors and machines. Examples to follow are PCTagcloud and I-Ag to see new products and services emerging. Some practical examples of where you can find value from digital agricultural tools include:

**TABLE 1 : Some common methods for precision management of crop inputs**

| Input | Method |
|---|---|
| **Variable rate planting (population)** | Matching the seeding rate to soil type and/or topography. |
| **Variable rate planting (hybrid)** | Changing crop hybrid varieties within a field to match soil conditions and/or topography. |
| **Variable rate fertiliser: Starter/ pre-sowing** | Redistributing fertiliser to allocate rates to specific production zones, created or ground-truthed from intensive soil nutrient sampling, crop history etc. |
| **Variable rate fertiliser: Topdress, in-crop** | Using remotely sensed multispectral imagery to identify zones of differing reflectance. Ground-truthing via in-crop inspections and tissue testing are critical to determining links between reflectance zones and crop biomass/crop nutrient status. |
| **Variable rate fertiliser: Soil ameliorant (gypsum, lime)** | Utilising EM surveys and/or grid soil sampling to create management zones. |
| **Variable rate herbicide** | Using multi-spectral imagery to identify high density populations of weeds or weeds surviving a herbicide, to identify areas for application of double knock or alternative control methods. |
| **Variable rate irrigation (in-crop, pivot/lateral)** | Utilising soil EM and topography derivatives (aspect, slope) to create management zones for production potential. |
| **Variable rate growth regulator (in-crop)** | Utilising in-crop multispectral imagery and subsequent ground-truthing to determine biomass/crop growth based management zones. |

New technology can offer innovative opportunities, but growers are encouraged to ask a lot of questions to make sure new products are adding value to their business.

- **Automation –** Once you have your information organised, you can explore opportunities to inform or automate decision making. For example, automating office functions and data management, or input management like irrigation is likely to result in labour savings.
- **Inputs –** Variable rate technologies can help you to maximise the yield potential of a field and precisely manage your inputs (see Table 1).

Ongoing collaboration with trusted professional advisors will help ensure a solid agronomic foundation and ground-truthing of digital agriculture concepts/services to your farm.

There are a number of tips to think about **before** entering into ag-data licences. We suggest you ask the following questions:

- What is the value of my data to me?
- Who owns or controls the management of my data? Check your data contract for any terms that outline rights in relation to ownership or control of your data.
- Have I agreed to share my data? If you agree to share your data, it is important to understand who will be storing that shared data, where it will be stored and who will have access to it.
- Who else might have access to my data? i.e. can my data be released to the public, or to a third party or to the Government?
- How will my data be used?
- How is my data aggregated and does aggregation protect/de-identify me?
- Is my personal data/information anonymised?
- Is my personal information/data protected by the Privacy Policy of the company and Australian Privacy Law and the Australian Privacy Principles?
- Can I stop sharing or withdraw my data once I have agreed to share? Some contracts allow you to stop sharing your data at any time. However, any data previously submitted is not usually retrievable and will not be erased from the company database.
- What happens if there is a data breach? i.e. your contract will often state which laws apply. It is important that your contract is governed by Australian law, where possible. Best practices for transparency and trust for producers have been developed into an Australian agricultural data governance framework and action plan. Issues addressed are the roles and responsibilities, policies, procedures and institutional arrangements and ensuring appropriate safeguards are in place to protect against risks associated with misuse of agricultural data.

## What skills do I need?

The three main ways digital agriculture can impact the workforce are that (a) technology replaces jobs, (b) technology creates new jobs, and (c) technology will assist our jobs. To meet the future of farming, which is likely to be augmented by new technology, we can prepare now for workforce changes and requirements.

Invest in your staff to ensure that you build their capability to manage and work with data in your business.

**Further resources:**

**Microsoft Digital Literacy Course www.microsoft.com/en-us/digitalliteracy/home**

**Pluralsight The Technical Skills Platform www.pluralsight.com**

**Qld and NSW TAFE**

**Coursera AI for Everyone**

**The Growing A Digital Future Project provides more guidance about digital skills and training for Australian agricultural workforce.**

**References/further reading**

**Accelerating precision agriculture to decision agriculture: Enabling digital agriculture in Australia Reports – www.crdc.com.au/precision-to-decision**

**AgGateway Adapt Standard: Ag Data Application Programming Toolkit – www.adaptframework.org**

**Agricultural Data Rules: Enabling Best Practice Fact Sheet – https://www.crdc.com.au/sites/default/files/Fact%20Sheet%20Growing%20digital%20-%20Data%20Rules%20Sep2019.pdf**

**Digital Business Interactive Tool. 2017. Deloitte Digital. MIT Sloan Management Review – https://sloanreview.mit.edu/2017-digital-business-interactive-tool/**

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**Lamb, D. (2017). Accelerating precision agriculture to decision agriculture: A review of on-farm telecommunications challenges and opportunities in supporting a digital agriculture future for Australia. University of New England and Cotton Research and Development Corporation, Australia – https://www.crdc.com.au/sites/default/files/P2D%20telecommunications%20-%20UNE%20Final%20Report.pdf**

**P2D Online Grower Toolbox and Materials – http://www.acipa.edu.au/p2d-online-grower-toolbox-home.html**

**Why a digital strategy is right for your operation. Precision agriculture news – https://www.precisionagreviews.com/post/why-a-digital-strategy-is-right-for-youroperation**

# Integrated Pest Management & Resistance Management

By **Paul Grundy** (Qld DAF/CottonInfo) & **Susan Mass** (CRDC),

**Acknowledgements: Sally Ceeney (Cotton Australia), Sandra Williams (CSIRO), Simone Heimoana (CSIRO), Mary Whitehouse (Macquarie University), Jamie Hopkinson (Qld DAF), Sharon Downes (CSIRO) & Lisa Bird (NSW DPI)**

## What's new…

**Resistance within silverleaf whitefly and two-spotted mites to key chemicals remains a concern throughout most production regions. Be sure to check current updates at the CottonInfo website.**

Cotton has several pests that affect yield and quality, and some populations (such as mites, mealybug and whitefly) can quickly increase if IPM is not implemented.

## What is Integrated Pest Management (IPM)?

Integrated pest management could be called intelligent pest management as it uses our knowledge and understanding of the pest, the crop, and the environment to minimise the likelihood of pest outbreak and reduce our reliance on insecticides. IPM is not a recipe, but instead requires the crop manager to implement a mix of pre-emptive and responsive pest management actions to reduce the risk of crop loss and improve the health of the environment and ourselves.

**What is IPM – www.youtube.com/CottonInfoAust**

### How do I implement IPM?

IPM does not have to be complicated – it's an evolving process that builds on taking practical steps to reduce the survival of pests. For example, a simple first step could be improved on-farm hygiene. This might be followed by a decision to avoid the use of a particular type of disruptive insecticide.

For first-time growers, the easiest way to start your IPM journey is to employ the services of an experienced consultant to help guide you through the process of pest management decision making. A consultant will provide information on what is going on in your crop and advise you on various management options that might be applicable to your situation. If you are a more experienced pest manager and are familiar with pest management principles, push your boundaries by asking yourself some simple 'WHY' questions such as "Why were silverleaf whitefly (SLW) higher or lower than last season?" or "Why am I using this particular insecticide?" Taking the time to consider the range of potential answers might provide insight as to the best next steps for your management program. These types of questions are also good starting points for discussions with your advisor.

The important thing about IPM is to appreciate that biological systems are continually evolving along with our knowledge about pest species and control options. Keeping up to date with the latest information is essential for effective IPM. The latest research findings are made available to growers and advisors via industry meetings and a range of CottonInfo information products. The *Cotton Pest Management Guide* (CPMG) is updated annually and is available in print and online. As your IPM program evolves, new practices will bring prospective benefits as well as potential trade-offs (e.g. a more selective insecticide may cost more to apply than a broad spectrum option but it reduces the likelihood of secondary pest outbreak which may require further spraying). Learning as you go is the key to success. When things change, be prepared to adapt what you are doing to overcome new challenges. If you have unanswered questions, have confidence that there is information and advice at hand via your consultant, industry resources and your peers to help you achieve your IPM goals.

## Dryland cotton…

- **Cotton has the same pests and beneficials with or without irrigation. IPM and resistance management are important regardless of where or how cotton is grown.**
- **A key IPM challenge for dryland crops grown in minimum tillage systems is to ensure that crop destruction is 100%. Ratoon cotton or volunteers that emerge in a subsequent grain crop can provide a green bridge for pests and diseases. Crop mulching or slashing alone at the end of the season is not sufficient to prevent pest carryover unless it is followed with tactics that prevent any regrowth.**

## Best practice…

- **Knowledge is the key that unlocks effective IPM.**
- **Seek to PREVENT pest outbreaks through good farm hygiene, complementary crop rotation and preservation of natural enemies.**
- **MONITOR pest species, beneficial insects and spiders, crop stage, crop growth and the weather to inform your decisions.**
- **Bring it together with effective management ACTION that is mindful of pest thresholds, resistance risks and potential impacts on natural enemies, bees and the environment.**

## IPM – the basics

While IPM is not a recipe, there are some established practices that form a solid basis for implementing IPM on your farm. These are:

- **Farm hygiene.** Minimising cotton volunteers, ratoons and other weeds in fallow fields, field edges, roadways and drainage lines on your farm can limit the survival and spread of overwintering pests such as mealybugs or resistant aphids that might also carry bunchy top disease. **CLEAN FARMS TEND TO HAVE LESS PEST PROBLEMS THAN DIRTY ONES.**
- **Preventing problems.** Sowing date, crop sequences and field selection are some of the tactics that you can use to disadvantage pests on your farm. For example, you could avoid back-to-back cotton in fields that had mealybugs to limit season carryover, or not plant as late so that your crop is not exposed to displaced populations of SLW.

# Hard on mirids
# Soft on beneficials


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Transform controls a range of cotton pests while proving soft on beneficials. Because of its unique Mode of Action, Transform can control insects that are resistant to other insecticides.

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- **Sample your crop effectively.** Detecting and being able to quantify pests and beneficials is a fundamental requirement for good decision making. Depending on the crop stage and pest or beneficial type, sampling techniques may vary. Refer to the CPMG for specific details on how to sample for key species.
- **Take note of where your crop is at.** The development stage of your crop has a big bearing on (i) whether it is susceptible to yield loss and (ii) if it can recover from pest damage without intervention.
  - Minimal squares on a normal crop at 10–12 nodes might indicate poor retention due to pest or weather damage, but if the plant has been developmentally delayed, the retention levels may be appropriate.
  - Cotton can compensate for early season damage, particularly of vegetative plant parts, if growing conditions remain favourable.
  - It is important to be able to distinguish between vegetative and fruiting branches when measuring retention during early crop development. See the CottonInfo videos that explains the difference between branch types: www.youtube.com/CottonInfoAust
  - Many pests become less important as bolls open whereas SLW or aphids (that can contaminate open cotton with honeydew) become more important.
- **Know your enemy.** There are about six key pests (helicoverpa, mirids, silverleaf whitefly, mites, thrips, aphids), that you would expect to deal with regularly when growing cotton. A key to managing these pests is to understand what they are, what damage they cause, preventative steps you can take to minimise their numbers or impact, how best to sample for them, when control is likely to be required (action thresholds), and what types of control techniques (chemical, biological or physical) are likely to be suitable and effective. The CPMG has specific information on these pests and their management.
- **Know your friends.** Cotton crops host a diverse array of beneficials that can suppress pests, particularly mites, silverleaf whitefly (SLW) and mealybugs. Noting which beneficials are present when sampling can help inform your control decisions. Conserving beneficials can have a significant impact on whether you develop a mite or mealybug problem later in the season. The impact of insecticides and miticides on predators, parasitoids and bees in cotton is outlined in Chapter 1 of the CPMG. It will allow you to compare the potential impact of different products so that you can make a balanced control decision.
- **Do you even need to spray?** Many pest insects have scientifically-based action thresholds that can help you decide whether a given level of pests or crop damage might require a control action. Resist the urge to use insecticides prophylactically with herbicide application operations. For action thresholds, refer to the individual pest sections in the CPMG.
- **Choosing an insecticide wisely.** When insecticide control is warranted make sure the product you have selected appropriately balances effectiveness against the target pest with any potential harm to natural enemies. Actively avoiding the use of broad-spectrum disruptive insecticides (e.g. organophosphates, pyrethroids and some neonicotinoids) wherever possible, especially early to mid-season, will go a long way to reducing mite, SLW and mealybug numbers later in the season. Also be aware of restrictions on the use of certain products as part of the industry's Insecticide Resistance Management Strategies (IRMS). Very detailed guidelines on the off-target impacts of insecticides on beneficials and the IRMS are provided annually in the CPMG.
- **Preserve the usefulness of insecticides and Bollgard.** The ability of insecticides or *Bacillis thuringiensis* (Bt) protein-expressing Bollgard crops to provide control of pests depends on pest populations being susceptible to those insecticides or insecticidal compounds. Follow the insecticide label directions and consider both your application technique and environmental conditions to optimise chemical efficacy. Adhering to industry stewardship programs is important to ensure that the industry continues to have pest control tactics that give good control.
- **Working with your neighbours.** Pests and beneficials do not recognise farm boundaries. Working with your neighbours to better co-ordinate planting, farm hygiene and crop spraying can provide benefits for the management of pests such as SLW on an area-wide basis. In some regions growers meet regularly at area wide management (AWM) meetings to discuss pest issues and work towards shared solutions. Talk with your local CottonInfo Regional Extension Officer (REO) about any AWM groups in your valley.

**Useful resources:**

**The *Cotton Pest Management Guide*.**
**www.cottoninfo.com.au/publications/cotton-pest-management-guide**

**Pest and Beneficial Insects in Australian Cotton Landscapes. Available from www.cottoninfo.com.au**

**This branch is vegetative as there is no square or abscission scar opposite the subtending leaf.**

**This branch is clearly a fruiting branch with a square opposite the subtending leaf.**

**This branch is also a fruiting branch denoted by the scar (following the loss of a square) opposite the subtending leaf.**

## What is resistance and why is it important?

Resistance can occur as a consequence of exposing pest populations to a strong selection pressure, such as repeated usage of the same type of insecticide. Within pest populations, genes that confer resistance to insecticide toxins are usually present but rare. However, when the population is exposed to a toxin, either from an applied pesticide or from a biotechnology trait, the frequency of resistance genes can increase due to the preferential removal of susceptible individuals from the population. If selection continues repeatedly, the proportion of resistant insects relative to susceptible insects continues to increase until the toxin no longer kills enough of the population for effective pest control, causing control failure. Long-term management of pests is therefore dependent on avoiding over-reliance on any one toxin-based control method and utilising complementary tactics such as encouraging natural enemies or implementing effective farm hygiene. The cotton industry has been seriously challenged by insecticide resistance in the past. As a result, resistance management has become a fundamental component of IPM, where the industry takes a proactive approach to protecting the efficacy and longevity of biotechnology traits and insecticides used to control pests.

The industry invests in testing for resistance, considering preventative measures, and working towards solutions. Each year the cotton industry reviews insecticide and Bt product performance and other relevant science through the Transgenic Insecticide Management Strategy (TIMS) advisory panel (through Cotton Australia) to ensure sustainable chemical control underpinned by IPM-compatible resistance management.

### What is Bt?

***Bacillus thuringiensis* (Bt) is a common soil bacterium. It produces proteins that are toxic to different species of insects. Bt cotton has been genetically modified with Bt genes that encode for proteins that are specifically toxic to moths like *Helicoverpa* spp. (bollworm and budworm). Bollgard 3 cotton produces three different insecticidal proteins. This 'stack' contributes to resistance management as it is more difficult for the pest to overcome all three toxins in unison.**

## What is stewardship?

The cotton industry has implemented stewardship programs for the prevention or management of resistance for insecticides and the Bt technology in Bollgard cotton. These science-based strategies seek to combine what is known about the pest, resistance levels and mechanisms, and how these factors might react to changes in response to how products are used.

**The Insecticide Resistance Management Strategy (IRMS)** aims to manage the risk of insecticide resistance of major pests in cotton including aphids, mirids, mites, SLW and *Helicoverpa* spp. and is applicable to both Bt and non Bt-cotton. One of the pillars of the strategy is to group chemicals according to their mode of action and ensure rotation of these product groups to avoid prolonged or repeated usage. The strategy advises crop managers on how and when each insecticide or insecticide group is best used and is updated annually to take into account the levels of field resistance in pests and any relevant changes within the farming system. The IRMS is designed to delay resistance development and to manage existing resistance and is reviewed by TIMS and published annually in the *Cotton Pest Management Guide*. It is critical to follow the IRMS to ensure the longevity of insecticides currently registered in cotton. Use the IRMS relevant to your region and look at what products are relevant at that stage of the season (shown across the top of the IRMS). Colours and notes depict limitations such as the number of times that active ingredients can be used, whether consecutive applications are allowed etc. Insecticides are listed in the IRMS chart according to the order of their impact on beneficial insects and bees – the most selective appear at the top of the chart and are available for use early in the season while the broad-spectrum products appear at the bottom and are restricted to the end of the season. Delaying or avoiding the use of disruptive insecticides and miticides helps to reduce resistance by enabling the survival of natural enemies that can predate/parasitise any resistant individuals that survive. Since some chemicals are registered to control or suppress several pest species, spraying for one pest can simultaneously select resistance in other pests, even though they may only be present at sub-threshold levels and not be specifically targeted. Because of this, the IRMS includes all insecticide actives commercially available for use in cotton, and should be consulted for every insecticide/miticide decision.

**The Bollgard Resistance Management Plan (RMP)** has been developed in conjunction with industry to help delay the development of resistance to Bt. The RMP is a mandatory component of the licensing agreement (Technology User Agreement or TUA) that growers sign with the technology provider to grow Bollgard cotton. These requirements* set out to:

- Limit the number of generations of *Helicoverpa* spp. exposed to toxin (planting window dates for temperate and tropical regions, control of volunteer and ratoon cotton plants, limitations on the use of foliar Bt products);
- Ensure that there is a population of susceptible moths that haven't been exposed to Bt during the season so as to dilute any resistant genes in the population (refuge type, area grown and agronomic management); and,
- Target the last moth generation of the season with an active control program to reduce the risk of resistant individuals carrying over to the next season (trap crop management, end of season management – including crop destruction and pupae busting).

***Note that requirements may vary between regions.**

The interaction of all these elements should effectively slow the evolution of resistance. Commercial access to Bt transgenic varieties is conditional upon the crop manager strictly adhering to the RMP as it applies to each cotton production region. Elements of the RMP may vary over time depending on changes in pest responses. Your technology provider will notify you of the latest requirements as part of the TUA contract that is signed each season.

**For more information:**

**View the Cotton IRMS and the Bollgard 3 Resistance Management Plan in the annual *Cotton Pest Management Guide*.**
**www.cottoninfo.com.au/publications/cotton-pest-management-guide**

### Resistance monitoring

Resistance monitoring (for *Helicoverpa* spp., two-spotted spider mites, aphids, mirids and SLW) is conducted each year by the cotton industry and provides the foundation for annual review and updating of the IRMS and RMP. All growers and consultants have access to this industry service to investigate suspected cases of resistance.

**Contacts for suspected resistance:**

**Aphids, mites and mirids: Dr Lisa Bird 02 6763 1128.**

**Silverleaf whitefly: Dr Jamie Hopkinson, Qld DAF, 07 4529 4152.**

***Helicoverpa* spp.: Dr Lisa Bird, NSW DPI, 02 6763 1128 and Dr Sharon Downes, CSIRO, 02 6799 1576.**

# Living in harmony with bees

By **Paul Grundy** (Qld DAF/CottonInfo),

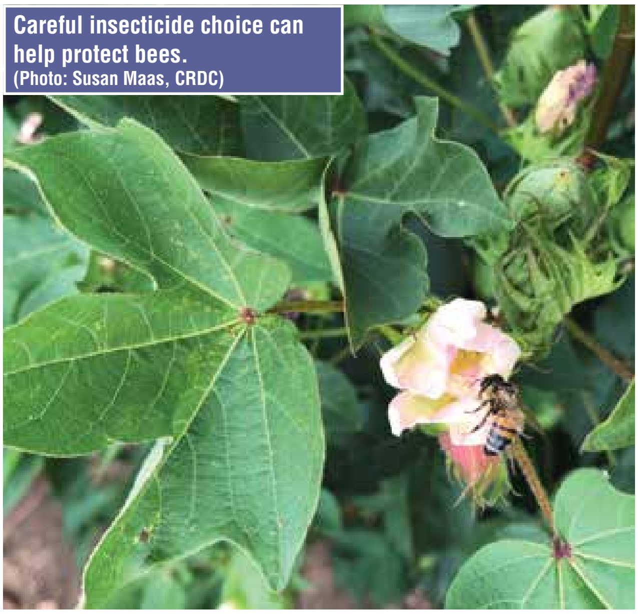
**Acknowledgements: Simone Heimoana (CSIRO), Sandra Williams (CSIRO) & Susan Maas (CRDC)**

Honey bees are essential for the pollination of fruit and nut trees, which are becoming more abundant in parts of the Murray Darling Basin. Bees will also use cotton as a source of pollen and nectar, particularly when other resources such as native vegetation or surrounding tree crops have limited floral resources. Although cotton does not require insect pollination to set fruit, several studies have shown significant increases in yield where honey bee pollination was encouraged. It is important to realise that bees can also be active in cotton crops before and after flowering, as bees can collect nectar from both flowers and cotton's extra-floral nectaries that occur on the underside of leaves. It is important when scouting crops for pests and beneficials to take notice of whether bees are present and are actively foraging. Insecticide use can make cotton crops a very high-risk environment for bees. Bees are particularly susceptible to insecticides such as fipronil, abamectin, indoxacarb, spinosad, pyrethroids, organophosphates and some neonicotinoids. Spinosad, which has an overall low ranking for disrupting many natural enemies, happens to be highly toxic to the Hymenoptera family of insects (ants, bees and wasp parasitoids) when freshly applied.

Insecticides that are toxic to bees are identified on the label. The productivity of hives can be severely impaired if foraging bees come into contact with insecticides during application. Foraging bees that survive insecticide sprays often carry residual insecticide back to the hive which can be detrimental to the developing brood via contact or feeding. These effects

**Coolibah trees *(Eucalyptus microtheca)* are a primary source of nectar and pollen for honey bees. These trees grow on the black soil plains along many of the river courses in the cotton growing areas. When heavy budding occurs, beekeepers often move large numbers of hives into cotton growing areas for honey production. Budding and flowering only occurs in response to good spring rains meaning the timing is likely to coincide with the time when insecticides are used in cotton.**

**Careful insecticide choice can help protect bees.**
**(Photo: Susan Maas, CRDC)**



can also occur when insecticide drifts over hives or over neighbouring vegetation that is being foraged by bees. The risk to bees can be reduced by:

- Notifying the apiarist when beehives are in the vicinity of crops to be sprayed to allow removal of the hives before spraying. Note that bees can travel up to 7 km in search of pollen and nectar. Beekeepers require at least 48 hours' notice to move an apiary (see information below on the BeeConnected app).
- Informing contract pesticide applicators operating on the property of the locations of apiaries.
- Always reading and complying with label directions. Look for special statements on the label such as: **"Dangerous to bees. DO NOT spray over plants in flower while bees are foraging."**
- Paying particular attention to wind speed and direction, air temperature and time of day before applying pesticides.
- Using buffer zones as a mechanism to reduce the impact of spray drift or overspray in vegetation used by bees.
- Avoiding drift and contamination of surface waters where bees may drink.

The annual *Cotton Pest Management Guide* provides additional information about insecticide risks to bees as well as tables showing the relative toxicities of cotton insecticides and residual toxicity risks for bees. With good communication and goodwill, beekeepers and cotton growers can work together to minimise risks to bees, as both the apiculture and cotton industries are important for regional development.

**Bee Aware – https://www.youtube.com/watch?v=LBRUaqZaVoQ**

**BeeConnected is a nationwide, user-driven smartphone app and website that enables collaboration between beekeepers, farmers and spray contractors to facilitate best practice pollinator protection.**

**For more information and to participate in the BeeConnected service go to https://beeaware.org.au/pollination/beeconnected/**

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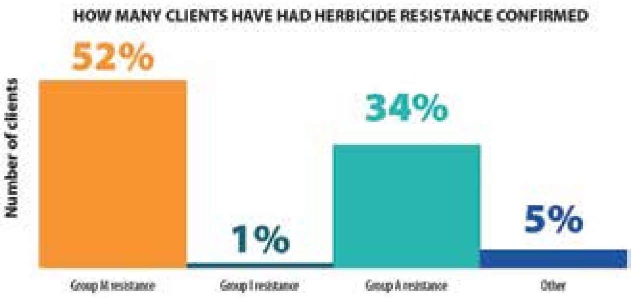
# Integrated Weed Management

By **Eric Koetz** (CottonInfo/NSW DPI)

**Acknowledgements: Graham Charles (NSW DPI), Ian Taylor (CRDC), Tracey Leven (formerly CRDC), Jeff Werth (Qld DAF), David Thornby (Innokas) and Susan Maas (CRDC)**

Integrated weed management (IWM) describes the strategy to manage existing herbicide resistance and prolong the use of life of each herbicide. It also reduces the rate of species shift, which can reduce the cost of future weed control by depleting the number of weed seeds in the soil, and improves crop productivity through effective weed management (Watch the CottonInfo YouTube video on minimising glyphosate resistance: www.youtube.com/cottoninfoaust).

**FIGURE 1:** Data from the 2020–21 CCA survey reports that 52% of growers have had herbicide resistance confirmed for glyphosate (Group 9).




## Herbicide resistance

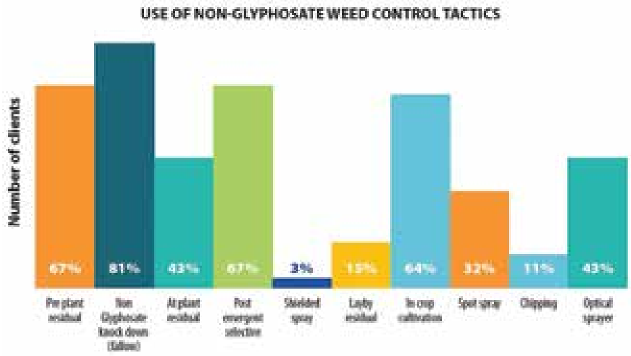
Herbicide resistance is often present at very low frequencies in weed populations before the herbicide is first applied. Using the herbicide creates the selection pressure that increases the resistant individuals' likelihood of survival compared to 'normal' or susceptible individuals. The underlying frequency of resistant individuals within a population will vary greatly with weed species and herbicide mode of action. Resistance can begin with the survival of one plant and the seed that it produces. Early in the development of a resistant population, resistant plants are likely to occur only in isolated patches. This is the critical time to identify the problem. Options are much more limited if resistance has spread over large areas before it is observed. Weeds may also survive herbicide applications due to spray failure, caused by poor preparation, equipment blockages, water quality and other factors. Completing the self-assessment (Table 1) will aid in determining if the weeds' survival was likely due to resistance or other factors (Watch the CottonInfo weed resistance demonstration YouTube video: www.youtube.com/cottoninfoaust).

Herbicide resistance has been confirmed in 48 grass and broadleaf species in Australia, across 11 distinctly different herbicide chemical groups (www.croplife.org.au). Cases of multiple resistance have also been commonly reported. Glyphosate resistant weeds continue to appear in Australian cotton farming systems. As of January 2021, 21 weeds of cropping systems have developed resistance to glyphosate. In the cotton growing areas, the number of growers who are reporting glyphosate resistance is increasing.

### Best practice…

- **Herbicides are applied according to label directions and the legislative requirements.**
- **Good farm hygiene is practised to minimise entry of new weeds.**
- **Key weeds are identified and weed burden assessed annually. Weed strategies are targeted to manage problem weeds.**
- **Fields are scouted regularly to assess weed pressure and efficacy of control measures.**
- **Herbicides are applied at the ideal weed and crop growth stages.**
- **Weeds that survive a herbicide application are controlled using an alternative mode of action prior to seed set.**
- **Key weeds and management practices that are at risk of glyphosate resistance are identified through use of a risk assessment tool.**

**FIGURE 2:** The 2020–21 CCA survey highlights the range of management tactics used by growers to control hard to kill weeds.




The Australian cotton industry has developed a Herbicide Resistance Management Strategy (HRMS). The key message from the HRMS to manage herbicide resistance is to use at least two non-glyphosate weed control tactics in fallow + two non-glyphosate tactics in-crop and ensure that there are no survivors (2+2 and no survivors). Data from the 2020–21 CCA qualitative survey shows growers are adopting a range of non-glyphosate weed control tactics (Figure 2).

Refer to the *Cotton Pest Management Guide* for more information.

## Planning weed management

It is important to strategically plan how different tactics will be used to give the best overall results for the existing weed spectrum. A short-term approach to weed management may reduce costs for the immediate crop or fallow, but is unlikely to be cost effective over a five or ten year cropping plan. Over this duration, problems with species shift and the development of herbicide resistant weed populations are likely to occur where weed control has not been the focus of an integrated plan. There are five principles in developing a successful long-term approach to weed management:

- Know the weed spectrum and monitor for changes.
- Use a diversity of cultural, in-crop and fallow management tactics to actively reduce the seed bank, as well as preventing emerged weeds from surviving through to seed set.
- Rotate herbicide modes of action and if crop safety allows mix two modes of action at full label rates.

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Look for the early signs of resistance before patches of survivors get too large like this annual ryegrass patch. (Photo: Dr Graham Charles, NSW DPI)

- Monitor and follow up to ensure weeds that survive a herbicide are controlled by another tactic before they can set seed.
- Come Clean Go Clean to prevent movement of weeds seeds onto, off, or around the farm. Planning and deployment of tactics should consider the full range of farming systems inputs that can impact on weeds as shown diagrammatically in Figure 3.

The HRMS should be used as a tool for planning weed management in irrigated and dryland cotton farming systems to help delay and manage glyphosate resistance. Refer to the *Cotton Pest Management Guide* for more information. For a more detailed assessment of the resistance risks for individual paddocks or to try out different scenarios to compare strategies, use the Online Glyphosate Resistance Toolkit, available at https://www.cottoninfo.com.au/glyphosate-resistance-toolkit

**TABLE 1: Self-assessment for possible herbicide resistance: Y/N**

| | |
|---|---|
| **1** | Was the rate of herbicide applied appropriate for the growth stage of the target weed? |
| **2** | Are you confident you were targeting a single germination of weeds? |
| **3** | Were the weeds actively growing at the time of application? |
| **4** | Having referred to your spray log book, were weather conditions optimal at the time of spraying so that herbicide efficacy was not compromised? |
| **5** | Can the weed patch be related to a previous machinery breakdown (such as a header) or the introduction of weed seeds from a source such as hay? |
| **6** | Are you confident the suspect plants haven't emerged soon after the herbicide application? |
| **7** | Is the pattern of surviving plants different from what you associate with a spray application problem? |
| **8** | Are the weeds that survived in distinct patches in the field? |
| **9** | Was the level of control generally good on the other target species that were present? |
| **10** | Has this herbicide or herbicides with the same mode of action been used in the field several times before? |
| **11** | Have results with the herbicide in question for the control of the suspect plants been disappointing before? |
| **12** | Are you having to increase herbicide rates each year to achieve the same level of control? |

**If you suspect herbicide resistance contact:**
**Dr John Broster (seed test), Charles Sturt University Herbicide resistance testing service, PO Box 588, Wagga Wagga, NSW 2650**
**Ph: (02) 6933 4001, Email:jbroster@csu.edu.au**
**Or**
**Dr Peter Boutsalis (seed test & quick test) 22 Linley Avenue, Prospect, SA 5082**
**Ph: 0400 664 460, Email: info@plantscienceconsulting.com**

# In-crop implementation of tactics

## Correct weed identification

Ensure that weeds are correctly identified before choosing a response. Similar species may respond differently to control measures. For example, the strong seed dormancy mechanisms of cowvine (*Ipomoea lonchophylla*) make it less responsive to a tactic like the spring tickle than bellvine (*Ipomoea plebeia*) which has very little seed dormancy. Herbicide susceptibility can also differ between similar species.

**For technical information on weed ID refer to the Weed Identification and Information Guide available from CottonInfo https://cottoninfo.com.au/publications/weedpak-weed-id-guide or download the Weeds of Australian Cotton App: https://www.cottoninfo.com.au/weeds-australian-cotton-app**

## Scouting

Scouting fields before weed control is implemented enables the weed control option to be matched to the species present. Scouting should be repeated to assess efficacy soon after a control is implemented. Timely scouting allows questions that affect the next weed control decision to be answered:

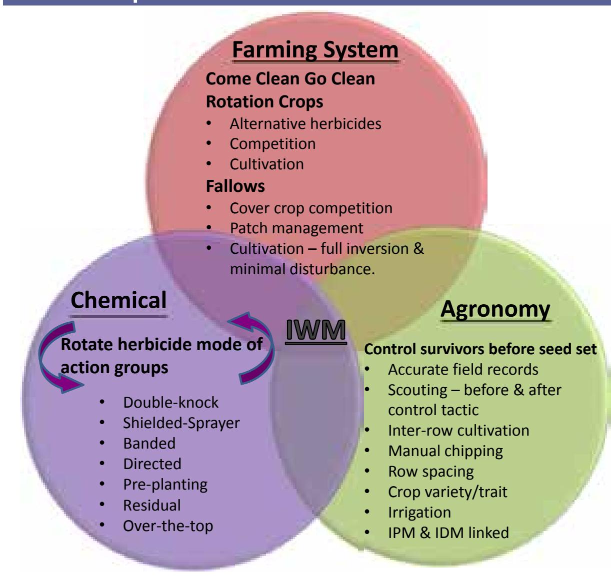
- Were there any survivors?
- Has control been better in some parts of the field than others?
- Has there been good control but a subsequent germination?

To be effective in preventing resistance, weeds that survive a herbicide must be controlled by another tactic before they are able to set seed (double knock). It is extremely important to check the efficacy of double knocks after recent reports of flaxleaf fleabane (*conyza bonariensis*) surviving glyphosate/paraquat double knock. Prompt scouting is required as some weeds are capable of setting seed while very small. Many weeds respond to varying day-length, so a winter weed emerging in late winter or spring may rapidly enter the reproductive phase of growth in response to lengthening daylight hours.

**For more information on the growth and development of common weeds refer to Weed Growth & Development Guide in WEEDpak www.cottoninfo.com.au/publications/weedpak**

Identify and closely monitor areas where machinery such as pickers and headers breakdown. Weed seeds are often inadvertently released when panels are removed from machines for repairs. Weeds such as parthenium

**FIGURE 3: An integrated weed management system should consider the full range of farming systems inputs that can impact on weeds.**



have been spread this way. Whenever possible, it is best practice to ensure that all machinery maintenance occurs in a centralised area, such as around the farm sheds, so that any new weed incursions will be readily observed and managed. Weed scouting in non-crop areas of the farm is a valuable source of information for planning future weed management strategies (Watch the CottonInfo YouTube video on sources of weed seed: www.youtube.com/cottoninfoaust).

Non-cropping areas, such as roadways, channels, irrigation storages and degraded remnant vegetation can be a source of infestation and can provide opportunities for newly introduced weeds to build up significant seed banks. Some of these weeds will also host pests and diseases. These can be moved into fields via water, wind and animals. Good managers should always be on the lookout for new weeds.

## Good record keeping

Good record keeping will help to develop strategies and is invaluable for mitigating problems if they occur. Good records are important as all modes of action have a predicted number of applications before resistance is likely to occur (Table 2). Consider the records from past years in this year's decisions, particularly in relation to rotating herbicide modes of action and safe plant-back periods for residual herbicides.

## Timely implementation of tactics

Often the timeliness of a weed control operation has the biggest impact on its effectiveness. Herbicides are far more effective on rapidly growing small weeds, and may be quite ineffective in controlling large or stressed weeds. In this case, cultivation may be a more cost-effective option. Additional costs can be avoided through being prepared and implementing controls at the optimum time.

## Timing to protect yield potential

In addition to targeting weeds in a timely manner, after planting it is important to manage weeds to prevent yield loss, as young cotton is not a strong competitor with weeds. The critical times when weed competition can cause yield loss are provided in Table 3 for a range of weed densities and weed types. Irrespective of the type of weeds, early season control is critical to prevent yield loss. The higher the weed population, the longer into the season weed control is required. Preventing yield loss as well as preventing weed seed set ensures there is an economic return from weed control.

## Rotate herbicide groups

All herbicides are classified into groups based on their mode of action in killing weeds. This system has recently changed from letters to numbers.

**TABLE 2: Years of herbicide application before resistance evolves.** (Adapted from Preston, 2006)

| Group, examples | Years |
|---|---|
| 1 (A) Verdict, Targa, Topik, Axial | 6–8 |
| 2 (B) Glean, Ally, Hussar, Flame | 4 |
| 6 (C Gesaprim, Gesatop,Terbyne, Diuron | 10–15 |
| 3 (D) Treflan, Stomp | 10–15 |
| 12 (F) Brodal, Sniper | 10 |
| 14 (G) Goal, Affinity, Valor, Sharpen | 10 |
| 27 (H Balance, Precept, Velocity | 10 |
| 4 (I) 2,4-D, MCPA, Starane, Tordon | >15 |
| 15 (K) Dual, Boxer Gold, Sakura | >15 |
| 22 (L) Gramoxone, Spray.Seed, Reglone | >15 |
| 9 (M) Glyphosate | >15 |

Rotate herbicide groups whenever possible to avoid using the same group on consecutive generations of weeds (Table 2). When this is unavoidable, use other methods of weed control in combination with the herbicide and ensure no weeds survive to set seed. The cotton industry is very fortunate to have registered herbicides in most of the mode of action groups. Refer to the *Cotton Pest Management Guide* for more information.

## Closely follow herbicide label recommendations

Herbicide efficacy is highly dependent on the use of correct application techniques. Always follow label directions, including ensuring that the rate you are about to use is right for the growth stage and condition of the target weeds, whether a wetter or crop oil is required to maximise herbicide performance and that the application set up you are about to use is consistent with the label – water volume, water quality, droplet spectrums and operating pressure. Always consider the suitability of weather conditions.

## Stop seed set, and actively manage the seedbank

Managing the weed seed bank is essential. This applies to resistance management as well as general weed management. Use a range of selective tactics – inter-row cultivation, lay-by herbicides, chipping and spot spraying – to prevent seed set in weeds that survived early-season tactics or have germinated late. As per the HRMS, ensure there are NO survivors.

## Consider other aspects of crop agronomy

Most agronomic decisions for cotton have some impact on weed management. Decisions such as cotton planting time, pre-irrigation versus watering-up, methods of fertiliser application, management of rotation

**TABLE 3: Guide to the critical period for weed control to prevent 2% yield loss.**

| Weed type | Weed density/ 10 m row | Cotton growth stage (day degrees) to prevent yield loss, control weeds | | | |
|---|---|---|---|---|---|
| | | From | | To | |
| Large broadleaf weeds such as: noogoora burr, thornapple, volunteer sunflower, sesbania | 1 | 1–2 leaf | (145) | 3 leaf | (189) |
| | 2 | 1–2 leaf | (144) | 5–6 leaf | (275) |
| | 5 | 1–2 leaf | (143) | first square | (447) |
| | 10 | 1–2 leaf | (141) | squaring | (600) |
| | 20 | 1–2 leaf | (139) | squaring | (738) |
| | 50 | 1–2 leaf | (131) | early flowering | (862) |
| Medium broadleaf weeds such as: bladder ketmia, mintweed, Boggabri weed | 1 | 1–2 leaf | (145) | 2–3 leaf | (172) |
| | 2 | 1–2 leaf | (144) | 4–5 leaf | (244) |
| | 5 | 1–2 leaf | (143) | pre-squaring | (387) |
| | 10 | 1–2 leaf | (141) | early squaring | (514) |
| | 20 | 1–2 leaf | (139) | squaring | (627) |
| | 50 | 1–2 leaf | (131) | squaring | (729) |
| Grass weeds such as; awnless barnyard grass, liverseed grass, Johnson's grass | 20 | – | – | – | – |
| | 30 | 1 leaf | (122) | 1–2 leaf | (139) |
| | 50 | 1 leaf | (122) | 2–3 leaf | (174) |
| | 100 | 1 leaf | (122) | 4–5 leaf | (248) |
| | 200 | 1 leaf | (122) | 7–8 leaf | (357) |
| | 500 | 1 leaf | (122) | early squaring | (531) |

crops, stubble retention and in-crop irrigation management all have an impact on weed emergence and growth. The influence of these decisions should be considered as part of any weed management program. For example, modify the timing and method of applying pre-plant N to achieve a 'spring tickle' in the same operation, enhancing management of winter weeds.

# Cultural control

Cultural controls provide opportunities to incorporate different tactics and suppress weed populations.

## Rotation crops

Rotation crops provide an opportunity to introduce a range of different tactics into the system, including herbicide groups not available in cotton, varying the time of year when different tactics are used and producing stubble loads that reduce subsequent weed germinations. Cover crops can also provide competition and reduce weed loads. (Refer also to *Field selection, preparation, rotation and cover crops* chapter and the *Integrated Disease Management* chapter.)

## Herbicide tolerant cotton traits

Herbicide tolerant cotton allows the use of non-selective herbicides for summer weed control in-crop. Incorporating this tactic into the strategy allows for more responsive, flexible weed management. Weeds need only be controlled if and when germinations occur, meaning herbicide application can be timed to have maximum impact on weed populations. Even where glyphosate-resistant weed species are present, Roundup Ready cotton is still likely to be a useful part of the farming system. But the use of other tactics to control any weed survivors will be critical to preserving the long-term value of the traits. Avoid using the same herbicide group to control successive generations of weeds. Additional tactics (to protect glyphosate) are an important component of an integrated weed management plan (Table 4).

**TABLE 4: Effect of tillage type on emergence of fleabane.**

| Tillage type | % Plants untreated |
|---|---|
| Zero tillage | 100.0 |
| Harrows | 9.0 |
| Tynes | 8.1 |
| Off set discs | 2.6 |
| One-way disc | 1.3 |

## Crop competition

An evenly established, vigorously growing cotton crop can compete strongly with weeds, especially later in the season. Factors such as uneven establishment (gappy stands) and seedling diseases reduce crop vigour, and increase the susceptibility of the crop to competition from weeds (see *Crop establishment* chapter). Planting weedy fields last gives more opportunity to control weeds that emerge prior to planting and better conditions for cotton emergence and early vigorous growth. Canopy closure in irrigated cotton is important to maximise light interception for optimum cotton yield but also provides a very important method of minimising light for weeds growing below the crop canopy. Many weeds will fail to germinate once row closure occurs, and many small weeds will not receive enough light to compete with cotton plants and will produce few seeds (refer to the *Crop establishment* chapter).

## Irrigation

Weed emergence is often stimulated by rainfall and irrigation events. Reduce the impact of weeds by coordinating irrigation with planting, cultivation and herbicide events. Pre-irrigation allows a flush of weeds to emerge and be controlled before cotton emergence. Each irrigation during the season will cause another weed flush, providing another opportunity for a planned control tactic, as well as reducing moisture stress for existing weeds, making these more easily controlled by herbicide applications (refer to the *Irrigation management* chapter).

## Post-harvest management

Some weeds will be present in the crop later in the season even in the cleanest crop. These weeds will produce few seeds in a competitive cotton crop but can take advantage of the open canopy created by defoliation and picking. The choice of defoliant may also provide an opportunity for late season weed control. To reduce the opportunity for these weeds to set seed, it is important to destroy crop residue and control weeds as soon after picking as practical (refer to the *Managing cotton stubble/residues* chapter).

Watch the CottonInfo YouTube video on late season weeds www.youtube.com/cottoninfoaust

## Patch management

Intensive management of small patches of herbicide resistant weeds can allow options to be used that would be considered too expensive or intensive to be done over a whole paddock or the whole farm. Research has found that patch management could be particularly effective for weeds such as awnless barnyard grass that are predominately self-pollinating species, that have a relatively short seed bank life and are not transported by wind. Use GPS to mark coordinates and remove existing weeds before they flower. Tactics could include chipping, spot spraying or spot cultivation. Monitor for subsequent germinations until the seed bank has been exhausted. www.cottoninfo.com.au/barnyard-grass-understanding-and-management-bygum

# Herbicides

Herbicides continue to play a vital role in weed management. Understanding how the herbicide works can help you improve its impact and sustainability.

**Mode of action (MOA) –** refers to how the herbicide acts against the weed to kill it. CropLife Australia has recently aligned the Australian herbicide mode of action classification with the international standard numbering system. Repetitive use of the same mode of action group over time is closely associated with the selection of herbicide resistance within weed populations. Refer to the product label for mode of action. Rotation of herbicide mode of action groups is a key principle for integrated weed management as well as herbicide resistance management. Ensure any weeds that survive a herbicide application are controlled with another tactic (different mode of action, cultivation, chipping). https://www.croplife.org.au/media/industry-news/moa/

**Contact herbicides –** have limited movement within the plant. While results are usually quite rapid, coverage of the target weed is critical. Target small weeds, and optimise application technique and conditions.

