2025 AUSTRALIAN COTTON PRODUCTION MANUAL

CRDC

CottonInfo

Bringing you the latest in cotton RD&E


POLYTEX


CP 770

Contents...

COVER: Changing of the seasons, Emerald CQ. Taken by Tegan Brownie.

THIS PAGE: Image by Greg Bramley, Gwydir REO.

Foreword

By **Megan Woodward** (CottonInfo) & **Annabel Twine** (CottonInfo)

On behalf of the organisations responsible for cotton industry research, development and extension (RD&E) – the Cotton Research and Development Corporation (CRDC) and CottonInfo – it is our pleasure to deliver the key reference tool for industry, the Australian Cotton Production Manual, to you again in 2025.

A partnership between the Australian cotton industry and the Australian Government, CRDC exists to enhance the industry's performance and invests in RD&E projects for Australian cotton. CottonInfo is the Australian cotton industry's extension program. Launched in 2012, it is a partnership of the Cotton Research and Development Corporation (CRDC), Cotton Seed Distributors (CSD) and Cotton Australia. The program gratefully acknowledges CRDC's investment in the management of the team and Technical Leads, CSD's investment in the Regional Extension Officers and Cotton Australia's investment in *my*BMP.

The CottonInfo team takes the research and development invested in by the industry and turns it into practical information and knowledge, applicable to you and your farm, to provide information to help you grow.

The Manual is tailored to guide you through the four key phases of the cotton growing cycle:

- **Planning:** From selecting the perfect variety to laying the groundwork for integrated pest management, this section sets the stage for a successful growing season.
- **In-season:** Navigate the nuances of crop establishment, growth, and optimal management practices to maximise yield and quality.
- **Harvest and post-harvest:** Explore the final on-farm stage of cotton management, from preparing for harvest to navigating off-farm processes such as ginning and classing.
- **Business:** Information to help simplify the complexities of your farming business, from marketing your cotton to managing your people.

This year's edition contains a new chapter that looks at greenhouse gas emission reduction. Relevant RD&E is now highlighted near the start of chapters to give you a quick overview of the latest information.

With the growth of the Northern Australian cotton industry, we are working to improve the knowledge and resources available to those expanding areas. A specific Northern Australian production pullout will be sent to Northern growers with the Manual to compliment production in that region. A downloadable version will also be made available at cottoninfo.com.au/northern-aus-cotton-production.

As always, we extend our sincere gratitude to the authors, reviewers and contributors whose expertise enhances this publication and its worth to the cotton industry. We hope the 2025 Australian Cotton Production Manual serves as a valuable resource that offers guidance toward greater efficiency, productivity and best practice.

For more information:

- **CottonInfo:** cottoninfo.com.au
  To access the CottonInfo team of regional extension officers, technical leads and *my*BMP experts for assistance with all your cotton information needs head to the 'Contact Us' page.
- **CRDC:** crdc.com.au
- ***my*BMP:** mybmp.com.au

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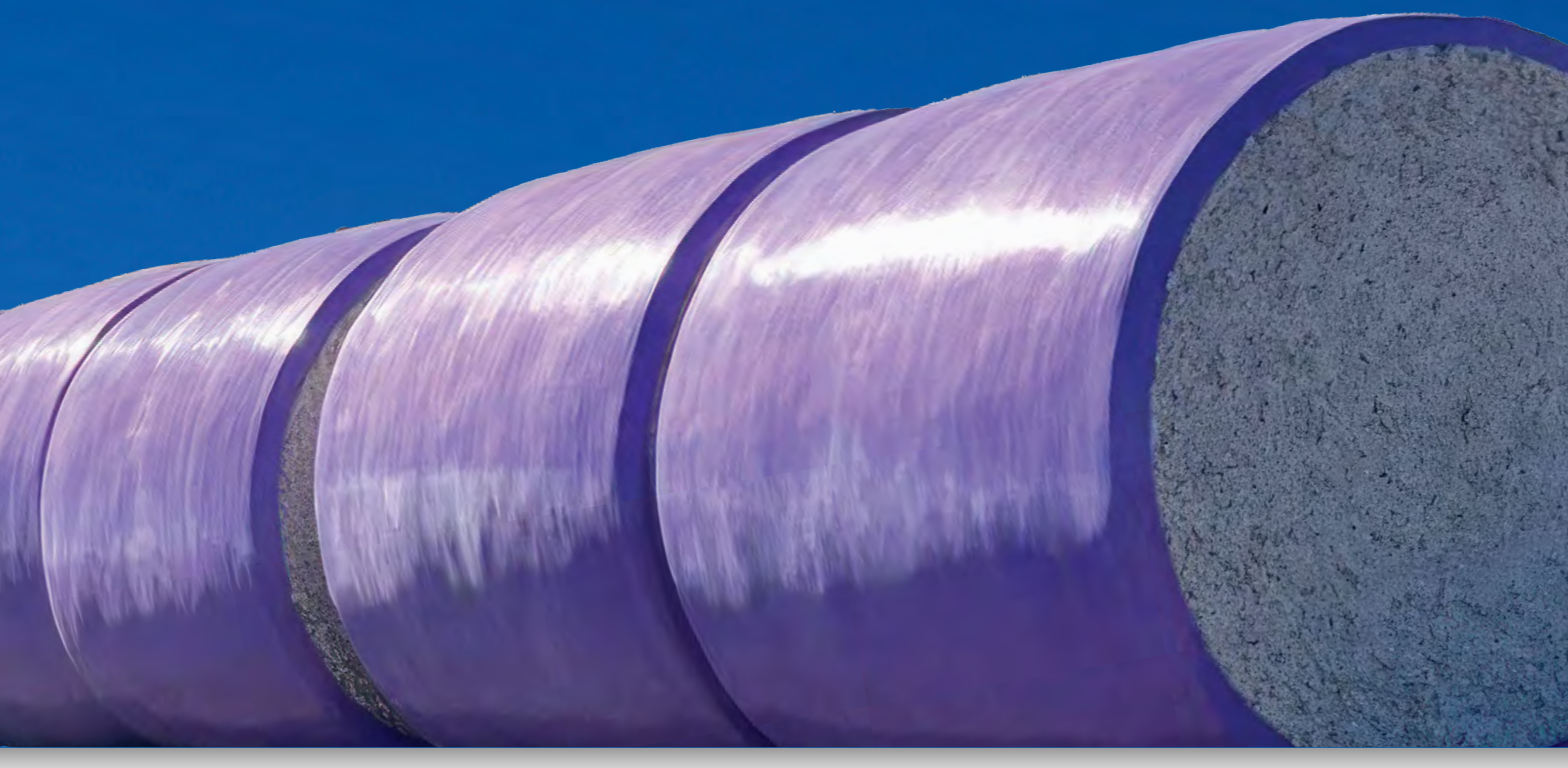
PLAN FOR GROWTH