**Translocated herbicides –** move within the plant using the xylem, where water and nutrients are transported from soil to growth sites, and/or the phloem, which moves products of photosynthesis to growth and storage sites. Response to the herbicide can appear quite slow. Understanding how the herbicide is translocated can help identify suitability for a situation. For example, atrazine is only translocated in an upwards direction, and so is not well suited for post-emergence applications, as herbicide entering the leaf will not effectively translocate to the roots. However, in open canopies, applied atrazine that reaches the soil will be available for root uptake.

**Herbicide uptake –** will vary with product (foliar, root absorption, coleoptile and young shoots absorption). Herbicides generally require the weed to be actively growing for uptake. It is important to refer to label for directions on the need for additives such as ammonium sulphate, wetters and oils.

**Selective herbicides –** have a limited range of target weed(s). This can help to target problem weeds under different scenarios. It is important to follow label recommendations about use or otherwise of adjuvants and avoid use in stressed crops. If only grass weeds are targeted by the use of a selective herbicide, consider how broadleaf weeds will be controlled.

**Non-selective herbicides –** such as glyphosate or paraquat control a broad spectrum of both broadleaf and grass weeds. Despite being 'nonselective', these herbicides are not effective on all species, and it is essential to check the label and not just assume a given species will be controlled.

**Herbicide mixtures –** refers to application of more than one herbicide in a single operation, which can reduce application costs. It is important that full label rate of each component is used. Refer to the label or manufacturer to determine suitable mix partners, as some products are antagonistic, reducing weed control, damaging the crop when mixed together or are physically incompatible (form a sludge).

**Shielded spraying –** uses shields to protect the crop-rows while weeds in the inter-row area are sprayed with a nonselective herbicide.

**Band spraying –** applies a given area (band) of selective herbicide to weeds in either the crop-row or inter-row area.

## Double knock tactic

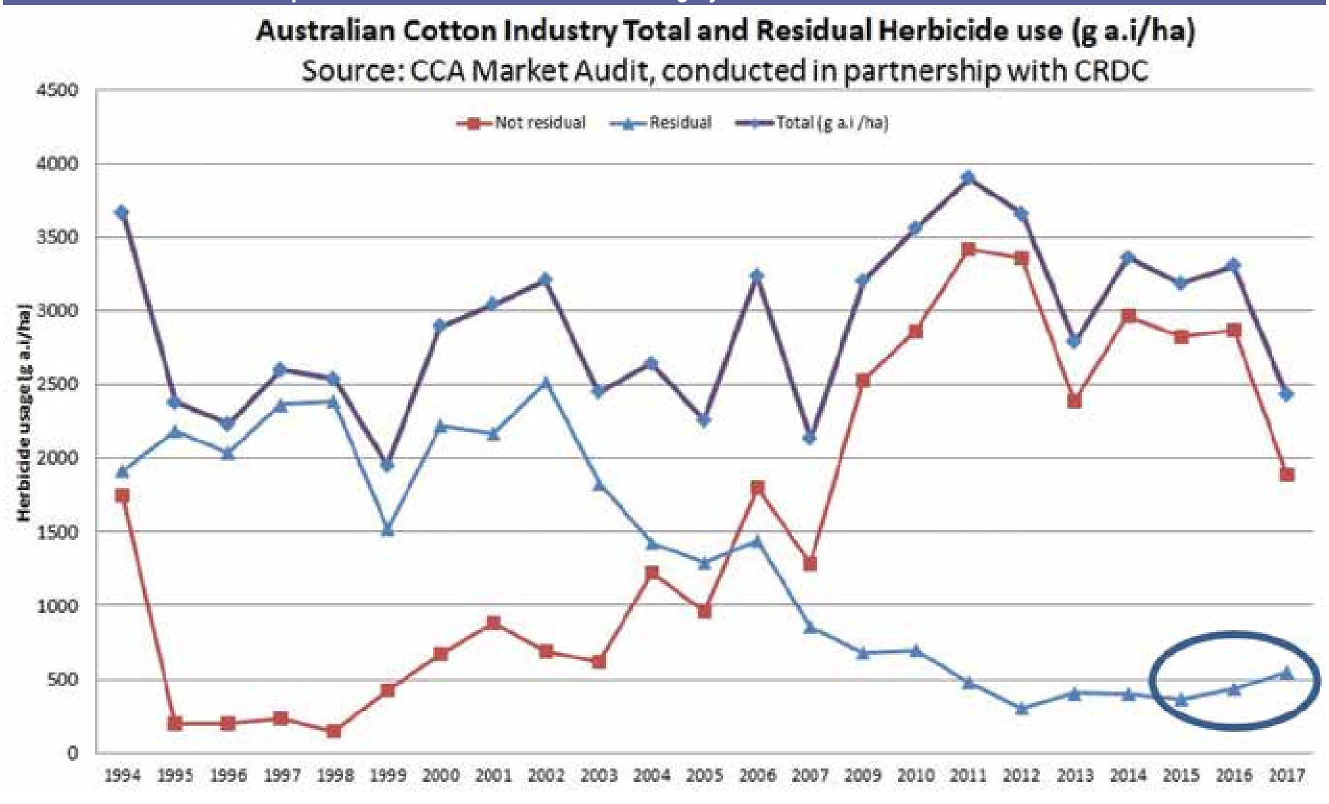
A double knock is where two weed control tactics, with different modes of action, are used on a single flush of weeds to stop any survivors from the first application setting seed. The tactics do not need to be herbicides. Cultivation, heavy grazing or fire could also be used as the second knock. When executed well (right rates, right timing, right application) the double knock tactic can provide up to 100% control of the target weeds.

However, it is still important to monitor for survivors after the double knock has been applied. Improper use of this tactic may lead to resistance in one or both of the herbicides used. Results from surveys conducted by NSW DPI researchers have identified two populations of tall fleabane resistant to the double knock of glyphosate followed by paraquat. When using two herbicides, the basis of the double-knock is to apply a systemic herbicide, allowing sufficient time for it to be fully translocated through the weeds, then return and apply a contact herbicide, from a different mode of action group, that will rapidly desiccate all of the above-ground material, leaving the systemic product to completely kill the root system. The optimum time between the treatments is dependent on the weed targets, but is generally 7–10 days. (Refer to the *Cotton Pest Management Guide* for some suggested intervals for common double-knock herbicide combinations.)

### Non-residual herbicides

Non-residual, foliar-applied herbicides can be used to control emerged weeds while they are young and actively growing. Some herbicides from Group 14 mode of action may also provide short-term residual control of subsequent germinations, depending upon the herbicide, weed and application rate combination. Cotton with Roundup Ready Flex technology provides an excellent opportunity to rotate the herbicide mode of action by using the Group 22, 14 or 10 products prior to planting. These alternate mode of action products can also be used to control herbicide tolerant

**FIGURE 4:** Herbicide use patterns in Australian cotton farming systems.



Windmill grass in cotton. (Photo: T. Cook NSW DPI)

cotton volunteers. Depending on the weed spectrum, more selective products from other modes of action may also be used.

### Spot spraying

Spot sprayers may be used as a cheaper alternative to manual chipping for controlling low densities of weeds in-crop. Ideally, weeds should be sprayed with a relatively high rate of a herbicide from a different herbicide group to the herbicides previously used to ensure that all weeds are controlled. This intensive tactic can be particularly useful for new weed infestations where weed numbers are low, or where weeds are outside of the field and difficult to get to such as roadside culverts. New weed detection technologies provide an opportunity to use spot spraying across large areas of fallow. This can provide opportunities to reduce herbicide costs, while still ensuring robust label rates are applied to problem weeds. Growers using optical sprayer technology should check individual product labels for direction of use and application rates. Limited brands are approved for use via this application method. For growers using WeedSeeker® technology, check the APVMA website for additional use patterns. Be aware of longer plant back periods when using higher rates.

### Residual herbicides

Residual herbicides remain active in the soil for an extended period (weeks or months) and can act on successive weed germinations. This can be particularly effective in managing the earliest flushes of in-crop weeds, when the crop is too small to compete. Residual herbicides must be absorbed through either the roots or shoots, or both. The use of residuals in the farming system requires good planning as they must be applied in anticipation of a weed problem. Knowledge is required of the potential weed species, expected density and understanding of the seedbank dynamics. Recent industry-wide surveys indicate that there is a trend toward an increase in the use of residuals in cotton farming systems, a key component in prolonging the efficacy of glyphosate (Figure 4). Most residual herbicides need to be incorporated into the soil for optimum activity. Adequate incorporation of some residual herbicides is achieved through rainfall or irrigation, but some products require incorporation through cultivation which may conflict with other farming practices such as minimum tillage and stubble retention. Soil surfaces that are cloddy or covered in stubble may need some pre-treatment such as light cultivation to prevent 'shading' during herbicide application.

While advantageous to weed management, the persistence of residual herbicides needs to be considered within the farming system in terms of rotation cropping sequence. Persistence is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. It can be quite complex. For example, moisture can be a big factor, although it is not the volume of rain, but the length of time the soil is moist, that is the critical factor. A couple of storms, where the soil dries out quickly, won't contribute as much to the breakdown of residuals, compared with soil staying moist for a few days. Refer to product label for more information. Product labels provide information on plant back limitations. If growers are concerned in the lead up to planting, look for the presence of susceptible weeds in the treated paddock or pot up soil from the treated and an untreated area, sow the susceptible crop and compare emergence. Where there may be a problem, consider planting an alternative crop that is tolerant of the herbicide, or if cotton is to be used, plant the paddock last and pre-irrigate if it is to be irrigated. Runoff and persistence in the environment can also be a concern for industry, and it is important to ensure that best practice is followed in terms of capture and management of runoff water.

## Tillage and cultivation

### Inter-row cultivation

Inter-row cultivation can be used mid-summer to prevent successive generations of weeds from being exposed to repeated applications of post-emergent herbicides with the same mode of action. Cultivating when the soil is drying out is the most successful strategy for killing weeds and will reduce the soil damage caused by tractor compaction and soil smearing from tillage implements. But letting the soil dry down too much will result in poor implement penetration, bring up clods, require more horsepower and be hard on equipment.

### 'Spring tickle' (flush and cultivate)

The spring tickle uses shallow cultivation in combination with a nonselective, knockdown herbicide. The aim of the spring tickle is to promote early and uniform germination of weeds prior to sowing, which is then controlled with a herbicide mode of action not used in the crop, to ease weed pressure in the crop. Some weed species are more responsive to the spring tickle than others. Highly responsive weeds include bellvine and annual grasses – liverseed grass and the barnyard grasses. Weeds that are less responsive include cowvine, thornapple, noogoora burr and Bathurst burr. The shallow cultivation (1–3 cm) can be performed using implements such as lillistons or go-devils. Best results are achieved when the cultivation follows a rainfall event of at least 20 mm. Adequate soil moisture is needed to ensure that weed germination immediately follows the cultivation. Where moisture is marginal, staggered germination may result in greater weed competition during crop establishment.

### Manual chipping

Manual chipping is ideally suited to dealing with low densities of weeds, especially those that occur within the crop row. It is normally used to supplement inter-row cultivation or spraying. Historically chipping has been an important part of the cotton farming system, but this has dramatically reduced in recent years. As a tool to prevent survivors setting seed, chipping has been shown to be a cost-effective means of preventing survivor seed set.

### Bury seed of surface-germinating species

Use strategic cultivation to bury weed seeds and prevent their germination. Some weed species, such as common sowthistle (milk thistle), feathertop Rhodes grass and flaxleaf fleabane, are only able to germinate from on or near the soil surface (top 20 mm). Tillage operations such as pupae busting, where full disturbance of the soil is required, can be timed to assist in situations where these species have set seed. Burying the seed more than 20 mm below the surface will prevent its germination. This tactic is most successful when used infrequently as seed longevity of common sowthistle and flaxleaf fleabane will be extended from ~12 months to ~30 months by seed burial, meaning that a cultivation pass burying seed which is on the surface could at the same time expose older but still viable seed buried in a previous operation (see Table 4).

## Control survivors before they set seed

Some weeds escape control by herbicides. Missed strips due to blocked nozzles, inadequate tank mixing, poor operation of equipment, insufficient coverage due to high weed numbers, applying the incorrect rate and interruptions by rainfall are just a few reasons why weeds escape control. If herbicide resistant individuals are present, they will be amongst the survivors.

**It is critical to the longer-term success of the IWM strategy that survivors not be allowed to set seed; NO survivors.**

### WeedSmart Summer Big 6

WeedSmart has developed a simple approach to managing weeds by increasing diversity through a range of control tactics with the aim of disrupting the life-cycle of weeds to prevent seed set (refer to *Cotton Pest Management Guide* page 74).

- **Use diverse rotations**
- **Double knock – To stop seed set**
- **Mix and rotate herbicides and tillage**
- **2+2 and no survivors in crop or fallow**
- **Crop competition in grain crops**
- **Harvest weed seed control in rotational grain crops https://www.weedsmart.org.au/big-6/**

## Come Clean Go Clean

To minimise the entry of new weeds into fields, it is important to clean boots, vehicles, and equipment between fields and between properties. New risk management requirements have been implemented in NSW under the *Biosecurity Act 2015.* Pickers and headers require special attention. Eradicate any new weeds that appear while they are still in small patches. Monitor patches frequently for new emergences. Irrigation water can be a source of weed infestation with weed seeds being carried in the water. While it is not practical to filter seeds from the water, be on the lookout for weeds that gain entry to fields via irrigation. Give special consideration to water pumped during floods, as this has the greatest potential to carry new seeds. If possible, flood water should be first pumped into a storage to allow weed seeds to settle out before being applied to fields. Control weeds that establish on irrigation storages, supply channels and head ditches. (Watch the CottonInfo YouTube video on preventing pests, weeds and diseases via Come Clean. Go Clean: www.youtube.com/cottoninfoaust)

**For more information refer to the Weed section of the *Cotton Pest Management Guide*. www.cottoninfo.com.au/publications/cotton-pest-management-guide**

**NSW *Biosecurity Act 2015*: www.dpi.nsw.gov.au/about-us/legislation/list/biosecurity-act-2015**

## Dryland cotton…

**Weed management is critical in fallows for moisture conservation and depleting the weed seedbank prior to a dryland summer cotton crop. Opportunities also exist in the winter crop rotation for weed control using different modes of action coupled with crop competition. In the 2020–21 CottonInfo gross margins for dryland cotton, the estimate for weed control in fallows was at $57/ha with an additional $84/ha for in-crop herbicides. These are significant costs and recent survey results show that a quarter of dryland cotton growers are relying on glyphosate + one other tactic for weed control (Table 5).**

**TABLE 5: Number of weed control tactics used to control weeds in cotton crops.**

| | Irrigated | Dryland |
|---|---|---|
| Glyphosate + 1 tactic | 33% | 26% |
| Glyphosate + 2 tactics | 14% | 21% |
| Glyphosate + 3 tactics | 14% | 6% |
| Glyphosate + >3 tactics | 36% | 46% |

Source: CCA Qualitative survey 2020–21.

**Some points to consider when controlling weeds in dryland cotton;**

- **Do not rely on glyphosate for all knockdown applications, rotate to Group 22 (L) (paraquat) or add “spikes” to glyphosate such as Group 4 or 14 herbicides, target small weeds.**
- **Adopt double knock tactic for hard to kill weeds.**
- **Use different modes of action in a winter crop rotation.**
- **Introduce residuals in the fallow phase. Aim to have overlap of the residuals to maintain ongoing control of late germinations; be aware of plant back periods.**
- **Consider cover crops during the winter period to control weed emergence and preserve ground cover.**
- **Use pre-plant or post plant residuals.**
- **Incorporate layby residuals prior to boll fill.**
- **Use strategic/targeted tillage: there is an opportunity after chickpeas or cotton as ground cover is minimal.**
- **Use chipping to control patches in fields.**
- **Scout fields and remove or control all survivors either in-crop or during the fallow, especially after the double knock.**
- **Stop seeds re-entering the soil seedbank.**
- **The Herbicide Resistance Management Strategy (HRMS) = 2 + 2 & No survivors.**
- **The number one goal is to start the cotton crop weed free to take the pressure off glyphosate.**

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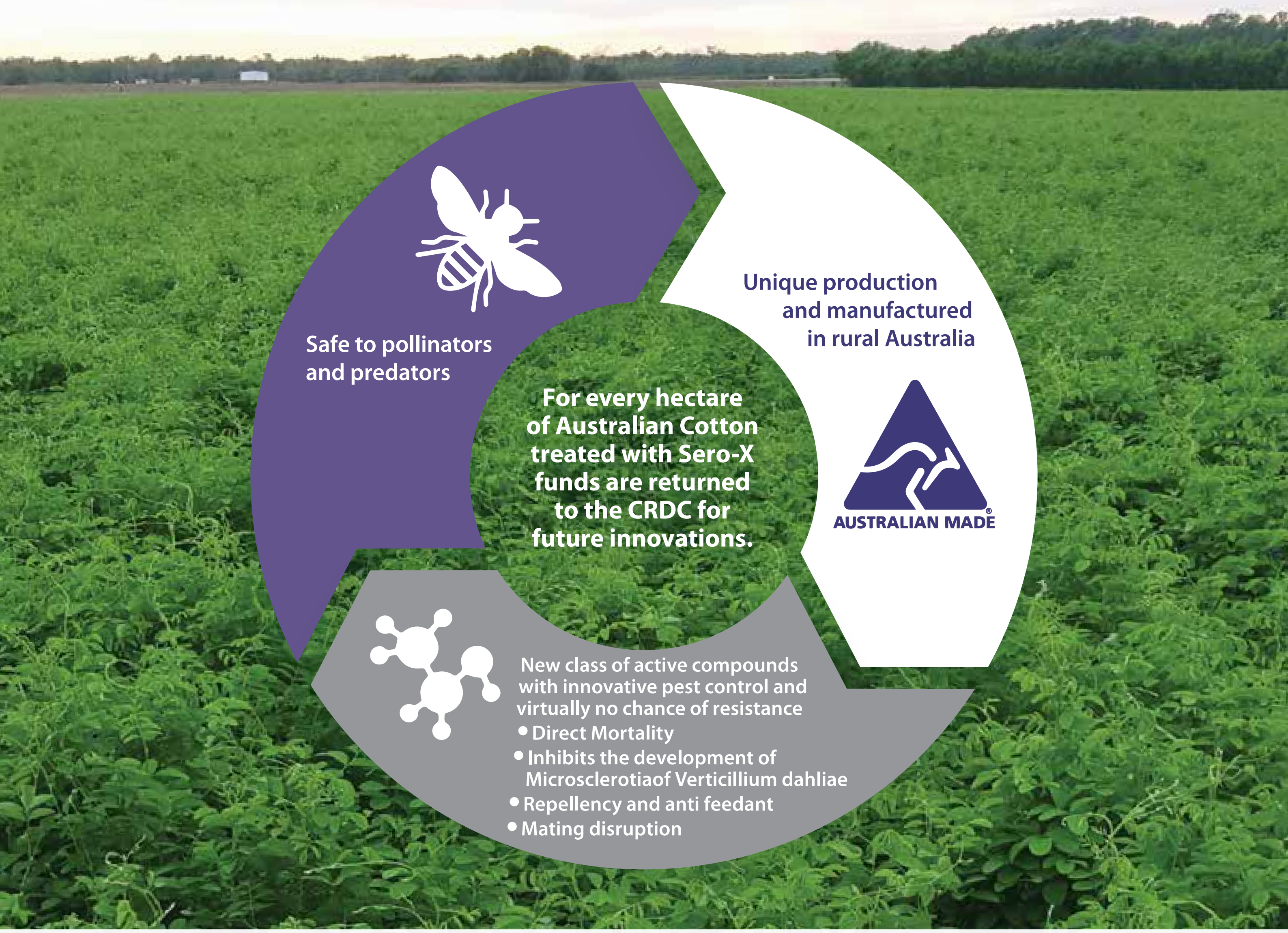


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# Integrated Disease Management

By **Beth Shakeshaft** (NSW DPI/CottonInfo)

**Acknowledgements: Susan Maas (CRDC), Stephen Allen dec. (Cotton Seed Distributors), Karen Kirkby (NSW DPI), Peter Lonergan dec. (NSW DPI), Linda Smith (Qld DAF), Linda Scheikowski (Qld DAF), Cherie Gambley (Qld DAF), Murray Sharman (Qld DAF), Duy Le (NSW DPI), Gupta Vadakattu (CSIRO) and Oliver Knox (UNE and CottonInfo)**

### What's new…

- **Continued experimentation with rotation and cover crops and Verticillium wilt has led to adjustments to the rotation crops suggested for fields with Verticillium wilt.**
- **There is an increasing need to focus on overall soil health and increasing soil microbial biomass to improve disease suppression potential of soils.**
- **Breeding programs focusing on resistance to Fusarium wilt, Verticillium wilt and Black Root Rot are continuing.**

## Developing an integrated disease management (IDM) strategy for your farm

Cotton production systems have become more efficient in terms of nutrition, water, and pesticide use, but diseases are an ongoing problem with very few 'quick fix' solutions. In this sense, disease remains an ongoing constraint to cotton production in Australia.

A plant disease occurs when there is an interaction between a plant host, a pathogen and the environment. Effective integrated disease management (IDM) involves a range of control strategies, including those that improve disease suppression potential of soils, which must be integrated with management of the whole farming system. Disease management does not always mean complete control of the disease through eradication of the pathogen, but rather aims to reduce the disease incidence, suppress the negative impacts of the disease and improve the resilience of the farming system.

Most disease control strategies should be implemented regardless of whether a disease problem is evident, as the absence of symptoms does not necessarily indicate an absence of disease. Many strategies may help to reduce the disease burden for subsequent crops and minimise the risk of diseases spreading within and between farms and regions.

## IDM at planting

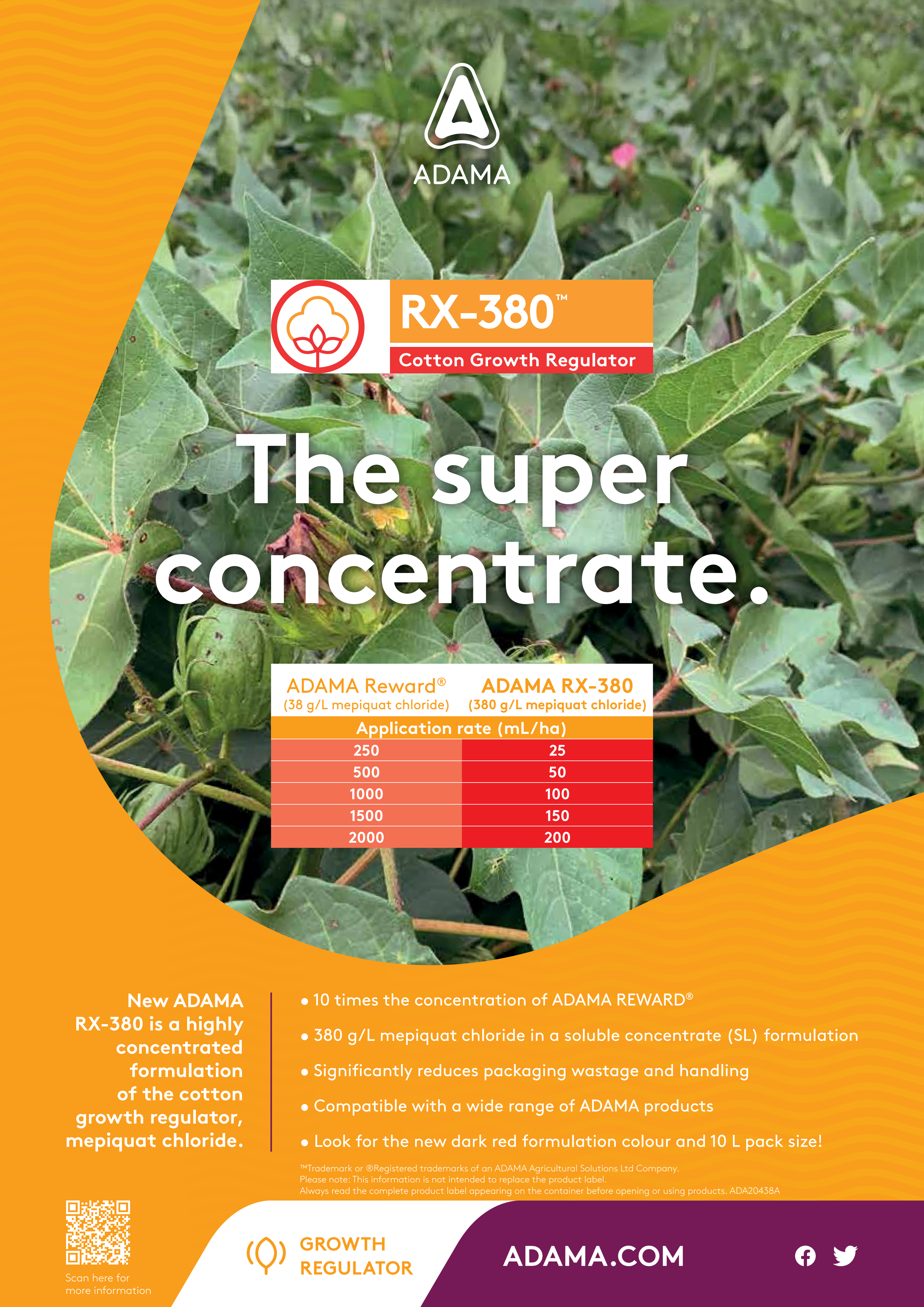
### Preparing optimal seed bed conditions

- Choose fields with low disease burden and avoid back-to-back cotton where possible.
- Plant into well prepared, firm, high beds to optimise stand establishment and seedling vigour.
- Carefully position fertiliser and herbicides in the bed to prevent damage to the roots.
- Ensure fields have good drainage and do not allow water to back-up and inundate plants.

### Best practice…

- **Monitor the crop for disease symptoms. Identify where disease occurs on the farm and monitor the disease over time.**
- **Select disease resistant varieties where possible.**
- **Practice good integrated disease management at planting, in-crop and post-harvest.**
- **Ensure all farm personnel are made aware of diseases on farm and unusual symptoms are reported.**
- **Be aware of insect-vectored diseases and if required control insect vectors according to industry thresholds.**
- **Follow good farm hygiene and biosecurity practices.**
- **Ensure all farm personnel are aware of farm biosecurity requirements.**
- **Brief all farm personnel on action to be taken in the event of identifying unusual pests or plant symptoms, or a potential exotic pest, disease or weed.**
- **Prepare a documented farm biosecurity plan which assesses the risk of pests, diseases and weeds entering the farm and how these risks are minimised.**
- **Ensure all crops and farm inputs are monitored.**
- **Ensure a wash down facility is available and that all machinery, vehicles and equipment are mud and plant debris free before moving on and off the property.**
- **Provide a sign-posted designated parking area for visiting vehicles and contractor equipment that is away from fields and production areas with a record of visitors kept.**
- **Use farm vehicles to transport people around the farm.**

Monitor for plants with unusual symptoms. (Photo: Linda Smith)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# Sowing date/temperature

Sowing in cool and/or wet conditions will slow the plant growth and favour disease development. Cotton should be planted once the soil reaches at least 14°C (measured 10 cm deep at 8 am) for three consecutive days, with a consistent or increasing temperature forecast for the next seven days. However, from a disease and establishment perspective, it is best to wait until 16°C and rising. Refer to the *Crop establishment* chapter.

**Also see the CSD Faststart Cotton Soil Temperature Network https://www.csd.net.au/soil-temperature**

## Variety selection

There are several varieties that have some resistance to Verticillium wilt or Fusarium wilt, with levels of resistance indicated by higher V rank and F rank respectively. It is important to know the disease status of each field to inform this planning. In addition to resistance, consider the seedling vigour of a variety, particularly when pre-irrigating or planting early. Refer to CSD's variety notes for more information (https://csd.net.au/variety-guide). When Black root rot is present, use the more indeterminate varieties that have the capacity to catch up later in the season where regionally appropriate. Avoid growing cotton in fields that contain infected crop residues. For back-to-back fields, disease risks can be higher, increasing the importance of planting resistant varieties and using other IDM strategies. Different seed treatment options are also available and must be chosen when seed is ordered. See the CSD website for information on the options available.

## Replanting

Replanting decisions should be made early based on plant stand losses and gaps, not the size of seedlings. For example, eight plants per metre may perform as well as 15 per metre with appropriate management. Refer to the *Crop establishment* chapter.

# IDM in crop

## Fungicides

All cotton seed in Australia for planting is treated with a standard fungicide for broad spectrum disease control. Australian research has shown some other seed treatments, including biostimulants and fertilisers, can also aid in the seedlings' early vigour and ability to suppress seedling diseases. Evidence suggests in-crop foliar sprays of registered/permitted products can be used in conjunction with other IDM options to manage some diseases.

**Useful resources for current registrations:**

**The *Cotton Pest Management Guide* https://www.cottoninfo.com.au/publications/cotton-pest-management-guide and APVMA PubCRIS website https://portal.apvma.gov.au/pubcris**

## Irrigation scheduling

Pre-irrigating fields before planting can provide better conditions for seedling emergence than watering after planting, provided the hills or beds sub-up adequately. However, water through irrigation or rainfall will lower the soil temperature, resulting in an increased risk of disease. Watch for signs of water stress early in the season if the root system has been weakened by disease and irrigate accordingly. Avoid waterlogging as much as possible, especially early and late in the season when temperatures are cooler. Irrigations late in the season that extend plant maturity can result in a higher incidence of Verticillium wilt. Tail water should also be managed to minimise the risk of disease spread. If possible, apply water from least infected fields to most. General traffic, sprays, and picking should also follow the same order as much as possible.

## Agronomic management

High planting rates can compensate for seedling mortality, but a dense canopy favours development of bacterial blight, Alternaria leaf spot, *Sclerotinia sclerotiorum* and boll rots. Optimise nutrition and irrigations and consider the use of growth regulators where required. If Black root rot is present, either manage for earliness to get the crop in on time (in short season areas) or manage for delayed harvest to allow catch up (in longer season areas). Pre-irrigation as opposed to watering-up can avoid an early cold shock that may give the disease the upper hand.

## Balanced crop nutrition

A healthy crop is better able to express its natural resistance to disease. Adopt a balanced approach to crop nutrition, especially with nitrogen and potassium. Both Fusarium and Verticillium wilt favour the conditions provided by excess nitrogen. Excess nitrogen also greatly increases the risk of boll rot, particularly in fully irrigated situations. Potassium is important for natural plant defences, with deficiency being associated with the expression of more severe disease symptoms. For example, infection by *Alternaria* spp. is more severe under conditions of potassium deficiency. Refer to the *Nutrition* chapter.

## Conduct your own in-field disease survey

It is important to be aware of what diseases are present, where they are present on-farm and whether the incidence and severity is increasing. Monitoring and recording disease allows a comparison over time (see below for in-season monitoring). Train farm staff to look for and report unusual symptoms. Contact your state department cotton pathologist for assistance in identifying suspected disease and for confirming the pathogen's strain.

**Qld DAF pathologist, Linda Smith – 0457 547 617.**

**NSW DPI pathologist, Duy Le – 0439 941 542. Do not send suspected Fusarium wilt samples to ACRI.**

**Exotic Plant Pest Hotline 1800 084 881.**

**Refer to www.cottoninfo.com.au or the *Cotton Pest Management Guide* for instructions on how to send a sample.**

**Useful resources: The CottonInfo YouTube Channel has a great video with the Qld DAF pathology team which talks you through how to take stem and leaf samples for disease diagnosis: www.youtube.com/cottoninfoaust**

## In-season disease monitoring

Early season disease surveys can begin as soon as the cotyledons have unfolded, but are best from the two true leaf stage. Walk the field and look for plants that show signs of poor vigour or unusual symptoms. Examine roots by digging up the seedlings – DO NOT pull seedlings as this may damage the root system, remove characteristic symptoms on the roots or remove infected parts of the roots. Examine multiple plants at multiple locations as diseases are often unevenly distributed. Compare the number of plants established per metre with the number of seeds planted. Refer to the *Crop establishment* chapter for replanting considerations.

During the season, disease surveys should be conducted frequently. Walk the fields and look for plants that show unusual symptoms, have poor vigour, or have died. Cut plants in several places along the stem and look for discolouration. Cut plants with no external symptoms as well, as a high percentage of plants with no external symptoms have presented with internal discolouration indicating Verticillium or Fusarium wilt. A high F rank can also mask Fusarium wilt infection as there may be no external symptoms showing.

Perform a final disease survey after the final irrigation but before defoliation. This will give an indication of the disease burden the field has been under and how it will perform in the following years.

**Useful resources on disease symptoms include:**

**The current *Cotton Pest Management Guide***

**A series of CottonInfo videos on disease management – www.youtube.com/cottoninfoaust**

**The *Cotton Symptoms Guide* (2012)**

# IDM post-harvest

## Control alternative hosts and volunteers

Having a host-free period prevents build-up of pathogen inoculum and carryover of disease from one season to the next. The pathogens that cause Verticillium wilt, Fusarium wilt, Black root rot, Tobacco streak virus and Alternaria leaf spot, some rots, and Cotton Bunchy Top can also infect common weeds found in cotton growing areas (Refer to WEEDpak F5 Table 1 for weeds known to be hosts of cotton pathogens.) It is particularly important to have a host-free period as some diseases, such as Cotton Bunchy Top, can only survive on living plants. Controlling alternative hosts, especially cotton volunteers and ratoons, will help reduce the risk of quality downgrades and yield loss from carryover diseases. Use the off-season to rotate herbicide chemistries and explore alternate mechanical means of weed control. See the *Integrated weed management* chapter for more. For more information on checking your farm for volunteer plants visit www.youtube.com/cottoninfoaust

## Crop residue management

The pathogens that cause Verticillium wilt, Fusarium wilt, Black root rot, boll rots, seedling disease and Alternaria leaf spot can all survive in association with cotton and some rotation crop residues. Manage crop residues carefully to minimise carryover of pathogens into subsequent crops. If Fusarium wilt is known to be present in a field, slash and retain residues on the surface for at least one month prior to mulching, in order to disinfect the stalks through UV light exposure. In all other circumstances (including the presence of Verticillium wilt and other diseases), incorporate crop residues as soon as possible after harvest to promote faster decomposition.

**Cotton trash after 140 days solarisation. The colour of trash can be used to determine when to incorporate Fusarium infested fields.** (Photo: Scott Brimblecombe)

**Look out for high incidence of leaf spot in the canopy or different leaf spot symptoms. There are numerous leaf spot pathogens recorded overseas. Send leaf samples for confirmation of the pathogen, to determine if the cause is *Alternaria* spp.**

## Use crop rotations to assist in disease management

Successive crops of cotton, or other susceptible hosts, can contribute to a rapid increase in disease incidence, particularly if susceptible varieties are used. Employ a sound crop rotation strategy by using crops that are not hosts for the pathogens present (see Table 1 for potential disease implication of rotation crops with cotton, in relation to the following cotton crop).

A diverse crop rotation that includes cereals and/or carefully selected green manure and cover crops can increase soil microbial diversity and the potential for biological disease suppression. The use of legumes as green manure crops should be approached with caution in some fields as they may pose an increased disease risk. Only crops that are non-hosts to diseases on farm should be used in rotation with cotton.

Rotations with repeated or regular fallows could decrease pathogen inoculum level and in turn reduce disease incidence, but regular fallows as part of the rotation can cause a significant decline in the microbial biomass and activity in turn reducing disease suppression potential in cotton soils. Cover crops such as sorghum and corn significantly increase soil bacterial and fungal diversity and populations of known beneficial microbes. Different cover crops significantly alter the genetic composition, diversity and abundance of beneficial soil fungal and bacterial communities.

If disease is suspected in your crop, remember to sample healthy plants along with those suspected of disease for submission to the pathologists. Occasionally, symptoms of nutrient deficiency can be misinterpreted for disease, so if the disease diagnostics are negative, consider nutritional issues. The Cotton Rotation Finder can assist with developing a rotation strategy www.cottoninfo.com.au/cotton-rotation-tool.

# IDM all year round

## Control of insect vectors

Diseases caused by a virus are often prevented by controlling the vector that carries the pathogen. Cotton bunchy top (CBT) is transmitted by aphids feeding on infected plants then migrating to healthy plants. Transmission of Tobacco streak virus (TSV) to plants relies on the virus from infected pollen entering plant cells through the feeding injury caused by thrips. Control of insect vectors should consider IPM principles and resistance risks (See *IPM* chapter). For example, the control of aphids in cotton may be warranted if there is evidence of spread of cotton bunchy top, however controlling thrips when TSV is observed is not likely to be useful due to thrips and TSV migrating into the crops from nearby weeds, and damage due to TSV is negligible. Viruses can only survive in living plants. Control of cotton ratoons and volunteers throughout winter will reduce pathogen levels and lower vector insect populations, drastically reducing disease risk for the following season.

## On-farm biosecurity

Biosecurity is the protection of your property from the entry, establishment and impact of exotic and endemic pests. Minimise the risk of moving pathogens on or off your farm, from field to field, or farm to farm, by considering vehicle and machinery movements within and between farms. Have a strategy for ensuring clean movement of vehicles and machinery onto and around the farm. Minimise spillage and loss when transporting modules, hulls, cotton seed or gin trash. Ensure all staff, contractors and visitors are aware of the requirements and your commitment to 'Come Clean. Go Clean' before entering the farm.

**Useful resources:**

**www.cottoninfo.com.au and www.mybmp.com.au**

**CottonInfo youtube video: Keep your farm free from pests, weeds and diseases: Come Clean Go Clean and Lone Stranger adventures. Part 1: Come Clean. Go Clean www.youtube.com/cottoninfoaust**

**Biosecurity top tips videos: www.youtube.com/cottoninfoaust**

**For more information go to www.mybmp.com.au or contact CottonInfo Technical Lead for Biosecurity, Sharna Holman (0477 394 116)**

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# Case study:

## Crop rotation an important tool in our arsenal against disease

By **Brad Pfeffer** (CottonInfo)

**Mick Humphries.**

Gwydir Valley cotton grower Mick Humphries is taking a long-term view to managing production at the property, "Caroale". The farm, which Mick runs in partnership with cousin David Lemmon, has been in family for five generations and has grown cotton for over 40 years.

Long-term sustainability is critical for Mick and David, which is why they have adopted a strategic approach with crop rotations to ensure disease does not become a major problem at the property.

"This farm has a strong bore water resource, which means it has a long history of cotton," Mick explained. "In the 1980s and 1990s, some of the paddocks grew back-to-back cotton for 10 years."

Because of this history, Mick always keeps a careful watch on the farm to spot the potential damage of Fusarium wilt and Verticillium wilt, which have arisen in small patches in the past.

To combat diseases on his farm, Mick is managing the risk through selective crop rotation, avoiding back-to-back cotton and avoiding crops that will host the problem diseases.

"We've scrapped legumes from the rotation for the time being and have moved mostly to irrigated sorghum as a rotation," he said. "We've moved away from the traditional wheat/cotton rotation and are pushing summer grass crops to lessen the disease risk.

"We may look at up to three years of straight sorghum, but we will also assess how it stacks up economically."

He said the approach required discipline when the cotton price was high, but it was also an easy decision to make when looking at the impact of disease on yield, even in patches.

"We are aiming to average 14 plus bales per hectare, but when you see small areas down to 5–6 bales per hectare, you have to address the problem."

With the risk of both Verticillium and Fusarium wilts, which have different strategies for fallow management, Mick said his best approach to management was through crop rotations.

In 2021–22, Mick and David grew about 800 hectares of cotton, consisting of 70 percent 748B3F and the rest 746B3F. With excellent growing conditions, reliable water availability, low insect pressure, and strong retention, Mick had high hopes for this year's crop when CottonInfo visited him in mid-January.

For more information on rotation crop considerations for disease management refer to Table 1.

**Fusarium wilt** can cause some leaves to develop a yellow mottle.

A key feature of **Fusarium wilt** is the brown discolouration in the woody part of the stem.

**Fusarium wilt** can cause plants to die back from the top and may regrow back from the base later in the season.

Early symptoms of **Verticillium wilt** are leaf wilting and mottling.

**Verticillium wilt** causes a speckled vascular discolouration throughout the stems.

Severe **Verticillium wilt** infection may cause defoliation.

**Reoccurring wilt** causes a reddening of the roots and root decay. May see reddening of the vascular tissue.

The reddening of the roots (**Reoccurring wilt**) is not as extensive in mature plants as the reddening in younger plants (see left).

Plant death caused by **Reoccurring wilt.** Dead leaves usually remain on the dead plant.

**Reoccurring wilt** causes the plant or patches of plants to wilt, bronzing of leaves and petioles, and sudden death of plant.

Cotton can be impacted by a wide range of diseases. In order to manage these diseases, it is important that the disease is identified correctly. The *Cotton Pest Management Guide* is published in September each year and has detailed descriptions and images of diseases of cotton.

This page illustrates three key wilt diseases: Fusarium wilt, Verticillium wilt, and the recently-observed Reoccurring wilt.

Qld DAF and NSW DPI also offer a free disease diagnostic service for cotton growers. Visit the CottonInfo website for more information on this service, and management options for several diseases.