CGS

cropping + nutrition + agronomy

The Australian cotton industry

By **Megan Woodward** (CottonInfo)

Australia boasts a proud history as one of the world's leading producers of cotton. First taking off in the late 1950s, Australia's modern cotton industry took root in the 60s, flourishing in the Namoi Valley of New South Wales. From humble beginnings, Australia's cotton sector has blossomed into a prized agricultural export commodity.

Today, cotton stands as a cornerstone crop in numerous regions of Queensland and New South Wales and has expanded into the Northern Territory and Western Australia.

Despite accounting for only about 3-5% of the worldwide crop, the Australian cotton industry has global influence, and production is managed by approximately 900 dedicated cotton growers on around 1500 farms spread across Australia.

As a major player in the global cotton market, Australia's entire national cotton crop is exported, contributing to an impressive annual export value that was tipped to reach $3.8 billion in 2024-25 according to the Australia Bureau of Agricultural and Resource Economics and Sciences (ABARES).

Beyond its economic impact, the cotton sector plays a pivotal role in supporting regional and remote rural economies. With over 12,000 individuals employed across more than 250 communities, it serves as a vital economic lifeline, generating substantial wealth and stability.

The industry's thriving culture of innovation, bolstered by a robust RD&E framework, stands as a foundation of its success. Through RD&E-driven advancements, practices have evolved significantly, leading to a remarkable reduction of insecticide use by over 97% and a noteworthy enhancement of water-use efficiency by 48%.

Today's top cotton producers have achieved a major milestone, yielding more than two bales of cotton per megalitre (ML) of water. This achievement nearly doubles the industry average from just a decade ago, showcasing the industry's commitment to sustainable practices and efficiency.

Moreover, the industry remains at the forefront of environmental management systems, actively engaging in climate variability mitigation and adaptation efforts, all of which is underpinned and supported by CRDC and Cotton Australia's PLANET. PEOPLE. PADDOCK. Sustainability Framework. The framework is focused at farm-level and is helping to achieve the Australian cotton industry's vision of being a global leader in sustainable cotton production (australiancotton.com.au/planet-people-paddock).

These achievements, along with a number of other collaborative and strategic industry efforts, exemplify the commitment to recognising and addressing the need for a dynamic RD&E system to drive meaningful progress.

Growing cotton through best management practices

The Australian cotton industry has invested heavily in its best management practices program, *my*BMP. Extensive industry experience and research underpin *my*BMP – from growers, researchers and industry bodies – making it a key online tool for growers to achieve best practice in growing cotton. *my*BMP provides all cotton growers with centralised access to 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 and register to access best management information. Once registered, you can watch virtual tours of all the *my*BMP features from the Grower homepage. Call your local Cotton Australia Regional Manager who will arrange a farm visit or call 1800cotton (1800 268 866). The *my*BMP program is proudly supported by Cotton Australia and the Cotton Research and Development Corporation (CRDC).

Connecting growers with research to help them grow

Australian cotton growers have enthusiastically embraced RD&E leading to significant advancements in water use efficiency and pesticide reduction on farm. The CottonInfo program was launched in 2012 and is a partnership of the Cotton Research and Development Corporation (CRDC), Cotton Australia and Cotton Seed Distributors (CSD). Under the CottonInfo program, CRDC invests in the management and communication needs of the CottonInfo team and the Technical Leads, CSD invests in the Regional Extension Officers and Cotton Australia invests in myBMP.

CottonInfo is tailored to assist growers to enhance productivity and profitability through best practice, in coordination with *my*BMP. Additionally, it serves as a vital resource when addressing emerging or urgent issues within the industry. The CottonInfo team, comprising of regional extension officers, technical experts, and *my*BMP specialists, is dedicated to providing growers with the latest research-driven information across various cotton-related topics. For more visit cottoninfo.com.au.

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, by focusing on five priority areas: advocacy, trust, sustainability, leadership and governance. 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 and is a partner in CottonInfo.

cottonaustralia.com.au

CRDC: science underpinning the cotton industry's success

The Cotton Research and Development Corporation (CRDC) delivers outcomes in cotton 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 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.

Since CRDC formed in 1990, $444 million has been invested in more than 4000 cotton RD&E projects by growers and the Government, 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. Meanwhile, the single biggest investment in CRDC's history – the five-year CRDC, GRDC and Goanna Ag collaboration, Weather and Networked Data (WAND) – has an estimated benefit-cost ratio of $12.54 to $1; that is, a $12.54 benefit returned to growers and the wider industry for every one dollar invested via CRDC.

All of CRDC's investments are guided by Clever Cotton: CRDC's Strategic RD&E Plan for 2023-28. The plan is built on three pillars (Paddock, People and Planet) and nine investment areas:

- Paddock: data-driven decisions, adaptive systems, connected market intelligence.
- People: design and innovation, leadership and capacity, adoption and impact.
- Planet: natural capital, carbon, circular economy.