**TABLE 1: Potential disease implications of rotation crops (in relation to the following cotton crop).**

| | Allelopathy | Seedling disease | Phytophthora boll rot | Alternaria leaf spot | Black root rot | Fusarium wilt | Verticillium wilt | Sclerotinia | Nematodes |
|---|---|---|---|---|---|---|---|---|---|
| Spread | N/A | Soil-borne and waterborne spores, infected crop residues, infected stubble. | Waterborne spores (including rain splash onto bolls), infected crop residues. | Airborne and waterborne spores, infected crop residues, infected stubble. Seed-borne dispersal has been reported overseas but is thought to be insignificant. | Soil-borne and waterborne spores, infected crop residues. | Soil-borne or waterborne spores, infected crop residues, seed-borne dispersal. | Soil-borne or waterborne spores, infected crop residues. | Waterborne spores (including rain splash onto bolls), infected crop residues. | Spread by anything that can move contaminated soil. |
| Survival | N/A | Soil-borne pathogenic fungi can survive indefinitely as saprophytes on plant residues in the soil. | Infected crop residues. | Infected crop residues, volunteer cotton plants and alternative crop/ weed hosts (can be living or dead/dying plant tissue). | Volunteer cotton plants and alternative living crop/weed hosts. | Can survive in organic matter in the soil/ rhizosphere of some other crops/weeds. It may not cause disease in these other plants but can survive at a reduced population level. | Can survive in soil or infected crop residues in the absence of a host. | Survives in the soil for many years. May also survive in infected crop residues. | Reniform nematode can survive at least two years in the absence of a host in dry soil through anhydrobiosis. |
| Canola | Increases risk of allelopathy | Reported host of Rhizoctonia and Pythium species. | Non-host | Decreases risk | Non-host; repeated use of non-hosts to decrease. Can be biofumigant crop. | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Increases risk | Increases risk | Non-host |
| Chickpeas | Planting into freshly incorporated, unweathered residues may cause allelopathy. | Reported host of *Pythium* sp. and *Rhizoctonia solani.* Survives in crop residues. Incorporate infected residues early. | Non-host | Decreases risk | Increases risk | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Reported host. May increase risk*. | Increases risk | Increases risk |
| Cotton (i.e. back to back) | Decreases risk | Survives in crop residue; incorporate infected residues early to minimise risk. Good bed preparation is important. | Early incorporation may reduce carry over. | Early incorporation may reduce carry over. | Increases risk | Increases risk, especially if growing low F rank varieties. | Risk is related to inoculum level and environmental conditions. Fields with a history of Verticillium are at greater risk. | Increases risk | No resistant varieties available, increases risk. |
| Faba beans | Planting into freshly incorporated, unweathered residues may cause allelopathy. | Reported host of *Pythium* sp. | Non-host | Decreases risk | Increases risk | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | May increase risk.* | Increases risk | Decreases risk when resistant varieties are grown |
| Long fallow | No | Decreases risk if crop residues incorporated. | Decreases risk in weed free fallows | Decreases risk if previous crop residues incorporated. | Fungal spore load remains persistent in the soil so risk does not change. | Decreases risk with repeated bare fallows. | Decreases risk in weed free fallows. | Decreases risk | Decreases risk in weed free fallows, but nematodes can survive for long periods in dry soil |
| | | Reduces overall microbial diversity/inoculum and so may not actually decrease the risk of disease in the following season. Research suggests a suitable rotation crop is more beneficial than long fallow. | | | | | | | |
| Maize | Decreases risk | Reported host of *Pythium sp.* and *Rhizoctonia solani* | Non-host | Decreases risk | Non-host; repeated use may decrease | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Reported internationally as a potential asymptomatic host. Research in Australia suggests maize/ corn reduces risk. | Decreases risk | Non-host |

**TABLE 1 continued.**

| | Allelopathy | Seedling disease | Phytophthora boll rot | Alternaria leaf spot | Black root rot | Fusarium wilt | Verticillium wilt | Sclerotinia | Nematodes |
|---|---|---|---|---|---|---|---|---|---|
| Mung beans | Planting into freshly incorporated, unweathered residues may cause allelopathy. | Reported host of *Rhizoctonia solani* | Non-host | Decreases risk | Increases risk | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Reported host. May increase risk*. | Increases risk | Increases risk |
| Pigeon pea | Planting into freshly incorporated, unweathered residues may cause allelopathy. | Reported host of *Pythium sp.* | Non-host | Decreases risk | Increases risk | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | May increase risk* | Increases risk | Increases risk |
| Safflower | Planting into freshly incorporated, unweathered residues may cause allelopathy. | Reported host of *Pythium ultimum.* | May increase – listed as a host in Qld and WA | Decreases risk | Non host; repeated use of non-hosts to decrease risk. | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Increases risk | Increases risk | Non-host |
| Sorghum | Increases risk of allelopathy | Reported host of *Rhizoctonia solani.* | Non-host | Decreases risk | Non-host; repeated use may decrease risk. | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Decreases risk | Decreases risk | Non-host |
| Soybean | Decreases risk of allelopathy. | Reported host of *Pythium ultimum.* Only some strains of *Rhizoctonia solani* are reported to infect soybean. Survives in crop residues. Incorporate infected residues early. | Non-host | Decreases risk | Increases risk | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Reported host. May increase risk*. | Increases risk | Decreases risk when resistant varieties grown |
| Sunflower | Increases risk of allelopathy | Reported host of *Pythium* sp. and *Rhizoctonia solani.* | Non-host | Non-host | Non-host; requires repeated use of non-hosts in the rotation to reduce incidence. | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Reported as a host. Choose resistant varieties. | Increases risk | Increases risk |
| Vetch | Planting into freshly incorporated, unweathered residues may cause allelopathy. | Reported host of *Pythium* sp. | Non-host | Decreases risk | Might be a biofumigant when incorporated. | Increases risk in crop residues – a saprophyte. Incorporate infected residues early. | Asymptomatic host that may increase risk. | Increases risk | Increases risk |
| Wheat/barley/triticale/oats | Planting into freshly incorporated, unweathered residues may cause allelopathy. | All major grain crops in Australia are reported to host *Pythium* species. Reported hosts of *Rhizoctonia solani.* Oats are most tolerant followed by triticale, wheat and then barley, which is the most intolerant. | Non-host | Decreases risk | Non host; repeated use of non hosts to decrease risk. | Increases risk in crop residues – a saprophyte. Residues could be also be removed by baling or burning. | May increase risk.* | Decreases risk | Non-host |

Red shaded box = Potential disadvantage. Green = Generally positive interaction. Yellow = Cautionary note.
Some crops have been reported as hosts of diseases, such as Verticillium wilt and seedling diseases, in international literature however this has not been proven in Australian climates and conditions. Due to these reports, these crops have been given a cautionary note in the above Cotton Rotation Crop Comparison Chart.
*Host in glasshouse trials when tested against Australian Verticillium isolates.
Some information in this table has been extracted from 'Disease implications of rotation crops following sunflower,' authored by Sue Thompson et al.

# Sustainable cotton landscapes

By **Stacey Vogel** (CRDC/CottonInfo)

Natural areas on and surrounding cotton farms provide benefits to the farming enterprise, known as ecosystem services. For example, natural vegetation can be an important year-round habitat for beneficial insects, providing a source for nearby crops, increasing natural pest suppression early in the growing season in adjacent fields.

Diversity in vegetation (native and other crops) can act as a refuge for cotton pests that haven't been exposed to Bt toxins/insecticides used in cotton providing an additional source of susceptible individuals and slowing the development of resistance. Riparian vegetation prevents erosion along waterways and provides a natural filter for farming inputs, preventing soil, nutrients and chemicals from entering rivers and protecting fish and their habitats.

Woody vegetation such as river red gums (*Eucalyptus camaldulensis*) sequester and store large amounts of carbon, which offsets agricultural emissions and can help cotton farms achieve carbon neutrality. Healthy soils can sequester carbon and improve nutrient cycling. In this chapter, we talk through key management principles to assist you to understand and manage the natural assets on your farm for environmental and production benefits.

## Healthy landscapes

Improving the health of individual stands of natural vegetation and linking them on your farm and in the district will improve the number and diversity of plants and animals on your farm, including beneficial insects, bats and birds, which provide natural pest control. CottonInfo's Managing Biodiversity in Cotton Landscapes tool provides biodiversity information for each Local Government Area (LGA) in Australian cotton growing regions. https://www.cottoninfo.com.au/managingbiodiversity-cotton-landscapes

### Manage for groundcover and diversity

Complex vegetation has many layers such as trees, shrubs, grasses and herbs, each with a range of plant species in each layer. The understory layer of grasses and herbs is most easily changed through management and season. The presence of livestock can result in simplification of the species if grazing periods are too long or there are too few watering points. In time, allowing stock to graze selectively can not only result in loss of the best species, but bare areas will also occur.

Drought can result in similar degradation or exacerbate the impacts of over-grazing over time. Loss of groundcover and species diversity favours the establishment of weeds. Many of the annual broadleaf weeds of cropping, such as marshmallow weed (*Malva parviflora*) and milk/sowthistle (*Sonchus oleraceus*) in winter; and bladder ketmia (*Hibiscus trionum*) and thornapples (*Datura* spp.) in summer are better hosts for pests than they are for beneficials. Some weed species also host viruses such as the Noogoora burr complex (*Xanthium* spp), a known host for the pathogen Verticillium wilt (*Verticillium dahliae*). When planning revegetation, prioritise the incorporation of trees and shrubs that flower prolifically. Eucalypts and melaleucas attract feeding insects that are not pests of cotton, which in turn attract a broad range of predator insects that will move into cotton. If seeding of ground species is possible, look to establish a mix of tussocky and sprawling grass together with a mix of winter and summer active legumes. Leaving logs, dead trees and litter where they fall will enhance the habitat and reduce erosion.

### Best practice…

- Assess and monitor groundcover and remediate erosion problem areas.
- Maintain healthy rivers by protecting riverbanks from erosion; leave dead standing and fallen timber.
- Maintain and improve native vegetation connectivity and diversity for ecosystem service provisions of pollination, natural pest control, water quality and carbon sequestration and storage.
- Control environmental weeds and volunteer crop plants that act as hosts for pest species.
- Monitor water quality and apply irrigation water efficiently.

### Prioritise connectivity

The size and configuration of native vegetation in the landscape is important. Small, isolated remnants provide stepping-stones across the landscape, but the most effective natural pest control is attained from well-connected areas of native vegetation located near the crop. Native vegetation corridors between remnants facilitate the dispersal of beneficial insects through the landscape and provide local habitat when crops aren't present. Where there is little remnant vegetation in an area, focus revegetation efforts on the creation of corridors that link areas together. Fenceline plantings, wind breaks and roadside verges can provide effective habitat for beneficials

**The golden headed cisticola is a small insectivorous bird known to feed on cotton insect pests. Her eggs shown here in a nest made from cotton lint.** (Photo: Elsie Hudson)


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and facilitate movement into and between crops. Plant species diversity and perennialism is as important in corridors as it is in larger areas of vegetation to favour predators over pests.

What to do:

- Map areas of natural vegetation on and around your farm.
- Map areas and density of pests and weeds that occur on your farm.
- Work with your neighbours to map areas of potential weed and pest threats in your district.
- Investigate the plants and animals in your natural vegetation.
- Graze areas of natural vegetation sustainably.
- Consider removing stock access to sensitive areas such as riverbanks and wetlands.
- Leave logs, rocks, dead trees and litter in natural areas wherever you can.
- Protect big old trees with hollows.
- If you would like to vegetate areas on your farm, think about linking corridors between natural areas and use local species to increase survival rates, improve natural pest control and increase the numbers of plants and animals on your farm.

**Refer to the CottonInfo NRM webpage for more information: www.cottoninfo.com.au**

**Improving connectivity of habitat corridors and patches – an overview www.youtube.com/cottoninfoaust**

## Healthy rivers

On many cotton farm rivers, wetlands and billabongs are lined with majestic River Red Gums and iconic Coolibahs. Studies have shown that these areas are in good condition ('near natural') and harbour many species of birds. The riparian zone also provides an important buffer between agricultural activity and the waterway, helping to maintain water quality and protect aquatic habitats. Most irrigation farms growing cotton are designed to retain water runoff on the farm. In addition to the value of the water itself, this attribute of farm design significantly reduces risks to the environment from pesticide residues that move in water. Closed water systems have enabled cotton growers to retain regulatory access to pesticides.

Channels that are bare of vegetation maximise the reticulation capacity of the system in major events. But establishing grass/reed vegetation on some channel areas significantly improves the capacity of the system to break down pesticide residues that are on the farm. Where water flows more slowly, residues are filtered by the vegetation and broken down by the enhanced microbial activity associated with vegetated areas. Vegetating distances of 100–200 metres of channel can link habitats for insect movement, reduce erosion risk and protect the environment beyond your farm from pesticide residues. Different pesticides break down in different ways. Strategically combining vegetation on some channels flowing into non-vegetated storage areas means the system will be efficient at both microbial and UV degradation of pesticides.

What to do along waterways:

- Be extra careful when spraying.
- Reduce or exclude traffic access to prevent erosion.
- Work with neighbours upstream and across the river to control weeds and pests.
- Leave logs, rocks, dead trees and litter.
- Allow shrubs and young trees to regenerate.
- Protect existing trees and revegetate.
- Retain or replace natural snags in the river.
- Work with your local catchment body to secure eroded riverbanks.
- Leave a grassy buffer zone between your fields and the riparian corridors.
- Graze conservatively.
- Enter into your local Carp Muster.

**Refer to the CottonInfo videos on Healthy rivers and Maintaining healthy riparian areas for more information. www.youtube.com/cottoninfoaust**

## Healthy soils

Whether in your field or in the natural areas of your farm, healthy soil can make farming easier. Maintaining healthy soils reduces the risk of issues like salinity, sodicity and erosion. Simple practices to maintain soil biology, structure, organic matter and carbon will protect your farm.

**Approximately 21% of the combined extent of cotton farms retains native vegetation (2019, Biodiversity assets of NSW & QLD cotton growing areas) of which 85% is actively managed (2019 Cotton industry survey).**


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Consider the impact of water quality on irrigation equipment as well as soils.

What to do:

- Manage irrigations to minimise deep drainage and salinity risks (see the *Irrigation management* chapter and the following section on healthy water).
- Manage traffic.
- Maintain groundcover.
- Graze sustainably.
- Match land use and land capability.
- Benchmark % groundcover based on soil type/capability.

**For more information and supporting resources go to the natural assets module of *my*BMP. www.mybmp.com.au**

## Healthy water

Decreasing quality of the water used for irrigation (from streams and groundwater) and rising groundwater levels are threats to the irrigation industry as well as the environmental functions of these ecosystems. Monitoring water quality and efficiently applying irrigation water are two important management practices for reducing this threat. By regularly monitoring your water and keeping records of test results, a baseline can be established. Any trends or changes in water quality and level can be acted upon and considered in the farm management plan to both maximise crop yield and to ensure the long-term viability of the farm water resources.

### Water quality monitoring

As a minimum, test pH, Electrical Conductivity (EC) and Sodium Absorption Ratio (SAR). A wider range of baseline water quality parameters such as hardness, turbidity, nutrients, nitrates, organics and trace metals can also be assessed.

### pH

pH (potential of hydrogen) measures the concentration of hydrogen ions in water. The higher the concentration, the lower the pH value is. pH ranges from 0 (very acidic) to 14 (very alkaline), with 7 being neutral. Changes in pH can affect chemical reactions in water and soil, influencing solubility of fertilisers, types of salts present, the availability of nutrients to plants and the health of aquatic biodiversity.

| pH thresholds for irrigation water. | |
|---|---|
| pH 5.5 – 8.8 | Suitable for most plants |
| pH <4 | Can contribute to soil acidity |
| pH >9 | May contribute to alkalinity |
| pH >8.5 or <6 | May affect spray mixes i.e. precipitation of salts and/or corrosion and fouling |

### Electrical conductivity of water (ECw)

EC is the measure of a material's (water or soil solution) ability to transport electrical charge. When measured in water it is called ECw, and is measured in deciSemens/metre (dS/m). Salts conduct electricity, so readings increase as salinity levels increase. Salinity can have major long-term impacts on production as well as the health of aquatic ecosystems and is costly to remediate. While cotton is reasonably tolerant to salinity in the later stages of development, it is very sensitive during its early stages (see WATERpak chapter 2.10 for details).

## Sodium adsorption ratio (SAR)

SAR is a measure of the suitability of water for irrigation, providing an indication of the sodium hazard of the applied water. SAR is determined by the ratio of sodium to calcium and magnesium in water. Long-term application of irrigation water with a high SAR can lead to the displacement of calcium and magnesium in the soil reducing soil structure, permeability and infiltration. The effects of sodic water applied through irrigation will depend on the electrical conductivity of the soil (salinity of the soil) as well as the soil type.

## Monitor groundwater levels

Groundwater levels can change over time. Aquifers can gain or lose water, with local influences often overriding regional trends. Falling groundwater levels have significant implications for farm and catchment water availability, and can result in the mobilisation of poor quality water towards the zone of extraction, whereas rising water tables pose significant salinity risks. Determining the age of your groundwater can also assist with long-term planning. Is your groundwater young (<70 years old) and well connected to recharge zones? Or is your groundwater many thousands of years old? Sustainable access to groundwater where ancient groundwater is being used requires ongoing review in the context of our constantly improving knowledge of each groundwater system.

## Reducing the risk of deep drainage

Deep drainage is the movement of water beyond the root zone of crops. It varies considerably depending on soil properties and irrigation management, and is not necessarily 'very small' as believed in the past. Rates of 100 to 200 mm/yr (1–2 mL/ha) are typical, although rates of 0 to 900 mm/yr (0.03 to 9 mL/ha) were observed. It is of concern, as it leads to:

- Farming systems that are less water-efficient.
- Leaching of chemicals (including fertiliser), which may be a loss to the farming system and contribute to poorer off-site water quality.
- Leaching of salts which can cause salinisation of underlying groundwater systems.
- Raising of water levels in shallow groundwater systems.

Drainage can occur through the soil matrix or through soil cracks when furrow irrigation occurs. Some drainage, or leaching fraction, is needed to avoid salt build-up in the soil profile. Generally this is provided by rainfall. As much of the seasonal deep drainage can occur early in the season, irrigation management at this time is critical. Furrow irrigation should be managed to minimise the time available for infiltration by getting the water on and off quickly.

Near saturated conditions can be found two to six metres below irrigated fields, conditions that do not exist under native vegetation. The consequences of deep drainage are distinctly different where underlying groundwater can be used for pumping (fresh water, high flow rate) and where it cannot (saline water or low flow rate); significant areas of irrigation occur on groundwater areas of both classes.

**Useful resources:**
**The Australian Cotton Water Story**
**WATERpak**
**DIY Groundwater Monitoring Fact Sheet**
**Cotton Soil and Water Quality Fact Sheet**
**Ecosystem Services Fact Sheet**
**All available via www.cottoninfo.com.au and www.mybmp.com.au**
**Salinity Management Handbook (www.publications.qld.gov.au/dataset/salinity-management-handbook)**
**Your local NRM groups or Local Land Services (LLS) may be able to provide additional advice and resources:**
**Fitzroy Basin Association www.fba.org.au**
**Southern Qld NRM: www.sqlandscapes.org.au/**
**NSW – www.lls.nsw.gov.au**
**Northern Territory – www.depws.nt.gov.au**
**Western Australia – www.agric.wa.gov.au**

### Tolerance of crops and pastures to water salinity and root zone soil salinity.

| | Water salinity limits for surface irrigation (in dS/m) | | | | | |
|---|---|---|---|---|---|---|
| **Soil type** | **Well-drained** | | **Moderate to slow draining** | | **Very slow draining** | |
| **Yield reduction** | **Up to 10%** | **25%** | **Up to 10%** | **25%** | **Up to 10%** | **25%** |
| **Winter crops** | | | | | | |
| Wheat | 6.0 | 9.5 | 4.0 | 6.3 | 2.0 | 3.1 |
| Canola | 6.5 | 11 | 4.3 | 7.3 | 2.1 | 3.6 |
| Barley | 8.0 | 13 | 5.3 | 8.6 | 2.6 | 4.3 |
| **Summer crops** | | | | | | |
| Grain sorghum | 1.0 | 1.5 | 0.7 | 1.0 | 0.3 | 0.5 |
| Maize | 1.7 | 3.8 | 1.1 | 2.5 | 0.6 | 1.2 |
| Soybeans | 2.0 | 2.6 | 1.3 | 1.7 | 0.6 | 0.8 |
| Sunflowers | 5.5 | 6.5 | 3.6 | 4.3 | - | - |
| Cotton | 7.7 | 12.5 | 5.1 | 8.3 | 2.5 | 4.2 |

# In season

# Crop establishment

By **James Quinn** and **Sam Lee** (Cotton Seed Distributors)

Achieving even establishment is critical to get a cotton crop off to a good start, as it can influence how the crop is to be managed. The aim for every cotton grower should be to plant the crop once and achieve the desired plant stand. If the crop has a strong start, obtaining yield potential is much easier. At first flower, the aim is to have a uniform plant stand of 8 to 12 plants per metre for irrigated crops, and 6 to 8 plants per metre for dryland crops, with a healthy root system, and free of biotic stresses such as diseases, insects and weeds. The plant should have access to optimal nutrition and adequate water and be developing good plant architecture and canopy cover.

## Plant population and seeding rate

When determining the optimal plant population, consider:

- Soil type and condition (including water holding capacity);
- Irrigated or dryland;
- Planting into moisture, watering up or pre-irrigating;
- Long-term average yields – based on area with plant population rates;
- Germination rates;
- Seedling mortality – disease and insects;
- Rainfall and temperature (soil temperature and forecast air temperature); and,
- Row spacing.

CSD has conducted numerous plant population trials in recent years to look at the optimum plant stand for maximum yield. Overall findings were that growers should aim to have 10 to 12 established plants per metre for irrigated cotton (Figure 1).

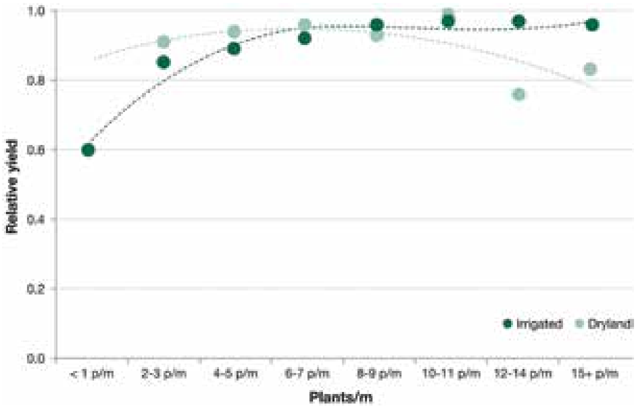
### Current recommendations

- Approximately 10–12 plants per metre established is ideal for warm growing areas (north of Dubbo, NSW).

**Best practice…**

- **Use CSD's free seed retesting service to check carry-over seed from previous seasons.**
- **Ensure your planter is well serviced and operational before planting time.**
- **Plant when conditions are right – soil temperature at 10 cm depth is above 14°C at 8am AEST, and forecast average temperatures for the week following planting are on a rising plane.**
- **Aim to establish approximately 10–12 plants per metre in warm growing areas; and 12 plants per metre in cooler growing areas.**
- **Some varieties have lower seed density and require careful management with seed bed, soil temperature, and planter set up and operation.**
- **Base replant decisions on good field information about the current population, its health and the cause of the stand loss.**
- **Use the resources available at www.faststartcotton.com.au or via the QR code located on your bag of seed.**

**FIGURE 1:** Summary of CSD plant population trials (21 irrigated and 9 dryland trials).




- Approximately 12 plants per metre established is ideal for cooler growing areas, due to the fruiting positions being set closer to the main stem with very few third and fourth positions, which can take longer to mature and can cause significant issues associated with lower micronaire.

There are some situations where growers should target the upper or lower end of this range. Aim for the lower end of the range when:

- Planting dryland/or into marginal conditions.
- You normally grow a larger plant size that can compensate well into gaps in the plant stand (e.g. in wetter, warmer climates and good soil types).

Aim for the higher end of the range when:

- Early crop maturing is essential where crop compensation is limited, and diseases can have an impact (e.g. southern and eastern regions).
- You normally grow a smaller plant size that cannot compensate well into spaces (e.g. tight soils).

## Planting rate

### Cotton planting rate calculator

The cotton planting rate calculator www.csd.net.au/planting-ratecalculator (membership may be required) can assist in determining the planting rate required to achieve a desired plant stand. There are several factors that need to be considered in order to determine this:

- Variety;
- Field conditions;
- Disease levels of planting region and individual fields;
- Establishment method;
- Seed germination percentage;

**Dryland cotton…**

**In addition to the best practice recommendations:**

- **Always plant on a full soil moisture profile.**
- **Aim to establish 6–8 plants per metre.**
- **Monitor soil moisture in the planting zone and adjust planting depth to ensure good seed soil moisture contact.**
- **Uniformity in plant stand is critical – gaps are accentuated by skip row configurations.**
- **Ensure stubble is cleared from the planting operation as it can impact seed placement and moisture contact.**

**Aim to avoid gaps greater than 50 cm – they have a large impact on yield.** (Photo: CSD)

- Soil temperature at planting; and,
- The seven day forecast.

It is important to note that all these factors will influence the calculated seeding rate required to achieve an adequate plant stand. Therefore, it is important that each field is treated as a separate operation and the calculator is used as a tool in the decision-making process. The seed size and germination data for the variety grown will have a large impact on the final planting rate. On average, there are between 10,000 and 11,000 seeds per kilogram; however, there are differences between varieties, which can impact significantly on the final kilograms per hectare planting rate.

The seeds per kilogram information for cotton planting seed can be obtained via the AUSlot number (Figure 2 red circle) and QR code on your bag of seed. This will link you directly to access your statement of seed analysis from CSD's website www.csd.net.au/auslots.

## What information is contained in a 'statement of seed analysis'?

The key information contained in the statement of seed analysis is specific quality data for an AUSlot, including results for germination, seeds per kilogram, mechanical damage, and physical purity. The germination results represent the physiological quality of the seedlot. The standard 'warm' germination test measures the germination potential or seed viability and represents the maximum germination rate under ideal conditions. This is a seven-day test which is conducted under a cyclic 20/30°C temperature regime. To be considered germinated, a seedling must have a length from hypocotyl hook to radicle tip of no less than 40 mm and be free from abnormalities. The minimum seven-day warm germination percentage for cotton planting seed is 80%. The cool germination test measures seed vigour, which represents the seeds' potential for rapid and uniform germination and development of normal seedlings under a range of conditions. This test follows the same protocol but is conducted at a constant 18°C for seven days. The minimum value for seven-day cool germination of cotton planting seed is 60%, but sample values are typically above 70%. CSD provides both warm and cool germination data on all AUSlots with the intent of providing growers and agronomists with useful and relevant data to make informed decisions at planting time. Data is also provided on physical purity, as well as mechanical damage, which is assessed as a percentage of seeds with physical defects such as cracked or holed seed coat, or broken seed. All germination values reported are for the whole sample including mechanically damaged seed.

**FIGURE 2: Example of the seed variety, technology and quality information that is printed on the bag sticker.**


## Seed stored on-farm

Carry-over seed originally purchased in previous seasons may have different seed quality from when it was purchased and should be re-tested. Growers are encouraged to use CSD's free carry-over seed testing to ensure seed viability. For more information, or to organise a seed sample submission, please contact your preferred agent.

## Having accurate seed quality information is essential in refining the planting operation:

- View estimates on seed size at: www.csd.net.au/seeds-perkilogram
- AUSLot information:
  - – Each seed lot has a batch number on the label of each bag. This number can be used to access actual seed quality at www.csd.net.au/auslots
  - – Select your variety, enter your AUSlot number and select search – Data includes warm and cool germination percentage, physical purity and seeds per kilogram.
  - – Each bag also has a QR code on the label, which can simply be scanned with a smart phone and you will be taken directly to the statement of seed analysis for your specific AUSlot.

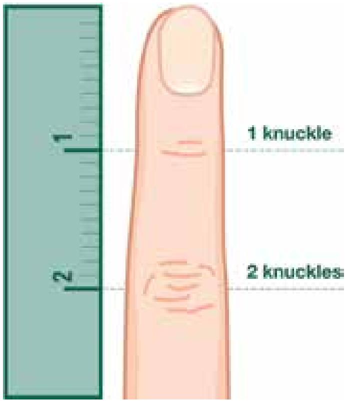
# Planter setup

Ensure the planter is well serviced and operating well before planting because breakdowns in the field cost time and allow surface soil moisture to further dry away:

- Check CSD's planter maintenance checklist at www.csd.net.au/resources/69-planter-maintenance-checklist (membership may be required).
- Ensure the planter is level.
- Check that discs and press wheels are uniform and engage the soil correctly.
- Check that monitors are calibrated and working correctly.
- Adjust and lubricate chains and cogs.
- Clean spray lines and filers top stop blockages when planting with herbicides or when in-furrow sprays are to be used.
- During the operation, regularly check seed depth and the condition of the soil around the seed – this is especially important when planting on rain moisture where you may have in-field variability.
- Keep a kit of spare parts (seed tubes, press wheels, scrapers, monitor cables, chains, and nozzles) in the cabin to allow for quick and minor repairs.
- Calibrate planter seeding rates as well as granular insecticide rates (if used).

## Planting depth

**FIGURE 3: Checking planter depth using your knuckles (1 inch = 2.5 cm).**




The depth you want your seed depends on the method of establishment and soil conditions. Many people use the 'knuckle method' as a quick and easy measurement tool in the field (Figure 3). When planting into moisture, some dry soil above the seed slot is useful to prevent moisture loss from around the seed. If there is too much, however, a rainfall event after planting will turn this dry soil into wet soil and increase the difficulty for young seedlings pushing through, while also increasing your seed depth. Check the consistency of the soil above the seed. If the pressure from the press wheels on the planter is set too high, you can get a compacted zone above the seed and the young seedling will have a tough time emerging. It is important not to plant too deep, as planting at depths of more than 5 cm can compromise establishment, even under ideal conditions (Table1).

**TABLE 1: Generic recommendation for planting depth based on establishment method.**

| Establishment method | Ideal depth |
|---|---|
| Planting into moisture (rain or pre-irrigated) | 2.5 and 4.5 cm (1 to 1.5 knuckles) |
| Planting dry and watering up | 2.5 cm (1 knuckle) |

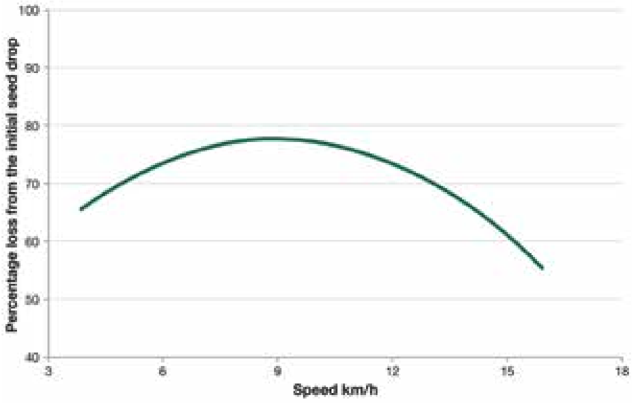
## Planting speed

Although cotton does have an ability to compensate for gaps or unevenness of plant stand, it is critical to achieve plant stand uniformity to assist crop management through the season. Precision planters allow for even seed spacing and a uniform seed depth. Press wheels enable good seed/soil contact to be achieved; and there is also the opportunity to additionally apply starter fertiliser, insecticides or fungicides through various attachments. One of the keys to plant stand uniformity is planter speed. The aim should be to plant with precision, not speed. Results from trials conducted by CSD on traditional MaxEmerge planters showed an ideal planting speed of about 8 to 10 km/hour. The average population decreased when planting faster than 10 km/hour, and slower than 8 km/hour (Figure 4).

## Planting time

The ideal planting time will vary between seasons and regions. Growers should check the Bollgard 3 Resistance Management Plan for the planting window relevant to their region. Don't plant until minimum soil temperatures at seed depth are maintained at 14°C or more for three days and rising. Planting at temperatures below this will diminish seedling and root growth, reduce water and nutrient uptake and the plants are much more susceptible to seedling diseases and insect pests.

**FIGURE 4: Effect of planting speed on establishment percentage** (Cotton Seed Distributors).




## Soil temperature and forecast

Temperature plays a vital role in the germination and rate of development of a cotton seedling. Below 12°C, the growth of a cotton plant is severely retarded and enzymatic activity within the cotton plant does not function properly until temperatures are above 15°C. There is a strong relationship between time to establishment and soil temperature. The higher the temperature, the faster the rate of development and germination. This is demonstrated in Figure 6 which depicts the relative growth of seed from the same seedlot germinated under laboratory conditions for seven days in a range of temperatures. Cotton deals with the extremes of temperature by shutting down or slowing physiological processes in the plant. Temperature experienced post-planting will also have an impact on the time taken for the plant to emerge.

The slower the plant grows, the greater the chance of seedling death occurring through disease and insect damage. Figure 5 shows that the most sensitive time for chilling injury is when the seed takes in moisture and this sensitivity reduces as the germinating seedling progresses through to establishment. This is why it is so important to monitor soil and air temperatures to find the appropriate window to plant the crop. It has been an Australian cotton industry guideline for many years that cotton planting should not begin before soil temperatures reach 14°C or above at 10 cm depth, at 8am AEST. In some of the southern growing regions, it can be difficult to reach these temperatures in early October and therefore a forecast for rising air temperature and hence soil temperature will allow growers to start planting. Furthermore, the average temperature forecast should be on a rising plane for the week following planting.

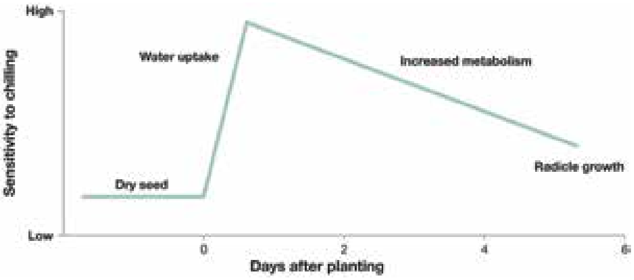
This will ensure that the developing seedling takes the least time to emerge and has good vigour in early development. Although it is a less common issue in traditional cotton growing areas, there is also an upper limit: temperatures above 35–40°C may also negatively affect germination, depending on the situation (Figure 7).

### FastStart Cotton tools

The FastStart™ Soil Temperature Network consists of a network of approximately 50 automatic weather stations located across cotton production areas in New South Wales, Queensland, the Northern Territory and Western Australia, available to CSD members at: www.csd.net.au/soiltemperature. These sensors are a real-time measure of the soil temperature at 10 cm and can be used as a guide to whether conditions are suitable for planting cotton.

**Visit www.faststartcotton.com.au/tools-and-calculators for other useful resources.**

**FIGURE 5:** Cotton seed sensitivity to chilling injury through germination and establishment (National Cotton Council, 1996).




# Establishment method

## Planting dry and watering up

This method has advantages in hot climates, as it cools the soil and crop establishment is rapid. When planting dry, it's very important to be aware of the consistency of the seed bed. A poorly consolidated (or cloddy) hill can collapse and crack when the water hits it and can drop the seed down to greater depths, resulting in poor or variable establishment. This is especially important for crops coming out of corn or sorghum. Planting can be followed by an over-the-top application of Roundup Ready herbicide, targeting newly emerged weeds.

## Pre-irrigation

Consider pre-irrigating when there is a large seed bank of difficult to control weeds and the soil is very dry and temperatures are high. Planting any shallower than 2.5 cm doesn't allow the emerging cotton plant the chance to scrape off the seed coat at germination and the growth of that plant will be quite slow until the coat is thrown off. If the beds are too wet at planting, you end up with a shiny, smeared planter slot which is very difficult for the young roots to penetrate. The result is often young seedlings dying from moisture stress, even if there is plenty of moisture below.

### Have you got the green light for planting?

**Ask yourself:**

- ☐ **Is the soil temperature at 10 cm depth above 14°C at 8am AEST for 3 consecutive days?**
- ☐ **Are forecast average temperatures for the week following planting on a rising plane?**

- **If you cannot give a green tick next to at least one of these statements, then planting conditions are definitely unsuitable – STOP!**
- **If you can give a green tick to only one of these statements – be CAUTIOUS. Adjustments may need to be made.**
- **If you can give both statements a green tick – it's GO!**


## Planting on rain moisture

Although the common method for dryland crops, many irrigators also aim to establish their crop on rain moisture to save water on pre-irrigation or watering up. There are several factors that will improve the likelihood of success with this method and some cautionary points for those attempting it on irrigated country:

**Stubble:** The presence of standing stubble will dramatically increase the chance of seedling survival in moisture planting situations because it increases the amount of infiltration and hence moisture available to the seedling. It also reduces surface evaporation and protects the young seedling from the elements. However, too much stubble can have a negative impact at planting time with stubble causing hair-pinning and blocking planter discs.

**Bare fallows in irrigation country:** A bare fallow can be a risky practice and often results in replanting if conditions are not ideal. Fields hilled for irrigation are designed to shed water, so you need to check whether moisture has infiltrated to any depth within the seed zone.

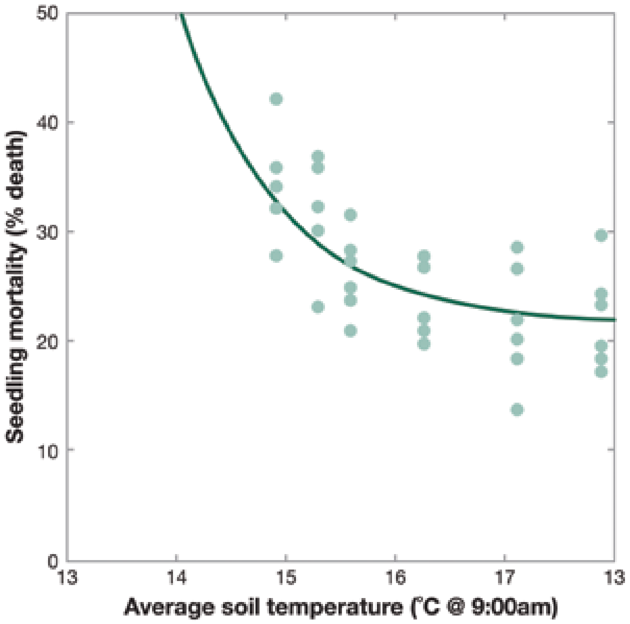
- In cloddy seedbeds the fine materials may be wet but the larger clods may be dry and may draw moisture away, drying the seed bed.
- Check across a field to see whether the rainfall has been uniform.
- When planting, check soil moisture levels in the seed zone regularly – planting depth may need to be adjusted throughout the planting operation due to movements in seed zone moisture.
- In furrowed fields, rainfall will usually not fill the soil profile as well as irrigation, so after emergence soil moisture levels and the vigour of the young seedlings need to be monitored closely.

# Do I need to replant?

The decision to replant comes down to whether it is more likely to achieve better results with the current planting or by replanting. It is desirable to have 8 to 10 plants (10 to 12 plants in cooler areas) per metre of row, distributed along the row as uniformly as possible. Potential yield declines as planting is delayed. An inadequate plant stand generally results in a decline in yield, and also a decline in maturity of the crop. Cotton plants will compensate for gaps in the crops, but the delay in maturity will start to become an issue as these plants around the gaps take longer to mature, compared to those within a uniform plant stand. This is particularly important in southern growing regions.

**FIGURE 6:** Effect of temperature on 7 day germination on the same AUSlot.

**FIGURE 7: Impact of soil temperature on seedling mortality. Temperature is the average minimum soil temperature for the seven days after sowing** (Nehl, NSW Department of Primary Industries).




## Factors to consider with replanting

It is important to understand the issues that caused the low plant stand. You will need to be confident you can overcome these issues before you replant, or they will likely happen again. Before you replant, consider:

- Replanting date – be aware of when yield potential will start to decline. Consider the micronaire period, especially in cooler areas. Not only will yield decline but you may not be able to mature the fibre. Visit www.faststartcotton.com.au/tools-and-calculators to access the Replant Calculator.

**Particularly when planting on rain moisture, beware of uneven moisture throughout the bed which will cause variable crop development.** (Photo: CSD)

- Insects – will damage by wireworms, thrips, or other pests reduce the stand further?
- Weeds – will a low population or 'gappy' plant stand encourage a weed problem?
- Disease – will Rhizoctonia, Pythium or black root rot reduce the stand further; and are the current seedlings still being affected by disease?
- Hail damage – will the seedling regrow?
- Herbicide damage – has rain washed residual herbicides into the root zone?
- Water – will a flush help to wet the bed to germinate dry seeds or waterlog the seedlings?
- Temperature – what is the outlook? Is the soil temperature above 14°C, and do you have a rising temperature plane for the following week? (Refer to traffic light for planting temperature).

Figure 8 demonstrates the relative yield potential of plant stands that are variable or non-uniform compared with a uniform stand. A plant stand with high variability is described as having two or more gaps greater than 50 cm in length every five metres of row. A variable stand will reduce yield for all plant populations.

## The implications of replant

**Replanting date:** Relative yields decline by late October in warmer growing regions and earlier in cooler. This reduction in yield potential should be factored into replant decisions, as a low population or gappy stand may have a greater yield potential than the replanted one.

**Soil moisture status:** In seasons where irrigation water is a limiting factor, the soil moisture status is critical in determining whether a replant is justified:

- Is flushing or rainfall going to get dry seeds up?
- Does this have implications for the remaining planted area's water budget?

**Dry seeds:** Seeds can survive in soil for a long time. Consider if a stand will improve if rainfall or irrigation germinates these dry seeds.

**Variety selection:** If the replant means you are planting late in the window, choose a variety which has performed well in late planted scenarios in your area. These are typically the more determinant varieties with inherently longer, stronger, and mature fibre as cooler conditions at the end of the season can negatively impact on fibre quality. Check CSD's variety guides for suitable varieties.

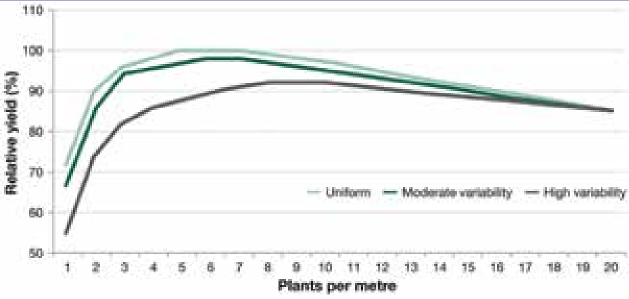
## The implications of not replanting

Sometimes sticking with the plant stand you have is a better option than replanting. There are some considerations when managing a low plant population:

**Lower yield potential:** If possible, prioritise resources to fields with a better plant populations and higher yield potentials. This is particularly relevant in limited water situations.

**Weed populations:** Low plant populations with gaps may encourage weed problems later in the season due to lack of competition. A plan for their management should be devised early.

**FIGURE 8: Relative yield potential at a range of plant stand uniformities** (Constable, CSIRO, 1997).




**Useful resources:**

**PLEASE NOTE: Membership may be required to use the CSD website.**

**FastStartTM Cotton website: www.faststartcotton.com.au**

**FastStartTM Cotton Establishment Guide: www.faststartcotton.com.au/downloads**

**Have you got the green light for planting? www.csd.net.au/green-light-for-planting**

**Statement of Seed Analysis: www.csd.net.au/auslots**

**FastStartTM Cotton Soil Temperature Network: www.csd.net.au/soil-temperature**

**CSD Cotton Planting Rate Calculator: www.csd.net.au/planting-rate-calculator**

**CSD Replant Calculator: www.csd.net.au/replant-calculator**

**CottonInfo YouTube series – planting and establishment www.youtube.com/cottoninfoaust**

Chapter 16 sponsored by – VALLEY The Leader in Precision Irrigation.

# Irrigation management

Contributing authors: **Louise Gall** (GVIA), **Janelle Montgomery** (CottonInfo) & **James Quinn** (Cotton Seed Distributors)

## What's new…

**Goanna Ag's GoField PLUS technology is now available commercially. It uses soil moisture and canopy temperature field data with analytics developed in Australia by CSIRO and CRDC to enhance understanding of what is happening in both the soil and the crop to help growers optimise irrigation scheduling.**

Irrigation can be used to regulate vegetative and reproductive growth to maximise yields and fibre quality. Appropriate irrigation scheduling improves water use efficiency, reduces waterlogging, controls crop canopy development and improves the effectiveness of rainfall.

## Best practice…

- **Monitoring the plant, the soil and the expected weather conditions will help you schedule irrigations to meet crop demands and avoid plant stress.**

**Weather stations provide additional information on local conditions.** (Photo: Lou Gall, GVIA)

**TABLE 1: Yield loss (%) per day of water stress (extraction of >60% plant available water).**

| | Past conventional* | Bollgard** |
|---|---|---|
| Squaring | 0.8 | 1.1 |
| Peak flowering | 1.6 | 1.7 |
| Late flowering | 1.4 | 2.7 |
| Boll maturation | 0.3 | 0.69*** |

* Hearn and Constable 1984, ** Yeates et al. 2010, *** 14 days post cut-out

## Water use by cotton plants

Plants lose water through their leaves to keep cool and to move nutrients around the plant. They absorb water from the soil to replace water they have lost. Water is necessary for photosynthesis, cell expansion, growth, nutrient supply and turgor pressure (prevents plant from wilting and controls stomatal opening).

## Irrigation efficiency – plant response to water

### Too little – water stress

Cotton is naturally a perennial plant. Under favourable conditions, the number of leaves, new nodes, fruiting branches and squares can increase rapidly and continue to be produced, unlimited by a phenological time frame and nutrition, while conditions remain favourable. During the pre-flowering stages of growth, production of carbohydrates (through photosynthesis) is in excess of demand, and as a result vigorous vegetative growth occurs. As plant growth continues, the demand for carbohydrates by the component plant parts such as bolls increases, and production becomes limited by environmental conditions as the season progresses. Boll growth exerts large demand for carbohydrates, and it is through the balance between boll demand and leaf production that vegetative growth becomes restricted. Water stress can restrict both vegetative and boll growth.

No matter what degree of water stress is imposed on a crop, the proportionality between vegetative growth and boll development remains relatively constant. Similar results have been achieved with crops receiving different amounts of nitrogen. This implies that, independent of water or nutrient supply, the plant will always attempt to form a balance between vegetative growth and boll development.

**Monitoring and maintaining consistent channel head heights ensures more even siphon flow rates and more efficient irrigation.** (Photo: Lou Gall, GVIA)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Like many crops, cotton is most sensitive to water stress during peak flowering. Table 1 illustrates the potential yield loss for Bollgard crops per day of stress for squaring, peak flowering, later flowering, and boll maturation.

**Useful resources:**

**WATERpak Chapter 3.1 pg 239–247.**

**WATERpak Chapter 3.2 pg 248–263.**

**www.cottoninfo.com.au/publications/waterpak**

## Too much – waterlogging

The major and immediate effect of waterlogging is a reduction in the transfer of oxygen between the roots and the soil atmosphere. Plant roots may become so oxygen deficient that they cannot respire. As a consequence, root growth and absorption of nutrients is decreased, leading to less overall plant growth. A reduction in node numbers leads to a reduction in the number of fruiting sites and consequently a reduction in the number of bolls produced. Research has shown a reduction of 48 kg/ha (0.2 b/ha) of lint for each day of waterlogging.

Cotton is most susceptible to waterlogging during the early stages of flowering as this is when the plant is setting the fruit load that will dictate final yield. As the plant gets older there will still be effects, but they won't be as severe because the fruit is basically established on the plant. Plants exposed to rainfall-induced waterlogging may also suffer from the reduced sunlight availability associated with overcast conditions. Under these conditions, the plant cannot fix enough carbon to maintain normal functions and may shed fruit as occurs under any other form of stress.