CRDC's goal through this plan is to add an additional $1 billion in economic value to the Australian cotton industry.

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 formed 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 while providing 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.

csd.net.au

The Australian cotton industry: working together

Collaboration is king in the Australian cotton industry. The many joint programs and initiatives where industry bodies, research organisations and individual researchers, consultants, agronomists and growers work together all contribute to the industry' success.

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 and Regional Development.
- Queensland Department of Primary Industries.
- Department of Agriculture, Fisheries and Forestry
- Crop Consultants Australia.
- Universities.

The cotton plant

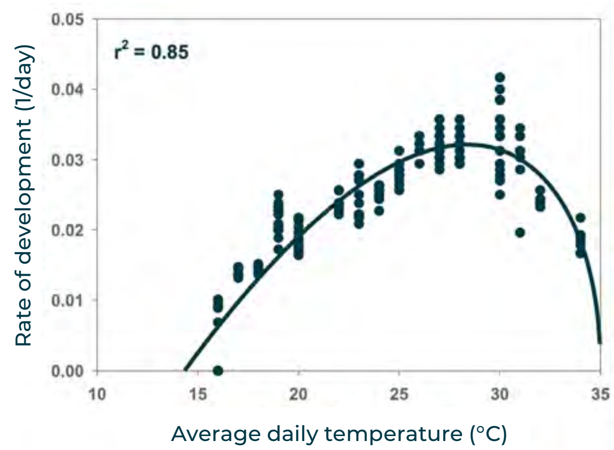
By **Sandra Williams** (CSIRO) &
Michael Bange (Cotton Seed Distributors)

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; grown commercially it rarely exceeds 1.6 m, although its tap root can reach depths of 1.8 m.

While 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), cotton in Australia is managed as an annual crop, and 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.

When cotton is picked, the seed and the attached fibre are harvested, compressed into rectangular or round 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. Cotton seed, a valuable by-product of the ginning process, is used as livestock feed and pressed for oil.

FIGURE 1.1 How quickly cotton develops is impacted by temperature. This graph shows the development rate (comparing the daily fraction of growth up to first square for a range of average temperatures) under controlled environment conditions in a glasshouse.
(SOURCE Bange and Milroy)



Dryland cotton...

- Being perennial, cotton's priority is survival. So during periods of stress, the plant can drop fruit to preserve its resources for supporting the growth of existing leaves, branches, roots, and older fruit.
- In good growing conditions 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.

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. Being a perennial, the cotton plant has an indeterminate growth habit. This means that the plant develops fruit over an extended period, so can often compensate after stress (such as pest attack or physiological shedding), by continuing to grow and produce new fruit if time and environmental conditions permit.

TABLE 1.1 Cotton growth stages with target DD 15_32 approach.

Cotton development	Notes	Accumulated DD 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.	50
Vegetative growth	A cotton plant adds a new node every 29 DD or 2–4 days. This rate will slow as the crop approaches cut-out to around every 62 DD.	
First square	A square is a flower bud. The first square occurs on the first fruiting branch at approximately the 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.	339
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 petals 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.	584
Max boll size	After the flower petals fall off, a fertilised boll (fruit) is visible. After fertilisation, the boll begins to develop. In 20–25 days this boll will reach its maximum boll size. 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.	708*
Open boll	Under optimum conditions it takes about 50 days from flowering to having an open boll (first position bolls).	1093*

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

Cotton development and day degrees

The development of a cotton plant is strongly influenced by temperature (Figure 1.1). 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.

The new DD formula used for Australian cotton production has a base temperature of 15.6°C (average) and an optimum of 32°C (maximum):

$$\text{Day Degrees} = (T_{max} - T_{min}) \div 2 - 15.6$$

where Tmax is less than 32°C

Or

$$\text{Day Degrees} = (32 - T_{min}) \div 2 - 15.6$$

where Tmax is greater than or equal to 32°C

Tmin is the minimum temperature and Tmax is the maximum temperature for the day. Where the daily value of DD is below zero the daily DD = 0.

This accumulation of DD has been calibrated with specific targets for a range of cotton development events (Table 1.1). CottonTracka® provided by Cotton Seed Distributors can be used to calculate and track day degrees during the season (Figure 1.2).

For further information watch 'Using day degrees in cotton production' on the CottonInfo YouTube channel youtube.com/cottoninfoaust

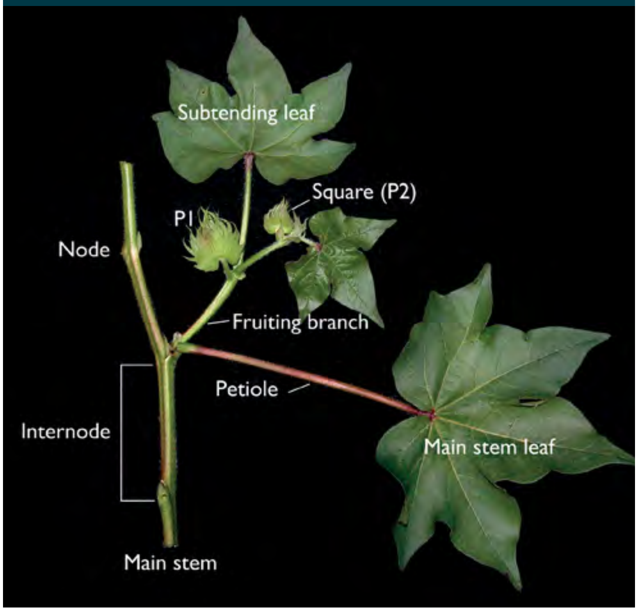
Cotton growth

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 as the plant continues to grow.