In addition to the immediate physiological impacts of waterlogging on the crop, there are also significant impacts on nutrient availability and uptake. Waterlogging increases the rate of denitrification and changes plant uptake of nutrients caused by a decline in soil oxygen. Nitrogen (N), iron (Fe), and zinc (Zn) uptake is reduced, while manganese (Mn) uptake is increased. Irrigation strategies designed to avoid potential waterlogging events contribute towards improved yield and water use efficiencies and can also benefit crop nutrient efficiencies.

Waterlogging also tends to decrease the plant's ability to regulate sodium uptake. Although cotton is reasonably tolerant of salinity, exposure to increased concentrations may impinge on yield potential. Optimised irrigation system designs allow crops to be watered with optimal start and end times, and appropriate volumes. Delivery of water to the head ditch and efficient drainage of tailwater from the field reduce potential exposure to waterlogging and minimise losses via deep drainage.

**Useful resources:**

**CottonInfo video: Waterlogging in cotton**
**www.youtube.com/cottoninfoaust**

**WATERpak Chapter 3.4**
**www.cottoninfo.com.au/publications/waterpak**

# Monitor to manage – irrigation efficiency

**Monitoring the conditions, the plant, and soil moisture will help in scheduling irrigations to meet crop demands and avoid plant stress.**

A successful philosophy to follow from the start is 'measure to manage'. The use of water meters, soil moisture probes, channel level sensors, canopy temperature sensors and water advance sensors enable the fine tuning of management strategies that can lead to improved efficiencies.

**Monitoring soil moisture and irrigation performance helps schedule irrigations.** (Photo: Lou Gall GVIA)

**TABLE 2: Advantages and disadvantages of different options for the first irrigation.**
(Adapted from WATERpak Table 3.3.2. pg 256. S Henggeler)

| Pre-irrigation | Watering-up | Pre-irrigation and late flush |
|---|---|---|
| **Likely advantages** | | |
| • No time pressure to apply the water.<br>• In a heavy clay, water losses can be less than keeping it in an on-farm storage.<br>• Soil temperature is less likely to drop after planting – potentially less disease pressure.<br>• Allows a flush of weeds to emerge and be controlled before cotton emergence. This is a good opportunity to incorporate a non-glyphosate tactic into the system. Particularly useful for glyphosate resistant weeds and volunteer cotton. | • Potential to take advantage from pre-plant rain events, so the irrigation may require less water.<br>• Easier to plant, especially when beds are not 100% even.<br>• Faster planting operation and less machinery needed.<br>• Reduced potential for compaction because sub-soil is dryer. | • Helps in fixing up plant stand problems.<br>• Can give the crop the necessary "boost" to get going after a slow start. |
| **Likely disadvantages** | | |
| • Soil drying out too quickly.<br>• Dry rows in uneven fields.<br>• Soil stays too wet when followed by rain.<br>• Unable to capture rainfall before planting.<br>• Potential to increase compaction by trafficking wet soil. | • Reduction in soil temperature after planting in cool conditions; cool, wet soils can result in higher disease pressure.<br>• Herbicide damage more likely.<br>• Sides of beds might erode when flushing for a long time.<br>• Can germinate weeds at the same time as the crop.<br>• Potential for waterlogging if rain occurs after flushing. | • Likely to use more water. |

It's also important to monitor crop growth. Monitoring of squaring nodes, fruit retention and nodes above white flower (NAWF) will help keep track of how a crop is progressing compared to potential development when under stress. Knowing what stage the crop is at will help in predicting crop water use. This is most important during peak water demand, which occurs during peak flowering.

Dryland growers can access tools such as the GRDC's Australian CliMate analysis tool or Soil Water App. These tools use climate data to estimate how much plant available water has been stored in the soil. CliMate also estimates the amount of organic nitrogen that has been converted to an available form during a fallow (non-crop period). The program tracks daily evaporation, runoff and soil moisture using estimates of weather conditions and rainfall input by the user. Accumulation of available nitrogen in the soil is calculated based on soil moisture, temperature, soil type and age of cultivation.

**Useful resources:**

**https://climateapp.net.au/**

**http://soilwaterapp.net.au/**

# Scheduling irrigations

## Pre-irrigation or water-up

The decision whether to pre-irrigate or water up the crop has to be made specifically to suit a particular farm and conditions. In certain situations, it may also be necessary to combine the two options by pre-irrigating to plant into moisture and then giving the crop a quick flush. Every farm is different, and a range of questions need to be considered; for example, is it likely to rain before/during/after planting, what are the implications associated with the different tactics in relation to seedling disease, soil temperature, compaction and weed control, am I set up for dry or moisture planting? The likely advantages and disadvantages of pre-irrigation and water-up are summarised in Table 2. Refer also to the *Crop establishment* chapter.

# Scheduling in-crop irrigations

Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximise crop productivity. Good scheduling should provide plants with water that is within a desired range and should limit over or under irrigation so that balanced growth is achieved. For some Bollgard 3 varieties, insufficient available water prior to and during flowering will reduce plant size and lead to early cut-out while too much water can lead to rank growth or waterlogging.

**Useful resources:**

**CropWaterSched irrigation scheduling tool. www.waterschedpro.net.au**

## First irrigation

The first irrigation plays an important role in setting up for plant growth and fruit retention, fibre quality and boll weight. Its timing is perhaps the most difficult irrigation scheduling decision. It is a balancing act between not stressing the plant from waterlogging while ensuring stored water in the soil profile is fully explored by the developing root system before applying that first irrigation.

It's crucial to set up the plant for the rest of the season, particularly with high retention Bollgard crops. Irrigating too late will incur yield penalties due to the impact of water stress on plant development. It is difficult to recover the growth needed for supporting fruit development if water stress has slowed growth. The timing of first irrigation will vary depending on seasonal conditions and in-crop rainfall and would need to be earlier on lighter soils with compaction which inhibits root penetration.

- Monitor your soil moisture, root extraction patterns, daily water use and plant vigour.
- As a rule of thumb, irrigate at 50% available soil water within the root zone.
- Check weather forecasts as hot and dry, cool or wet weather near the time of first irrigation can be detrimental to crop growth and water use efficiency.
- Ensure fresh roots are accessing moisture.
- Use tools such as canopy temperature sensors to give an indication of plant stress.

**Useful resources:**

**CottonInfo: First Irrigation webinar – www.youtube.com/cottoninfoaust**

**SIP2: https://smarterirrigation.com.au/plant-based-sensing-optimising-irrigation-timing-in-limited-water/**

**https://smarterirrigation.com.au/responsive-irrigation-management-with-canopy-temperature-stress-technology/**

## Subsequent irrigation scheduling

Once in-crop watering has started, stick to the target soil moisture deficit. As a rule, the best deficit to aim for is approximately 50% of the plant available water-holding capacity (PAWC). This is conservative for heavy clays and at times it may be possible to dry them to a 60% deficit without penalty. On light or compacted soils (see WATERpak chapter 2.5 Managing soil for irrigation: Pores, compaction and plant available water) or under conditions of high evaporative demand (very hot and dry conditions or hot winds) the deficit as a percentage of PAWC needs to be reduced because the stress occurs more rapidly, and the crop can't adjust its growth and metabolism quickly enough.

For all irrigated cotton crops, water stress should be avoided during peak flowering and early boll fill stages. If irrigation water is limited, it should be saved for the flowering period. Stress during peak flowering will result in greatest yield loss. The use of plant-based sensing with canopy temperature sensors as found in the GoField Plus (www.goannaag.com.au) will help growers monitor crop water stress and schedule irrigations more effectively. Soil moisture monitoring in combination with canopy temperature monitoring and weather forecasts will help irrigation scheduling decisions. The inclusion of weather forecasts is important; for example when the forecast is for low evaporative demand (ETo<5 mm/day) irrigation can be delayed past the normal target deficit and if rainfall occurs during this period then there is opportunity to capture this rainfall in the crop and save water.

Careful monitoring of soil moisture extraction graphs, daily crop water use and crop development (squaring nodes, first position fruit retention and NAWF) and growth will assist with getting the irrigation schedule right. It is generally better to skip the last irrigation rather than stretching irrigations during flowering.

## Final irrigation(s)

Ideally the last irrigation will provide sufficient water to optimise final yield and fibre quality, adequate soil moisture to enable defoliants to work effectively, and a soil profile that is sufficiently dry to enable picking with minimal soil compaction.

Assessing the water requirements and knowing the amount of soil moisture remaining will allow calculation of the best strategy with the remaining water. Options to consider include stretching the second last irrigation, bring the last irrigation forward (smaller deficit) so that less water is applied in the last irrigation or skipping the last irrigation. End of season water requirements can be determined by:

- Estimating the number of days until defoliation; and,
- Predicting the amount of water likely to be used over this period.

**The number of days to defoliation** can be predicted in two ways: by determining the date of the last effective flower (cut-out) or by counting the number of nodes above (last) cracked boll (NACB) (Refer to *Preparing for harvest* chapter for more information on NACB). The last effective flower method is useful as a forward planning technique for budgeting water requirements in advance. The NACB is useful for monitoring final irrigation requirements as the crop matures. An example of each method is provided in WATERpak, Chapter 3.2 Managing Irrigated Cotton Agronomy.

The date of the last effective flower can be used to match the time when a manager may choose to cut-out the crop to ensure crops can realistically mature in suitable growing conditions, as well as determining the approximate number of days until defoliation to plan irrigations after cut-out. Cut-out occurs when the plant's demand for assimilate (products of photosynthesis) finally exceeds supply so that production of new squares and flowers virtually ceases, normally when the plant reaches 4–5 NAWF.

The last effective flower works on the principle that it takes 430 day degrees for a square to become a flower, and 750 day degrees for a flower to become an open, mature boll. NACB can also be used to estimate the number of days until defoliation using:
*Days to defoliation = (total NACB -4) x 3*

This is based on the principle that it takes about 42 day degrees for each new boll to open on each fruiting branch. If warm, sunny conditions prevail this could be around three days per node, however, mild and overcast conditions will slow opening.

**Estimate the predicted water requirements and compare to remaining soil moisture.**

At the time of first open boll, crop water use may be 5–7 mm/day, but this can decline to only 3–4 mm/day during the two to four weeks prior to defoliation. If roots are extracting to a good depth (at least 1 m) at cut-out, plants can easily extract 70% of the available water prior to maturity of the boll set from the last effective flower. In cracking clay soils, plants can extract 125 to 150 mm soil moisture, which is equivalent to 25 to 30 days' water use (assuming 5 mm/day) with little effect on yield or quality.

Therefore, on most cotton soils unless water use is above 5 mm/day there is no need to irrigate in the 20 to 25 days before defoliation. Any new flowers that develop in that last 25 days will not have time to mature with the last bolls, making up a small contribution to yield. Hence, you have only 25 to 30 days in which to schedule irrigations.

Assuming an irrigation is made at cut-out, the final irrigation will occur 25 to 30 days later. You can plan to apply one or two irrigations between the cut-out irrigation and the final irrigation depending on soil type, the deficit you prefer, rooting depth and plant water use. While yield and quality losses can still occur after cut-out the reduction in yield is lower compared to stress during flowering (see Table 1). Therefore, if water is becoming limiting, you can stretch irrigations after cut-out with relatively little impact on yield – refer to Scheduling with limited water, later in this chapter.

### Timing final irrigation

Crops that experience stress before 65 to 70% of bolls are opened or before reaching 4 NACB can suffer yield and quality reductions. If bolls do not reach maturity before harvest, there will be high levels of immature fibres.

**Measuring nodes above (last) cracked boll (NACB is most commonly used method to accurately time final irrigation and defoliation.**

There will be crops with lower plant stands, poor development or damaged crops where measuring NACB will not work well and you will have to cut bolls, even on vegetative branches, to find the most mature boll to accurately time final irrigation. The objective of the last irrigation is to ensure that boll maturity is completed without water stress. Once a boll is 10–14 days old, the abscission layer responsible for boll-shed cannot form. Consequently, late water stress (beyond cut-out) does not significantly reduce boll numbers and therefore yield. However, fibre quality can be more seriously affected by late water stress. Crops that come under stress prior to defoliation (60 to 70% open – four nodes above cracked boll) can suffer some fibre quality reduction, especially micronaire. The degree of reduction obviously increases the earlier the stress occurs. Key points to note:

- Where retention of first position bolls is high monitor NACB to accurately time final irrigation and defoliation.
- Determine the water requirements of your crop from cut-out to defoliation by estimating the number of days until defoliation and predicting the amount of water likely to be used over this period.
- If water is becoming limiting, you can stretch irrigations after cut-out because the water use drops off significantly. Stretching irrigations prior to cut-out results in significant yield losses, so where water is limited the impact will be less at the end of the season.

**Useful resources:**

**CottonInfo: Late Season Irrigation Management www.youtube.com/cottoninfoaust**

**Timing your last irrigation www.youtube.com/cottoninfoaust**

**WATERpak, Chapter 3.2**
**www.cottoninfo.com.au/publications/waterpak**

**CSD Fact Sheets: https://www.csd.net.au/resources?select_category=Fact+Sheets (membership may be required) *Flowering a critical period of crop development***

## Best practice…

- **For all irrigated cotton crops, avoid water stress during peak flowering and early boll fill stages.**
- **The last irrigation should ensure that boll maturity is completed without water stress.**

## Scheduling with limited water

When water is limited, growers may need to modify their normal irrigation practice to optimise yield, quality and water use efficiency. As with fully irrigated production, the aim is to limit or minimise the amount of crop stress. Cotton's response to water stress depends on the stage of growth that stress occurs, the degree of stress and the length of time the stress is present. To determine when to irrigate under limited water conditions it is important to monitor crop water use and crop development as the timing of stress can have significant impacts on yield and water use efficiency.

### Monitoring crop development to determine crop stress

A cotton plant, when not stressed, grows in a predictable way, which allows its development to be predicted using daily temperature data (day degrees). Monitoring of squaring nodes, fruit retention and nodes above white flower (NAWF) will help keep track of how a crop is progressing (compared to potential development) when under stress. Knowing the stage of the crop will help predict crop water use. Monitoring NAWF will assist in deciding which fields need irrigating when water is limited.

When fruit retention is high, crops with more NAWF generally have more vigour. Where there is sufficient water available the aim is to extend the flowering period as long as possible to match the season length. Once the crop has reached cut-out (NAWF <4–5), the most critical period for


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minimising water stress has passed. Stressed crops may reach cut-out earlier as leaf expansion and the development of new nodes slows in response to water stress.

Water stress has less of an impact if it occurs late or early in the season but stress during the flowering period can lead to significant yield loss as this is the period when the crop is most susceptible to stress. Visual signs such as leaf colour and wilting can be indicators of stress; however, many of these occur after stress has occurred so are not useful in anticipating crop requirements.

## Measuring current and predicting future crop water use

Stretching the time between irrigations beyond the target deficit can lead to significant yield losses. Therefore, in most seasons, it is better to skip the last irrigation rather than stretching irrigations during flowering. With very severe water shortages, delaying the first irrigation is preferable to lengthening the irrigation interval during flowering. Soil moisture monitoring is invaluable for timely irrigations, and when water is limited predicting how much water will be needed to refill the profile. The short-term forecast can help refine scheduling in predicting future crop water use.

## Current recommendations for limited water situations

- Aim to concentrate water applications during flowering (first flower to cut-out) and minimise stress during this period.
- Monitor crop to determine how a crop is performing in comparison to the expected growth of a well-watered crop.
- Continue to use a variety of tools to schedule irrigations including soil moisture and weather forecasts.

**Useful resources:**

**CottonInfo:**
**WATERpak Chapter 3.1.**
**WATERpak, Chapter 3.2.**
**www.cottoninfo.com.au/publications/waterpak**

**CottonInfo youtube irrigation series:**
**www.youtube.com/cottoninfoaust**

**CSD Fact Sheets: https://www.csd.net.au/documents/fact-sheets (membership may be required)** ***Finishing the crop with limited water***

**The authors would like to acknowledge original contributions to WATERpak by Rose Brodrick, Nilantha Hulugalle, Mike Bange, Steve Yeates, Dirk Richards, Guy Roth, Dallas Gibb and Stefan Henggeler.**

# Developments in irrigation scheduling technologies

A deficit approach to scheduling is a commonly used technique on irrigated cotton farms. 70% of cotton growers use soil moisture probes to understand how much water their soil holds and how much is available for crops. More recently, R&D has led to advances in sensing and satellite imagery to assess crop stress and spatial variability.

## IrriSAT: Weather-based irrigation scheduling

IrriSAT is a weather-based irrigation scheduling and benchmarking technology that uses remote sensing to provide site specific crop water management information across large scales at relatively low cost. The IrriSAT technology uses two sources of information:

1. A local weather station for reliable estimates of reference evapotranspiration (ETo).
2. Satellite imagery to determine crop coefficients (Kc) that are site specific for individual irrigation fields which are then combined with ETo to calculate crop water use (ETc).

IrriSAT assists with your irrigation scheduling decisions and can be used to examine variation in crop productivity within a field or across a farm or region.

Canopy temperature and soil probe data can help inform irrigation scheduling.

**Useful resources:**

**IrriSAT: https://irrisat-cloud.appspot.com**

**CottonInfo:**

**Video: Using IrriSAT for irrigation scheduling www.youtube.com/cottoninfoaust**

**Webinar – IrriSAT use and applications for irrigation management in cotton www.youtube.com/cottoninfoaust**

## Canopy temperature sensors: Plant-based scheduling

Crop canopy temperature sensors are a plant-based irrigation scheduling technology, providing a measure of plant stress. Compared to a well-watered crop, a water stressed crop has a higher canopy temperature. The use of canopy temperature sensors and canopy temperature data to schedule irrigations is ideal for a number of reasons:

- Canopy temperature is a good indicator of plant water status.
- The data is processed continuously and in real time.
- Canopy temperature sensors are available in combination with soil moisture probes to give information on both soil and plants and hence improve irrigation scheduling.
- The Goanna platform now also includes predictive canopy temperatures which enhances irrigation planning.
- Canopy temperature sensors are non-contact and non-invasive.

The use of crop canopy temperature sensors will provide confidence when making irrigation decisions, particularly during times of unusual weather conditions and will improve crop water stress management and improve water use efficiency.

**Useful resources:**

**Smarter Irrigation for Profit 2:**

**Case study: https://smarterirrigation.com.au/responsive-irrigation-managementwith-canopy-temperature-stress-technology/**

**Podcast: https://smarterirrigation.com.au/plant-based-sensing-optimisingirrigation-timing-in-limited-water/**

**Factsheet: https://smarterirrigation.com.au/plant-based-sensing-for-cottonirrigation-2/**

**CottonInfo:**

**Webinar: https://youtu.be/7Ap4744Y23w**

**Video: https://youtu.be/i2fPMCVG9dU**

**GoannaAg: https://www.goannaag.com.au/gofield**

## Dynamic deficit scheduling

Dynamic deficit is an irrigation scheduling tool that involves having a flexible or dynamic soil water deficit in surface irrigation scheduling to more effectively match irrigations with potential crop stress and short-term forecasted climatic conditions. This means dynamically changing the soil water deficits to improve growth by avoiding plant stress during periods of high evaporative demand, ETo >5 mm/day (lower soil deficits) and improve water use efficiency by reducing the need for irrigation during periods of low evaporative demand, ETo <5 mm/day, (larger soil deficits). Delaying irrigation in response to forecasted low ETo can also provide an opportunity to capture rainfall in the crop and save water.

A measure of plant stress is required to successfully implement a dynamic deficits approach; hence this tool works well with crop canopy temperature sensors.

**Useful resources:**

**2015 Cotton Irrigation Technology Tour Booklet. www.cottoninfo.com.au/publications/cotton-irrigation-technology-tour-booklet**

**Crop Canopy Temperature Sensors. https://scisoc.confex.com/crops/2014am/webprogram/Paper88636.html**

**CropWaterSched irrigation scheduling tool www.waterschedpro.net.au**

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# Managing crop growth

By **Michael Bange** (Cotton Seed Distributors) and **Sandra Williams** (CSIRO)

**Acknowledgements: Greg Constable (CSIRO, retired), Dave Kelly, John Barber, Bernie Caffery (retired), James Hill, Brad Cogan and Steve Warden (cotton consultants).**

## Vegetative growth

Maintaining vigorous vegetative growth before flowering is important as it is these leaves, fruiting branches and roots that will support future boll load. After flowering, this vegetative growth will normally slow down as the plant prioritises its resources to boll growth. Vegetative and reproductive growth will only continue when there are excess resources to the needs of fruit growth. Eventually, when all the resources are allocated and there is no excess, further growth (vegetative and reproductive) ceases and the crop will cut-out.

Competition for water, nutrients and carbohydrates between vegetative and reproductive growth is constantly occurring within each cotton plant. This is normally well regulated by the plant, but in some situations can become unbalanced. This is when growth regulators like mepiquat chloride (MC) may be required. When fruit is lost, such as shedding during prolonged cloudy weather, very high temperatures, or due to insect attack, the resources that were being used by the fruit are now available for other growth.

If growing conditions are good, the plant will respond by growing larger leaves and more stem. New fruiting sites will continue to be produced. Similarly, in conditions where there is abundant moisture, humidity, heat, ample nutrients, and no soil constraints, there may be excess resources to the needs of the developing bolls. The crop will respond by growing more lush vegetative growth. Excessive vegetative growth can be a symptom of too much nitrogen, or too frequent irrigations. All cotton varieties have a similar response in vegetative growth.

Control of growth, where excessive, can increase canopy light penetration and air circulation (reducing physiological shedding), and increase fruit retention, possibly increasing yield. Mepiquat chloride is also credited for a range of responses including inducing cut out, which can lead to earlier crops; a reduction in attractiveness to late season pests; and improvements in crop maturity. This chapter explains mepiquat chloride's mode of action and how to decide whether an application is needed.

### Best practice…

- Mepiquat chloride manages excessive vegetative growth by shortening internodes and reducing leaf area to restore the balance between reproductive and vegetative growth.
- Simple observations of height will not necessarily identify appropriate mepiquat chloride response.
- Caution: Some defoliant products containing ethephon, such as Prep, are labelled as a 'Growth Regulator'. Ethephon has devastating consequences on a growing cotton crop. Ethephon is used for preparing the crop for harvest and may cause significant fruit loss if used at the wrong time.

## Mode of action

Mepiquat chloride reduces the production of gibberellic acid (GA) in a plant by partially inhibiting one of the enzymes involved in the formation of GA. GA belongs to a group of plant hormones, Gibberellins, which are natural growth regulators in plants. They play an important role in stimulating plant cell wall loosening which allows stretching of the wall by internal cell pressure. This is known as cell expansion and is one mechanism allowing a plant to grow. In addition to GA, cell expansion is driven by a number of factors including water availability, humidity and temperature.

## Impact on cotton growth

When cell expansion is inhibited following an application of mepiquat chloride, any new plant growth will normally have shortened internode length and smaller, thicker leaves. As cells are smaller and denser, and because the green coloured chlorophyll molecules are sitting closer together, the leaf colour is generally a dark green. Even though mepiquat chloride is rapidly distributed throughout the entire plant, it only significantly limits the cell expansion in new growth. So, generally, it is only the top three or four internodes that will be shortened. The concentration of mepiquat chloride becomes diluted as growth continues and the formation of GA and normal cell expansion resume at the growing point. Thus larger plants growing more rapidly will require higher rates of mepiquat chloride to slow cell expansion.

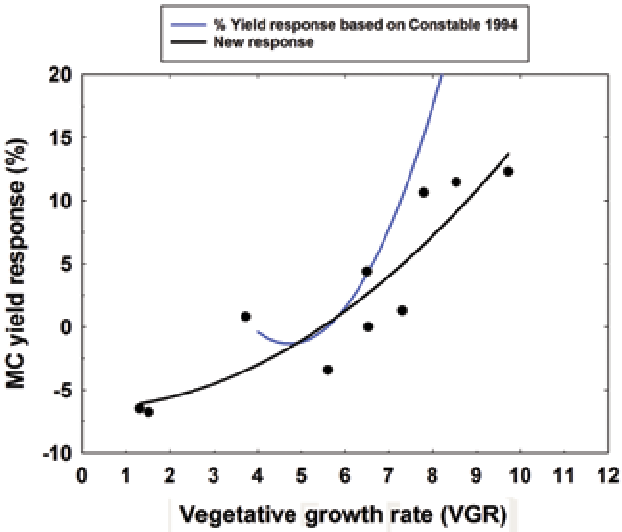
### Yield

Research has been conducted to investigate the response between VGR at early flowering and % yield response to mepiquat chloride in Bt cotton. Results have shown a positive yield response to applying mepiquat chloride on cotton with a high VGR (>5), but a negative yield response in a crop with a low VGR (<5). As can be seen in Figure 1, these negative responses in Bt cotton have been more severe than previously measured on non-Bt cotton varieties before 1994.

### Dryland cotton…

- In conditions where the plant has excess resources above the needs of the developing bolls, vegetative growth can occur and controlling this growth with mepiquat chloride is an option.
- The same growth management principles apply with both dryland and irrigated cotton.
- Measuring plant height and nodes to calculate vegetative growth rate (VGR) is useful to assist with growth management decisions.
- Do not use mepiquat chloride if the crop is stressed or likely to be stressed following the application. This is particularly important for dryland cotton. Good rainfall after a shedding event may result lush vegetative growth. Keeping an eye on this new vegetative growth and the weather forecast is important in these situations.
- Using mepiquat chloride to aid crop cut-out is a useful tool to help prepare a late or uneven crop for a timely harvest.

**FIGURE 1:** VGR (cm per node) at flowering and the corresponding yield response % when MC is applied. The graph also compares the response curve from non-Bt cotton with the new response measured in Bt cotton crops.

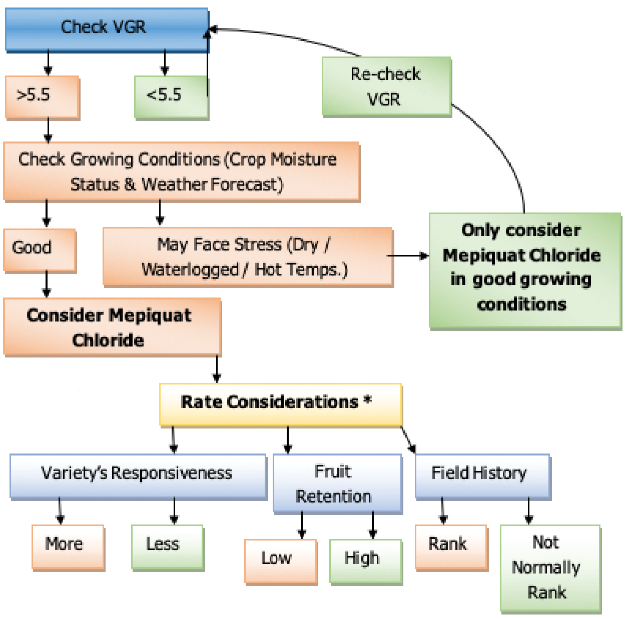



## Managing crop maturity with mepiquat chloride

Mepiquat chloride can be used to assist in managing cut-out and thus crop maturity for a timely harvest. Restricting vegetative growth means that there are less assimilates (products of photosynthesis) produced by the plant from new leaves to enable new growth at optimal rates thereby causing the plant to approach cut-out and thus maturity more rapidly. Getting the timing right of crop maturity is important for producing quality cotton by:

- Ensuring a timely harvest to avoid adverse weather conditions.
- Allowing an effective defoliation to reduce trash content.

**FLOW CHART 1:** Early Flowering Decision Tree – This flow chart incorporates all of the factors and the decision processes that should be considered when making the decision to apply mepiquat chloride early in the season around flowering.




*Use Figure 2 for assisting with decisions regarding mepiquat chloride rates.

- Reducing the number of immature bolls that may increase the incidence of neps.

Optimising the timing of crop maturity is a balance between the opportunity to produce more fruit to contribute to yield and the risk of a late harvest with quality downgrades. This is important for shorter season and southern areas where adverse weather conditions can occur earlier. The time of cut-out is generally directly related to crop maturity. Cut-out can be monitored using a simple count of the number of nodes above the first position white flower (NAWF) where four NAWF = Cut-out. The latest cut-out date where all the fruit on a cotton plant will be picked will differ from region to region. Using the average date of the first frost or a pre-determined date, the date of the last effective flower can be used to estimate the latest cut-out date.

## Crop uniformity

A crop can become patchy with excessive vegetative growth, such as when the crop has had a pest infestation that has not affected all plants, cases of uneven soil types, or head ditch and tail drain effects. In these situations, mepiquat chloride can make the crop more uniform, allowing for uniform defoliation and timely harvest. Crops that do not have uniform maturity can be attractive to late season pest infestations and are susceptible to fibre quality issues such as lower micronaire (due to increased numbers of immature bolls) and increased leaf trash. The use of variable rate technology in these situations can offer opportunities to optimise the effectiveness of mepiquat chloride.

# Making the decision at early flowering

Cotton's response to mepiquat chloride depends on several factors, the most critical being whether there are other sources of stress already controlling growth, and the rate and timing of the application. Since GA plays an important role in cell expansion, preventing the plant's production of GA can be detrimental to plant growth. Hence using a high rate of mepiquat chloride at an inappropriate time can reduce yield. In deciding whether mepiquat chloride is needed, it is important to consider causes behind any excessive growth. In assisting these decisions at early flowering, consider information on VGR, field history, fruit retention, irrigation scheduling, current and future weather conditions, and variety.

## Measuring VGR – early flowering

VGR is an effective technique to monitor vegetative growth as it accounts for both the developmental rate of the crop as well as the growth rate. Both need to be considered as increases in plant height can sometimes be associated with production of new nodes which is important for crop development. Also, a measure of increased internode length alone can be a result of excessive growth; however in many instances the time for management actions to reduce growth may have passed. VGR is the rate of change of plant height relative to the rate of node development. The VGR measures the rate of internode increase and is better able to capture situations where crops are moving from optimal to poor conditions, or vice versa. This method can identify the need for canopy management before crops are excessively vegetative. Simple observations of height will not necessarily identify accurate mepiquat chloride response.

$$\text{VGR (cm/node)} = \frac{\textit{This week's height (cm) – Last week's height (cm)}}{\textit{This week's node number – Last week's node number}}$$

Measurements should commence as the crop approaches first flower, normally late November for many regions, and the plant has roughly 12

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Mepiquat chloride manages excessive vegetative growth by shortening internodes and reducing leaf area to restore the balance between reproductive and vegetative growth, as shown here by Sandra Williams, CSIRO.

mainstem nodes. The monitoring should continue during the first half of the flowering period as rapid increases in growth rate can occur at any time in this period. During early flowering, if the VGR is over 5.5 then applying mepiquat chloride should be considered. But before deciding on the timing and the rate, other factors need to be considered (refer to Flow Chart 1).

## Field history/soil type

Knowing how the cotton is likely to grow in each field is important. Some fields have a greater tendency towards rank growth, such as fields with lighter textured soil types that allow better access to nutrition. In these situations, you would expect a positive response from mepiquat chloride application/s, although it is important to monitor these fields to determine the correct application rate and timing.

## Fruit retention

After flowering the cotton plant will naturally become committed to giving more of its resources to the developing bolls. Therefore, a high fruit load may already reduce the tendency of a crop to produce excess vegetative growth, hence reducing the need for mepiquat chloride. Caution should be applied to crops with early high fruit retention (like many Bt cotton crops) as limitations to canopy size early in flowering will impact yield more than crops with lower fruit retention. Crops with larger boll loads will need larger canopies to support the growth of fruit.

## Future stress events

It is important to ensure that crops are not stressed for at least a week after the mepiquat chloride application as additional stresses can substantially limit vegetative growth and thus limit yield. Hot weather and/or water stress are examples. Stress (especially moisture stress) will reduce vegetative growth and production of new fruiting sites, allowing existing fruit on the plant to develop. This may lead to early termination of flowering and a probable yield reduction. In cases of severe stress (water, prolonged period of cloudy weather, or a period of very high temperatures) fruit loss may occur. In these cases, a symptom can be excessive vegetative growth once stress has been removed. Crops should be monitored closely following these events.

Applying mepiquat chloride in anticipation of stress events is not recommended as the growth regulator could add to the stress, or the event may not eventuate, in which case the application may limit vegetative growth needed for continued fruit growth.

## Variety

Research has shown that Australian cotton varieties vary in their yield response to mepiquat chloride. Varieties may differ in the response to mepiquat chloride because of determinacy (ability to regrow), rate of canopy development or fruit production, or because of differences in their architecture. Less responsive varieties may still require mepiquat chloride, so monitoring their VGR and considering other factors remains important.

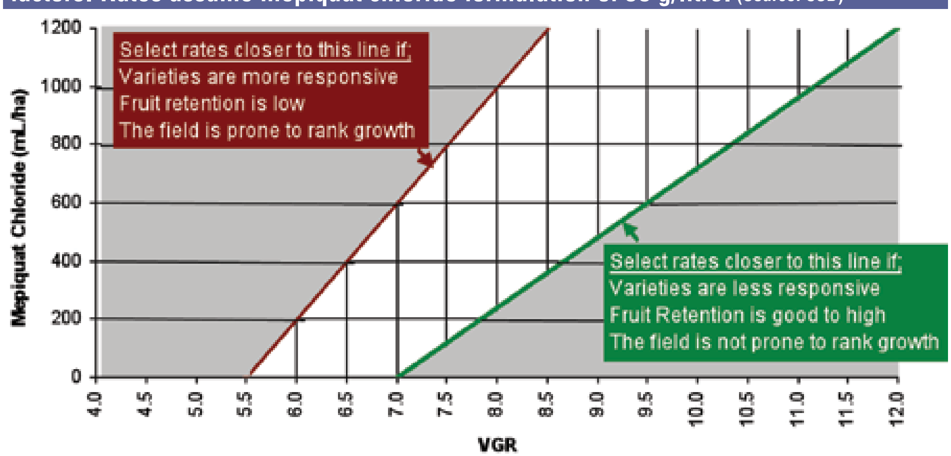
## Rate considerations at early flowering

Figure 2 has been designed to consider all factors when deciding on the rate of mepiquat chloride. The following examples will explain how to use the graph.

**Example one:** A crop has a VGR Measurement of eight, low fruit retention and the field is normally prone to rank growth. Information from the seed company has indicated that the variety is moderately responsive to mepiquat chloride, so using Figure 2 the application rate may be at a higher rate (for example 600–1000 mL/ha).

**Example two:** A crop has a VGR of six, good fruit retention, the field has no history of rank growth and information from the seed company has indicated that the variety is not greatly responsive to mepiquat chloride, therefore using Figure 2 applying mepiquat chloride may not be a benefit, although monitoring should continue.

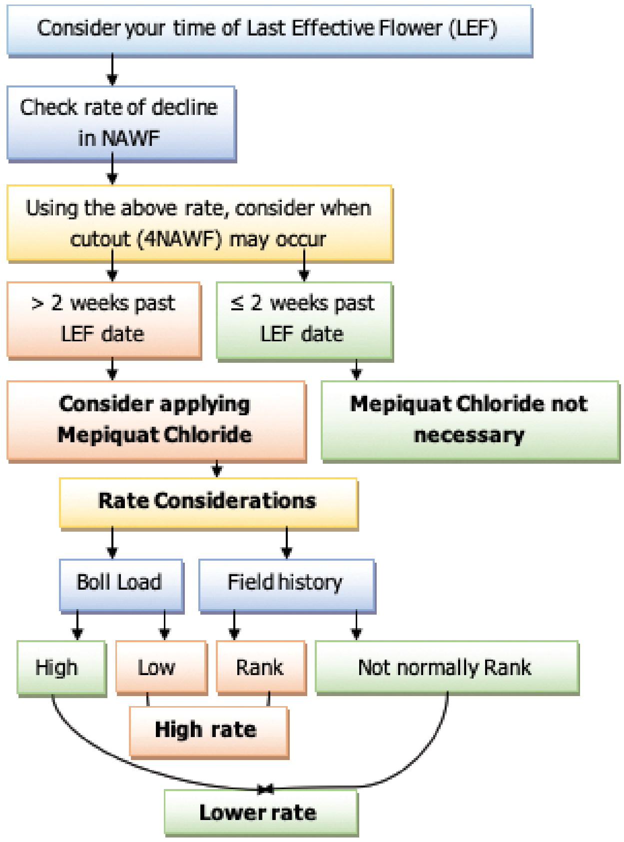
**FIGURE 2:** Mepiquat chloride requirement graph incorporating VGR and other factors. Rates assume mepiquat chloride formulation of 38 g/litre. (Source: CSD)




## Making the decision before cut-out

Given the right conditions, cotton will continue to grow late in the season. This late growth can increase the crop's attractiveness to late season pests and can also increase the number of immature (low quality) bolls at harvest. This is when mepiquat chloride may be considered in order to slow down further vegetative growth. It is also important that if earlier or timely cut-out is to be achieved, water and nutrient management should aim to meet only the requirements of the fruit that will be taken through to harvest.

**FLOW CHART 2:** Cut-out Decision Tree – This cut-out chart is designed to help with late season decisions to apply mepiquat chloride.




Decisions regarding a late application of mepiquat chloride are based on whether the crop is already approaching cut-out at an acceptable pace (refer to Flow Chart 2). These decisions are generally made in late January for most regions or about three weeks before the last effective flower (LEF) date.

## Monitoring NAWF – late season

An effective technique used to assess how quickly cut-out is approaching is monitoring the number of nodes above the most recently opened white flower (NAWF). This measures the position of first position white flowers relative to the plant terminal. The closer a white flower is to the terminal, the less nodes produced since that particular flower was initiated as a new square.

**NAWF:** Count the number of mainstem nodes above the uppermost white flower in the first fruiting position. These counts are typically collected weekly from first flower until cut-out. Also monitor post cut-out to ensure that any regrowth is identified and managed if necessary. In an optimal situation, the NAWF should fall at the rate of one per 55–65 day degrees. Where there is a slow rate of NAWF decline and the forecast cut-out (four NAWF) is beyond the LEF, then applying a cut-out rate of mepiquat chloride should be considered. The NAWF measurements in Figure 3 indicate a normal rate of decline as they reach the last effective flower date at four NAWF. Therefore, in this case, mepiquat chloride application would not have been necessary.

**Useful resources:**

**CottonInfo YouTube video on vegetative growth rate in cotton www.youtube.com/cottoninfoaust**

**www.cottoninfo.com.au and www.mybmp.com.au**

**FIBREpak 2nd Edition (available from www.cottoninfo.com.au)**

**Cothren JT (1995). Use of growth regulators in cotton production. Proceedings of the World Cotton Research Conference – 1: Challenging the future. Brisbane, Australia. Feb 14–17, 1994. GA Constable and NW Forrester (Editors). CSIRO: Melbourne, pp 1–3.**

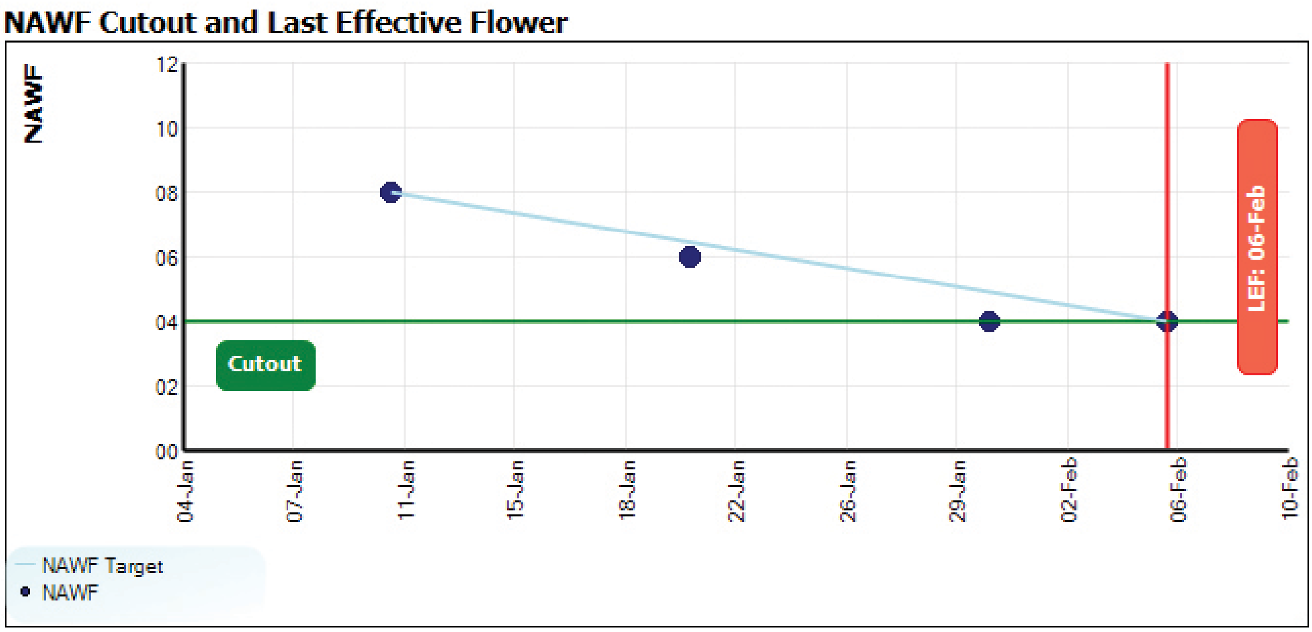
**Constable GA (1995). Predicting yield responses of cotton to growth regulators. Proceedings of the World Cotton Research Conference – 1: Challenging the future. Brisbane, Australia. Feb 14–17, 1994. GA Constable and NW Forrester (Editors). CSIRO: Melbourne, pp 6–24.**

**Kerby, TA (1985). Cotton response to Mepiquat chloride. Agronomy Journal. 77, 515-518. Kerby, TA, Hake, K and Keely, M (1986).**

**Williams SA and Bange MP (2015). Cotton fruiting modification with Mepiquat chloride. Agronomy Journal. 78, 907-912. Reevaluating mepiquat chloride use in Bollgard II. The Australian Cottongrower 36, 16–21.**

**Get the latest information on Australian cotton varieties at www.csd.net.au**

**FIGURE 3:** An example of using the number of nodes above white flower to forecast the timing of cut-out.



# Effective spray application

By **Susan Maas** (CRDC)

**Acknowledgements: Nicola Cottee (NSW EPA), Graeme Tepper (Micro-met Research and Educational Services), Bill Gordon, Mary O'Brien (Mary O'Brien Rural Enterprises)**

## What's new…

**Hazardous surface temperature inversions occur when air temperature increases with height from the ground surface, leaving a layer of cool air trapped below warm air. In this situation, droplets can remain suspended in the inversion layer in concentrated form and be carried significant distances from the target area.**

**A network of 100 Profiling Automatic Weather Stations across some of the grain and cotton regions of NSW and Qld is planned for the 2022/23 summer cropping season.**

**This network will provide a provide a 24-hour forecast (broken into two-hourly segments) of hazardous temperature inversions periods.**

No one wants spray drift. Movement of spray off the target area creates added costs through wastage and exposes non-target sensitive areas to potential damage. Mitigating drift and correct set up (nozzles, tank mix, water rates and ameliorants) and operation (weather condition, speed, pump pressure, boom height) will reduce costs through better efficacy and reduce risk of off-target damage.

## Best practice…

- **Keep comprehensive records.**
- **Establish communication processes for staff, agronomists, spray applicators and neighbours to manage safety and reduce risks.**
- **Give careful consideration is given to selecting and applying pesticides.**
- **Use the correct application equipment and techniques. Have systems to monitor and record suitable weather conditions before and during spraying.**
- **Ensure chemicals are transported, handled and stored appropriately.**
- **Ensure unwanted chemical and chemical containers are disposed of appropriately.**
- **Participate in spray application training and field days to ensure skills and understanding are up to date.**

## Plan ahead

Spray application is complex and planning is important to ensure all necessary factors are considered. The development of a comprehensive Pesticide Application Management Plan (PAMP) prior to the season is an important part of the Best Management Practice (*my*BMP) program for cotton. Having a PAMP in place helps to ensure that everyone involved in pesticide application has a clear understanding of their responsibilities.

***my*BMP Pesticide Management module – https://www.mybmp.com.au/home.aspx**

**Bayer XtendFlex Applicator training videos: Spray Planning – https://youtu.be/HMSz-8DRLPU**

## Understand your legal requirements

Start with the label or permit when handling and applying chemicals. Product labels may specify spray quality, and spray conditions including mandatory wind speed range, and mandatory buffer zones. Applicators must be aware of federal and state regulations for chemical application. All staff responsible for handling and applying pesticides must be qualified according to relevant state and federal requirements. In some states, growers and staff may not require a license under specific circumstances, but participation in training is still encouraged. There may also be workplace health and safety requirements related to storage and use of hazardous chemicals, which require risk assessments to be completed, in addition to maintaining an inventory and Safety Data Sheets for hazardous chemicals. The *Cotton Pest Management Guide* has more information on the legal requirements of pesticide use. The *my*BMP program helps growers understand their legal obligations regarding pesticide application.

## Neighbour communication

It is good practice to discuss cropping intentions with neighbours as well as spray contractors and consultants before seeds go in the ground. Developing a Pesticide Application Management Plan (PAMP) helps identify the farm specific risks associated with pesticide applications and the practices that are to be put in place to minimise the risks. Implementing a PAMP makes everyone involved in a pesticide application aware of their responsibilities. A PAMP has two essential functions:

1. Establishes good communication with everyone involved in the application of pesticides. This communication is required both pre-season and during the season. It should exist between the grower, the applicator, the consultant, farm employees and neighbours, including apiarists.
2. Establishes the application techniques and procedures that are to be used on your farm.

Farm maps that highlight sensitive areas can be useful. Refer to https://satacrop.com.au for sensitive crops near you and to map your cotton crop. BeeConnected can help identify nearby location of hives and facilitate communication between spray applicators and beekeepers (www.beeconnected.org.au).

## Record keeping

It is important that there is enough information recorded to show compliance with all regulatory requirements including those listed on the labels and permits. This should include detailed information about:

- Who applied the pesticide;
- When the pesticide was applied;
- Details of the product/s that were used;
- How much pesticide was used;

# Adapt to your farming

AUSTRALIAN MADE AND OWNED

## The G4 Crop Cruiser self-propelled sprayer, a stable application platform.

3TS nozzle technology gives the operator a larger speed range while maintaining the spray rate. RapidFire ensures quick on / off times and RapidFlow recirculates back to tank.

- 4000L product tank
- 24 to 36m TriTech boom
- RapidFire application technology
- RapidFlow boom recirculation
- TightTurn 5m turning radius
- Massive 1.4m under chassis clearance
- 2-3m wheel track adjustment
- 165hp Cummins engine
- Allison 5 speed transmission
- Hydraulic or manual track width adjustment
- Class leading fuel effiency
- Light tare weight 9.4 tonne*

*3TS RapidFire / RapidFlow (boom recirculation)*

Spraying just became a lot more enjoyable with the G4 Crop Cruiser - Built just down the road.

**TriTech boom**
Unmatched boom suspension system

**Dynamic Drive**
Mechanical direct drive

**Track adjustable**
2-3 wheel track adjustment

GOLDACRES

goldacres G4

*Weight may vary according to sprayer specifications.

- Where the pesticide was applied, location and situation (e.g. crop stage/ fallow), how the pesticide was applied (including equipment used (e.g. nozzle type) and operation (e.g. boom height, speed and spray pressure measured during application);
- Weather conditions during application including any changes; and,
- Other information relevant to risks associated with the use of the product (e.g. buffer zones).

Refer to your relevant state department for specific requirements. Note some labels also have record keeping requirements.

Refer to the *Cotton Pest Management Guide* for further details about legal responsibilities in applying pesticides.

**Useful resources:**

https://www.cottoninfo.com.au/pesticide-input-efficiency

https://www.epa.nsw.gov.au/your-environment/pesticides/compulsory-record-keeping

https://agriculture.vic.gov.au/farm-management/chemicals/keeping-records-of-chemical-use

www.dpi.nsw.gov.au/agriculture/chemicals/farm-chemical-management/records

https://www.commerce.wa.gov.au/publications/working-pesticides-overview

https://nt.gov.au/industry/agriculture/farm-management/using-chemicals-responsibly/keeping-records-of-chemical-use

https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls/using-chemicals/keeping-records

# Product and tank mix

Product choice (the active, mode of action and formulation) is key to efficacy against the target pest, but should also consider risk to sensitive areas such as susceptible crops and vegetation, and beehives and habitats. Be sure to refer to the industry IRMS when selecting products.

Before mixing it is important to check that products and adjuvants are physically and biologically compatible. Products that are not physically compatible can result in undesirable interactions. Correct mixing order reduces the risk of products interacting in a way that reduces their efficacy or stability in the tank mix. Refer to manufacturer information (label, tech notes, product guide) or discuss with your supplier. It is also important to check that the different modes of action will not conflict within the plant and reduce efficacy.

Volatility refers to the likelihood that the herbicide will turn into a vapour. Vapours may arise directly from spray or from the target surface for several hours or even days after application. The risk of vapour drift can be reduced by choosing actives/formulations with low volatility. Products with very low volatility are still susceptible to droplet and particle drift.

Tank mix and adjuvants can change the drift potential and/or volatility of some compounds.

## Suitable water volumes and quality

Water quality is important as water is the largest component of any spray operation and water quality can impact on efficacy and driftability of products. Water testing (pH, total hardness (including bicarbonate levels), total dissolved salts (TDS) and EC should be conducted regularly. Refer to manufacturers for guidelines about tolerances of products to different water quality parameters, as well as suitable products to treat poor quality water.

Application volume is an important consideration in achieving efficacy for all spray jobs. Always follow label recommendations regarding water volumes for application. Volumes required will vary depending on whether the product is a contact or translocated product, and whether the application is in-crop or in-fallow with high or low stubble situations.

**Useful resources:**

**GRDC Spray Mixing Requirements Fact Sheet**
https://grdc.com.au/resources-and-publications/all-publications/factsheets/2019/mixing-requirements-for-spraying-operations

**GRDC Spray water quality fact sheet**
https://grdc.com.au/GRDC-FS-SprayWaterQuality

**Bayer XtendFlex Applicator training videos: The impact of water quality:**
https://youtu.be/3ub5VkvTmL4

# Application timing

Weather conditions are not only a primary determinant of efficacy; they determine whether the spraying operation should proceed, be delayed or be aborted.

## Review forecast conditions and monitor weather throughout spray operation

There are a number of online resources to help with planning and decision making for timing spray application (e.g. www.spraywisedecisions.com.au and www.crop.bayer.com.au/tools/weather-inversion)

It is important that weather conditions including temperature, humidity, wind speed and direction, and surface temperature inversion are regularly monitored during spray applications. This means continual visual observations and actual measurement at least every 20–30 minutes) and recorded. For example, some labels require measurement of weather parameters at the site of application. This can be done with handheld equipment (e.g. Kestrel 3000, 3500, 4000 or equivalent) or portable weather stations. Alternatively, on-board weather stations that provide live weather information while the sprayer is operating (such as the Watchdog system) are available. Do not spray if conditions are not suitable.

## Temperature and humidity

For some products, efficacy can be affected when plants are stressed due to high temperatures. Higher ambient air temperatures and lower relative humidity conditions can also increase evaporation rates. Since droplet size of water-based sprays decreases rapidly with higher evaporation rates, driftable fines can increase. Spraying is best conducted when the delta T (the difference between the wet bulb and dry bulb) is more than 2 and less than 10°C, however this is a guide only. When using coarse sprays at high water volume rates, evaporation may be less significant, which may allow some applications to continue into marginal delta T conditions (where soil moisture exists, and the targets are not in a stressed condition).

**Useful resources:**

**Tips for reducing drift fact sheet** www.grdc.com.au/GRDC-FS-SprayPracticalTips

# Surface temperature inversion

**DANGER – DO NOT spray when a hazardous surface temperature inversion exists.**

Hazardous surface temperature inversions occur when air temperature increases with height from the ground surface, leaving a layer of cool air trapped below warm air. In this situation droplets can remain suspended in the inversion layer in concentrated form and be carried significant distances from the target area (refer to Figure 1 and Figure 2). Surface temperature inversions are often associated with calm, low wind conditions, dust remaining suspended, fog or mist forming in low areas and sounds travelling long distances. All these signs indicate the risk of inversion drift is significantly high. Applicators should anticipate that a surface temperature inversion will be present every night before sunset and shortly after sunrise, unless there is heavy low-level cloud, it is raining or the wind speed remains above 11 km/h for the entire evening.

The Grains Research and Development Corporation (GRDC) and CRDC are working in partnership with Goanna Ag to develop a spray drift hazardous weather warning system that will provide real-time weather data and alerts to growers and spray operators about the presence of temperature inversions. Goanna Ag will establish, operate and maintain a network of 100 Profiling Automatic Weather Stations (PAWS) across the grain and cotton regions of NSW, southern and central QLD. The PAWS have remote sensing capability and new proprietary software to provide growers and spray contractors real-time weather data every 10 minutes. Being able to accurately identify the presence of hazardous temperature inversions will reduce the spray drift risk for growers and spray contractors. Currently, regulations do not permit spraying agricultural chemicals when hazardous surface temperature inversions are present.

The network will provide a 24-hour forecast, broken into two-hourly segments, of hazardous temperature inversions periods, significantly helping growers and spray contractors to plan the logistics of spray operations. For more information go to www.goannaag.com.au/spray-inversion-network

### Wind

It is important to apply pesticides when the wind is blowing away from sensitive areas and crops. Wind speed must be steady between 3 km/hr and 15 km/hr during daylight hours, and above 11 km/h at night. Avoid calm, variable or gusty wind. If the wind speed drops at night– stop spraying immediately (see inversions). Be aware of local topographic and convective influences on wind speed and direction. Always read the label to see if a mandatory wind speed requirement exists, or if a mandatory downwind buffer zone is required.

**Useful resource:**

**GRDC spray drift hub**
**www.grdc.com.au/resources-and-publications/resources/spray-drift**

**Bayer XtendFlex Applicator training videos: Environmental considerations**
**https://youtu.be/WRuxK0o9wHY**

## Droplet size, nozzle choice and pressure

### Nozzle selection and droplet size

Nozzle selection should be based on flow rate, spray quality, fan angle and nozzle type. Spray quality refers to the standard range of droplet sizes produced by a nozzle at a particular pressure (ASABE standard 572.1).

These are extremely fine, very fine, fine, medium, coarse, very coarse, extremely coarse and ultra-coarse. Select the nozzle producing the coarsest spray quality without compromising efficacy. Fan angle determines the width of the spray pattern. It is important to set the height of the boom

**It is important to set the height of the boom at the minimum practical height from the target to achieve the correct spray pattern for the nozzles.**

**FIGURE 1: Air movement under a surface temperature inversion differs from a typical wind profile (left). Surface winds de-couple from the surface, accelerate and flow over the inversion. Within the inversion, winds are typically light and often drain down slope, regardless of the overlying wind direction. Under an inversion the shape of the landscape also influences the direction in which airborne droplets will move (right).** (Source: Graeme Tepper)

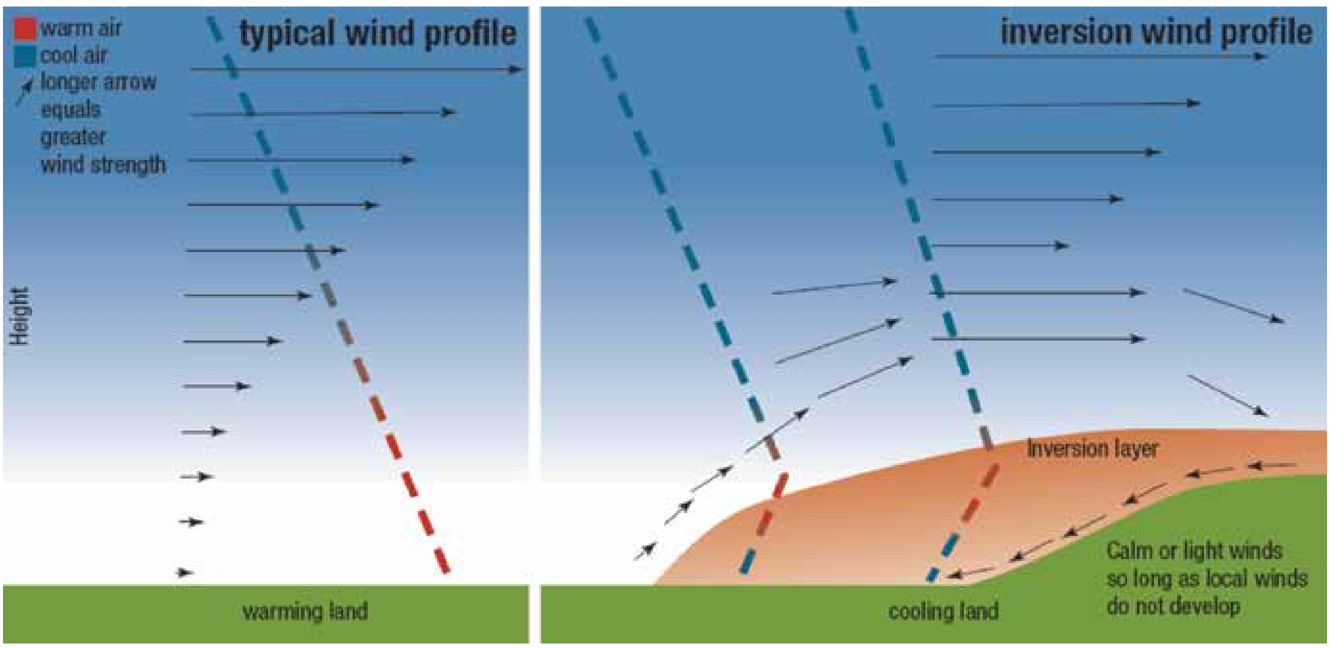
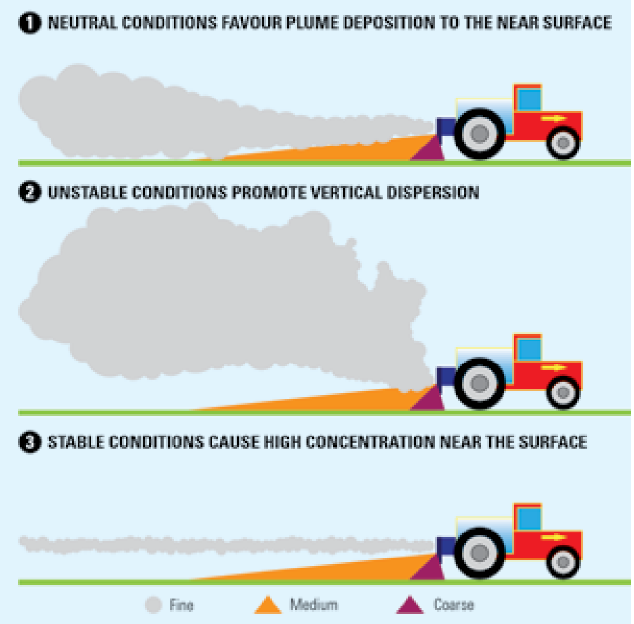


**FIGURE 2:** Three common states of atmospheric stability and their relationship to spray application.




**Source:** GRDC Weather Essentials for Pesticide Application Booklet, 2017; author: Graeme Tepper.

at the minimum practical height to achieve the correct spray pattern for the nozzles. Pulse width modulation (PWM) is a spraying system where the flow rate is controlled by a pulsing solenoid at each nozzle, unlike a standard spray system that directly controls the overall flow rate. Many PWM sprayers are operating with nozzles that are too big, compromising coverage when slowing down and operating at low duty cycles.

**For more information refer:**

**GRDC Nozzle Selection for Boom, Band and Shielded Spraying: The Back Pocket Guide**

**https://grdc.com.au/GRDC-BPG-NozzleSelection**

**Pulse width modulation sprayers: what we have learnt, correct operation and looking ahead**

**https://grdc.com.au/resources-and-publications/all-publications/publications/2019/pulse-width-modulation-sprayers**

**Nozzle selection guides for standard and pulse modulation:**

**https://grdc.com.au/PulseModulationNozzleSelectionGuide**

**https://grdc.com.au/resources-and-publications/all-publications/publications/2019/grdc-nozzle-selection-guide**

**Information on nozzle selection tools:**

**Teejet Nozzle Selection App**

**Hardi Nozzle App**

**Bayer XtendFlex Applicator training videos:**
**Nozzle selection https://youtu.be/UZ4Es3rU5B4**

### Using adjuvants to manipulate droplet size

Many adjuvants, especially non-ionic surfactants (wetter 1000 products) can increase spray drift potential by increasing the number of small droplets produced. Other adjuvants such as oils, Dead Sure® and LI700® may reduce drift potential when used with certain products at recommended rates and with appropriate nozzles. Care should be taken when selecting adjuvants intended for drift reduction to ensure that there is a decrease in small driftable droplets (less than 100–200 µm), and not just an increase in the average droplet size (or volume median diameter (VMD)). When considering adjuvants, compatibility with the tank mix and spraying system should also be considered, since some adjuvants do not perform as well when combined.

### Pressure at the nozzle

Never operate nozzles outside of the pressure range recommended by the manufacturer. Higher or lower than recommended pressures change the droplet spectrum and the spray pattern, affecting both the risk of drift and the efficacy of the spray application. Always assess the spray pattern and spray quality information (droplet size) at various pressures to determine an appropriate minimum operating pressure. Where automatic rate controllers are fitted to the machine, carefully consider the true range of speeds the machine is likely to operate, from the slowest field to the fastest field. Identify what the pressure at the nozzle will be at your lowest speed and your fastest speed and identify a nozzle that will produce the required spray quality across that range of speeds. Operating at recommended pressures can also minimise wear and tear on nozzles.

**Useful resources:**

**For more information refer to GRDC's documents:**

**Nozzle Selection for Boom, Band and Shielded Spraying: The Back Pocket Guide**

**https://grdc.com.au/GRDC-BPG-NozzleSelection**

## Boom height

### Setting appropriate spray release height

The amount of spray chemical left in the air may increase by up to 8 to 10 times as nozzle height increases from 50 cm above the target to 1 m above the target. It is important to set the height of the boom at the minimum practical height to achieve the correct spray pattern for the nozzles. Minimise vertical movement (boom bounce) of the spray boom should be minimised. Vertical movement can be limited by tuning the boom suspension and matching travel speed to release height. Alternatively, consider fitting auto boom height.

Auto boom height devices use ultrasonic sensors to detect the height of the boom above the target. These adjust the boom hydraulically to maintain the nozzles at a constant height above the target. These systems will require a machine with good hydraulic capacity, but allow the machine to maintain boom height at higher travel speeds.

**Useful resources:**

**GRDC Spray Manual – https://grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual**

## Application speed

### Travel speed for ground rigs

Speeds above 15 km/h have been shown to increase the risk of drift for boom spraying; and speeds above 10 km/h increase the risk when using shielded sprayers. Higher speeds reduce deposition of spray droplets in the wheel track and behind stubble, and also increase the drift potential due to droplets being drawn into the machine's wake. When considering operating at higher travel speeds, greater attention must be paid to the potential risk of spray drift and ways of reducing that risk, such as nozzle selection. Avoid spraying over 21 km/hr.

## Maintenance and hygiene

### Calibration – replace worn nozzles

The output of each nozzle should be checked pre-season and regularly during the season. Replace nozzles that vary more than 10% from the manufacturer's specifications. Regularly check wheel sensors and flow meters for accuracy, check pressure across the boom for evenness and monitor total volumes against areas on your GPS logs to indicate when things may have changed since your last calibration.

## Decontamination

Application equipment that has been used to apply herbicides should be thoroughly decontaminated before being used to apply any product to a susceptible crop. Select a suitable area for the wash down and cleaning process and use appropriate personal protective equipment (PPE). Strictly follow the method of decontamination recommended on the label or by the manufacturer. No matter how much time is spent decontaminating the equipment there is always a risk of herbicide residues causing a problem.

**Resources:**

**Bayer XtendFlex Applicator training videos: The importance of a clean sprayer https://youtu.be/iPCLHPCqr0Q**

# Optical sprayers

Optical sprayers such as Weedseeker and WEEDit can reduce the amount of product applied and so have the potential for less particles to be in the air. It is still important that the principles of good spray application are applied, including ensuring all label/permit conditions are followed, ensuring conditions are appropriate and that equipment set up correctly.

# Calculating banded sprays

Banded sprays allow you to place the recommended rate of the product onto an area smaller than the whole field. This uses less chemical overall, but still applies the equivalent rate per hectare to the target. There are often big differences between the consultant's recommendation, the applicator's instincts and what the machine can do with the nozzles available.

Commonly asked questions are:

- What is the actual application rate?
- How much chemical to put in the tank?
- How many paddock hectares can be treated with each tank load?
- What rate to put in the spray controller?
- What nozzles will achieve the required application rate?

To determine the true application rate we need to know the sprayed width, or average sprayed width, for each nozzle. This allows us to calculate the litres per sprayed per ha. Label rates are always given as L/sprayed ha. Advisors should always give recommendations as L/sprayed ha. To apply the correct L/sprayed ha there are two main things to work out:

- **How much chemical to put in the tank,** which is based on L/sprayed ha.
- **What to put into a controller,** which is based on paddock ha per tank.

## Calculations

### Application rate

You need to know:

Band width in metres: **e.g. 0.7 m band** ÷ 1 m row spacing = band width (m) ÷ row spacing (m).

Sprayed width per nozzle (m): = **band width (m) ÷ number nozzles per band** (e.g. 3 nozzles per 70% band of a 1 m row = 0.7 m ÷ 3 = 0.23 m)

Calculate:

| |
|---|
| The application rate =<br>**L/sprayed ha = L/min/nozzle x 600 ÷ speed (km/h) ÷ sprayed width per nozzle (m).** |

L/sprayed ha applies to each band (row), whether you spray 1 band (row), or many rows, whether it is a solid plant, single skip or double skip.

### How much chemical per tank

You need to know:

Number of sprayed ha per tank = **Tank size (L) ÷ L/sprayed ha.**

Calculate:

| |
|---|
| Amount of chemical to add per tank =<br>**Sprayed ha per tank x chemical rate/ha.** |

### Paddock hectares per tank

Calculate:

| |
|---|
| Paddock ha per tank (solid plant): =<br>**Sprayed ha per tank ÷ band width (m)**. |

For skip row configuration, you need to calculate an adjusted band width:

Adjusted band width (m) = **band width (m) x width of boom ÷ row width (m) ÷ number of planted rows under the boom.**

Calculate:

| |
|---|
| Paddock ha per tank (skip) =<br>**Sprayed ha per tank ÷ the band width (m) x width of boom ÷ row width (m) ÷ number of planted rows under the boom.** |

### Rate to put in the Controller

Calculate:

| |
|---|
| Rate to put in the Controller: = **Tank Size (L) ÷ Paddock ha per tank*.** |

***This works if you don't want to change the section widths in the controller.**

## Nozzle selection

To select the correct spray nozzle, you need to calculate the required flow rate of each nozzle (L/min). This is simple if all nozzles are the same size, as the flow rate will be the same for each nozzle.

You need to know:

The average sprayed width per nozzle:

e.g. For 5 nozzles per 1 m row at 100% band: **1 m ÷ 5 = 0.2 m**

For 4 nozzles per 1 m row and a 70% band: **0.7 m ÷ 4 = 0.17 m**

Calculate:

| |
|---|
| Required flow rate per nozzle<br>**L/min/nozzle = L/sprayed ha ÷ 600 x speed (km/h) x average sprayed width per nozzle (m).** |

Always remember to check the spray quality produced to ensure it is consistent with what is required by the product label.

**Useful resources:**

- **The *my*BMP Pesticide application module, www.mybmp.com.au**
- **NuFarm Australia Ltd: 03 9282 1000, www.nufarm.com.au**
- **Cotton Pest Management Guide, www.cottoninfo.com.au**
- **GRDC fact sheets on:**
  - **Spray Mixing Requirements**
  - **Spray Water Quality**
  - **Pre-season check and Controller Settings**
- **Information on weather:**
  - **Weather essentials for pesticide application, Graeme Tepper, GRDC.**
  - **GRDC Fact Sheet on Weather Monitoring Equipment**
- **Information on weather forecasting tools:**
  - **www.spraywisedecisions.com.au**
- **Information on pesticide application:**
  - **Spraywise Broadacre Application Handbook, Dr Jorg Kitt, Nufarm Australia**
- **Information on nozzle selection tools:**
  - **Teejet Nozzle Selection App**
  - **Hardi Nozzle App**

**Web link www.grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual**

## Selecting a contract spray applicator

It is important to ensure that any aerial, ground and drone spray contractors have the appropriate training and license as required in your state. Professional accreditation programs provide additional confidence that contract spray applicators are committed to best practice.

- Operation Spray Safe is an Aerial Application Association of Australia (AAAA) initiative which aims for continuing improvement and professionalism in the application of agricultural chemicals by aircraft. More information can be found at www.aaaa.org.au/spraysafe/
- SprayPASS, developed by the Australian Groundsprayers' Association, is a national, industry-led stewardship program promoting and supporting the safe and sustainable application of pesticides in Australia, by delivering professional development and certification for groundsprayers. https://www.spraypass.org.au/

## Update your skills and knowledge

Scientific and legal requirements for spray application continue to change and are complex. All growers, farm staff, contractors and advisors are encouraged to continue to stay up to date with new information and best practice. In addition to state mandated training, there are numerous opportunities for spray application training and workshops such as the Bayer XtendFlex Cotton Spray Applicator Training Sessions. CottonInfo can help connect you with spray application training and extension activities or to link to regional groups, such as Stop Off-target Spraying (SOS) in your local region (https://sos-nsw.com).

**Useful resources:**

**Summary of spray application best practice (Source: CSD):**

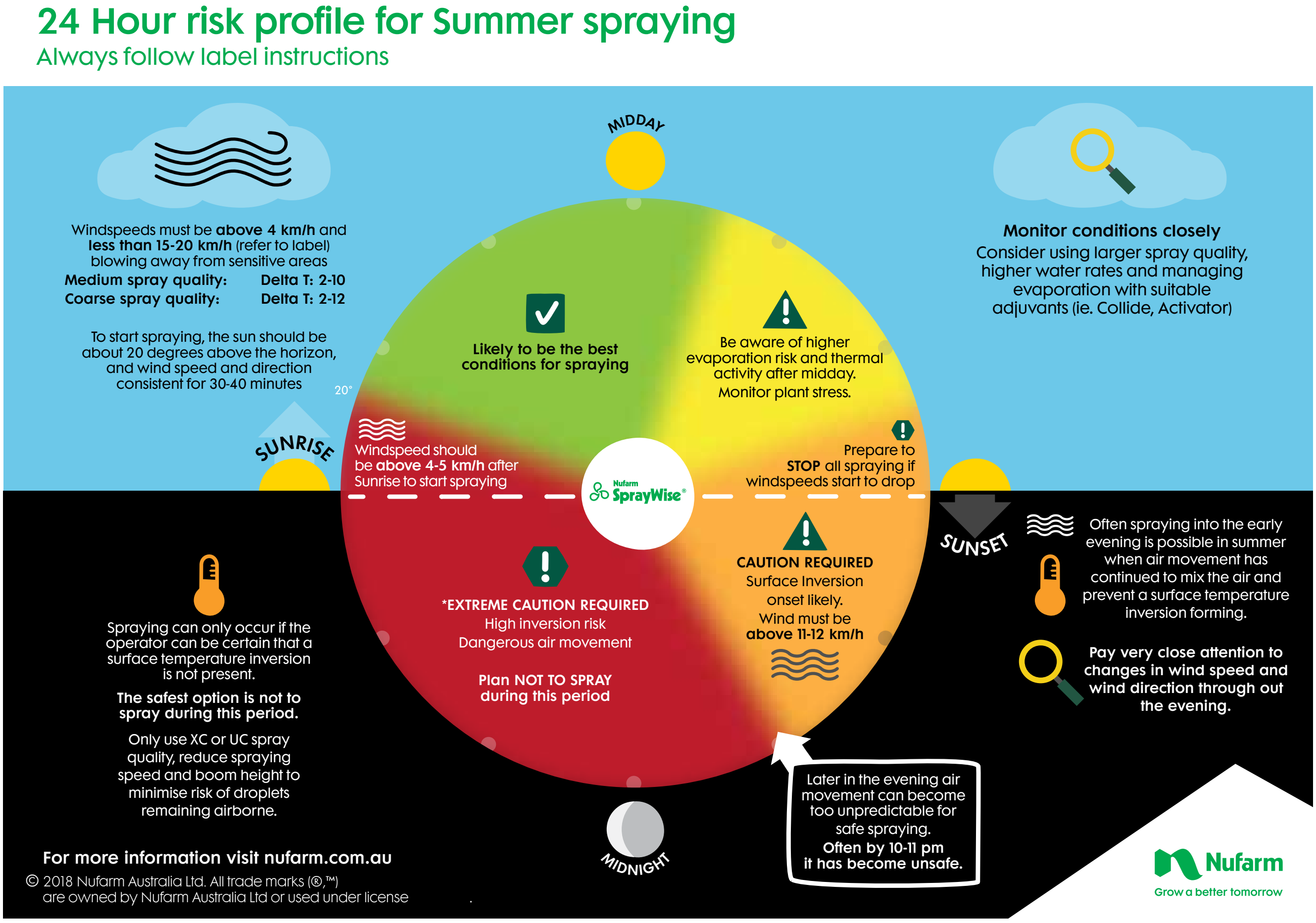
***my*BMP Pesticide Application module www.mybmp.com.au**

**GRDC Spray Application GrowNotes™ manual https://grdc.com.au/spray-application-manual**

**CottonInfo have a number of pesticide and application videos www.youtube.com/cottoninfoaust**

**For more information about using vegetative barriers in spray drift management, see CottonInfo NRM/Pesticide Input Efficiency fact sheet – Using vegetative barriers to minimise spray drift on cotton farms www.cottoninfo.com.au/publications/nrmpesticide-input-efficiency-usingvegetative-barriers-minimise-spray-drift-cotton**

**FIGURE 3:** 24 hour risk profile for summer spraying developed by Nufarm.



# Case study:

## Careful approach leads to good outcomes at Delungra

By **Brad Pfeffer** (CottonInfo)

The area around Delungra is different to a lot of cotton country. The dryland farming area has large rolling hills, generally cooler temperatures than the Gwydir Valley to its west, and also a slightly higher than average rainfall than its western neighbour.

Being dryland, production is strongly linked to seasonal conditions, making cotton one of many crops grown in the district. Production can vary significantly each year. In 2021–22 the region grew a relatively large cotton area at over 1500 hectares, but the district also commonly has sunflowers, soybeans, mungbeans, along with sorghum and plenty of grazing country.

For all these reasons, grower Charles Boileau is extra careful in how he approaches spray management at his property, "Bella".

Charles has been farming near Delungra for the last five years, having previously grown irrigated cotton near Gunnedah.

The 21/22 season was his third cotton crop at "Bella" and he said that some aspects of the farming system had been a learning curve, including making sure he understood the local conditions when spraying.

"The conditions for spraying can be harder to manage than on the plains country," he said. "At the bottom of a hill the wind can be blowing one direction and then it might be completely stopped at the top of the hill or moving in a slightly different direction.

"This country gets changes in wind direction and swirling around the ridges, and we still get inversions like anywhere else."

It's an extra reason for caution every time the spray rig comes out of the shed. Charles follows a few simple strategies to make sure the herbicide is going exactly where it needs to go.

"We have our own self-propelled sprayer with air-inducted nozzles and we use ultra-coarse to very-coarse droplets," he said.

He limits speed to 15 km/hour. Anything faster and there is too much turbulence, particularly if he hits an occasional stone in the paddock, jostling the boom, and as the rig goes over large and rolling contour banks on the farm.

He also has a smoker on the spray rig to assess wind direction and speed. If conditions are not correct, then he doesn't start. If conditions become unsuitable, he stops.

He added that this was one of the benefits of having his own spray rig, as it allowed him to wait until conditions were right, which has been handy when growing adjacent cotton and sorghum.

"We sprayed Starane® in the sorghum this season and had no issues. It was a matter of working to the right wind conditions."

Also on the topic of spraying, Charles is also very supportive of efforts right across the industry to use diversified weed management tactics and avoid herbicide resistance in weeds.

He is mindful to make sure fleabane does not become a major problem at the property and uses persistent strategies including the use of double knock-downs and residuals.

Typically, he would apply a residual herbicide in autumn or early winter. Ahead of the 21/22 cotton, he sprayed Roundup® and Valor®. After planting, he applied Terbyne®, Dual® and Gramoxone®.

"That gave us a good clean start to the crop," he said. "With fairly heavy wheat straw, we had the odd fleabane that escaped the residual herbicide, but it has been quite clean overall. Being timely with the application allows us to not have to use the higher rates, which helps reduce costs in spraying."

**Delungra dryland grower Charles Boileau with the 2021–22 crop, pictured on January 20.**

# Connecting with **CottonInfo** for **new growers**

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Our team of regional extension officers, technical leads and myBMP experts can help with information on nutrition, soil health, water management, pesticide efficiency, energy, carbon, biosecurity, disease and insect management, natural resource management, stewardship and weed control.

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**3.** Come along to an upcoming industry event in your area to connect with other growers, researchers, industry bodies and the CottonInfo team.

Chapter 19 sponsored by – Tama

# Managing for fibre quality

By **Michael Bange** (Cotton Seed Distributors)

**Acknowledgements: Rene van der Sluijs (TTS), Greg Constable (retired), Sandra Williams, Stuart Gordon, Robert Long and Geoff Naylor (CSIRO)**

## Importance of quality fibre

Australian cotton holds a reputation of being purchased for a premium and the consequences of producing poor fibre quality are substantial (see Table 1). To maintain fibre quality, it is important to understand the nature of fibre and the interacting factors that affect its quality. Optimising fibre quality starts with good crop management and selecting the right variety. See Table 1 Capter 7 for information on variety-specific fibre characteristics.

## Crop management for improved fibre quality

Most crop management factors that increase/optimise yield also optimise fibre quality. One exception may be instances of high yielding crops with undesirable high micronaire cotton. Fibre length and micronaire are significantly affected by agronomic and climate effects, but fibre strength is more influenced by variety choice. Fibre growth and development is affected by most factors which influence plant growth. Since the fibre is primarily cellulose, any influence on plant photosynthesis and production of carbohydrate will have a similar influence on fibre growth. Cell expansion during growth is strongly driven by turgor (the pressure of fluid in the plant cell), so plant-water relations will also affect fibre elongation early in the flowering period. Thus in terms of primary responses, water status (irrigation) strongly influences fibre growth and ultimately final fibre length. Fibre elongation will also be affected by temperature and carbohydrate limitations.

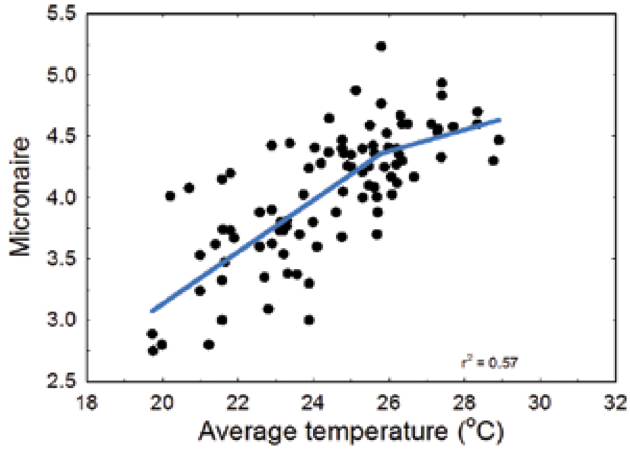
Within this manual, fibre elongation refers specifically to the elongation of a fibre in length during its growth. In terms of fibre quality characteristics, fibre elongation also refers to the elongation in a fibre before it breaks in a strength test. Fibre thickening is also affected by temperature and radiation effects on photosynthesis. Large reductions in fibre thickening can occur following long periods of low temperatures or cloudy weather, leading to low fibre micronaire.

Data from sowing time experiments in a range of locations over the past three decades have shown that sustained changes in temperature during fibre thickening can lead to explained differences in micronaire. Figure 1 shows the relationship of average temperature during the phase when most bolls have their fibres thickening to influence micronaire. Recent research is showing that the effects of growing conditions during boll filling are the predominant factor on micronaire (reflected mostly in the size of bolls).

### Best practice...

**The key management considerations for optimising fibre quality are variety selection and avoiding crop stress. So good water and fertiliser management is critical. Producing poor quality fibre can lead to significant price discounts.**

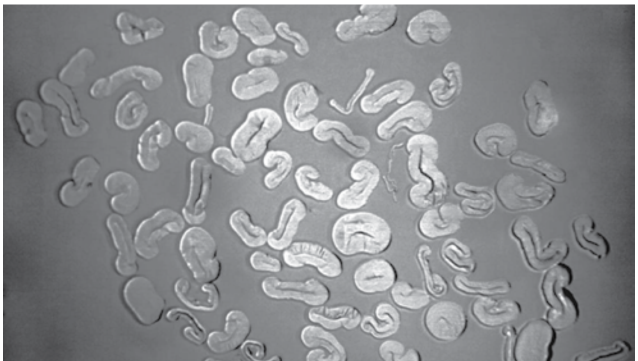
**FIGURE 1: The response of micronaire to daily average temperature during fibre thickening taken from planting time studies. Varieties used in this study had an average micronaire of 4.05 generated at an average daily temperature of 24.4°C.**
(Adapted from Luo, Bange and Johnston (2014))




Leaf area around flowering is also having an impact (lower leaf area = lower micronaire), but the effect is less when growing conditions during boll development are improved.

Potassium deficiency can have a significant impact on fibre length because of the role of potassium in maintenance of cell turgor by osmotic regulation. Other nutrient deficiencies can also reduce fibre length. But where nutrient deficiencies are not the major factor in a production system, nitrogen or potassium fertiliser treatments will not necessarily improve fibre length. Early crop defoliation or leaf removal can cause substantial reductions in fibre micronaire due to the cessation in carbohydrate supply for fibre thickening. Few agronomic or climatic conditions have been shown to consistently affect fibre bundle strength as strength is mainly determined by variety. Severe weed competition in cotton can have strong effects on fibre properties as well as contribute to trash contamination.

Cotton's indeterminate growth habit also leads to many secondary (indirect) impacts of climate and management on fibre properties. Any management which delays crop maturity can lead to reduced micronaire due to exposure of a greater proportion of a crop to unfavourable conditions such as cooler or cloudy weather. Early stress with subsequent recovery, excess nitrogen, and insect damage causing compensation with later fruit production are examples.



**Cross section of a cotton yarn showing the packing and interaction of individual fibres (78 individual fibres are distinguishable). Changes in micronaire affect how many fibres make up the cross section of the yarn, affecting its strength.**
(Photo: CSIRO)

Therefore, adoption of appropriate and efficient management (both strategic and tactical) for improving yield will also contribute to improved fibre quality and textile outcomes (Figure 2). The issues to consider for each crop management phase are summarised in Table 2.

**For more information the following resources and tools are available at www.cottoninfo.com.au and www.mybmp.com.au**

**FIBREpak 2nd Edition (available from www.cottoninfo.com.au)**

**Bange, M.P., Longe, R.L., Caton, S.J., and Finger, N. (2021). Prediction of upland cotton micronaire accounting for the effects of environment and crop demand from fruit growth. Crop Science. https://DOI: 10.1002/csc2.20679**

**TABLE 1: Consequences of poor fibre quality.**

| Fibre trait | Trait description | Ideal range | Consequences of poor fibre quality (cotton price) | Consequences of poor fibre quality (spinning) |
|---|---|---|---|---|
| Length | Fibre length varies with variety. Length and length distribution are also affected by stress during fibre development, and mechanical processes at and after harvest. | Upper half mean length (UHML) in excess of 1.125 inch or 36/32nds. For premium fibre 1.250 or 40/32nds. | Premiums can be gained for long staple length. Significant price discounts below 33/32nds. | Fibre length determines the settings of spinning machines. Longer fibres can be spun at higher processing speeds and allow for lower twist levels and increased yarn strength. |
| Short fibre content | Short fibre content (SFC) is the proportion by weight of fibre shorter than 0.5 inch or 12.7 mm. | <8% | No premiums or discounts apply. | The presence of short fibre in cotton causes increases in processing waste, fly generation and uneven and weaker yarns. |
| Uniformity | Length uniformity or uniformity index (UI), is the ratio between the mean length and the UHML expressed as a percentage. | >80% | Small price discounts at values less than 78. No premiums apply. | Variations in length can lead to an increase in waste, deterioration in processing performance and yarn quality. |
| Micronaire | Micronaire is a combination of fibre linear density and fibre maturity. The test measures the resistance offered by a weighed plug of fibres in a chamber of fixed volume to a metered airflow. | Micronaire values between 3.8 and 4.5 are desirable. Maturity ratio >0.85 and linear density <220 mtex. Premium range is considered to be 3.8 to 4.2. (linear density <180 mtex) | Significant price discounts below 3.5 and above 5.0. | Linear density determines the number of fibres needed in a yarn cross-section, and hence the yarn count that can be spun. Cotton with a low micronaire may have immature fibre. High micronaire is considered coarse (high linear density) and provides fewer fibres in cross section. |
| Strength | The strength of cotton fibres is usually defined as the breaking force required for a bundle of fibres of a given weight and fineness. | >29 grams/tex, small premiums for values above 29 grams/tex. For premium fibre >34 grams/tex. | Discounts appear for values below 27 grams/tex. | The ability of cotton to withstand tensile force is fundamentally important in spinning. Yarn and fabric strength correlates with fibre strength. |
| Grade | Grade describes the colour and 'preparation' of cotton. Under this system colour has traditionally been related to physical cotton standards although it is now measured with a colorimeter. | >MID 31, small premiums for good grades. | Small premiums for good grades. Significant discounts for poor grades. | Aside from cases of severe staining, the colour of cotton and the level of 'preparation' have no direct bearing on processing ability. Significant differences in colour can lead to dyeing problems. |
| Trash/dust (leaf grade) | Trash refers to plant parts incorporated during harvest, which are then broken down into smaller pieces during ginning. | Low trash levels of <5%. Less than or equal to leaf grade 3. | High levels of trash and the occurrence of grass and bark incur large price discounts. | Whilst large trash particles are easily removed in the spinning mill, too much trash results in increased waste. High dust levels affect open end spinning efficiency and product quality. Bark and grass are difficult to separate from cotton fibre in the mill because of their fibrous nature. |
| Stickiness | Contamination of cotton from silverleaf whitefly, cotton aphid, or solenopsis mealybug. | Low/none | High levels of stickiness incur significant price discounts and can lead to rejection by the buyer. | Sugar contamination leads to the buildup of sticky residues on harvest, ginning and textile machinery, which affects yarn evenness and results in processing stoppages. |
| Seed coat fragments | In dry crop conditions seed coat fragments may contribute to the formation of a (seed coat) nep. | Low/none | Moderate price discounts. | Seed coat fragments are difficult to remove as they are attached to the fibre and do not absorb dye and appear as brown 'flecks' on finished fabrics. |
| Neps | Neps are fibre entanglements that have a hard central knot. Harvesting and ginning affect the amount of nep. | <250 neps/gram. For premium fibre <200 | Moderate price discounts. | Neps typically absorb less dye and reflect light differently and appear as 'flecks' on finished fabrics. |
| Contamination | Contamination of cotton by foreign materials such as woven plastic, plastic film, jute/hessian, leaves, feathers, paper leather, sand, dust, rust, metal, grease and oil, rubber and tar. | Low/none | A reputation for contamination has a negative impact on price, sales and future exports. | Contamination can lead to the downgrading of yarn, fabric or garments to second quality or even the total rejection of an entire batch. |


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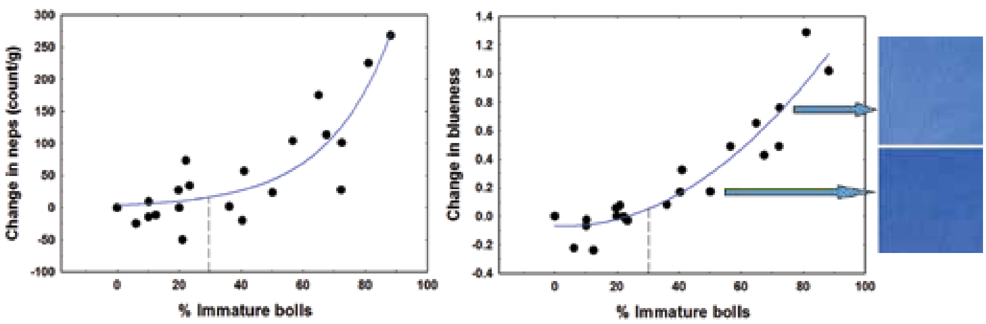
**TABLE 2: Key in-field management considerations for optimising fibre quality.**

| Objectives | Pre planting | Sowing to first flower | First flower to open boll | Open boll to harvest | Harvest to gin |
|---|---|---|---|---|---|
| Realising the genetic potential for fibre length | Variety selection. Strategic planning for irrigation availability. Consider skip row for dryland. | Monitor soil moisture and schedule irrigation to optimise plant vegetative size. | Monitor soil moisture. Schedule irrigation to optimise plant vegetative size and to avoid stress on developing fibres. | Minimise immature bolls at defoliation by applying harvest aids at appropriate time. | Avoid delayed harvest and end of season rainfall. |
| Maintaining fibre strength | Variety selection. | | Maintain healthy crop. | | |
| Producing fibre with mid-range micronaire to avoid fibres that have too high linear density or are immature | Variety selection. | Monitor soil moisture and schedule irrigation to optimise plant vegetative size. Sow at appropriate date for the region to avoid early crops in hot areas or late crops in cool areas. | Management of plant vegetative size, structure and balance with boll setting pattern. Uniform boll set is achieved by having the appropriate plant type for the variety, region and climate. Optimise agronomic management such as water, fertliser and growth regulators. Adopt IPM to protect fruit and leaves. | Timely harvest to avoid bad weather. Use appropriate nitrogen fertiliser rates to match crop requirements and assist cut-out. Schedule last irrigation to leave soil at refill point at defoliation. Use appropriate timing, product and rate for defoliation. | |
| Reducing the incidence of neps | Variety selection. | | Optimise timing of cut-out to match season length to avoid significant amounts of immature open bolls at harvest. | Begin harvest aid application at 60% open bolls to avoid immature bolls at harvest. | Maintain spindles and doffers daily. Reduce spindle twist by not picking too wet. |
| Delivering clean white cotton with no stickiness | Weed management. | Weed management. | Avoid use of broad-spectrum pesticides to conserve beneficial insect populations. | Fertiliser, irrigation and defoliant management as above. Refer to IPM guidelines for aphid, mealybug and whitefly management. Consider defoliating earlier if crop shows signs of maturing rapidly. | Harvest with moisture levels of ≤12%, ensure that the harvester is setup according to the operators manual and that regular cleaning and servicing of the harvester is conducted before, during and after harvesting has been completed. |
| Preventing contamination | Farm hygiene to avoid contamination during harvest. Weed management. | Weed management. | | Employ Come Clean Go Clean practices and where practical remove plastic and other contaminating debris from the field prior to harvest. | Farm hygiene, all workers should be made aware of the consequences of contamination. Care taken when transporting and staging modules to prevent damage to the module wrap. |

**FIGURE 2: Impact of the time of defoliation on neps and fabric bluenesss related to the immature bolls at defoliation. Defoliation with more than 29% immature bolls increases the risk of neps and lowers the ability of fabric to take up dye.** **(Adapted from Long and Bange 2011)**



# Harvest & post-harvest

# Preparing for harvest

By **Michael Bange** (Cotton Seed Distributors)

**Acknowledgements: Rene van der Sluijs (TTS), Sandra Williams, Greg Constable (retired), Stuart Gordon, Rob Long and Geoff Naylor (CSIRO)**

## Timely and effective cut-out

Cut-out is when the crop stops producing new fruiting sites. Later timing of cut-out must consider opportunity for further fruit production (yield) and potential losses in fibre quality and harvesting difficulties. The cut-out date should aim to optimise yield and quality, allowing squares and bolls on the plant to mature and open, enabling harvest before cool or wet weather.