The first fruiting branch will generally arise from nodes six or seven (depending 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 1.3 shows a fruiting branch that has formed above a main stem leaf. This branch has produced two fruiting structures along with their subtending leaves.

Fruit develops from a tiny flower bud or 'square' into a hibiscus-like flower that desiccates after about 3 to 4 days, exposing a small green boll. This boll will continue to grow until it matures. Paul Grundy, Qld DPI

FIGURE 1.3 A developing fruiting branch and associated structures (P - stands for position). Paul Grundy, Qld DPI

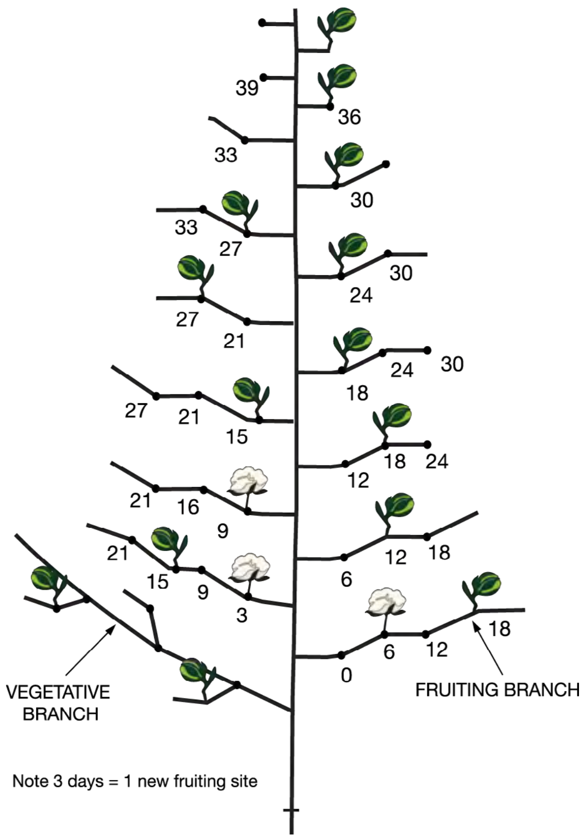


The pattern of development and growth of the plant is described in Figure 1.4, where the development of new fruit occurs at the top of the plant on new fruiting branches as well as along older fruiting branches. Maintaining vigorous vegetative growth before flowering is important as it is these leaves, 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 divert resources to the developing fruit. If resources surplus to the needs of the developing fruit are available, additional vegetative and reproductive growth will occur.

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. Generally, the more fruit produced before cut-out, the higher the yield.

FIGURE 1.2 CottonTracka® available at www.csd.net.au can be used to calculate day degrees and be used to track your crop's progress during the season.

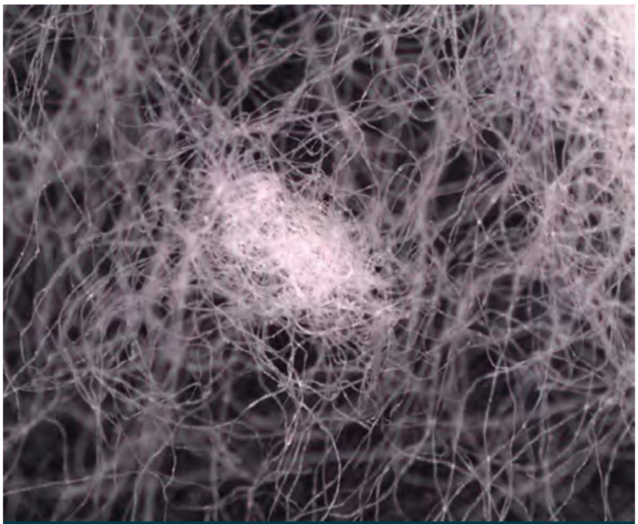
FIGURE 1.4 Rate of development of fruiting sites on a cotton plant, adapted from Oosterhuis 1990. Numbers represent days from appearance of first square to the production of a new fruiting site.



At cut-out the supply of carbohydrates, water and nutrients equals the amount needed by the developing bolls and fruit development 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 resources available for new growth. NAWF (nodes above white flower) is the number of nodes from the uppermost first position white flower to 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. Crops are considered mature and ready for defoliation decisions if they have reached greater than 30% mature bolls as defined by the boll cutting technique (approx 4 or 5 Nodes above cracked boll (NACB)). Information on measuring NACB can be found in the *Preparing for harvest* chapter.



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).
CSIRO

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 1.2.

USEFUL RESOURCES:

For more information see *Managing for fibre quality* chapter.

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

Bange, MP, 2022. Where did DD15_32 come from? – Improving our understanding of temperature responses of cotton. *The Australian Cottongrower* 43(7): 17–20.

TABLE 1.2 Cotton fibre development.

Stage	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	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	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	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**

Before a farmer makes a decision to grow cotton for the first time it is important that they understand both the unique requirements of the crop and their responsibilities at each stage of the growing process. By doing so, growers will be better equipped to work towards a positive first year cotton growing experience.

With cotton being grown as far north as the Northern Territory and as far south as the Victorian border it's understandable that there are a variety of factors involved in producing a profitable and sustainable crop, and what might work in one location may not work in another.

Growers agree however that it's important to plan for the long term and to approach each task with dedication and commitment.

What is evident and demonstrated regularly among the cotton growing community is the strength of the bonds formed and the value in the information shared. The Australian cotton industry benefits from the extremely cohesive and cooperative environment fostered by growers and their families. There are several industry organisations which support growers, from research extension to agronomy, community relations and advocacy. You will also find that your fellow cotton growers, including your next-door neighbours, will routinely be prepared to willingly share their experiences and offer invaluable advice. It's how cotton growers work.