### Management tips

During flowering, monitor cut-out at least weekly using the nodes above white flower (NAWF) technique. NAWF = four to five is generally the accepted time of cut-out. Crops approaching cut-out too rapidly are stressed (either not enough water or nutrition or carrying a very high fruit load). Use a strategy to provide new growth such as more frequent irrigation or increased nutrition. To time cut-out appropriately consider how much time is left in the season. This can be done by estimating the date of the last effective flower (see Table 1). Crops approaching cut-out too slowly can indicate that there has been a loss of fruit and/or have plenty of access to water and nutrition. If crops are continuing to grow and the time of last effective square and flower have passed, consider extending irrigation intervals and using a late season, high-rate growth regulator application to restrict further vegetative growth, induce cut-out and avoid immature bolls at harvest. The application of a high rate of a growth regulator at cut-out is unlikely to have a negative effect on fibre quality and yield, and may help reduce neps in late crops that would have produced immature bolls. The practice can also reduce risk of providing a late season food source for insect pests. Decisions on cut-out application of growth regulators are based on:

- Attaining target boll numbers.
- Resumption of unnecessary late vegetative growth or fruiting.
- Reaching the last effective square or flower date for the region.
- Ensuring that the crop will not endure significant stress following application of the growth regulator as the combination may reduce yield substantially more than the effect of the stress alone.

**Best practice...**

- **Management practices that delay maturity can lead to reduced micronaire, and should be avoided where possible.**
- **Timing of harvest should strike a balance between further boll development and the potential losses from adverse weather and inclusion of immature fibre.**
- **In addition to timing of harvest aids, it is important to consider product, rate and application issues.**

**TABLE 1: Average dates for the last effective flower for various locations for different times when crops are expected to finish. These have been calculated using historical climate data since 1957.**

| Town | Date when you want your crop to be finished (date of last harvestable boll) | | | | |
|---|---|---|---|---|---|
| | 1st Mar | 15th Mar | 1st Apr | 15th Apr | 1st May |
| Jerilderie | 30th Dec | 11th Jan | 22nd Jan | 30th Jan | 5th Feb |
| Griffith | 31st Dec | 12th Jan | 24th Jan | 31st Jan | 7th Feb |
| Hillston | 5th Jan | 17th Jan | 29th Jan | 5th Feb | 12th Feb |
| Warren | 6th Jan | 18th Jan | 29th Jan | 6th Feb | 13th Feb |
| Bourke | 13th Jan | 25th Jan | 6th Feb | 15th Feb | 22nd Feb |
| Walgett | 11th Jan | 22nd Jan | 4th Feb | 13th Feb | 20th Feb |
| Wee Waa | 8th Jan | 20th Jan | 2nd Feb | 10th Feb | 18th Feb |
| Gunnedah | 4th Jan | 16th Jan | 29th Jan | 6th Feb | 14th Feb |
| Spring Ridge | 31st Dec | 12th Jan | 24th Jan | 1st Feb | 9th Feb |
| Moree | 8th Jan | 20th Jan | 2nd Feb | 11th Feb | 20th Feb |
| Mungindi | 11th Jan | 23rd Jan | 5th Feb | 14th Feb | 22nd Feb |
| St George | 12th Jan | 24th Jan | 6th Feb | 15th Feb | 23rd Feb |
| Goondiwindi | 8th Jan | 20th Jan | 2nd Feb | 11th Feb | 19th Feb |
| Dalby | 2nd Jan | 14th Jan | 28th Jan | 6th Feb | 15th Feb |
| Theodore | 9th Jan | 21st Jan | 5th Feb | 15th Feb | 25th Feb |
| Emerald | 11th Jan | 24th Jan | 7th Feb | 18th Feb | 28th Feb |

Note that as the date of last harvestable boll is delayed, the time for last effective flower is not increasingly delayed. This is especially the case for cooler growing regions.

Bolls produced after the optimum cut-out date may not contribute greatly to yield or quality. Along with monitoring NAWF it may also be useful to identify fruiting branches (with ribbons or tags that can be removed before harvest) that produced the last effective flower (Figure 1). This will assist in ensuring that bolls produced on fruiting branches above this marked position are not included in assessment of harvest aid timing decisions.

**FIGURE 1: Tagging flowers around cutout will assist in identifying bolls that are most likely to be mature at harvest** (Photo: Jane Caton, CSIRO)


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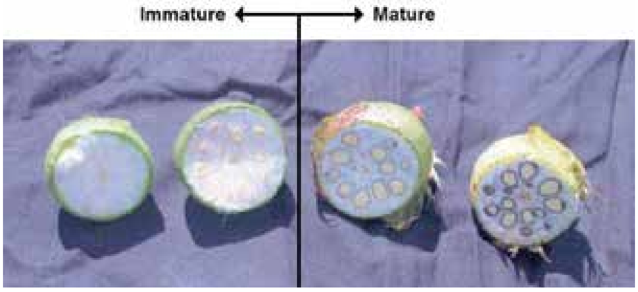
**FIGURE 2:** Bolls that are mature have seed coats that are turning brown. (Photo: CSD)




## Ceasing crop growth for a timely harvest

Late flowering and especially regrowth will cause fibre quality problems directly (reflected in reduced micronaire and increased neps), and indirectly with poorer grades. Delayed harvests expose clean lint to increased chances of weathering. Humid conditions or rainfall increase microbial damage, which potentially reduces colour grades. Poor and untimely defoliation can have a significant impact on fibre maturity as well as leaf trash. Management considerations from open boll to harvest include:

- Appropriate irrigation management for finishing the crop and avoiding regrowth.
- Managing aphid, mealybug and whitefly infestations to avoid sticky cotton.
- Accurately determining crop maturity.
- Ensuring timeliness of harvest to avoid wet weather.
- Effective application of harvest aids.

A perfect system to attain the highest quality cotton would be to have a field with 70–80% mature bolls, generated from uniform flowering and boll retention resulting in an abrupt cut-out that had ample water and nutrition to meet only those requirements of the fruit present at cut-out. Naturally-matured leaves would allow for easy defoliation at an appropriate time when temperatures were warm. The crop would be ready to harvest when the chances of rainfall were small.

### Irrigation management for finishing the crop

Crop management to synchronise crop maturity dates and harvesting operations with climate and weather is one aspect of timeliness. Excess nitrogen rates or events which cause late regrowth (such as excess soil moisture at harvest) can interfere with defoliation practices and picking. Delayed growth may also mean that fibre development can occur in cooler weather (reducing fibre maturity, lowering micronaire and increasing neps). Unnecessary and late season growth also supports late season insects which can damage yield and quality. In wet or humid weather leafy crops may also contribute to boll rot. Timing of last irrigation is a balance between ensuring there is enough moisture to allow the growth and maturity of harvestable bolls, and fields are dry enough to assist defoliation, limit regrowth, and minimise picking delays and soil compaction. The moisture required for late crop growth is related to the time of defoliation. The broad aim is to plan to manage irrigations effectively to finish the crop and to limit regrowth by having soil moisture levels to refill points by the time of defoliation.

Factors to consider:

- Days to defoliation.
- Boll maturity.
- Crop water use.
- Plant available water – ability to extract water below normal refill point.
- Soil moisture objective at defoliation.

### Days to defoliation

There are several rules of thumb to help estimate days until defoliation and generate values for your own district:

- Defoliate when nodes above cracked boll (NACB) is equal to four. However, you should only consider those nodes that have fruit that will be harvested.
- Allow for it to take 42 degree days (around three days; up to four days in cooler regions) for each new boll to open on each fruiting branch.
- (Total NACB – Four) x three = days to defoliation.

### Monitor crop maturity to avoid early crop cessation and have a timely defoliation

To determine crop maturity and have a timely defoliation, monitor plants that are representative of the crop. Methods include:

- **Percentage of bolls open –** Crops can be safely defoliated after 60–65% of the bolls are open. This method is simple and works well in crops with regular distribution of fruit. Crops can be defoliated earlier than 60% bolls open when there are strong signs that bolls have matured in warm weather.
- **NACB (nodes above cracked boll) –** In most situations four NACB equates to the time when the crop has 60% bolls open. This is a useful methodology on crops that are uniform in growth, and is less time consuming than percentage of open bolls.
- **Boll cutting –** The easiest and probably the most effective method to determine if bolls are mature or immature. It can be used even when crops are not uniform (e.g. tipped out plant, gappy stands). Bolls are mature when they become difficult to cut with a knife; the seed is well developed (not gelatinous) and the seed coat has turned brown (refer to Figure 2); and when the fibre is pulled from the boll it is stringy (moist but not watery).

### Whitefly and aphid infestations are monitored and managed to avoid sticky cotton

A significant proportion of all cases of stickiness are attributable to honeydew exudates of the silverleaf whitefly (*Bemisia tabaci*) (SLW), and the cotton aphid (*Aphis gossypii*) and mealybugs (*Phenacoccus solenopsis*). The sugar exudates from these insects lead to significant problems in the spinning mill. Presence of honeydew on the surface of cotton late in the season can also contribute to reductions in grade as it provides a substrate for sooty moulds and other fungal growth. In humid conditions the growth of fungal spores along with honeydew may increase the grey colour of the lint. SLW and aphids prefer to feed on the under surface of the leaf, allowing the small transparent droplets of honeydew to fall to leaves and open bolls below. Mealybugs also shelter inside the bracts of bolls and squares in the upper half of the plant. The level of contamination by honeydew is directly dependant on the numbers and species of insects present. Control of these pests is especially important once bolls start to open. The best way to manage honeydew contamination is to avoid it in the first place. Refer to the *Cotton Pest Management Guide* for more information.

### Timeliness of harvest operation

Cotton that is severely damaged from weather is also undesirable in textile production because the lint surface has deteriorated and this is perceived to have dye uptake problems. It can increase the roughness of the fibre which alters its frictional properties and thus how the fibre performs in the spinning mill. As cotton weathers it loses reflectance, becoming grey due to moisture from both humidity and rain, exposure to ultraviolet radiation (UV) and from fungi and microbes that grow on the lint or wash off

**TABLE 2: Dates of first frost for cotton production.**
(Source: www.longpaddock.qld.gov.au/silo/)

| Region | Years of climate data | Average date of first frost | Date of earliest frost recorded |
|---|---|---|---|
| Emerald | 111 | 9 Jun | 23 Apr |
| Dalby | 111 | 26 May | 17 Apr |
| St George | 43 | 7 Jun | 7 May |
| Goondiwindi | 107 | 2 Jun | 23 Apr |
| Moree | 111 | 28 May | 12 Apr |
| Narrabri | 43 | 25 May | 27 Apr |
| Gunnedah | 62 | 22 May | 11 Mar |
| Bourke | 43 | 12 Jun | 10 May |
| Warren | 43 | 27 May | 27 Apr |
| Griffith | 59 | 14 May | 14 Apr |
| Hillston | 43 | 17 May | 1 Apr |

the leaves. Damage to the fibre will reduce micronaire as the fibre surface becomes rough, which retards air movement in the micronaire chamber. Weathering will also reduce fibre strength, making fibres susceptible to breakage during ginning, reducing length and increasing short fibre content, leading to issues in yarn production. When a boll opens under humid conditions microbes begin to feed on the sugars on the surface of the fibre and stain the lint. Under very humid conditions fungi can multiply on the lint causing 'hard' or 'grey locked' bolls which can reduce quality and yield. If bolls are opened prematurely by frost, often the lint has a yellow colour that varies with intensity of the frost. Injury to moist boll walls from frost damage releases gossypol which stains the cotton yellow. Examine your harvest capacity, regional weather patterns, and monitor crop development to avoid excessive weathering. Specific considerations include:

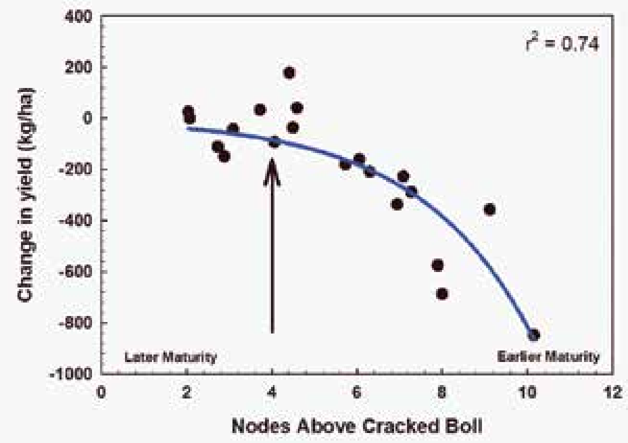
- Time harvest to avoid excessive rainfall once bolls are open. Tools to assess rainfall frequency include: CliMate (www.climateapp.net.au) and the Bureau of Meteorology (www.bom.gov.au).
- Plan to have the crop defoliated before first frost (see Table 2).

## Effective application of harvest aid chemicals

Defoliation induces leaf abscission which is the formation of a break in the cellular structure joining the leaf to the stem allowing the leaf to fall off. Leaf removal is critical for reducing the amount of leaf trash in machine harvesters. These chemicals allow timely and efficient harvest of the lint to reduce quality losses from weathering and leaf stain from excess leaf trash. Boll opening is also accelerated by defoliation as removal of leaves exposes bolls to more direct sunlight, promoting increased temperatures for maturation, and drying and cracking of the boll walls. Application of harvest aids is determined by the timing; the type of chemical used; and, the rates applied. The effectiveness of harvest aids is dependent on uniformity of plant growth; weather conditions; spray coverage; and adsorption and translocation of the chemical by the plant. Optimum timing of harvest aids must strike a balance between further boll development and potential losses from adverse weather and the inclusion of immature fibre which can lower yield (Figure 3), micronaire and increase neps (Figure 4).

Avoiding regrowth resulting from residual nitrogen and moisture in the soil will also contribute to harvest aid effectiveness, as regrowth plants have high levels of hormones that can interfere with defoliation (refer Figure 3).

**FIGURE 3:** Effect of early application of harvest aids on lint yield (adapted from Bange et al. 2009). Yield is reduced if defoliation occurs before 4 nodes above cracked bolls (NACB) approximately 60% bolls open.




### Types of harvest aids

The categories of harvest-aid chemicals include herbicidal and hormonal defoliants, boll openers, and desiccants each with a different mode of action:

**Defoliants** (thidiazuron, diuron, dimethipin) – All defoliants have a common mode of action to remove leaves. They increase the ethylene concentration in leaves by reducing the hormone auxin and/or enhancing ethylene production. Dimethipin alters the concentration of ethylene by reducing the amount of water in the leaf, stimulating ethylene production. This change in ethylene concentration triggers separation in the abscission zone at the base of the petiole (leaf stalk). Chemical defoliant enters leaves through the stomates (minor route) or through the leaf cuticle (major route). Hormonal defoliants are applied to reduce auxin and/or enhance ethylene production, while herbicide defoliants injure or stress the plant into increasing ethylene production (similar to waterlogging or drought effects). If herbicide defoliants are applied at too high rates the plant material may die before releasing enough ethylene to cause defoliation resulting instead in leaf desiccation (leaf death).

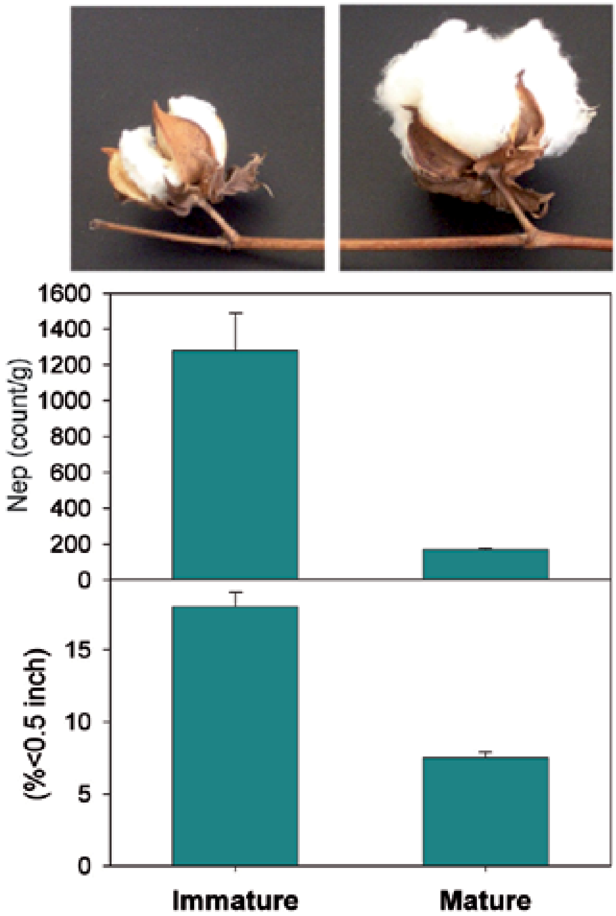
**Boll openers/conditioners** (ethephon, cyclanilide, amino methanamide dihydrogen tetraoxosulfate) – These chemicals specifically enhance ethylene production by providing a chemical precursor for the production of ethylene, which leads to quicker separation of boll walls (carpels).

**Desiccants and herbicides** (sodium chlorate, magnesium chlorate, glyphosate, diquat, paraquat, carfentrazone-ethyl) – Desiccants are contact chemicals that cause disruption of leaf membrane integrity, leading to rapid loss of moisture, which produces a desiccated leaf. Desiccants should be avoided as they dry all plant parts (including stems) which can increase the trash content of harvested lint. Sometimes it is necessary to use desiccants if conditions do not enable the effective use of defoliants (e.g. very cold weather). Desiccants are also a reliable method to reduce leaf regrowth. High rates of some defoliants can act as desiccants.

### Timing the application of harvest aids

The type of defoliation product is unlikely to impact on fibre quality if timing is correct, but early defoliation can cause a significant reduction in all desirable fibre properties. Defoliating too early will increase the number of bolls (often from the top of the plant) harvested that have immature fibre

**FIGURE 4: Pursuing late bolls may put fibre quality at risk. Un-fluffed immature bolls contribute little to yield but significantly increase neps and short fibres.**
(Rob Long, CSIRO)




with reduced fibre strength and micronaire. This may cause fibres to break during ginning lowering fibre length and uniformity and increasing short fibre content and neps. It is important to note that immature fibre will not allow for correct assessments of fibre strength using HVI™. Application of defoliations generally earlier than 60% of bolls open may reduce micronaire and increase neps. In crops that have non-uniform maturity it is advisable that there be no more than 29% immature bolls (of total boll number) defined, using the boll cutting technique, to avoid increasing neps.

## Key issues for use of defoliants

- Ensure defoliation practices occur before the onset of frost.
- Aim to have soil moisture at refill points at defoliation. Severely water stressed crops will not allow defoliants to act effectively.
- If boll openers/conditioners are applied before boll maturation they may cause bolls to shed and reduce yield.
- The use of boll openers/conditioners should only be considered if the bolls that will be forced open are mature.
- Avoid application of defoliants when there is a risk of rainfall shortly after. Some defoliants are taken up slowly by the leaves and will wash off by rain, resulting in incomplete defoliation.
- To avoid regrowth issues it is prudent not to defoliate an area bigger than can confidently be harvested within two weeks.

## Rate and chemical selection issues

- Varieties can sometimes differ in their needs for defoliation as they can differ both in plant hormone concentrations and in the quantity of wax on the leaf surface (which affects harvest aid uptake).
- Older leaves are most susceptible to defoliant. Higher rates of defoliant are needed for young healthy leaves. But there is a chance that young leaves may 'freeze' on the plant if defoliant is applied in too warm weather.
- Cool temperatures, low humidity and water stress prior to defoliant application can increase the waxiness and thickness of the leaf cuticle, reducing the efficiency of chemical uptake. Wetting agents or spray adjuvants can assist with this problem.
- Because leaf drop requires the production of enzymes, the speed with which a leaf falls off is highly dependant on temperature. There are different optimal temperatures for defoliant performance. Hormonal defoliants and boll conditioners have a higher optimal minimum temperature of around 18°C compared with herbicide defoliants that have optimal minimum temperatures ranging from 13 to 16°C. Higher rates are often needed to offset the effects of low temperatures.
- Chemical effects are usually complete seven days after application.

## Application issues

- Low humidity during application decreases uptake because chemicals dry rapidly on the leaf.
- For penetration of defoliants lower into the canopy consider using larger droplet size or directed sprays in the case of ground rig use. Use of spray adjuvants may decrease droplet sizes, which may work against chemical penetrating deeper into the canopy.
- Many growers use combinations of defoliants with different modes of action and multiple applications to enhance defoliation. Multiple applications are beneficial because leaves deep in the canopy can be covered fully.
- If increased waxiness of the leaves is suspected, applying the defoliant in warmer conditions can assist chemical penetration as the waxy layer is more pliable.
- Research is also highlighting that the efficacy of harvest aids is also related to the temperature of the canopy at the time of application. Warmer canopy temperatures have better outcomes. Research is still in progress but this aligns with similar research undertaken with herbicides.

**Useful resources:**

**FIBREpak 2nd Edition (available from www.cottoninfo.com.au)**

***Cotton Pest Management Guide* (available from www.cottoninfo.com.au)**

***my*BMP (www.mybmp.com.au)**

**All these YouTube videos can be viewed at: www.youtube.com/cottoninfoaust**

**Using harvest aids in cotton**

**Timing cotton defoliation**

**Assessing the maturity of a cotton crop**

**Making the decision to defoliate**

**Timing your last irrigation**

**Cotton growth stages: cut-out**

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# Harvesting

By **René van der Sluijs** (Textile Technical Services and CottonInfo)

## What's new…

- **Introduction of the new JD CP770 and CS770 will add additional benefits to the grower.**
- **Bigger and heavier modules will require extra caution with loading, unloading and storage.**

Preharvest preparation and harvesting plays an important role in determining fibre and seed quality, as the quality of ginned cotton is directly related to the quality of seed cotton prior to ginning. In Australia, spindle, or stripper harvesters, known as pickers and strippers respectively, harvest all of the crop each year. Irrespective of which mechanical harvesting method is used, the setup and adjustment of the machine, training and skill of the operators, and the effectiveness of defoliation and harvesting play a major role in the amount of trash and moisture present in the seed cotton.

## Use a properly maintained harvester that is setup correctly

The spindle harvester used to harvest the bulk of the Australian crop, is a selective type harvester that uses rotating tapered, barbed spindles to pull seed cotton from opened bolls into the machine. Spindle harvesters are large and complex machines that are expensive to purchase, costly to maintain and require precise setup, adjustment and trained and skillful operators to obtain the maximum yield and income per hectare. Proper maintenance and correct setup of harvesters will help to ensure a clean and effective pick. Your best source of information about maintenance and setup is your harvester operator's manual.

The other type of harvesting machine is the cotton stripper, a non-selective type harvester that uses brushes and bats to strip seed cotton from bolls. These harvesters are predominately used to harvest seed cotton from dryland and at times semi-irrigated cotton with shorter plant heights and lower yields. Stripper harvesters remove not only the well opened bolls but also the cracked, immature, and unopened bolls along with the burrs (carpel walls), plant sticks, bark, and other foreign matter, which often increases ginning costs and results in lower turnout and possibly lower grades.

## Best practice…

- **Regular maintenance and correct set up of harvesters must be conducted for a clean and effective harvest.**
- **Check tarpaulin quality of conventional modules and condition of plastic wrap of round modules.**
- **Check moisture levels of seed cotton prior to and during harvesting and in modules.**
- **Come Clean Go Clean – Ensure farm hygiene practices are in place to avoid contamination, especially when constructing, loading, and transporting modules.**

**The stripper uses brushes and bats to strip seed cotton from bolls.** (Photo: René van der Sluijs)

Agronomic practices that produce high quality uniform crops contribute to harvesting efficiency. Soil should be relatively dry to support the weight of the harvesting machinery and avoid unnecessary soil compaction. Row ends should be free of weeds and grass with a field border for turning and aligning the harvesters with the rows. Banks in drains should not be too steep an angle and plant height should not exceed 1.2 m for cotton that is to be harvested and 0.8 m for cotton that is to be stripped.

As Australian cotton is mainly harvested by means of the spindle harvester, this chapter will focus mainly on this system, however, many of the guidelines apply to both harvesting systems.

### Pre-season maintenance

A successful harvest requires a cotton harvester that is in good condition; even older harvesters can do an efficient job, if they are in good mechanical condition. Special care should be given to the spindles, moistener pads, doffers, bearings, spindle bushings, and the cam track. Your best source of information regarding maintenance and setup is the operator's manual:

- Check and replace damaged tyres.
- Inflate tyres to the pressure specified before making any field adjustments.
- Replace bent, broken, or worn spindles and ensure that all spindles are sharp and free of rust.
- Check spindle bushes for excessive wear.

**FIGURE 1: Spindle pickers require regular maintenance to operate at high efficiency.**

- Ensure all spindles turn when the row unit is rotating.
- Doffers need to be ground and reset properly as required. Replace when damaged.
- Check moisture pads, bar heights and grid bars. Moisture pads should wipe each spindle clean to remove plant juices (sap) that may cause spindle twist.
- Check cam track, roller, drum head and bar pivot stud for excessive wear.
- Check pressure doors for wear, bends, gap and alignment.
- Clean basket pre cleaners and harvester basket top.
- Check hydraulic lines, components, and air hoses for leaks.
- Ensure drive belts are adjusted correctly and universal joints in the drive train are lubricated and in good condition.
- Check condition of steps and handrails on harvester.

### Daily setup and checks

- Proper cleaning and servicing of the harvester before, during and after harvesting will result in better performance and lower the potential of fire.
- Check engine oil and coolant levels before starting the harvester's engine for the first time in the morning.
- Picker heads should be greased when they are warm. To prevent excessive wear, systems also require light greasing every two to four hours throughout the day. Spin heads to remove excess grease and wash down if required.
- Ensure head heights are set correctly (too high and bolls are not harvested, too low and soil is collected).
- Ensure correct setting of pressure doors for crop conditions. Dented or worn doors cause inefficient harvesting. Adjust doors to allow efficient removal of lint but avoid excessive green boll and stem bark removal.
- Doffers need to be checked daily and throughout operation. Too much clearance leads to improper doffing and spindle twist in the lint while lack of adequate clearance leads to rapid abrasion of doffer plates by the spindles leading to the presence of doffer pad specks (often not detected until textile manufacture).
- Spindles and bushes should be regularly checked for wear, especially the ones near the ground. Worn parts should be replaced.
- Spindles should be kept clean as dirty spindles cause spindle twist (wrap) and incomplete doffing, resulting in excessive accumulation that causes the unit air system to choke, as well as inefficient harvesting.
- Use a recommended spindle cleaner in conjunction with the correct nozzle output determined by existing conditions (especially if there is green leaf on the plants).
- Perform regular cleaning, either using a broom, your hands or compressed air. Dispose of fly cotton where it cannot contaminate the module.
- Adjust water volume correctly according to the time of day and harvesting conditions. Higher rates are usually needed in the middle of the day when conditions are drier.
- To avoid harvesting green bolls, pressure doors should be set to light to medium and all grid bars should be in position.
- Seed cotton should be harvested at moisture levels of ≤12% to prevent downgrading of fibre and seed.

## Guidelines for module placement, construction, tarping and transport

Irrespective of which harvesting method is used, the key considerations for module production to maintain quality are: module placement; construction; tarping; storage; and transportation to the gin. Typically, harvesters with basket systems require module builders to produce conventional (traditional) modules that can weigh 12–16,000 kg which produces an average of 24 bales. In contrast, harvesters with on-board module building capacity produce round modules which weigh 2000–2600 kg which produce an average of four bales for spindle and three bales for stripper harvesters. The new second generation harvesters can produce even larger modules and as a consequence, more bales per module.

### Module placement

Incorrect placement of modules has the potential to contribute to significant losses caused by moisture damage as well as contributing to contamination. When choosing a site for module pads:

- There should be enough space to allow easy access for the equipment and trucks.
- The site should be on a well-drained field road and avoid areas where water accumulates.
- The surface of the site should be free from gravel, rocks, stalks, and debris such as long grass or cotton stalks.
- The site should have a smooth, even and firm compacted surface that allows water to drain away.
- It should be accessible to transport and inspection in wet weather.
- It should be away from heavily travelled and dusty roads, and other possible sources of fire and vandalism.
- It should be clear of overhead obstructions, especially power lines.

### Round modules

John Deere harvesters with on-board module building capacity offer labour and efficiency gains (due to non-stop harvesting and the elimination of in-field unloading to boll buggies and processing in module builders) and have been rapidly adopted. In Australia, these machines harvest more than 95% of the total crop. The round modules are covered with polyethylene film that protects the seed cotton and provides compressive force to maintain the module's density. Despite the advantages of these harvesters, there are concerns regarding seed cotton moisture, contamination, soil compaction and the potential effect on yield of subsequent crops, variability in quality, as well as the high cost of the plastic wrap.

As this harvester can harvest without stopping to unload, the operator needs to determine where and when to drop the module that has been completed and is being carried. Typically, the finished module is carried until it can be dropped on a turn-row. But if the yield is very high, or the row lengths are long, it may be necessary to drop the modules within the field. This action has no impact on the operation of the harvester, but stalks may puncture or tear the plastic wrap.

### Module staging (method used to place modules together for transport)

The modules must be picked up from where they were dropped in the field and staged together for transport to the gin. The most common system is a mast type tractor-mounted implement that holds the module with the axis parallel to the tractor rear axle. Because the round modules can weigh up to 2600 kg, a large tractor is required for staging. Other considerations:

- Keep transport speed of the tractor with a module on the handler to a safe speed to suit current conditions (do not exceed 16 km/h).
- When transporting modules through harvested rows, carry the module high enough to minimise contact with those rows.
- The gap between the underside of the module and the ground should be sufficient and never be less than 15 cm during module staging to

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**Round module harvesters have almost entirely replaced the more traditional harvesters, allowing a more manageable and safer approach, with less casual labour. Growers utilising these harvesters should consider soil compaction, round module handling and contamination.** (Photo: Renée Anderson)

prevent drag and tearing of the underside of wrap.

- Modules should be staged only in well-drained areas of bare soil, such as turn-rows. If the soil is wet, wheel slip by the truck can cause the loading chains to tear the plastic wrap.
- Modules should be staged on a high, flat surface. Staging on well-defined flat driveways or a flat disked surface is optimal. Modules will take the shape of the surface they are placed on. Setting on beds or uneven surfaces requires digging into the ground with the module truck chain to safely get under the entire surface of the module.
- If possible, avoid staging in areas where the truck cannot access the modules if it rains.
- Do not allow module ends to touch, as this will cause water to enter the modules rather than to run off down the ends. The modules should be aligned so that the centrelines are within a +/- 13 cm band.
- Stage round modules for transport as per transport operators' required method. The two typical staging types are "sausage" (end to end) and "wagon wheel" (at 90 degrees from end to end). The wagon wheel is more common for loading and transport. Sausage staging is for more specialised self-loading chain-bed trailers. Modules staged for sausage chain-bed module truck pickup must have gaps of between 10 and 20 cm at module cores to prevent the plastic tearing. Also, having module ends contacting each other during long-term storage can increase chances of mould. Gaps between modules allow ventilation.
- Significant wrap tears must be repaired in the field before module truck pickup to prevent further wrap damage and ginning problems.
- Loose outer tails must be secured with a high strength spray adhesive (3M™ 90) or lint bale repair tape.

## Conventional modules

### Module construction

A tighter module better sheds moisture on the sides and less cotton is lost during storage, loading, and hauling.

Build modules in a straight line to assist the carrier in avoiding misalignment of modules on the trailer, which could result in an over-width load, breakage of the module and lost cotton. Ensure ample space around the module builder so that harvesting equipment, trucks and infield loaders have easy access. The top of the module should be rounded to allow it to shed water when covered. In addition, a well compacted module will help reduce freight costs.

Cotton that is spilled from modules should be carefully added back into the module avoiding contamination whilst following strict WHS guidelines. A constant lookout for oil leaks on cotton harvesters and module builders is needed to prevent contamination. Oil-contaminated cotton should be removed from the module.

### Module tarpaulins and tarping

Use of a high-quality tarpaulin on modules is important to avoid moisture affecting quality as well as avoiding significant contamination of the cotton from the tarpaulin itself. Before using tarpaulins inspect them for holes, tears, and frayed edges and check that they repel water.

Tarpaulins should be chosen with consideration of their tensile strength to avoid tearing, resistance to puncturing and abrasion, adhesion of coatings, UV resistance, and cold crack temperature. If tarpaulins have seams, they should be double stitched, with a minimum number of stitches. Centre seams (unless heat sealed) should be avoided as it is a potential weak point to allow water to enter the module. Consider all these factors against the overall cost of the tarpaulin and its life expectancy. Tarpaulins should be kept in a dry, vermin-free store to maintain quality and life expectancy.

Cotton rope is the most appropriate fastener to limit contamination. Never use synthetic rope.

## Keeping good module records

Identifying when and where each module is produced can help with producing better fibre quality outcomes as the grower can discuss with the ginner the quality of the cotton of each module and thus tailor the ginning process to suit. Use these records to understand the variability that exists within a field to refine management practices for that field in subsequent seasons. Each module should have a record (with a duplicate kept in a safe place), which includes the date and weather conditions when harvested. Any records or numbers assigned to modules should be as permanent as possible. Permanent marker pens should be used on cards attached to modules in a sealable plastic bag. Round modules have radio-frequency identification (RFID) tags that are embedded in the module wrap of the round modules that can document up to 11 data points during module formation. This data can be used to improve traceability of cotton modules as they move from the field to gin, storage at the gin and processing through the gin.

## Module transportation

The safe loading and transport of cotton modules (round or conventional) is important to prevent injury to module transport operators, other road users and in preventing damage to property. The Cotton Australia Module Restraint Guide has been created to provide growers and transport operators with information and advice to help meet relevant legal compliance and avoid unnecessary accidents and/ or penalties through the safe loading, restraint, and transport of cotton modules on Australian roads where flat-top open sided trailers are used.

**The Guidelines can be downloaded at www.cottonaustralia.com.au/transport**

## Work health and safety at harvest

It is vital that all contractors and farm staff complete a safety induction at cotton harvest. The key to managing farm safety during harvest is to involve all staff in identifying potential hazards and implement a plan to manage these safety risks. This process is also important for contractors. Developing procedures of how the harvesting operation should progress will ensure that everyone is aware of the correct and safe operation of equipment. The following are examples of procedures:

- Read and understand the operation manual and the basic safety procedures provided with the harvester.
- Establish procedures and harvesting patterns and then train and re-train all staff/contractors on how harvesting machinery will be serviced and operated.
- Wearing appropriate clothing and using protective equipment where necessary can reduce the risk of an accident occurring.
- Keep windows and mirrors clean for good visibility.
- Keep all lights and alarms in working order.
- Ensure walkways and platforms are free of tools, debris, or mud.
- Travel at safe speeds and limit unnecessary traffic around ground staff and equipment.
- Emphasise 'look up and live' to avoid contact with overhead obstacles such as power lines, trees, or sheds.
- If work continues at night, workers must take extra care and be aware of the position of other workers. Workers should wear reflective clothes or safety vests and audible warning sounds on machinery should be activated.

**For further information on WHS please refer to *People management* chapter.**

## Quality issues

### Moisture considerations

Cotton that is harvested wet will result in cotton being twisted on the spindle (spindle twist – roping that occurs when spindles are partially doffed) which may lead to seed cotton being more difficult to process in the gin. The harvesting operation will also be interrupted as pressure doors are blocked more often when cotton is too moist and efficiency declines as a result of poor doffing efficiency. Doffers and moisture pads on harvesters can also be damaged.

Seed cotton moisture has a significant influence on fibre quality. Increased moisture results in a microbial/bacterial action which leads to colour degradation (spotting) and discolouration which affects the colour grade, with the fibre becoming yellower and less bright with trash adhering to the lint. Modules are generally stored for three months prior to ginning and seed cotton with high moisture content can increase the risk of the module self-combusting and also emits a strong, unpleasant odour. Other fibre properties such as micronaire, length, strength and elongation can also be affected. Seed cotton moisture also has a significant influence on seed quality, with an increase in moisture content resulting in a decrease in germination and vigour, due to an increase in free fatty acid content and aflatoxin levels. Increased moisture content also leads to increased mechanical damage to the seed, resulting in an increase in the quantity and weight of seed coat fragments and mote. Furthermore, during ginning, increased moisture also leads to increased gas usage, reduction in production, and increases the possibility of blockages and fires.

Typically, cotton in Australia is too moist for harvest at dawn but cotton can be harvested well into the night provided relative humidity remains low. Moisture monitoring using moisture measuring equipment or dew point charts/calculators needs to be used more frequently at each end of the day as the change in moisture can be abrupt. Moisture can increase from 4% to 6% within 10 minutes as night and dew point temperature fall rapidly.

It is commonly accepted that seed cotton can be harvested with moisture levels of ≤12% without compromising the quality of the fibre and seed. Remember that up to 2% moisture is added to seed cotton by the spindles to keep them clean and to enhance the adherence of the fibre to the spindle and allow for its removal by the doffer. Round modules are smaller than traditional modules, resulting in less dilution of the cotton from across different harvesting times and moistures. The last round module harvested each night will have significantly higher moisture than those harvested in the middle of the day.

From a ginners' perspective this is an issue as they are unable to respond to rapidly changing moisture levels to gin efficiently. Round modules are very compact and wrapped in plastic, which is impractical and difficult to remove and replace, which limits the rate of moisture transfer to the atmosphere, which can affect fibre and seed quality if stored for an extended period prior to ginning. Round modules clumped tight in sausage formation will also limit airflow between modules. Isolation for express ginning of high moisture round modules can be difficult, as they can be lost in the multitude of modules produced in a shift.

Cartage of several round modules can also make isolation of these modules at the gin difficult. During storage on-farm and at the gin, modules should be monitored every five to seven days for temperature rises. A rapid temperature rise of approximately 8 to 11°C or more within this period signifies a high moisture problem and that module should be ginned as soon as possible.

Modules that have temperatures rising to 43°C need to be ginned immediately. The temperature of modules harvested at safe storage moisture levels will not increase more than 5.5 to 8°C in five to seven days and will level off and cool down as the storage period is extended.

**A round module with moisture contamination.**
(Photo: Rene van der Sluijs)

## Assessing moisture content

Some rules of thumb to consider relating to moisture on cotton to be harvested include:

- Install moisture measuring equipment on the harvester or use handheld moisture meters and calibrate to ensure correct readings.
- Handheld moisture meters are usually +/- 1% accurate
- Take reading from previously constructed modules.
- If moisture is present on vehicles while harvesting it is most likely that the cotton is too wet.
- The seed should feel hard (cracks in your teeth).
- When a handful of cotton collected in the palm of your hand is squeezed into a ball and then released, the moisture content is acceptable if the seed cotton springs back to near its original size.
- If you can feel moisture on the cotton, it is too wet.
- Moisture is added to the spindles to keep them clean and to enhance the adherence of the fibre to the spindle and allow for its removal by the doffer. Consider that spindle harvesters can also add 2% moisture to seed cotton.
- Green leaf will add moisture.
- A symptom of moist cotton is frequent blocked pressure doors, throwing cotton out the front of the harvesting heads.
- If cotton is being expelled into the basket in dense blobs and is not fluffy it may be too moist.
- Suitable harvesting conditions late into the night are rare.
- Notify your ginner of modules that may be too moist so that they may be ginned first, or at least monitored in the module yard.

## Contamination

Contamination of cotton with foreign substances often causes problems and increased costs for those processing the cotton at the gin and the spinning mill. Australian cotton is recognised as the least contaminated cotton in the world and receives a premium. Contaminants lower the value of the final product and can potentially damage Australia's reputation as a supplier of quality cotton. This standard must be maintained and the responsibility for keeping Australian cotton clean and contamination free rests with everyone involved in growing the crop, preparing it for harvest, harvesting and module construction, transport to the gin, ginning and shipping to the mill.

The largest contribution to contamination occurs during harvesting and module building and if a module is suspected of having a contaminant, clearly identify it, and notify the gin when delivering the module of the potential problem. The most prevalent contaminants found in Australian cotton are pieces of fabric and string made from woven plastic and plastic film (mainly from conventional module tarpaulins, round module plastic wrap and rope).

Other contaminants include:

**Natural –** Rocks, wood, leaf, bracts, bark, green leaf, burrs, and grass. Also honeydew produced by aphids, mealybug and whitefly, which is a sticky sugary substance and causes problems in ginning and spinning.

**Man-made –** Oil, hydraulic oil, grease, pieces of metal and equipment as well as food wrappers, drink bottles, mobile phones, and cleaning rags can find their way into a module. Trial markers (e.g. pink tape) are a source of contamination and should be removed before harvest.

Many of these contaminants can be avoided with careful management and good agricultural practices both prior to and during harvest. A site inspection before placing a module can be useful. Rocks and dirty and discarded cotton are common forms of contamination and can be avoided with an inspection. Workers should be trained to watch out for contaminants. Make staff aware of the potential problems and provide them with the facility to clean up and isolate rubbish; for example provide bins in which all waste is thrown and use only white cotton cleaning rags.

**Useful resources:**

**https://www.cottoninfo.com.au/index.php/publications/fibre-quality-managingcontamination-cotton**

***my*BMP (www.mybmp.com.au)**

**FIBREpak (www.cottoninfo.com.au)**

**Fibre quality videos (www.YouTube.com/CottonInfoAust)**

**Fibre quality podcasts (www.CottonInfo.com.au)**

**Round module plastic wrap in cotton bale.**
**(Photo: René van der Sluijs)**

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# Ginning

By **René van der Sluijs** (Textile Technical Services and CottonInfo)

**Acknowledgements: Australian Cotton Ginners Association.**

## What's new…

- **Best Management Practices for ginning and classing are updated annually.**
- **Gins and classing facilities are audited annually to ensure the best possible outcome for the grower and end-user.**

The ginning industry in Australia is comparatively modern, with higher throughput gins compared to other countries. The principal function of the cotton gin is to separate lint from seed and produce the highest possible return for the resulting lint and seed. Marketing quality standards reward cleaner cotton and a certain traditional appearance of the lint. A ginner has two objectives:

- To produce lint of sufficient quality and quantity to enhance and maximise the return to the grower (see Table 1).

## Best practice…

- **The main concerns during the ginning process are to maintain quality, optimise lint yield and contain the costs of ginning.**
- **Appropriate ginning and handling practices are important to maximise returns for growers and maintain the industry's reputation for high quality cotton.**
- **Effective communication between growers and ginners is a key factor in assisting this process.**

**TABLE 1: Summary of key post harvest decisions for optimising fibre quality.**

| Objectives | At the gin |
|---|---|
| Maintaining fibre length | In the gin, fibre length can be preserved and short fibre and nep content reduced by reducing the number of lint cleaner passages (depending on quality of seed cotton) and ensuring fibre moisture at the gin and lint cleaner does not exceed 7%. Lower combing ratios between feed rollers and the saw of lint cleaners also reduces the amount of fibre breakage. Replacing saw-batt lint cleaners with batt-less lint cleaners can also reduce fibre breakage and short fibre and nep content. |
| Reducing the incidence of neps | Lint cleaners are responsible for most of the neps found in baled cotton. Reducing the number of lint cleaners reduces neps. Maintenance of prescribed setting distances, e.g. feed and grid bar distances to the lint cleaner saw reduces fibre loss and nep creation, as does close and proper setting of the doffing brush to the saw. Preservation of fibre moisture as prescribed for length preservation also helps reduce nep creation. |
| Preventing contamination | Educate staff and maintain strict housekeeping practices. Use clean gravelled module yards. Carefully handle and store modules and bales. Frequently inspect tarps and plastic wrap on modules. |

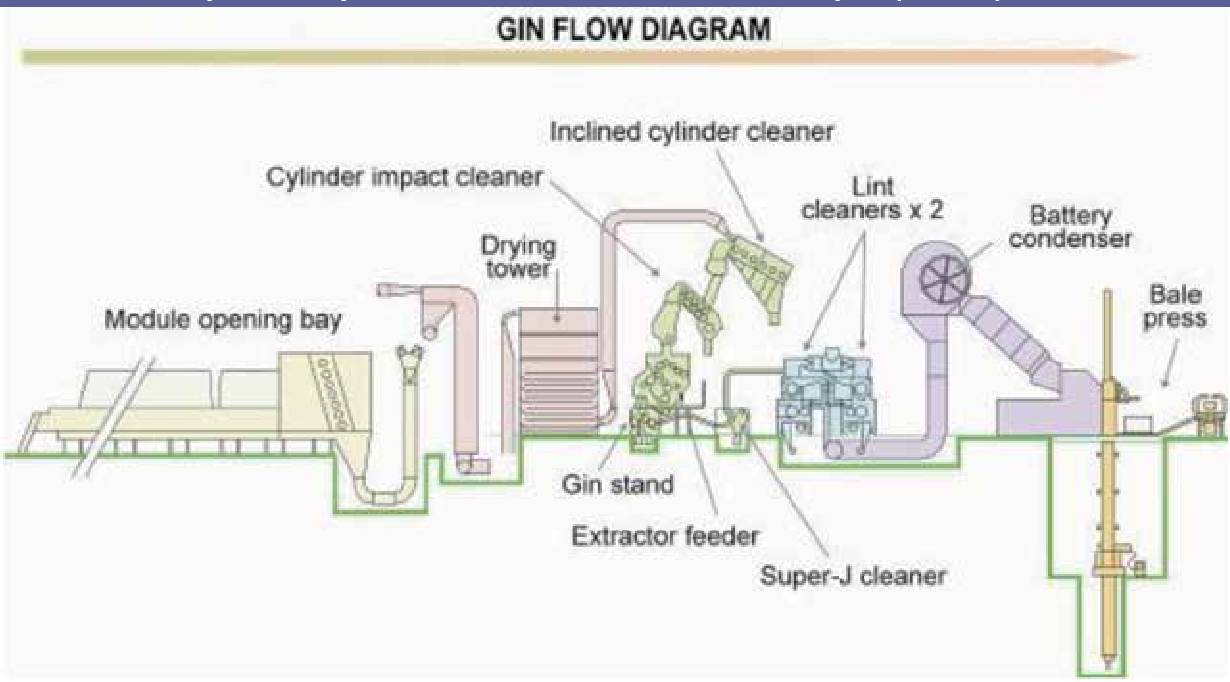
- To produce a fibre with minimum damage to satisfy the demand from the spinner and the consumer.

Ginning is, therefore, an essential link between the cotton grower and the cotton spinning mill. The gin, however, can, at best, only maintain the natural quality of cotton taken from the field - never improve it.

The spinner would prefer fibre without trash, neps and short fibres. Unfortunately, the highly mechanised (and productive) harvesting and ginning processes used today mean that removing trash is difficult without introducing some neps and increasing short fibre content.

The challenge for the ginner is to balance the amount of cotton produced (turn-out), production speed and the effects that the various cleaning and ginning components have on the fibre quality.

**FIGURE 1:** Gin flow diagram showing cross-sections of machines used in a modern gin to process spindle harvested cotton.



Settings in a gin for speed or heat can reduce fibre length and length uniformity and also increase nep and short fibre content. The use of lint cleaners, whilst removing trash, can reduce fibre length and length uniformity and also increase nep and short fibre content. While not included in existing classification systems for cotton, the presence of neps and short fibre can seriously affect the marketing appeal. The ginner must also consider the weight loss that occurs during processing. The pursuit of achieving higher grades can often result in increased fibre loss and reduced lint turn out. It is for this reason that most gins have process control systems that provide on-line measurement of important parameters such as moisture, colour, and trash. Cotton quality after ginning is a function of the initial quality of the seed cotton, and the degree of cleaning and drying it receives during ginning; the exact balance between turn-out and grade will depend upon the premium-and-discount (P&D) sheet applied to the cotton. For every P&D sheet there will be a point in the balance between turn-out and grade that maximises the return to the grower. Given this need to balance competing considerations, it is essential that growers seek to:

- Ensure defoliation and harvest practices limit trash.
- Limit contamination.
- Limit moisture during harvesting and ensure moisture in the module is <12%.
- Control silverleaf whitefly, mealybugs and cotton aphid to minimise sticky cotton.

It is important that growers communicate with ginners about these aspects of their harvest before the start of the ginning season. An understanding of the issues faced in the field may help the ginner to determine how the cotton can be handled to optimise turn-out and quality.

Modern gins are highly automated and productive systems that incorporate many processing stages. Gins must be equipped to remove large percentages of plant matter from the cotton that would significantly reduce the value of the ginned lint. Figure 1 is a simple schematic of the equipment that is typically found in a gin. At ginning the lint is separated from the seed. Moisture can be added to dry cotton prior to the gin stand at either the pre-cleaning stage or after the conveyor distributor above the gin stand. After ginning, fibre travels by air to one or two lint cleaners for further cleaning and preparation. At the lint cleaners, moisture content is critical to prevent cotton from significant damage (neps and short fibres). Cotton that is too dry (<5.5% moisture content) will be damaged to a greater degree during the lint cleaning process.

# Classing

**Acknowledgment Cotton Classing Association of Australia**

Cotton differs widely from growth to growth, crop to crop, lot to lot, bale to bale, within a bale and even fibre to fibre. In view of this and the important effect which variations in fibre properties have on processing performance, cost, and product quality, it is important that variations in fibre properties are determined and quantified.

Once cotton is ginned, and while it is being baled, a sample (minimum of 200 g) is taken from both sides of every bale, bulked together and sent to the classing facility for classification. Originally, cotton was classified by a classer's subjective assessment of fibre length as well as colour and leaf using the United States Department of Agriculture (USDA) Universal Upland Grade Standards and American Pima Grade Standards. These grade standards specify colour and leaf.

There are 25 official colour grades for Upland cotton and five categories of below grade colour. Universal Upland Grade Standards are valid for only one year, Cotton classers are skilled in visually determining the colour, trash and extraneous matter and then assigning such cotton to a certain established standard grade. As the Classer was not able to assess various important textile quality related fibre properties, such as strength, elongation and fineness, a number of instruments were developed which measure these properties. Due to the greater demand by modern spinning, the cost of raw material, and the increasingly competitive global market, there was a need to rapidly and accurately determine the cotton fibre quality parameters that affect processing performance and yarn quality in a cost-effective way on large numbers of bales of cotton.

This led to the development of high-volume automatic testing systems. These systems, termed High Volume Instruments (HVI™), not only supplement, but are increasingly replacing the traditional ways of cotton fibre quality determination and classing. Testing by HVI provides the cotton spinner with valuable information regarding the fibre length, length uniformity, strength and micronaire of every bale of cotton purchased thereby ensuring consistency in processing and yarn quality. In Australia, colour is determined by both visual and HVI, with leaf, extraneous matter (any substance other than fibre and leaf, such as bark, grass, seed coat fragments, contaminants, stickiness, and oil) and preparation (degree of smoothness or roughness of the cotton sample) still assessed by visual determination.

Cotton quality can be expressed by several different measurements which are performed by cotton classers. These measurements are described in a wide range of grades (Figure 2) and affect the final price that is paid for a bale of cotton. The price received for cotton is dependent on the quality of each bale of cotton. Cotton prices are quoted for 'base grade' 31-3-36, G5 (refer to Figure 2). Base grade refers to the grade of cotton that is used by cotton merchants as a basis for contracts, premiums and discounts

## Best practice…

**Classing is complex. While this chapter gives an overview, a more detailed understanding can be gained from visiting your nearest classing facility. Refer to: www.cottoninfo.com.au/publications/basic-guide-cotton-pricing-and-quality**

Premiums and discounts apply for higher and lower grades respectively. These pricing adjustments reflect the change in suitability for the spinning and dyeing process (see Chapter 19, Table 1, *'Consequences of poor fibre quality'* right column).

For this reason, variability in any quality characteristic may influence the price. Some of the key quality characteristics are:

- Colour.
- Leaf.
- Staple length.
- Micronaire.
- Fibre strength.
- Preparation.

## Colour

Colour can be classed either visually by a trained cotton classer or by a HVI. When cotton is classed visually, the classer compares the sample to a standard lint sample of a known grade provided by the United States Department of Agriculture (USDA). The colour grading of Upland cotton considers both major and minor differences in colour. Major colour differences occur between the five classes of 'white', 'light spotted', 'spotted', 'tinged' and 'yellow' stained cotton, chiefly due to increasing degrees of yellowness across the five classes. Within each of these classes the reflectance or whiteness of the fibre is assessed across another eight levels from 'Good Middling' to 'Below Grade'. There are 25 official physical colour grades for Upland cotton and five grades for below grade colour. Table 2 lists the official colour grades applied to Upland cotton.

**TABLE 2: Official Upland cotton colour grades**

| Designation | | White | Light spotted | Spotted | Tinged | Yellow stained |
|---|---|---|---|---|---|---|
| Good middling | GM | 11 | 12 | 13 | — | — |
| Strict middling | SM | 21 | 22 | 23 | 24 | 25 |
| Middling | M | 31 | 32 | 33 | 34 | 35 |
| Strict low middling | SLM | 41 | 42 | 43 | 44 | — |
| Low middling | LM | 51 | 52 | 53 | 54 | — |
| Strict good ordinary | SGO | 61 | 62 | 63 | — | — |
| Good ordinary | GO | 71 | — | — | — | — |
| Below grade | BG | 81 | 82 | 83 | 84 | 85 |

The colour of cotton as measured by HVI is determined by a colorimeter and defined with the Nickerson-Hunter colour model, in terms of reflectance (Rd) and yellowness (+b).

## Leaf

Also known as trash, this is a measure of the amount of leaf material remaining in the cotton sample. While the gin removes most of the trash, some remains in the sample which is removed during the spinning process, resulting in a reduction in lint yield and an increase in cost. For this reason, cotton with high levels of trash attracts a discount. Leaf grades range from one (lowest amount of trash) to seven (highest amount of trash), with the Australian base grade at level three.

## Staple length

Fibre length is a genetic trait and varies considerably across different cotton species and varieties. Length and length distribution are also affected by agronomic and environmental factors during fibre development, and mechanical processes during harvesting and ginning. Length is important to the spinning industry as longer fibres allow finer and stronger yarns to be spun. Length is measured on a sample of fibres either by pulling a hand staple or more generally by the HVI machine passing a beard of parallel fibres through an optical sensing point. Australian cotton is all classed using HVI measurements and is reported in 100ths and in 32nds of an inch. Under dryland conditions, staple length tends to range from similar to irrigated cotton (1 1/8 inches) down to very short (1 inch or less). Australian base grade is 36 or (1 1/8"). Table 3 gives an indication of both 32nds and 100ths of an inch.

**TABLE 3: Upland length conversion chart.**

| Length (32nds) | Length (Inches) | Length (32nds) | Length (Inches) |
|---|---|---|---|
| 24 | 0.79 & shorter | 36 | 1.11 – 1.13 |
| 26 | 0.80 – 0.85 | 37 | 1.14 – 1.17 |
| 28 | 0.86 – 0.89 | 38 | 1.18 – 1.20 |
| 29 | 0.90 – 0.92 | 39 | 1.21 – 1.23 |
| 30 | 0.93 – 0.95 | 40 | 1.24 – 1.26 |
| 31 | 0.96 – 0.98 | 41 | 1.27 – 1.29 |
| 32 | 0.99 – 1.01 | 42 | 1.30 – 1.32 |
| 33 | 1.02 – 1.04 | 43 | 1.33 – 1.35 |
| 34 | 1.05 – 1.07 | 44 & + | 1.36 & + |
| 35 | 1.08 – 1.10 | | |

## Micronaire

Micronaire is measured by placing lint in a chamber, compressing it to a set volume and subjecting it to a set pressure. The reading, when related to a variety, is an approximate guide to fibre thickness and has been used as a measure of fibre maturity. Other more accurate fibre maturity testing methods and devices are now available, but for now the general guidelines below still apply:

- Low (<3.5) Micronaire indicates fine (but possibly immature) lint.
- High (>4.9) Micronaire indicates coarse lint.

The premium range in Australia is 3.8 to 4.5 and the base range is 3.5 to 4.9 (G5); discounts apply for cotton with a micronaire outside the base range. Discounts for low micronaire can be substantial. Micronaire results are grouped on the schedule for premiums and discounts. Common causes of low micronaire include:

- Cool temperatures during fibre wall development.
- Potassium deficiency.
- Dense plant stands.
- High nitrogen.
- Excess irrigation/rainfall.
- Favourable fruit set and high boll retention.
- Early cut-out due to frost, hail, disease, or early defoliation.

Common causes of high micronaire include:

- Poor boll set.
- Small boll size due to hot weather or water stress.
- Variety.

Ginning has little or no effect on micronaire although low micronaire cotton is more susceptible to buckling and entanglement which creates neps that can affect preparation and subsequently grade. Dryland cotton normally falls into the acceptable micronaire range; but under hot, dry conditions some varieties are prone to produce high micronaire. Late planted crops are susceptible to low micronaire and heavy discounts sometimes apply.

Management practices that open immature bolls such as premature defoliation can contribute to the inclusion of immature fibres and an increase in neps. Experiments conducted at the Australian Cotton Research

**FIGURE 2: Interpretation of Australian Base Grade: 31–3–36, G5.**

**BASE GRADE: 31 – 3 – 36 G5**

Colour – Leaf – Staple Length Micronaire

| Colour | |
|---|---|
| **Descriptor** | **Code** |
| Good Middling (GM) | 1 |
| Strict Middling (SM) | 2 |
| **Middling (MID)** | **3** |
| Strict Low Middling (SLM) | 4 |
| Low Middling (LM) | 5 |
| Strict Good Ordinary (SGO) | 6 |
| Good Ordinary (GO) | 7 |
| Below Grade (BG) | 8 |

Discount applies (codes 4–8)

| Colour | |
|---|---|
| **Descriptor** | **Code** |
| **White** | **1** |
| Light Spotted | 2 |
| Spotted | 3 |
| Tinged | 4 |
| Yellow Stained | 5 |

| Leaf | |
|---|---|
| **Descriptor** | **Code** |
| Level 1 (least) | 1 |
| Level 2 | 2 |
| **Level 3** | **3** |
| Level 4 | 4 |
| Level 5 | 5 |

| Staple Length | |
|---|---|
| **Measurement** | **Code** |
| 1 inch | 32 |
| 1 1/32" | 33 |
| 1 1/16" | 34 |
| 1 3/32" | 35 |
| **1 1/8"** | **36** |
| 1 5/32" | 37 |
| 1 3/16" | 38 |
| 1 7/32" | 39 |

| Micronaire | |
|---|---|
| **Measurement** | **Code** |
| ≥5.3 | G7 |
| 5.0–5.2 | G6 |
| **3.5–4.9** | **G5** |
| 3.3–3.4 | G4 |
| 3.0–3.2 | G3 |
| 2.7–2.9 | G2 |
| 2.5–2.6 | G1 |
| ≤2.4 | G0 |

Institute confirmed that defoliating before 60% bolls open lowers micronaire (reduced fibre maturity) and increases neps.

## Fibre strength

Fibre strength is highly dependent on the variety, although environmental conditions can have a small effect. Dryland cotton strength is usually not adversely affected by growing conditions. Most Australian varieties are of high strength and local plant breeders have agreed to eliminate varieties that do not meet a minimum standard, thus keeping Australian cotton highly competitive in the world market. Fibre strength is measured by clamping a bundle of fibres between a pair of jaws and increasing the separation force until the bundle breaks. Strength is expressed in terms of grams force per tex with the following classifications:

- ≤23, weak.
- 24–25, intermediate.
- 26–28, average.
- 29–30, strong (most current Australian varieties).
- ≥31, very strong.

## Preparation

Preparation (often referred to as 'prep') relates to the evenness and/orientation of the lint in the sample. Factors contributing to poor preparation include spindle twist or wrapping during picking; or roping or knotting (neps) of immature or very fine fibres in the ginning process.

## Other quality characteristics

Pricing adjustments may be made for other undesirable quality characteristics, in terms of extraneous matter, including (but not limited to):

- Grass or bark in the sample.
- Contamination.
- Sugars (honeydew).
- Neps.

Several other fibre characteristics measured by HVI instruments that are of increasing importance to spinners but do not have a direct impact on price include:

- Length uniformity index.
- Elongation.
- Short fibre (fibres shorter than 12.7 mm).
- Maturity.

# Cotton grade and price

The price received for cotton is dependent on the quality of each bale. Cotton prices are quoted for 'base grade' 31-3-36, G5 (refer to Figure 2). Premiums and discounts apply for higher and lower grades respectively. Cotton merchants generally present actual classing results in an easy-to-read report displaying the AUD $/bale premiums or discounts. These pricing adjustments are calculated using their 'Premiums and Discount (P&D) Schedules' or 'Differential Sheets'. Australian merchants' P&D schedules are formatted similarly, and the adjustments are generally quite similar, but there may be some differences. P&D schedules often change between seasons and sometimes within the season; the merchant will generally set the season's P&D around ginning time. From this point, they can be requested from your merchant. Premiums or discounts may be displayed in either USD $/lb or USD points/lb. There is 100 points in a cent. For example, a 300-point discount is equivalent to -$0.03. To convert from per pound to per bale, multiply by 500. To convert into Australian dollars, divide by the USD/AUD exchange rate (ask your merchant the exact exchange rate applicable).

For example: A total discount of 800pts/lb = -$0.08/lb

$$= \frac{-\$0.08 \times 500}{.85}$$

= AUD -$47.06/bale

Multiple adjustments may apply to one bale of cotton. One adjustment for colour – leaf – staple length, while all other characteristics have their own adjustments.

**For more information talk to your merchant or their classing facility.**

**Refer to the following websites:**

**Australian Cotton Shippers Association (www.austcottonshippers.com.au/)**

**FIBREpak (www.cottoninfo.com.au)**

**www.cottoninfo.com.au/publications/basic-guide-cotton-pricing-and-quality**

# Managing cotton stubble/residues

By **Sharna Holman** (Qld DAF & CottonInfo),

Successful crop destruction is the first step in preparing a field for the next crop, as well as meeting grower requirements in the Bollgard 3 Resistance Management Plan (RMP). Cotton that has regrown from leftover root stock from a previous season (known as ratoon cotton) and volunteer cotton plants (cotton that has established unintentionally) need to be removed as soon as possible from all fields including Bollgard 3 crops, conventional cotton, refuge crops and fallow fields. Ratoon and volunteer cotton provide a green bridge for pests and pathogens to 'overwinter' between seasons, and impose additional resistance risks by extending the amount of time *Helicoverpa* spp. are exposed to Bt proteins outside the growing season.

## Post-harvest crop residue management

Returning cotton stubble to the soil enhances nutrient cycling by providing a source of energy for microbial organisms, which helps the breakdown of stubble and maintains the supply of nutrients to the crop.

Organic matter boosts the health of the soil by improving water infiltration and internal drainage, as well as reducing wind and water erosion. However, crop stubble also has the potential to encourage volunteer cotton plants and may block cultivation equipment or irrigation channels if not incorporated effectively. There are several tillage and operation options available to ensure crop residues are managed appropriately. Some are discussed below.

### Mulching and root cutting

The industry promotes the practice of mulching/slashing the stalk above ground and cutting the root below cotyledon height, preferably two to five centimetres below the top of the bed. Crop residues are then incorporated into the surface soil. This 'mulch and root cut' system can improve the amount and quality of soil organic matter and avoid implement blockages in future cultivation/planting operations if crop residue can be sufficiently buried into the hill or bed. As the cotton plant is quite woody it is preferable to break up the stalk as much as possible to help the material break down in the soil and reduce the possibility of bridging across subsequent tillage and cultivation operations. Stalks that are too long can cause problems in following operations. Mulching at slower speeds aids the potential reduction of stalk particle size as does the use of additional flails if available and mulch bars across the drum of the mulcher.

The efficiency of root cutting is maximised when machinery is run at a greater speed. However, it is important that the machines are set up properly (GPS systems are useful) otherwise ratoon cotton can become an issue in guess rows. Depending on the depth of root cut, some preliminary pupae control can also be achieved. The advantage of mulching and cut-off is the retention of stubble to help soil conditions and retention of existing hill or bed in situ. The disadvantages are dependent upon the soil type and moisture conditions as the ability to work the mulched stubble can be variable.

Stubble is difficult to incorporate in light, dry soils and tends to 'float'

**Dryland cotton…**

- **Bollgard 3 provides greater flexibility around crop destruction and pupae busting requirements that may enable double cropping in some seasons.**
- **Volunteer cotton can present a weed management challenge in some rotation crops.**
- **There are herbicides available for the control of volunteer and ratoon cotton plants in fallow, enabling effective control without tillage, to assist with conserving soil moisture.**

**Best practice…**

- **Pupae bust all Bt cotton fields regardless of defoliation date.**
- **Remove cotton volunteers and ratoon plants from all cropping and non-cropping areas to reduce resistance risks and carryover of pests between seasons.**
- **Where possible, all in-field operations (including picking) should be performed when soil is dry to reduce compaction risk.**

**Photo 1 (top) – how a field's trash content should look after only 2 workings (once mulched they were centre busted and then trace listered). Photo 2 (bottom) – large piles of trash left on the field can cause blockages and other management issues.**

to the top of the hill. Further trash management passes/implements may be needed to handle the stubble.

### Ploughing or off-set discs

Off-set discs incorporate standing stubble and provide the opportunity to include a pupae bust in a single pass, but the roughly cut stalks do not break down quickly. Soil moisture content must be low to minimise smearing and compaction, and ploughing destroys hills/beds, requiring a separate pass to re-hill. This stubble management method is less preferable to other methods due to the required subsequent field operations and the possibility of moving the cotton plant hill into a furrow line creating further issues with compaction.

### Pull, rake and burn

Cotton plants are pulled from the ground with a rubber tire stalk puller, raked into windrows and then burnt. While this method removes most crop residues, disadvantages include:

- The transfer of nutrients into lines across a field and into the air;
- The removal of organic matter that can help water infiltration and nutrient cycling;
- Issues with field access once winter rains start and if trash lines have not been burnt; and,
- The potential spread of pathogens across the field.

While 'pull, rake and burn' was used widely by the industry in the 1990s for crop residue management, very little of this method is still used except when a field may need laser levelling.

### Standard slashing

This method focuses on the slashing of crop residue and allows other operations to take care of the cotton stubble and root system. Standard slashing is not recommended for crop residues due to the issues associated with ratoon cotton. It can be used when going into a cereal rotation crop where broadleaf herbicides can kill the ratoon cotton that emerges from the standing stalk.

### Crop residues and disease management

Crop residues should be managed to minimise carryover of pathogens into subsequent crops. If Fusarium wilt is known to be present in a field, slash residues and retain on the surface for at least one month prior to mulching, to disinfect the stalks through UV light exposure – immediate stubble incorporation is likely to aggravate the Fusarium wilt problem. In all other circumstances (including the presence of Verticillium wilt and other diseases), incorporate crop residues as soon as possible after harvest to afford a host-free disease period (for more information refer the *Integrated Disease Management* chapter).

## Volunteer and ratoon cotton

The two most common methods of controlling volunteer cotton are cultivation and herbicides. Planning in-field volunteer management is important where back-to-back cotton is grown. Growers need to monitor and control volunteers located outside of the field, including roadsides, fence lines, channels, culverts, around sheds and other infrastructure. Ratoon cotton that has survived crop destruction can be difficult to control, having developed a large root system and small leaf surface area. Three herbicide options are available for the control of large volunteer or ratoon cotton amongst stubble or in fallow. These options are registered for both optical booms and broadacre application, enabling soil moisture conservation. Please refer to the Comet 400® label for further information.

## Reasons why ratoon and volunteer cotton must go:

1. **Volunteer and ratoon Bt cotton can impose additional resistance risks as they extend the amount of time *Helicoverpa* spp. are exposed to Bt proteins outside the growing season.**
2. **They provide a host plant for insects to survive over winter, increasing the risk of earlier infestations in the subsequent crop.**
3. **Past research indicates that 4 in 10 ratoon plants alongside roadsides in cotton growing regions are infected with cotton bunchy top virus.**
4. **The inoculum of soil-borne diseases can build up around ratoons and volunteer cotton plants.**
5. **Volunteer and ratoon cotton plants are a biosecurity risk and a potential point of establishment for exotic pests.**

The product user must be in accordance with the label instructions. It is important that ratoon and volunteer cotton is managed as part of an integrated weed management strategy, with these plants providing a high risk for disease and pest carryover. Refer to the *Cotton Pest Management Guide* for information about volunteer and ratoon control.

**For more information visit:**

**Checking the farm for volunteer plants – www.youtube.com/cottoninfoaust**

**Rogue cotton plants in the farming community – www.youtube.com/cottoninfoaust**

### Pupae control

Pupae destruction is a key recommendation for cotton crops under the Insecticide Resistance Management Strategy (IRMS). Bollgard 3 provides growers with more flexible pupae busting requirements depending on crop location and timing of defoliation. Refer to the Bollgard 3 RMP for further details at www.bollgard3.com.au, or the *Cotton Pest Management Guide*.

**Useful resources:**

***my*BMP at www.mybmp.com.au**

**CottonInfo at www.cottoninfo.com.au**

# Business

# The business of growing cotton

By **George Revell** and **Janine Powell** (Ag Econ)

**The information in this chapter has been prepared for general circulation and does not have regard to the circumstances or needs of any specific business or person. For financial advice see your accountant or agribusiness manager.**

## What's new…

**The CottonInfo suite of gross margins have been expanded to include Northern Australia. To see the 2021 update of gross margins search for 'gross margins' on the CottonInfo website.**

It has been said that 'farm profits are made in the office, not in the paddock'. This chapter aims to summarise some of the key business aspects of growing cotton including budgeting, marketing, finance and insurance. The chapter is aimed at growers who are new to cotton production. As cotton is an annually planted crop, farmers have the opportunity to decide each year if they want to allocate resources (i.e. land, water, labour) to a cotton enterprise. This decision can be guided by a comparison of gross margin budgets, which can give an indication of relative enterprise profitability.

## Gross margin budgets

A gross margin (GM) represents the difference between gross income and the variable costs of producing a crop. Variable costs within the budgets are those costs directly attributable to an enterprise and that vary in proportion to the size of an enterprise. For example, if the area grown to cotton doubles, then the variable costs associated with growing it such as seed, chemicals and fertilisers will also double. Gross margin budgets do not show profit because they do not include fixed or overhead expenses such as depreciation on machinery and buildings, interest payments, rates, taxes, or permanent labour.

These costs are usually discussed at a business level, as they are costs that must be met regardless of enterprise size or crop mix. The Australian Cotton Comparative Analysis is an industry benchmark from an accounting (or profit) point of view that includes overhead costs (details can be found at www.boyceca.com). If major operational changes are being considered, more comprehensive budgeting techniques (that include overhead costs) are required and consultation with financial advisors is recommended to estimate the range of expected profitability.

**A gross margin budget can assist with which crops to plant; indicate cash flow requirements; and if adjusted to actuals, create a useful record of operations and profitability of the enterprise for the season.**

Table 1 shows an example of a GM budget for 1 ha of Bollgard 3 cotton, both irrigated and dryland. The budget includes income sources, cost items and totals, with the GM calculated as the total income less total variable costs. For detailed cotton GM budgets, go to: https://cottoninfo.com.au/publications/australian-cotton-industry-gross-margin-budgets

You can use published budgets as a guide when developing your own GM budgets, altering costs and operations as necessary. The degree to which budgets reflect actual crop returns will be influenced not only by general factors common to all farms, such as prices and season conditions, but also by the individual farm or field characteristics such as soil type, crop rotation and management.

## Dryland cotton…

- **A gross margin budget is essential for dryland crops.**
- **Budgets do not take risk into account, so do your own. Make sure you understand your break even yield and cotton lint price.**
- **Do the maths. With the assistance of industry incentive programs, a decision to remove your crop could be the best way to minimise losses.**
- **Production risk is a major consideration for dryland growers and the merchants who contract with them.**
- **Ask your merchant about any marketing options that could reduce your production risk such as hectare contracts, balance of crop and force majeure. These options may not be available; if they are, it's more likely to be towards the end of the season and only if the merchant has a good understanding of your expected yield.**

## Best practice…

**Prepare your own gross margin budget using published budgets as a guide.**

**TABLE 1: Example gross margin budgets for Bollgard3®, Roundup Ready Flex®.**

| Yield | Irrigated 12 bales/ha | Dryland (double skip) 3.2 bales/ha |
|---|---|---|
| **Income** | **$/ha** | **$/ha** |
| Bales lint/ha @$600/bale | 7200 | 1920 |
| Cotton seed @ $75/bale | 900 | 240 |
| (Combined lint and seed price $675) | | |
| Less lint quality discount -$25/bale | 0 | -80 |
| **TOTAL INCOME (A)** | **8100** | **2080** |
| **Variable Costs** | **$/ha** | **$/ha** |
| Fallow management | 61 | 64 |
| Farming: Pre-planting | 33 | 51 |
| Nutrition | 804 | 52 |
| Planting & in-crop farming | 134 | 58 |
| Irrigation 9.41 ML **(C)** | 436 | |
| Insurance | 246 | 58 |
| Crop protection, application & licence fee | 816 | 344 |
| Defoliation | 151 | 70 |
| Picking, cartage & ginning | 1208 | 583 |
| Farming: Post-crop | 95 | 68 |
| **TOTAL VARIABLE COSTS (B)** | **3948** | **1348** |
| **GROSS MARGIN/HA (=A-B)** | **4116** | **732** |
| **GROSS MARGIN/ML (=(A-B)/C)** | **437** | |

Enterprise gross margins are sensitive to yield, price, and input costs. While a GM budget does not consider risks associated with yield, price, and production costs, understanding these risks is an important part of the GM budgeting process. Sensitivity analysis can be conducted to understand the effect that changes in yield and cotton prices have on the GM. The industry GM budgets include sensitivity analysis for key GM variables. Cotton pricing is discussed in detail below, along with further discussion of price and production risks.

**Create your gross margins using your last crop as an indication of operations and updated published budgets as a guide for costs. If you are new to cotton, your agronomist can help outline expected operations for the season.**

## Marketing

**Acknowledgements: Ross Brown (Ginning Marketing Solutions)**

The final cotton price is achieved through marketing. Cotton marketing involves the sale of cotton products (lint and seed) for a price. As such, cotton marketing incorporates production and price risks. Each marketing method balances production and price risks differently, so growers should seek advice from a reputable merchant about the alternatives suitable for their specific situation.

**Production risk** is separated into quantity (yield and area) and quality. The ability to 'lock in' a price before harvest is a key feature of the Australian cotton marketing system and can be a major advantage for cotton growers. However, while this reduces the price risk faced by farmers, it increases the production risk as there is uncertainty with both the area to be planted (due to seasonal conditions) and the yield that will be achieved. Yield risk also exists when a contract is entered into after planting, but before harvest. Variable yields may result in a grower under- or over-producing against contracted commitments. If production exceeds the commitments made, then the grower can sell the additional production at the prevailing market price. If the grower under-produced a fixed bale contract, then the grower may be obligated to fill the contract at market rates, which could result in a financial loss to the grower.

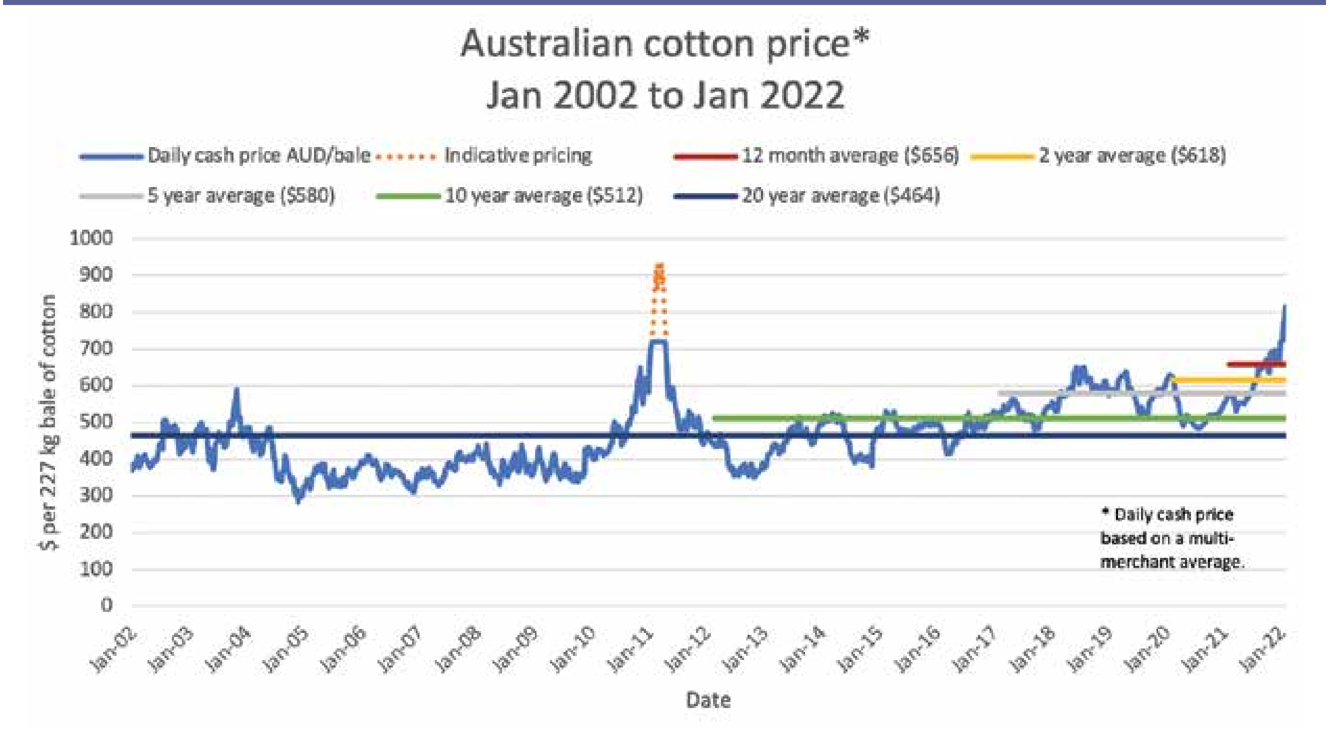
**Yield risk** is a particularly important consideration for dryland growers. Soil moisture, seasonal climate outlook and crop price at planting are the main factors for farmers who dryland crop. Chapter 3 provides a comprehensive overview of climate indicators. Given the increased production risk associated with dryland cotton, monitoring expenditure in relation to potential income (based on yield and price) is particularly important.

The decision to plant is due to a forecast profit, however if a forecast profit changes to a loss, the decision to destroy a crop to minimise losses may be financially prudent. Within the example gross margin (Table 1) the operations towards the end of the crop (defoliation, picking, cartage, ginning and levies) may represent up to 50% of the total variable costs. Understanding the timing of costs is particularly important if short-term finance is going to be utilised. A brief overview of crop finance options can be found later in this chapter.

Two industry incentives are available to manage production risk: CSD's Industry Support Program and Bayer's Cotton Choices Program™. These programs can make the decision to plant with limited water and dryland cotton easier, and in the event of a rainless season, reduce expenditure on failed or destroyed crops.

Varying quality is managed by merchants with all forward contracts priced on base grade. Once the cotton is ginned and classed, the final price paid to the grower is adjusted with a premium when the grade is higher than base, or a discount in price when the grade is inferior. These pricing adjustments can be found on a merchant's corresponding premium and discount (P&D) sheet. P&Ds may change between and sometimes during seasons; at times there may be considerable variance between merchants, P&Ds (for more information about quality see the *Managing for fibre quality* chapter).

**FIGURE 1: Australian cotton price AUD/bale. The lint price remains above long-term averages, supported by positive fundamentals.**



**Ring around and get copies of the merchants' P&Ds prior to selling cotton each season and note key differences.**

**When selling cotton mid-season, confirm the associated P&D – some merchants release multiple and often harsher P&Ds throughout the season.**

**Price risk,** in relation to a cotton grower, is when all or a portion of the crop is not sold and the value is reduced due to decreases in the cotton price. When this occurs, the grower is considered to have incurred an opportunity loss. There are three components of the Australian cotton price that cause day-to-day changes; each of these represent a different risk to the grower if they move against them.

1. ICE Cotton Futures;
2. The basis; and,
3. The AUD/USD foreign exchange rate.

Cotton is internationally traded and priced in US cents per pound (US c/lb), using the Intercontinental exchange (ICE) Cotton No 2 contract. Australian growers generally receive their income in Australian dollars (AUD), so the US Dollar (USD) price is converted into local currency using the AUD/USD exchange rate. This may not be the spot exchange rate, but the forward rate relevant to when the cotton will be delivered.

The cotton futures price and the AUD exchange rate are traded on public exchanges and are easily observable online or in many merchant market reports.

The basis is not traded on a public exchange and is less observable. However, basis can be calculated and is simply defined as the difference between the cash price for a physical bale of cotton and the futures price at any point in time. Basis is expressed in US c/lb (the same units as the futures price); it accounts for location and quality and is affected by local supply and demand conditions. Basis may be negative or positive and in the past 10 years has ranged from -15 to +20 US c/lb. Using these components, the AUD/bale cash price can be calculated as follows:

**Top line USD price per bale** — **Converts price from pounds to bales**

**AUD cash price per bale = $\frac{\text{(USD\$/lb Cotton Futures + USD\$/lb Basis) x 500 lbs}}{\text{AUD/USD exchange rate}}$**

**Converts price from USD/bale to AUD/bale**

**An example of pricing elements for AU$500/bale = $\frac{(0.75 + 0.10) \times 500}{0.70}$**

All three price elements change daily. The price of cotton in Australian dollar terms is therefore subject to daily volatility. The major merchants in Australia communicate their prices via email and SMS, which you can subscribe to. See Figure 1 for historical AUD/bale pricing.

## Marketing options

Australian cotton growers are well serviced by several cotton merchants who buy cotton from growers to sell in the international market. Due to the relatively small size of the Australian cotton market, it is often the cotton merchants approaching growers to buy cotton, thus creating a price competitive market. Merchants involved in the cotton market tend to build robust relationships with clients and may contract cotton with these growers up to five years into the future using forward contracts. A forward cotton contract is a customised agreement between two parties to deliver cotton on an agreed future date for an agreed price. Price will be determined in reference to the other terms of the contract including quality, quantity, and the time and place of delivery. From a grower perspective, this may mean selling the cotton before it has been harvested or even planted, which generates production risk, while mitigating price risk. Merchants will offer growers a range of marketing options which allows the grower the opportunity to create a marketing strategy that best suits their production plan, business needs and hopefully maximise their profit. However, despite intense competition in the Australian market, not all merchants will offer every style of contract listed below. The most common forward marketing options are:

**AUD fixed cash price:** This is the simplest and by far the most common method of marketing cotton in Australia and is generally known as the cash price (refer to Figure 1). This is a forward contract for delivery of a fixed number of bales of a given crop year (e.g. 2022–23) and potentially month (e.g. April-July) after they are ginned. Growers accept a fixed price in AUD for the bales which protects them from adverse movements in all three components of the cash price, but in turn the grower creates production risk by committing to deliver a set number of bales in the future. There may be financial penalty if a grower is unable to deliver the specified number of bales in the correct delivery period.

**Be cautious with fixed bale commitments. As a general rule, don't market more than 80% of your conservative yield estimate before picking. Ginning delays may affect your ability to deliver in contracted months.**

**USD fixed cash price:** This is similar to the AUD fixed cash price, however, in this contract the grower is leaving the foreign exchange component of their price unhedged, and therefore is exposed to price risk from an appreciating AUD. From here, merchants will usually give the grower the option of either being paid in USD according to their standard payment terms, or holding payment for the grower to fix the AUD/USD rate at a later date. This style of contract is advantageous when you think that the AUD/USD exchange rate is going to fall in the future and enhance your AUD/bale return.

**Basis on-call:** This marketing option involves the grower agreeing to deliver a fixed number of bales of a particular crop year at a set basis. The price will be expressed in US c/lb on (or off) a particular futures contract month; for example 5.50 US c/lb on May ICE Futures. In this case both the futures and foreign exchange components of price are left floating, or 'on-call', to be fixed by the grower at a later date. In this case, the grower should think that the futures price will increase and the AUD/USD exchange rate will decrease in the future.

**Closely monitor on-call contracts as you've only protected yourself against one of the three components of price risk to which you are exposed.**

**Fixed bale pool:** This is a commitment to deliver a specified number of bales to a pool of bales with a particular marketing organisation. Both price and yield risk are borne by the grower, but the price risk is managed by the marketing organisation. Most pools have an indicative price attached and often once that price is no longer achievable, the pool will be closed. As with all pools, payment is spread over a period of time as delivery of cotton from growers and sales to mills proceed.

**Other pools** may be offered by merchants to mirror the pricing profile of the fixed bale contracts above. Some pool contracts may have a guaranteed minimum price (GMP), with potential (but limited) upside risk. For these contracts, the grower bears production risk and some price risk. Due to the hedging requirements for the merchant to guarantee a certain minimum return, these contracts usually come at a discount to the cash market.

**Hectare contracts:** In a hectare contract, the grower commits a particular acreage, and all cotton produced from that area is covered by the contract. In this case, the production risk is borne by the merchant, and as such a minimum and maximum yield will often be specified. Hectare contracts are rare in the cotton industry today.

**Balance of crop (BOC)** is a contract where the grower commits their remaining unpriced bales. These contracts are generally available towards the end of the season when the grower can make a reasonable estimate of their yield. Often, the merchant will require the grower to commit to a minimum and/or maximum delivery rather than bearing the entire production risk for the grower.

**Force majeure (FM)** means 'compelling force, unavoidable circumstances'. When a FM clause is attached to a cotton contract it generally means that a production shortfall in the nominated bales stated in the contract need not be delivered. This variation is borne by the merchant.

**BOC and FM contracts are a good way to reduce production risk towards the end of the season. Ensure you understand the contract conditions.**

Timing of payment for cotton lint depends on the type of contract. Cash contracts are generally paid within 14 days of ginning, while pool contracts may pay up to 75% in July (after ginning) with further payments in September and December.

**Confirm with your accountant and merchant the best payment structure for your business prior to entering into any contracts.**

## Cotton seed

Cotton seed can be a significant component of the income from a cotton crop. Cotton seed is priced through the ginning company, which may not be the same organisation the cotton lint is sold through. Cotton seed is usually priced in bales (based on the amount of seed that is produced in the ginning process of one bale, and depending on the variety, this varies between 220–300 kg of seed). Given current varieties, most gins work on a yield between 240–260 kg.

The price of cotton seed is strongly correlated with feed grain prices and fluctuates with supply and demand. In recent years, high exports of cotton seed have supported domestic pricing. In the past, cotton seed has been worth up to $160/ginned bale (approx. $650/t of seed), and as little as $40/bale (approx. $160/t), with the latter not enough to cover ginning costs. A price closer to $65/bale (approx. $260/t) has been more common. When seed is priced at the same level as the cost of ginning (i.e. $65/bale), this is known as 'net ginning for seed', which means the income from the seed covers the ginning cost.