Some questions for first time cotton growers

- **Are you committed to growing cotton?**
  To be successful you must have a plan – be thorough, careful and timely in managing all aspects of your business and cotton production practices.
- **Who will harvest your crop?**
  Cotton picking machinery is expensive therefore most new growers employ picking contractors, but in good seasons there is high demand and finding a contractor can be difficult, so you will need to plan ahead.
- **Have you planned for cotton?**
  Some of 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 will growing 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.
- **Are you committed to IPM and reducing 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 follow the industry's best management practices (BMP) 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. Water availability is an important part of this decision therefore a water budget is crucial, aligned with your likely crop requirements. Irrigators should also consider whether their system is adequate for timely and efficient water application and can meet peak water demand. If you are considering dryland cotton, ensure that your soil's plant available water capacity (PAWC) and starting profile is sufficient and climate risks are considered.
- **Are you aware you need to comply with GM cotton regulations?**
  Growing genetically modified (GM) cotton means that you must sign a contract with the owner of the technology and in some cases you have to undertake specific training prior to signing the Technology Use Agreement (TUA). 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 *Preventing pest problems* chapter.
- **Have you talked to your neighbours about your plans?**
  It is every grower's responsibility to ensure that chemicals do not drift outside property boundaries. 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. Cotton is highly susceptible to phenoxy herbicides such as 2,4-D. 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. 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.

  There is also a new spray hazard warning system in Queensland and New South Wales for cotton and grain growers. The Weather and Networked Data – or WAND – technology provides real time weather data about the presence/absence of hazardous temperature inversions. To access it visit wand.com.au or for more information visit www.goannaag.com.au/wand-network

  Cotton growers need to be very mindful about the location of beehives, as foraging bees can be susceptible to some insecticides. BeeConnected can help identify if hives are nearby and facilitate communication between spray applicators and beekeepers (beeconnected.org.au). Refer to the *Managing pests in-crop* 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 for some, and it is recommended that you speak to a financial advisor if you feel you need advice. 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 austcottonshippers.com.au

- **Is your current machinery adequate?**
  Growing and harvesting cotton demands fit for purpose machinery and your existing farm equipment may not be suitable. Be sure about your long-term commitment to cotton growing before investing in additional equipment, and remember hiring contractors may be an option.
- **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. A great starting point can be local, experienced cotton farmers for general advice and on selecting the right consultant. Your local Cotton Grower Association (CGA) will be pleased to assist you, or for more information, contact Crop Consultants Australia at 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 informed of industry developments?**
  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. You can subscribe to eNews and other resources via:

- cottoninfo.com.au/subscribe
- crdc.com.au/subscribe
- cottonaustralia.com.au

Refer to the Australian cotton industry organisations on page 9.

myBMP

***my*BMP** – **Best Management Practices –** is the Australian cotton industry's voluntary cotton production certification standard. It is a comprehensive farm and environmental management system designed to improve all aspects of on-farm cotton production. *my*BMP uses practical tools to ensure growers are implementing world's best practice to produce economically, socially and environmentally sustainable cotton.

*my*BMP provides Australian cotton growers with:

- a central online access point to the industry's best management practice standards
- technical support
- self-assessment mechanisms
- practical tools
- an industry extension team to support growers on-farm
- independent auditing.

*my*BMP also acts as the industry's assurance mechanism. The program helps the industry to manage risks and provides evidence to stakeholders and the wider community that the industry is committed to the highest possible social and environmental standards of practice. Ahead of others in agriculture, the cotton industry commissioned the first whole-of-industry, independent environmental audit in 1991, and committed to repeating the comprehensive assessment every ten years. The fourth Independent Environmental Assessment was published in April 2024.

With a focus on environmental and social sustainability, the *my*BMP program is built upon five core principles:

- **COMMITMENT** to sustainably balancing social, economic, regulatory, and environmental factors.
- **RECOGNITION** that we cannot stop improving, investing, researching, and sharing best practice.
- **UNDERSTANDING** that working at a national scale drives international improvements.
- **BELIEF** in the benefit of working cooperatively with similar programs to advance sustainable cotton.
- **CONFIDENCE** in traceable cotton identification systems.

Did you know: There are currently 625 *my*BMP certified farms in Australia.

Information within *my*BMP is categorised into 10 key modules for growers:

- **Biosecurity** – for prevention, management and control of pests and diseases
- **Energy and Input Efficiency** – for more efficient energy inputs such as electricity, fuel and fertilisers
- **Fibre Qualit**y – for growing the best quality cotton possible
- **Human Resources and Work Health and Safety** – helps growers manage employees and contractors whilst providing a safe and compliant workplace
- **Integrated Pest Management (IPM)** – for management of pests, weeds and diseases
- **Pesticide Management** – for all aspects of pesticide management, storage and use on farm
- **Petrochemical Storage and Handling** – for managing fuels and lubricants on farm
- **Soil Health** – for maintaining and/or improving soil quality and fertility
- **Sustainable Natural Landscape** – for managing the vegetative and riparian assets on farm
- **Water Management** – covering water quality, efficiency of storage and distribution for both dryland and irrigated farming practices.

Australia's *my*BMP-accredited farms produce among the world's best cotton using responsible and efficient management practices. The program includes online self-assessment mechanisms and practical tools, and auditing processes to ensure that Australian cotton is produced according to best practice.

Where is *my*BMP certified cotton grown in Australia?

Certified cotton is grown in many regional Australian communities stretching over 4000 km from Kununurra in the northwest of Australia, to the Northern Territory and south to the Victorian boarder.

The number of farms growing cotton fluctuates depending on water availability.

Australia is a comparatively small global cotton producer, but the world's third-largest cotton exporter in a good season.

The preferred planting time for cotton in Australia varies from region to region starting in late August in Central Queensland through to January/February in Northern Australia.

Planning

Climate for cotton growing

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

Ideal conditions for cotton are sunny warm days with maximum daytime temperatures between 28 to 32°C and overnight minimums of 16 to 20°C. High temperatures combined with humidity can put stress on the crop by not allowing enough moisture to transpire from the plants to keep cool and function optimally (elevated canopy temperatures may reduce photosynthesis). Night temperatures above 22°C will begin to increase respiration processes (which consume resources), while average daily temperatures below 15.6°C or above 32°C may significantly delay crop development. Extended periods of low solar radiation (cloudy weather), too much or too little rain/water, and excessively hot weather, particularly during flowering can all combine to impact yields.

Planning

Assessing the climate risk for the 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), Southern Annular Mode (SAM) and Madden-Julian Oscillation (MJO).

El Niño-Southern oscillation index (ENSO)

ENSO is a coupled atmospheric/ocean phenomenon tracking the moisture 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 IOD value is favourable for moisture supply and cooler spring conditions.

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 IOD conditions consider using statistical models such as analogue years, SOI Phase seasonal outlook and check historical probabilities using 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 that features commentary from leading domestic and international research agencies.

Southern Annular Mode (SAM)

The SAM is a measurement of the mean sea level pressure around latitudes in Antarctica that looks at the difference or 'gradient' of the air pressure patterns that can affect daily variations in eastern Australian rainfall and temperatures. The key feature of the SAM is its influence on easterly moisture circulation patterns from 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. See the MJO CottonInfo YouTube explainer video at youtu.be/TXab5n3HxHA

TABLE 3.1 Tips for planting.

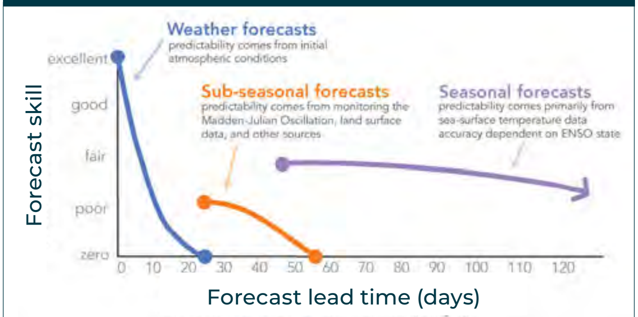
Things to consider	Rationale
ENSO phase	Models are more accurate in defined La Niña/El Niño events. ENSO 'neutral' does not mean average and variability will increase. Proceed with caution during neutral ENSO years.
Mode of variability the IOD is in	The IOD cycle commences in May and matures in October/November. A positive IOD will reduce moisture during planting in central and southern areas; conversely a negative IOD can improve planting conditions.
Use multiple sources of information for seasonal outlooks and weather modeling	While the Australian Bureau of Meteorology provides multiple predictive products, It is good risk management practice to also glean information from other research agencies. Any trends towards wet/dry can can give us more confidence.
Seasonal predictions for rainfall are most useful in winter/spring seasons	The primary ingredient for a General Circulation Models (GCM) 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 days delayed onset of rainfall in January and February.
Heat wave advice from the BOM site	Heat wave predictions are improving. Go to bom.gov.au and search for 'heat wave'. The forecast can aid in irrigation management decisions.

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 understand the 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 (monthly eNewsletter sent via CottonInfo) 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 3.1. Figure 3.1 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.

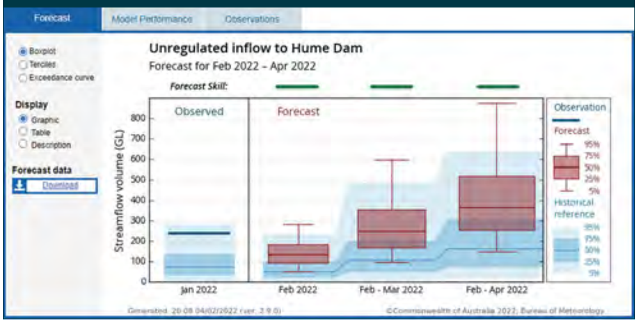
FIGURE 3.1 Forecasting skill for three different types of weather and climate models.
(Source: International Research Institute, 2015)



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 to help irrigators improve their water management and decision-making capability. Figure 3.2 provides an example of a an inflow prediction for 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 access streamflow forecasts and to learn more about this decision support, go to bom.gov.au/water/ssf/index.shtml

FIGURE 3.2 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 Australian CliMate App.

- **Australian CliMate:** Download the app (iPhone or Android) or go to 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 3.2 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 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. Refer to Table 3.3.

TABLE 3.3 Tips for in-crop.

Things to consider	Rationale
Survey seasonal temperature outlooks	These are useful for determining likely evaporation rates and crop water demand, and are 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 for 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' eNews 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's 'Water and the Land' site (bom.gov.au/watl) 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.

USEFUL RESOURCES:

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.

To sign up for the Moisture Manager (and other CottonInfo communications) visit cottoninfo.com.au/subscribe, and follow us on Twitter @CottonInfoAust. Visit 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. climateapp.net.au

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

TABLE 3.2 Southern Annular Mode (SAM) – Correlation strength with rainfall in cotton growing areas.
(Source: CottonInfo, BOM, CSIRO 2014)

	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/Sep	Sep/Oct	Oct/Nov	Nov/Dec	Dec/Jan
Emerald									High			
Dalby									Medium	High	Medium	
St George		Medium								Medium		Very High
Boggabilla								Medium		Medium		
Moree					Medium		Medium		Very High			
Wee Waa					Medium		Medium			Very 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).

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/rainfed 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 major production areas is 15 October to 15 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 during the production season in your region.
- Be aware of the ability of crops to access moisture in skip rows. Some soil types will limit root growth.

RD&E in focus

In coming years, the Australian cotton industry will move to having exclusively varieties that contain the XtendFlex® trait, which is tolerant to over-the-top applications of glyphosate, dicamba and glufosinate-ammonium herbicides, providing flexibility to manage a wider-spectrum of difficult-to-control and resistant weeds in-crop. The range of herbicides with different modes of action that can be applied over cotton crops can also add significant value in controlling resistant weeds.