The ginning organisation may quote the seed price as 'net of ginning and seed' (i.e. $65/bale = 'gin for seed', seed at $70/bale is 'Plus $5 back to grower', indicating the seed price covers the $65/bale cost of ginning, with $5 paid to the grower; an example of seed priced below the ginning cost, (seed at $60/bale) is '$5 payable by grower'). Talk to your preferred ginning organisation about current cotton seed pricing.

**For further information on marketing your cotton, talk to a merchant or you can find comprehensive marketing notes on the following website: Australian Cotton Shippers Association: www.austcottonshippers.com.au/downloads/Grower_Marketing_Risk_Handbook.pdf**

**Want more advice? An independent advisor has in-depth market understanding and closely monitors details such as P&Ds. They can assist growers in making an informed decision and potentially reduce contract risk.**

# Finance

Financing the crop is a major consideration. As well as the traditional banking finance options, credit and loans may be available through some of the agribusinesses you deal with. Crop credit is available through some agricultural resellers (chemical resellers) and allows growers the option of deferring costs until after picking. Interest is charged at current short term money market rates (bank bill rates). At picking, pre-ginning loans (module advances) are available from most ginners and merchants. Details can be discussed with your merchant. Most cotton growers have debt. Whether it is a seasonal overdraft or a long-term loan, it is important to understand the capability of your business to repay the loaned amount.

There are many ways to assess the financial sustainability of a business. The five indicators below are a good place to start, as these are some of the aspects that a financial institution will assess in a loan application:

- Debt levels;
- Ability to service interest;
- Net operating expenses;
- Interest expense; and,
- Equity.

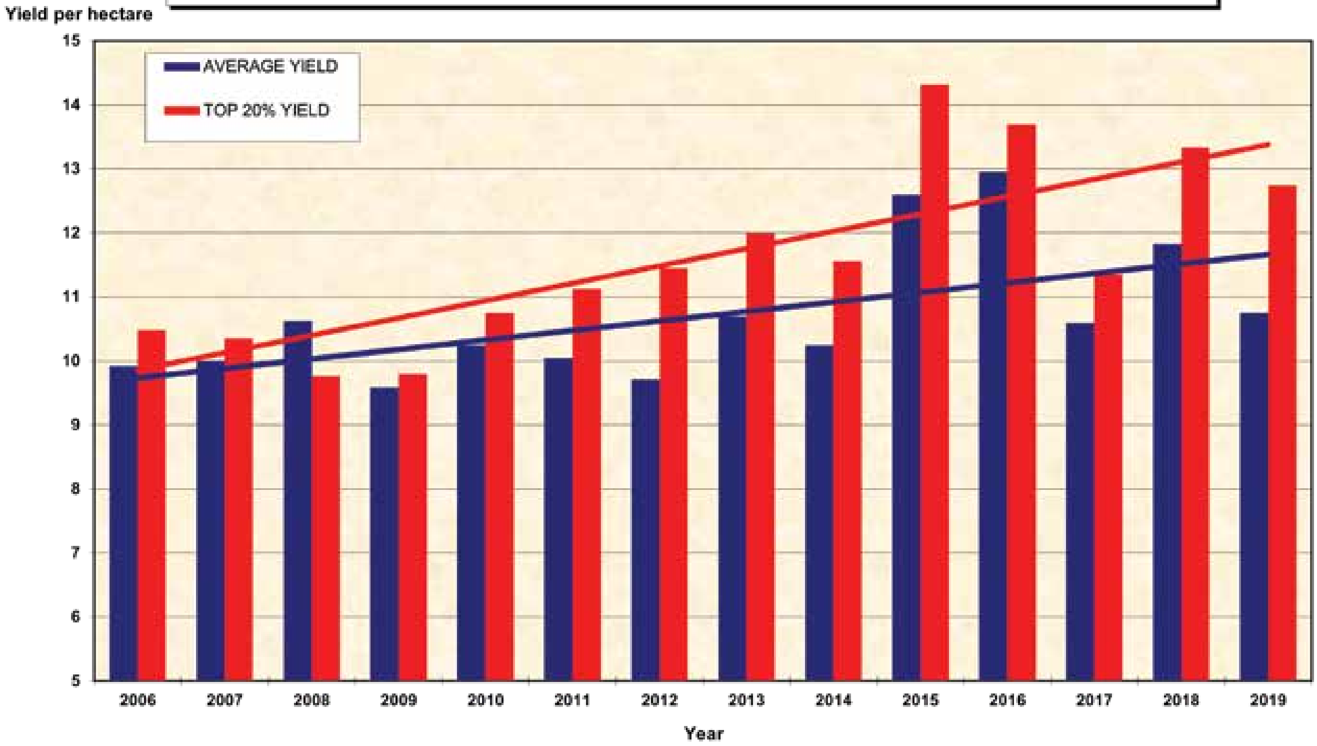
Looking at one indicator on its own may give a false impression of a business's financial health. To get the whole picture, it is important to consider all financial aspects of the business. If you are unsure how to calculate any of the five financial measurements above or have any other questions, it is recommended that you speak to a financial advisor for more information and advice on how these measurements impact your individual business financial assessment.

# Cotton Comparative Analysis

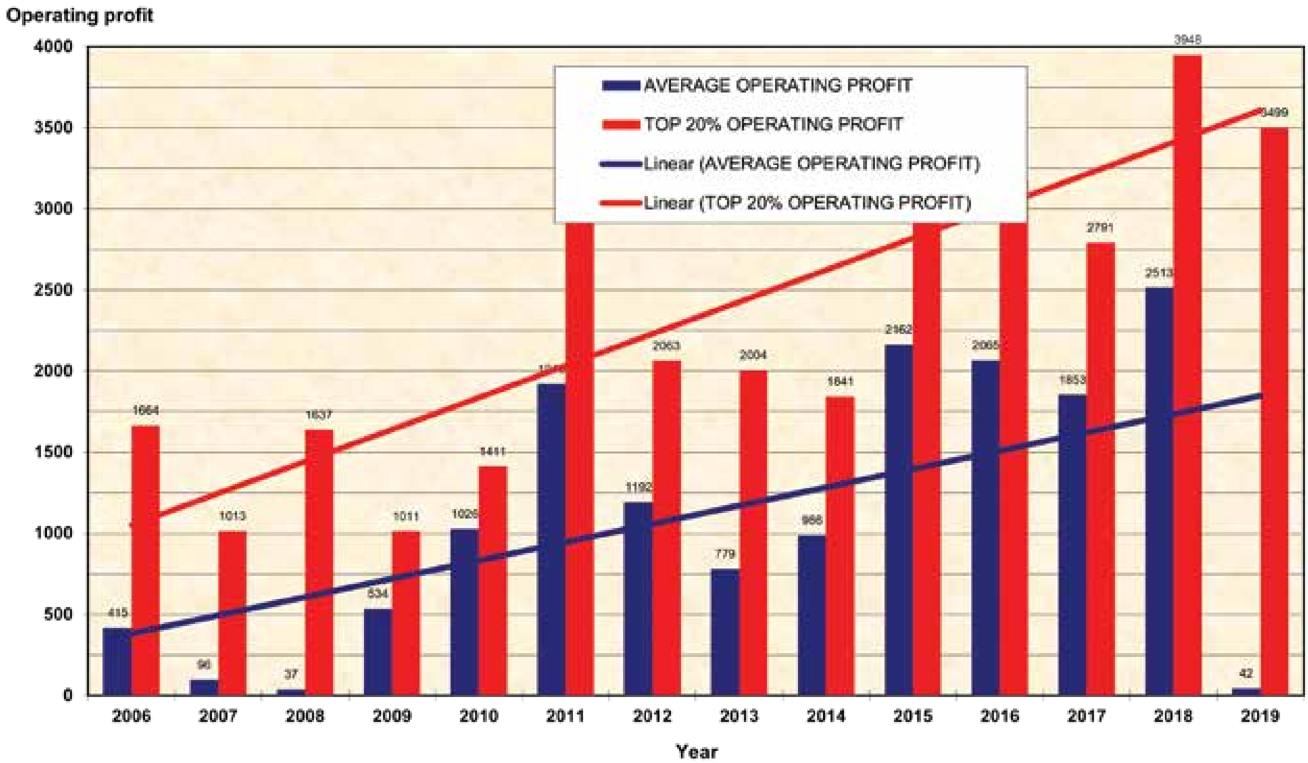
The Comparative Analysis is a joint initiative of the CRDC and Boyce Chartered Accountants to produce the industry benchmark for the economics of cotton growing in Australia. The primary purpose of the Comparative Analysis is to show the income and expenses of growing fully irrigated cotton on a per hectare basis. The reports are posted on the web pages of Boyce Chartered Accountants (www.boyceca.com) and CRDC (www.crdc.com.au). A new analysis was being prepared at the time of printing of this manual. Scan the QR code to access the latest information, which is expected to be published in mid-2022.

The following page illustrates two key graphs from the 2019 analysis (which was the most recent analysis at the time of printing this publication).

## Comparison of the yield for the average and the top 20% for landholders




## Comparison of the operating profit for the average and the top 20% for landholders



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# Insurance

By **Deidre McCallum** (AgriRisk)

**The information in this chapter has been prepared for general circulation and does not have regard to the particular circumstances or needs of any specific business or person. For more information please consult your preferred insurance specialist.**

Cotton farming is exposed to a variety of risks and hazards. To manage risk, growers need to determine if the risk can be avoided, minimised, retained or transferred to another party such as an insurer. Insurance is an effective tool to transfer risk and there are many types of insurance policies specifically designed for farming operations:

- **Protect your assets:** Including farm (machinery, buildings) and crop.
- **Cover your liabilities to others:** Including public and product liability.
- **Safeguard your people:** Including workers compensation and life insurance.

Some insurances are mandatory and required by law such as workers compensation and third party personal injury insurance which is purchased in conjunction with your vehicle registration. Other insurances may be imposed by others, such as financiers, requiring insurance to be purchased for machinery or crops where finance arrangements exist. While there are situations where insurance is mandatory, imposed or necessary, most insurance makes good business sense to safeguard your operations from financial losses that could impact on the viability of your business.

Insurance can be purchased via two different distribution channels:

- Directly with the insurer or via their agents; or by,
- Insurance brokers.

The difference between agents and brokers is that insurance agents act on behalf of the insurer and insurance brokers act on behalf of their clients. Generally, insurance brokers will have access to a number of insurers and therefore a broader range of insurance products. They can compare those products and make more meaningful recommendations to their clients. Agents can generally only access a single insurer and the products they provide. Growers should seek expert advice in determining what insurance products they require and how they will respond in the event of a loss. Brokers can help in this process as they work for the growers.

## Cotton hail insurance

Cotton hail insurance is a mature product that has evolved over the last 30 years. Growers can now effectively tailor their insurance to their exact financial requirements, including cover for various quality related downgrades.

The policies provide cover for yield losses as a direct consequence of hail damage. The following table highlights how most policies will respond to both partial and total yield losses at different times of the season.

A specialist agricultural loss adjuster will be appointed to quantify any losses by comparing the harvested yield to the potential yield of the crop – what the crop would have yielded if the hail had not occurred. The yield loss claim will then be indemnified based on the grower's specific coverage parameters.

While today's policies are similar in the way they respond to losses, the grower can select their yields, bale prices, excess, additional options and cost structures. Changes in these parameters will impact the premium charged by insurers and the policy response. When comparing products, seek specialist advice from your preferred crop insurance specialist.

| Timing of the loss | Types of yield losses | |
|---|---|---|
| | Partial losses | Total losses |
| **Within the planting window** | Yield loss will be indemnified PLUS any additional expenses | Replant payment PLUS any additional expenses PLUS any yield loss on the subsequent crop will be indemnified |
| **Outside the planting window** | Yield loss will be indemnified PLUS any additional expenses | 100% yield loss will be indemnified LESS any savings in growing costs, defoliation and harvest costs and licence fees |

## Other risk tools

### Parametric insurance

Parametric insurance policies have been available overseas for many years and are set to expand in Australia with new insurers entering the market. A parametric insurance policy responds based on the outcome of an index or parameter. Parametrics are designed to cover the financial impact of weather perils: rainfall – too much or too little; temperature – too high or too low; windspeed; humidity and others. They are suited to operations that have a high exposure to weather perils but have difficulty in managing the financial consequences as insurance cover is not available. Parametrics respond when a specific peril is triggered at a nominated location during a selected period. Once triggered, it pays a predetermined amount.

For example, a grower is concerned about too much rain at harvest causing downgrade. The grower selects their closest BOM station and the amount of rainfall likely to cause damage and how much they want to be paid. For example, payment of $100,000 if more than 100 mm falls from 15 March to 30 April at Moree Airport.

Unlike traditional insurance contracts where you are indemnified for the loss you have suffered, parametrics respond when the trigger is met at the recording station regardless of whether a loss is incurred on farm. This creates what is known as basis risk – which is the risk that the trigger is met at the recording station but there is no loss on farm and vice versa. This basis risk can be minimised by selecting a recording station close to the farm or selecting a specific weather grid. The cost of a parametric insurance policy depends on the likelihood of the trigger being met at the selected independent recording location based on historical weather records.

While the parametric insurance policies currently on offer are simple, we expect them to become more sophisticated in the future, providing an opportunity for growers to manage some of their key production exposures that they currently cannot traditionally insure.

# People management

By **Sonja O'Meara** (AgHR)

# Industrial (Employment) Relations

Industrial relations is about people. Without people, even the most sophisticated farms could not function, and industrial relations is the framework for your legal requirements for people management. At its core you will find the *Fair Work Act 2009* (Cth), that ensures a fair playing field for employers and employees. It covers things like pay, equity and employment standards that as an employer, you are legally required to meet.

## What is industrial relations?

Industrial relations is a big topic. From a political perspective, it is about driving the economy and a competitive business landscape. Employees are concerned with pay, job security and workplace safety. As an employer, you are focused on productivity, managing conflict and employment law. The key elements that make up the industrial relations framework include minimum terms and conditions of employment, enterprise bargaining, provision for flexible work arrangements, protections against unfair or unlawful employment termination and freedom to choose third party representation.

## Awards and pay equity

To meet the minimum terms and conditions of employment, you will need to know award wages. Most cotton farm employees will be employed under the Private Clerks Award (for office employees) or the Pastoral Award. Employees can be paid an annualised salary or an hourly rate.

## Annualised salary or hourly rate

It is common for employers to offer an all-inclusive salary as the rate of pay which is intended to compensate the employee for all monetary entitlements in relation to the work they perform. The alternate is for employers to pay wages and other entitlements separately as and when they fall (hourly rate).

### Best practice…

- **Ensure you are aware of the correct Award and classification and wage required for each employee.**
- **Remember that the award wage increases each year.**
- **Keep timesheets.**
- **Remember that contractors are workers under WHS. Your obligations are the same to them as your employees.**
- **Safety should be part of the culture of the farm, and it is crucial to the future of the industry – particularly for attracting and retaining staff.**
- **Focusing on steps to improve safety will lead to better productivity and improved returns.**

## Legal requirements

**Annualised Salary –** It has been a number of years since changes were introduced to the way annualised salaries were applied. These included:

- Keeping a record of all hours the employee worked including start, break and finishing times.
- Comparing the hours worked and wages paid with the minimum entitlements under the awards on an annual basis or when an employee leaves.
- If an underpayment is uncovered, the employer is required to pay the difference within 14 days.

Recommendation: Reconcile employee hours worked and the wages paid with the minimum entitlements under the relevant award.

**Hourly rate –** It is important to remember that the hourly rate listed in the relevant modern award is the rate applicable to 38 hours of work. Any employee working over 38 hours is entitled to a higher rate of pay (referred to as overtime rates in the award) and there are also higher rates of pay for employees working Sundays and public holidays. When paying an hourly rate, you need to:

- Keep a record of all hours worked including start, break and finishing times.
- Ensure that rate paid includes all entitlements under the award.

**Note – a number of states have now criminalised wage theft – which means wage theft will be treated the same as other forms of stealing.**

## Failure to comply – what if we get it wrong?

Where an employer fails to comply with the *Fair Work Act 2009* (Cth) including terms of a modern award, employers will be exposed to risks of underpayment, attract pentiles of up to $66,600 and possible criminal stealing (wage theft) charges.

**Useful resources: Employers and employees can access the following government websites for copies of awards and/or a range of industrial relations matters:**

**Fair Work Commission: www.fwc.gov.au**

**Fair Work Ombudsman: www.fwo.gov.au**

***my*BMP – Human Resources and Work Health and Safety module: www.mybmp.com.au**

# Work Health and Safety (WHS)

Managing safety is an integral part of managing the cotton farm business. It needs an understanding of the legislative requirements and how to create a safe work environment and culture.

## Work Health and Safety Legislation

Previous editions have identified the requirements under WHS legislation. However, it is important to remember that under current WHS legislation everybody has a duty of care and responsibility.

The **PCBU** (person conducting a business or undertaking) must meet his or her obligations, so far as is reasonably practicable, to provide a safe and healthy workplace for workers or other persons by ensuring:

- Safe systems of work.
- A safe work environment.
- Accommodation for workers, if provided, is appropriate.


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Rinse them out
Round them up
Run them in
drummuster provides Australian agricultural and veterinary chemical users with a recycling pathway for eligible empty agvet chemical containers.
drumMUSTER is a national product stewardship program that is supported by agvet chemical manufacturers, industry stakeholders including member and farming associations as well as state and local governments.
Recycle your empty eligible agvet containers. Visit the drumMUSTER website to find the nearest collection site to you.
Remember, every container counts.
drumMUSTER
rinse them out, round them up and run them in.
drummuster.org.au
Contact drumMUSTER P 02 6280 6888 | E info@drummuster.org.au

- Safe use of plant, structures and substances.
- Facilities for the welfare of workers are adequate (e.g., toilets, fresh drinking water, first aid).
- Notification and recording of workplace incidents.
- Adequate information, training, instruction and supervision is given.
- Compliance with the requirements under the work health and safety regulations; and,
- Effective systems are in place for monitoring the health of workers and workplace conditions.

PCBUs must also have meaningful and open consultation about work health and safety with their workers.

The definition of a **'worker'** includes any person who carries out work for a PCBU. This term **'worker'** includes any person who works as an:

- Employee.
- Trainee.
- Volunteer.
- Work experience student.
- Contractor or sub-contractor.
- Employee of a contractor or sub-contractor.
- Employee of a labour hire company.

### Duties of a worker

A worker must, while at work:

- Take reasonable care for their own health and safety.
- Take reasonable care for the health and safety of others.
- Comply with any reasonable instruction by the PCBU.
- Cooperate with any reasonable policies and procedures of the PCBU.

## Safety culture – beyond common sense

Developing a good workplace safety culture is a critical part of implementing WHS. It is a reflection on the values, attitudes, perceptions, competencies and behaviours of both the business and its workers. Research shows that the most safety minded business are also among the most profitable and that developing a safety culture pays off.

### So how do we create a safety culture?

Communicate the value 'Safety First' – safety needs become a part of our everyday values and actions and not be seen as an extra task. Demonstrate leadership – ensure there are clear and consistent messages about the importance of WHS and lead from the top and by example. Develop positive safety attitudes that support safe behaviour. Increase hazard and risk awareness – provide everyone with an understanding of the outcomes associated with their decisions. Discuss what happened when things have gone wrong. Allow workers to raise safety concerns – listen and action if valid

## What happens at a safe workplace?

At a safe workplace people will:

- Understand what they need to do and why.
- Think about what they are doing before they are doing it.
- Look for hazards proactively and manage risks before they cause harm.
- Take care of hazards.
- Believe they are responsible and accountable for making sure that they and their workmates remain healthy and safe.
- Follow workplace polices.
- Contribute through consultation to WHS management.

## Why is safety important

A serious workplace injury or death changes lives forever, and we don't just mean the worker. Families, friends, communities, co-workers are all affected too. Here we outline reasons why safety is so important in the workplace.

- Injury – if a worker is injured on the job, it costs the business in lost work hours, increased insurance rates, workers' compensation premiums and possible litigation.
- Death – this is the absolute worst possible outcome. A death can lead to a business dealing with many possible outcomes. Starting with caring for grieving co-workers, right up to the potential for legal action which now includes the possibility of imprisonment.
- Financial loss – increased workers compensation and other business-related insurances are just the beginning.
- Property damage – this could be any of the business's property. For example, a written-off vehicle to plant equipment, which has resulted from the accident.
- Worker productivity – any business knows that employee turnover and absenteeism can be major obstacles. When you create a healthy and safe workplace, you reduce those issues in several ways. Safe workers are loyal workers and productive contributors to the workplace.
- Improved quality – businesses that put safety first achieve better outcomes. In some cases, that is because a safe workplace tends to be a more efficient one. In other cases, it's a matter of focus. By working in a safe, efficient environment, workers are able to reduce distractions and truly focus on the quality of what they do.
- Corporate reputation – a business's reputation is their currency to trade on. If the reputation is not up to scratch, then that is likely to be represented in their bottom line.

Workplace safety is much more than legislation. It is about creating the kind of productive, efficient, happy and inspiring workplace that we all want to be a part of. It is about creating a highly profitable farm. That is why safety is important!

## What help is available to manage WHS on cotton farms?

The following are templates, resources and training to implement WHS/HR practices:

**Safe work Australia: www.safeworkaustralia.gov.au**

**AgSkilled NSW – WHS safety training www.agskilled.org.au**

**Qld WHS Law: www.worksafe.qld.gov.au**

**NSW WHS Law: www.safework.nsw.gov.au**

**Safework NSW has a small business safety rebate program in place. For further information and eligibility: https://www.safework.nsw.gov.au/advice-andresources/rebate-programs/small-business-rebates**

# Glossary & acronyms

## Glossary

**Adjuvant** Any substance added to a spray mixture to enhance its performance or overcome an inhibiting factor. This includes, wetting agents, 'stickers', thickeners and buffering agents. Always check the label to ensure the adjuvant is compatible with the pesticide, formulation and application method being used.

**Allelopathy** is a biological phenomenon where one plant inhibits the growth of another.

**Alluvium** Refers to sediment that has been deposited by flowing water, such as a flood plain.

**AMF** Arbuscular Mycorrhizal Fungi (formerly known as VAM). A partnership between soil borne fungi and most crop plants, including cotton (but not brassicas). AMF colonise the roots of the plant without causing disease. AMF act as an extension of the root system and transfer extra nutrients, especially phosphorus, from the soil to the plant. In return the plant provides the fungi with sugars as a food source.

**Area Wide Management (AWM)** Growers working together in a region to manage pest populations. AWM is a cotton industry vehicle driving adoption of on-farm IPM.

**At-planting insecticide** Insecticides applied in the seed furrow with the seed during planting. The insecticide may be applied as a granule or as a spray into the seed furrow.

**Beneficial insects** Predators and parasitoids of pests.

**Biological insecticides** Insecticides based on living entomopathogenic (infecting insects) organisms, usually bacteria, fungi or viruses, or containing entomopathogenic products from such organisms i.e. Gemstar, Vivus and Dipel (BT).

**Bollgard 3** Genetically modified cotton variety containing the insecticidal proteins Cry1Ac and Cry2Ab and the vegetative insecticidal protein Vip3a which provides control of *Helicoverpa* spp., rough bollworm, cotton tipworm and cotton looper under field conditions.

**Broad spectrum insecticide** Insecticides that kill a wide range of insects, including both pest and beneficial species. Use of broad spectrum insecticides usually reduces numbers of beneficials (predators and parasites) leading to pest resurgence and outbreaks of secondary pests.

**Bt** The *Bacillus thuringiensis* protein which is toxic to *Helicoverpa* spp.

**Buffer zone** A self-imposed area that is not sprayed when the wind is blowing towards a sensitive area to minimise risk of damage or residues from spray drift to areas beyond the buffer.

**Cold shock** Is when the daily minimum temperatures fall below 11ºC, delaying cotton growth and development the following day regardless of the maximum temperature reached. Cold shocks have greatest impact on early plant development and increase the susceptibility of plants to diseases.

**Conventional cotton** Strictly a cotton variety that does not contain transgenes (genes from other species), but used in this guide to indicate varieties that do not include genes to produce insecticidal proteins (i.e. Bollgard II, Bollgard 3) but which may include herbicide resistance genes i.e. Round-up Ready).

**Cotton bunchy top (CBT) or Bunchy top disease** A virus spread by the cotton aphid (*Aphis gossypii* Glover).

**Cotyledons** Paired first leaves that emerge from the soil when the seed germinates.

**Crop compensation** The capacity for a cotton plant to 'catch-up' after insect damage without affecting yield or maturity.

**Crop maturity** This usually occurs when 60–65% of bolls are mature and open. Cotton bolls are mature when the fibre is well developed, the seeds are firm and the seed coats are turning brown in colour.

**Crop Water Use Index (CWUI)** Describes plant water interaction at a crop scale, i.e. yield per megalitre.

**Cut-out** Occurs when the crop's demand exceeds its ability to supply fruit with assimilate (products of photosynthesis). Production of new fruit ceases. Cut-out should approximately equate to the timing of the last effective flower. Cut-out also equates to when the crop reaches 4–5 NAWF, which can occur at any time late in the season depending on how the crop is managed.

**Damage threshold** The level of damage from which the crop will not recover completely and which will cause some economic loss of yield or delay in maturity. Damage thresholds are usually applied in conjunction with pest thresholds to account for both pest numbers and plant growth. For instance a plant which has very high fruit retention may be able to tolerate a higher pest threshold than a crop with poor fruit retention.

**Day Degrees (DD)** A unit combining temperature and time, useful for monitoring and comparing crop and insect development.

**Deep drainage** Water from rainfall or irrigation that has drained below the root zone of the crop. A certain amount of deep drainage helps flush salts from the soil, but excess deep drainage means water and nutrients are being wasted.

**Defoliation** The removal of leaves from the cotton plant in preparation for harvest. This is done by artificially enhancing the natural process of senescence and abscission with the use of specific chemicals.

**Denitrification** A biological process encouraged by high soil temperatures. Denitrification occurs when there is waterlogging, such as during and after flood irrigation and/or heavy rainfall. The process converts plant available N (nitrate) back to nitrogen gases which are lost from the system.

**Desiccant** A chemical used as a harvest aid that damages the leaf membrane causing loss of moisture in the leaf, producing a desiccated leaf.

**Determinate/Indeterminate** Cotton is an indeterminate species which is capable of continuing to grow after a period of stress.

**Doffer** Doffers unwind and remove the cotton from the spindle so that it can be transported to the chamber in an air stream.

**Double knock** Is the sequential application of two weed control options with different modes of action in a short time-frame.

**Double skip** A row configuration used in dryland/semi-irrigated situations to conserve soil moisture.

**Earliness** Minimising the number of days between sowing and crop maturity. Within a cotton variety earliness usually involves some sacrifice of yield.

**Efficacy** The effectiveness of a product against pests.

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

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

**Flush** A high volume irrigation carried out in minimal time.

**Fly cotton** Fibres that fly out into the atmosphere during processing. In general, these fibres are often single or in small bunches and generally caused by low moisture content and short fibres.

**F Rank** A rank that each cotton variety is given in accordance with its resistance to the cotton disease Fusarium wilt.

**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 subtending leaf. Fruiting branches have a zigzag growth habit.

**Fruit load** Refers to the number of fruit (squares or bolls) on a cotton plant.

**Fruit retention** Refers to the percentage of fruit (squares or bolls) that the cotton plant or crop has maintained compared with the number it produced.

**Fruiting branch** Grows laterally from the main stem in a series of segments. Each segment finishes at a node at which there is a square and a leaf. At the base of the square the next segment originates, and so on.

**Gross Production Water Use Index (GPWUI)** Is the gross amount of lint produced per unit volume of total water input (b/ML). The total water input includes irrigation, rainfall and total soil moisture used where the rainfall component can comprise either total rainfall or effective rainfall.

**Habitat diversity** A mixture of crops, trees and natural vegetation on the farm rather than just limited or single crop type (monoculture).

***Helicoverpa* spp.** refers to species of moth from the genus *Helicoverpa*. In Australian cotton there are two species, *Helicoverpa armigera* (cotton bollworm) and *Helicoverpa punctigera* (native budworm). Larvae of these two moth species are major pests of cotton, capable of dramatically reducing yield.

**Herbicide Resistance Management Strategy** The HRMS is designed as a tool for weed management in irrigated and dryland farming systems incorporating herbicide tolerant (HT) cotton, to delay glyphosate resistance.

**Honeydew** A sticky sugar-rich waste excreted by feeding aphids or whiteflies. It can interfere with photosynthesis, affect fibre quality and cause problems with fibre processing.

**HVI™** High Volume Instrument that is able to quickly and accurately determine the fibre properties of a large volume of cotton.

**Irrigation deficit** Readily available water capacity.

**In-furrow insecticide** Insecticides applied in the seed furrow with the seed during planting. The insecticide may be applied as a granule or as a spray into the seed furrow.

**Insecticide resistance** Where a pest develops resistance to an insecticide, the insecticide will no longer kill individuals that are resistant. This usually results in poor control and may lead to failure of control with the insecticide in the worst cases. The resistant insects develop a mechanism for dealing with the insecticide, such as production of enzymes which break the insecticide down quickly before it kills the pest.

**Insecticide Resistance Management Strategy (IRMS)** An industry regulated strategy that sets limits on which insecticides can be used, when they can be used and how many times they can be used. This helps prevent the development of insecticide resistance.

**IPM** Integrated Pest Management (IPM) is a concept developed in response to problems with managing pests, insecticide resistance and environmental contamination. The basic concept of IPM is to use knowledge of pest biology, behaviour and ecology to implement a range of tactics throughout the year, in an integrated way that suppresses and reduces their populations. Conserving beneficials (natural predators and parasites) is at the heart of IPM.

**Irrigation system efficiencies** Compare water output to a water input at different points of the irrigation system of the farm as a whole, and are expressed as a percentage.

**Irrigation Water Use Index (IWUI)** Is the gross amount of lint produced per unit volume of irrigation water input (b/ML). This includes irrigation water used only and does NOT include rainfall or used soil moisture. It is a measure of irrigation management.

**Labile P/non-labile P** There are a few Phosphorus fractions within the soil including labile (available to the plant) P and non-labile (slow release) P.

**Lay-by herbicide** A residual herbicide used to control weeds during the growth of the cotton crop.

**Last effective flower** The uppermost/youngest flower on the plant that will fully mature to a harvestable boll. The time when this flower occurs is regionally specific and defined by a date. For a boll to become fully mature there must be adequate day degree accumulation before harvest aids are applied.

**Leaching fraction** Refers to the portion of irrigation water that infiltrates past the root zone

**Lodging** Towards the end of the season cotton plants with large and heavy boll loads will often fall into each other which is known as lodging.

**Main stem leaves** Are leaves that are connected directly with the main stem.

**Main stem node** A point on the main stem from which a new leaf grows. At these points there may also be fruiting or vegetative branches produced.

**Mepiquat chloride** Cotton growth regulator.

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

**Motes** Small, broken, or immature seeds with attached fibres that are mainly removed during lint cleaning.

**Mycorrhiza** See AMF.

**NACB** The number of main stem Nodes Above the first position Cracked Boll. This is an indication of the maturity of the plant and can be used in making decisions about the final irrigation or defoliation.

**Natural enemies** Predators, pathogens and parasitoids.

**Natural mortality** The expected death rate of insects in the field mainly due to climatic and other environmental factors including natural enemies.

**NAWF** The number of main stem Nodes Above the first position White Flower that is closest to the plant terminal.

**Neps** Entanglement of fibres.

**Node** A leaf bearing joint of a stem, an important character for plant mapping in cotton where nodes refer to the leaves or abscised leaf scars on the main stem.

**No Spray Zone** A legally required unsprayed distance between the sprayed area and a sensitive area that must be adhered to when the wind is blowing towards that sensitive area.

**Okra leaf type** Cotton varieties with deeply lobed leaves that look very similar to the leaves on the Okra (*Abelmoschus esculentus*) plant, which is related to cotton and hibiscus.

**OZCOT model** A cotton crop simulation model that will predict cotton growth, yield and maturity given basic weather, agronomic and varietal data.

**Pathogen** Refers to the microorganism, usually virus, bacterium or fungus, that causes disease. For example Fusarium wilt is a disease of cotton caused by the soil inhabiting fungus *Fusarium oxysporum f.sp. vasinfectum* (Fov).

**Partial root zone drying** The creation of simultaneous wet and dry areas within the root zone. Only part of the root zone is irrigated and kept moist at any one time.

**Pest flaring** An increase in a pest population following a pesticide application intended to control another species. This usually occurs with species that have very fast life cycles such as spider mites, aphids, mealybugs or whitefly. It occurs following the use of broader spectrum insecticides which control the target pest but also reduce the numbers of predators and parasites. This allows these 'secondary' or non-target pests to increase unchecked, often reaching damaging levels and requiring control.

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

**Pest damage** Damage to the cotton plant caused by pests. This can be either damage to the growing terminals (known as tipping out), the leaves, the roots, or the fruit (including squares or bolls).

**Pest resurgence** An increase in a pest population following a pesticide application intended to reduce it. This usually occurs because the insecticide has reduced the numbers of beneficials, which normally help control the pest, thereby allowing subsequent generations of the pest to increase without this source of control.

**Pest threshold** The level of pest population at which a pesticide or other control measure is needed to prevent eventual economic loss to the crop. See also 'Damage threshold'.

**Petiole** The stalk that attaches the leaf to the stem.

**Pima cotton** Is of the *Gossypium barbadense* species. It has an extra long staple and its growth is limited to regions with long growing seasons. Normal cotton is of the species *Gossypium hirsutum*.

**Pix** See mepiquat chloride.

**Plant Available Water Capacity (PAWC)** The amount of water in the soil that can be extracted by plants, usually full point (when the soil can hold no more water) minus wilting point (point at which the plant can no longer extract sufficient water from the soil and begins to wilt).

**Plant growth regulator** Chemical which can be applied to the plant to reduce growth rate (see also Rank crop and Pix).

**Plant mapping** A method used to record the fruiting dynamics of a cotton plant. This can be useful for understanding where the plant has held or is holding the most fruit in order to interpret the effects of factors that may affect fruit load such as pest damage, water stress, heat.

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

**Plastic limit** The water content where soil starts to exhibit plastic behaviour.

**Post-emergent knockdown herbicide** A herbicide used to rapidly control weeds after they emerge.

**Pre-irrigation** Irrigation water applied prior to planting. It has advantages when there are weed problems, if the soil is very dry or if planting temperatures are marginal.

**Premature cut-out** Is when the production of bolls exceeds the supply of carbohydrates too early in the crop's development and the production of new fruiting nodes stops. This results in a less than ideal boll load.

**Pre-plant knockdown herbicide** A herbicide used to rapidly control weeds prior to planting.

**Pupae** Once larvae of *Helicoverpa* have progressed through the larval (caterpillar) stages they will move to the soil and burrow below the surface. Here they will change into a pupae (similar to a butterfly chrysalis). In this stage they undergo the change from a caterpillar to a moth.

**Pupae busting** Effective tillage to reduce the survival of the overwintering pupal stage of *Helicoverpa*. Pupae busting is an important tool in reducing the proportion of the *Helicoverpa* population carrying insecticide resistance from one season to the next.

**Rank crop** A rank crop is usually very tall (long internode lengths) with excessive vegetative plant structures. This can be caused by a number of factors including excessive fertiliser use, pest damage and crop responses to ideal growing conditions especially hot weather. Rank crops can be difficult to spray and to harvest and may have delayed maturity or reduced yield (refer to VGR).

**Ratoon cotton** Also known as 'stub' cotton, ratoon is cotton that has regrown from left over root stock from a previous season. The control of unwanted cotton in the farming system is an essential part of good integrated pest and disease management.

**Refuge** The aim of a refuge crop is to generate significant numbers of susceptible moths that have not been exposed to the Bt proteins in Bt cotton. Moths produced in the refuge will disperse to form part of the local mating population where they may mate with any resistant moths emerging from Bt crops, delaying the development of resistance.

**Resistance management plan (RMP)** A proactive plan for Bt cotton established to mitigate the risks of resistance developing to any of the proteins contained in Bt cotton. Resistance management for Bt cotton is critical due to the season long selection of *Helicoverpa* spp. to the Bt toxins produced by Bt cotton. Compliance with the RMP is required under the terms of the Bt cotton Technology User Agreement and under the conditions of registration.

**Retention** Is the proportion of fruiting sites on a plant that are present versus those that have been lost.

**Secondary pests** Pests such as spider mites, aphids or whiteflies which do not usually become a problem unless their natural enemies (predators or parasites) are reduced in number by insecticides. See also 'Pest Flaring'.

**Seed treatment** An insecticide/fungicide used to coat cotton seeds to offer a period of protection during germination and establishment against some diseases, ground dwelling pests e.g. wireworm and some foliage feeders such as thrips or aphids.

**Selection pressure** The number of times insecticides from a particular chemical group are sprayed onto a cotton crop. Each of these spray events will control susceptible individuals, leaving behind those that are resistant. More selection events means that there is greater 'pressure' or chance of selecting a resistant population.

**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. Young fruiting forms (squares) are more likely to be shed than the more developed squares, flowers and bolls.

**Short fibre** Fibres shorter than 12.7 mm or 0.5 inch

**Side-dressing** Normally refers to adding an in-crop fertiliser.

**Single skip** A row configuration used in dryland/semi-irrigated situations to conserve soil moisture.

**Sodicity** A measure of exchangeable sodium in relation to other exchangeable cations. A sodic soil contains sufficient exchangeable sodium to interfere with the growth of plants.

**Soil water deficit** The difference between a full soil moisture profile and the current soil moisture level.

**Spray adjuvant** A substance added to the spray tank that will improve the performance of the chemical.

**Spring tickle** Uses shallow cultivation to promote early germination of weeds prior to sowing. These weeds can then be controlled with a non-selective knockdown herbicide.

**Square** Cotton flower bud.

**Squaring nodes** A node at which a fruiting branch is produced; defined as a branch with a square which has a subtending leaf that is fully unfurled and on which all central veins are visible.

**Standing stubble** Stalks from a crop that has been harvested or sprayed out and left to stand in the field.

**Subtending leaves** Are leaves that are connected directly to a fruiting branch.

**Terminal** The growing tip of a cotton stem, particularly the main stem.

**Tex** The yarn number or count in the Tex system is the weight in grams of 1000 m of yarn. For example, a 30 Tex yarn means that there are 30 grams of yarn per 1000 m or 1 km of that yarn.

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

**Trap crop** The aim of a trap crop is to concentrate a pest population into a smaller less valuable area by providing the pest with a host crop that is more highly preferred and attractive than the crop you are aiming to protect.

**Trap crop – Spring** A crop grown to concentrate *Helicoverpa armigera* moths emerging from diapause, usually between September and October. These moths will establish the first generation of larvae in these crops, where they can be killed using biological insecticides (i.e. virus sprays) or by cultivation to kill the resulting pupae.

**Trap crop – last generation/Summer** A crop grown to concentrate *Helicoverpa* moths emerging late in the cotton season from the non-diapausing component of pupae from the last generation in autumn. These pupae are likely to be more abundant under conventional cotton and will have had intense insecticide resistance selection. The aim is to have these moths lay their eggs in the trap crop where the resulting pupae can be controlled by cultivation.

**True leaves** Any leaf produced after the cotyledons.

**Upland cotton** *Gossypium hirsutum* main species grown in Australia.

**Vegetative barrier** Deliberately planted narrow strips of trees and shrubs designed to protect adjacent sensitive areas (remnant vegetation, waterways, other crops) from spray drift by capturing and filtering airborne spray droplets.

**Vegetative branches (laterals)** Are 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.

**Vegetative growth** The roots, stems and leaves as distinct from the reproductive growth of flowers and bolls.

**Vegetative Growth Rate or VGR** Is a measurement of plant height and the number of nodes used to help with decisions regarding early season growth regulators.

**Volunteer cotton** Plants that have germinated, emerged and established unintentionally and can be in field or external to the field (roadsides, fencelines etc). The control of unwanted cotton in the farming system is an essential part of good integrated pest and disease management.

**V Rank** A rank that each cotton variety is given in accordance with its resistance to the cotton disease Verticillium wilt.

**Water-up** Planting the seed into dry soil and applying the first irrigation post planting, is an establishment method that has advantages in hot climates, because it cools the soil. In cool regions, decreases in soil temperature may be disadvantageous.

**Water use efficiency (WUE)** Is a term used to describe the relationship between system inputs and outputs, and will vary depending on the inputs, outputs and boundary conditions.

**Wetters** Wetting agents that increase pesticide coverage by reducing surface tension on the leaf surface so that the droplet spreads over a larger area. Check product label for compatibility and specific requirements.



## Acronyms used in the cotton industry

**AAAA –** Aerial Agricultural Association of Australia.
**ACGA –** Australian Cotton Ginners Association.
**ACRI –** Australian Cotton Research Institute, Narrabri.
**ACSA –** Australian Cotton Shippers Association.
**APSRU –** Agricultural Production Systems Research Unit.
**APVMA –** Agricultural Pesticides and Veterinary Medicines Authority.
**AWM –** Area Wide Management.
**CA –** Cotton Australia.
**CCA –** Crop Consultants Australia Inc.
**CCAA –** Cotton Classers Association of Australia.
**CGA –** Cotton Growers Association.
**CPMG –** *Cotton Pest Management Guide*.
**CRDC –** Cotton Research & Development Corporation.
**CSD –** Cotton Seed Distributors.
**CSIRO –** Commonwealth Scientific & Industrial Research Organisation.
**CTF –** Controlled Traffic Farming.
**CWUI –** Crop Water Use Index.
**DAF –** Department Agriculture & Fisheries.
**DAP –** Di-ammonium phosphate.
**EC –** Electrical Conductivity.
**EHP –** Environment and Heritage Protection (Qld).
**ENSO –** El-Niño Southern Oscillation.
**EM Survey –** Electromagnetic Survey.
**EPA –** Environmental Protection Authority (NSW).
**ESP –** Exchangeable Sodium Percentage.
**GNSS –** Global Navigation Satellite System.
**GPS –** Global Positioning System.
**GPWUI –** Gross Production Water Use Index
**GVB –** Green Vegetable Bug.
**GVIA –** Gwydir Valley Irrigators Association
**HRMS –** Herbicide Resistance Management Strategy.
**ICAC –** International Cotton Advisory Committee.
**ICE –** Intercontinental Exchange.
**IPART –** Independent Pricing and Regulatory Tribunal.
**IPM –** Integrated Pest Management.
**IRMS –** Insecticide Resistance Management Strategy.
**IWM –** Integrated Weed Management.
**IWUI –** Irrigation Water Use Index.
**LEF –** Last effective flower.
**MAP –** Mono-ammonium phosphate.
**MIS –** Multispectral Imaging System.
**NACB –** Nodes above (last) cracked boll.
**NAWF –** Nodes above white flower.
**NFUE –** Nitrogen Fertiliser Use Efficiency.
**NSW DPI –** New South Wales Department of Primary Industries.
**OGTR –** Office of the Gene Technology Regulator.
**PAMP –** Pesticide Application Management Plan.
**PAWC –** Plant available water capacity.
**Qld DAF –** Queensland Department of Agriculture & Fishery.
**RCMAC –** Raw Cotton Marketing & Advisory Committee.
**RFID –** Radio Frequency Identification.
**SAM –** Southern Annular Mode.
**SLW –** Silver Leaf Whitefly.
**SPAA –** Society of Precision Ag Australia.
**TIMS –** Transgenic & Insect Management Strategy (Committee).
**TSP –** Technical Service Provider.
**TSV –** Tobacco Streak Virus.
**TUA –** Technology User Agreement.
**UAV –** Unmanned Aerial Vehicle (e.g. drones).
**USQ –** University of Southern Queensland.
**ULV –** Ultra Low Volume.
**VGR –** Vegetative Growth Rate.
**WUE –** Water Use Efficiency.

# Meet our team

Led by CottonInfo Program Manager Warwick Waters (0437 937 074, warwick.waters@crdc.com.au), and supported by Communications Lead Brad Pfeffer (0457 152 548, brad.pfeffer@crdc.com.au) the CottonInfo team of Regional Extension Officers, Technical Leads & *my*BMP experts are all here to help.

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Regional Extension Officers provide cotton research outcomes and information directly to growers, agronomists, consultants and agribusinesses in each region. Contact your local Regional Extension Officer for the latest research, trials and events in your area.

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Technical leads are experts in their fields and provide in-depth analysis, information and research to the industry, for the benefit of all growers. Contact the technical leads to learn more about water use efficiency, nutrition, soil health and much, much more.

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