Rainfed growers and their consultants would like to fully exploit the XtendFlex technology to help manage weeds and costs. Investigations are needed across all regions where rainfed cotton systems are present such to deliver this technology effectively and responsibly.

A project supported through CSD's Richard WIlliams initiative along with Bayer and NuFarm will assist the formation of rainfed grower groups who will share their experiences on the use of XtendFlex® at workshops and at field days. It is hoped that sharing these experiences will help facilitate the responsible uptake of this technology.

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 4.1). 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.

TABLE 4.1 Average rainfall for cotton producing regions for October to April versus December to March.
(Source: ARM Online – *www.armonline.com.au*)

Region	Rainfall October to April (mm)	Rainfall December to March (mm)
Hillston	232	134
Narromine	350	210
Warren	314	190
Gunnedah	429	269
Coonamble	344	217
Wee Waa	411	261
Bellata	445	289
Moree	414	269
Croppa Ck	426	281
Goondiwindi	419	275
Dalby	462	299
Biloela	487	326
Emerald	464	329

Note for growers: you will notice throughout the Manual, references to both dryland and rainfed cotton. These terms essentially mean the same thing.

Predicting dryland cotton yield potential

The examples provided in this chapter use the OZCOT crop simulation model developed by CSIRO (using climate data from 1957 onwards) with the following assumptions: 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. The model simulates potential yield and 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 15 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 15 September for dryland cotton production than for most other areas especially for the period 15 October to 15 December (Table 4.2). Refer to the *Climate for cotton growing* chapter for more information on assessing the climate risk for the coming season.

TABLE 4.2 Probability of failing to sow based on the sowing opportunity for different periods.

Region	Probability of failing to sow (%)			
	15 Sep – 15 Oct	15 Oct – 15 Nov	15 Nov – 15 Dec	Overall 15 Sep – 15 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

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 4.1).

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, 120 inch [3 m]). 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 4.2 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 yields for the alternate row configurations are generally 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. Similar to the improved yield of the 1 in 1 out configuration compared to double skip rows, it is highly likely that the equidistant spacing for 60 inch/1.5 m cotton row spacing will also comparably have higher levels of yield improvement over the single skip configuration spaced at 1 m.

In Tables 4.3 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

FIGURE 4.1 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 has been measured rather than simulated.

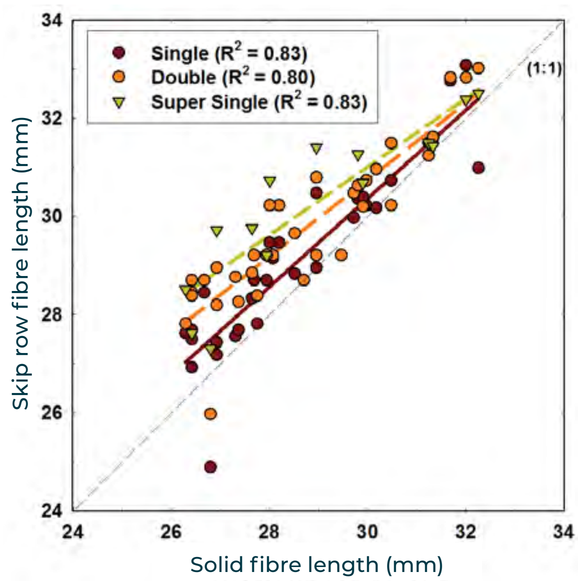


FIGURE 4.2 Illustrates the relationship of lint yield of alternate row (80 inch / 2 m) and super single skip row configurations to double skip row configurations. Also shown is the 1:1 line (dotted). Where values are on the 1:1 line they are equal. Note that this data has been measured rather than simulated.

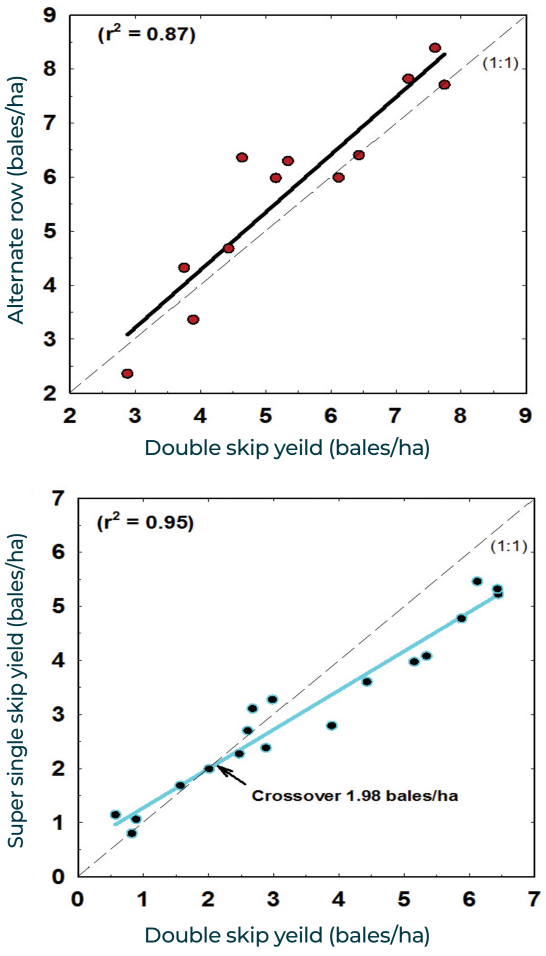
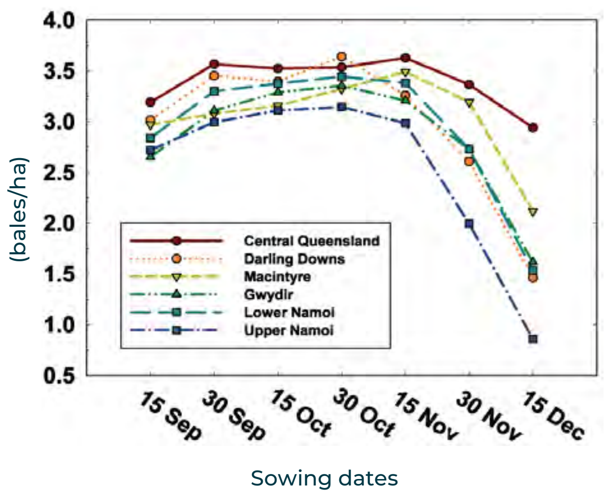


FIGURE 4.3 Change in expected mean crop yield with sowing date. Yields have been predicted using a single skip configuration and plant available water holding capacity of 200 mm.



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) (Table 4.3).

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 15 October to 15 November. In all regions of this study, mean yields of crops grown in single skip configuration were less when crops were sown early before 30 September (Figure 4.3). The latest sowing date where there was no substantial penalty to average yield was 15 November for all regions with the exception of the Darling Downs, where yield reduced after 30 October. Later sowings within this window can give 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 15 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.

Price and cost risks in dryland

Significant consideration must be given when planning dryland cotton systems to the variability associated with cotton price and input costs. Recent research utilising the OZCOT crop simulation model to capture environmental effects was coupled with historical input costs and price variability. The research investigated different row configurations and planting time effects. Results showed that while solid configurations had the highest yield sown at the end of October the use of skip row configurations that managed costs still had the best chance of achieving positive gross margins across all regions, despite the added price and cost volitility.

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 grower-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 (*Climate for growing cotton* chapter) provide useful tools to help evaluate the risk. Refer also to Figure 5.3 in Chapter 5 for further explanations of row configurations.

TABLE 4.3 OZCOT predictions, 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	Solid row configuration						Single skip row configuration						Double skip row configuration					
	200 mm plant available soil water			250 mm plant available soil water			200 mm plant available soil water			250 mm plant available soil water			200 mm plant available soil water			250 mm plant available soil water		
	Mean	80%	20%	Mean	80%	20%	Mean	80%	20%	Mean	80%	20%	Mean	80%	20%	Mean	80%	20%
Gunnedah	3.1	1.9	4.6	3.9	2.5	5.5	3.3	2.4	4.3	3.8	3.0	4.8	3.2	2.5	4.0	4.0	2.9	4.9
Wee Waa	3.3	2.0	4.8	4.0	2.7	5.7	3.4	2.4	4.4	4.2	3.2	5.0	3.4	2.3	4.6	4.2	2.7	5.2
Bellata	3.4	2.2	4.7	4.1	2.8	5.4	3.6	2.6	4.8	4.3	3.4	5.0	3.6	2.6	4.6	4.3	3.1	5.4
Moree	3.1	2.0	4.4	3.8	2.7	5.3	3.3	2.2	4.4	4.0	3.0	5.0	3.3	2.4	4.3	3.4	2.5	4.2
Croppa Ck	3.4	2.1	4.9	4.1	2.8	5.5	3.6	2.4	4.8	4.4	3.2	5.5	3.3	2.3	4.5	4.3	3.1	5.9
Goondiwindi	3.3	1.9	4.7	3.9	2.5	5.4	3.4	2.4	4.3	4.1	3.4	4.9	3.4	2.3	4.3	3.6	2.8	4.3
Dalby	3.4	2.0	4.7	4.1	2.8	5.2	3.6	2.5	4.4	3.9	3.1	4.6	3.2	2.2	4.0	4.0	2.7	5.2
Biloela	3.4	2.5	4.5	4.3	3.2	5.5	3.5	2.7	4.0	3.9	3.0	4.6	3.4	2.6	4.0	4.2	3.3	5.1
Emerald	3.5	2.4	4.4	4.2	3.1	5.2	3.5	2.5	4.5	4.3	3.1	5.2	3.4	2.4	4.2	4.1	3.1	5.2

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.
- Dryland production systems require varieties that yield well in water-limited situations – refer to *Variety selection* chapter.
- Cotton can be a useful rotation option in many dryland cropping systems. Refer to *Healthy Soils* chapter 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 to ensure 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 *Preventing pest problems* chapter.
- 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 *Post harvest pest & stubble management* chapter.
- For an example of a dryland cotton gross margin refer to CottonInfo's gross margin budgets: cottoninfo.com.au/publications/australian-cotton-industry-gross-margin-budgets

USEFUL RESOURCES:

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

Bange, Michael (2024) Home Truths on Row Configurations youtu.be/M0mtYyzJIpE

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Godfrey, S.S. et al. (2023). Untangling the mix of agronomic and economic uncertainties inherent in decisions on rainfed cotton. Crop and Pasture Science 74: 1223-1237.

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Row spacing in dryland cotton: youtu.be/0mc0jMVtdz4st

Dryland cotton. Ruth Redfern

Irrigation system choices & water budgets

Contributing authors: **Louise Gall** (Gwydir Valley Irrigators Association and CottonInfo), **Janelle Montgomery** (CRDC), and **Malem McLeod** (NSW DPIRD)

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.

Preparation of a water budget each season enables you to estimate how much cotton can be grown with the available irrigation water, stored soil water and forecast rainfall.

Water budget

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.

Estimating crop water requirements (crop evapotranspiration or ETc) is crucial for planning the planted area, crop mix and irrigation management. Daily crop evapotranspiration (ETc) is the water transpired by a crop and evaporation from the soil/crop surface 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 water depth over 1 ha. Total ETc varies seasonally but will usually be within the range provided in Table 5.1.

The daily ETc varies throughout the season in response to weather conditions, crop stage (canopy size) and soil water availability as shown in Figure 5.2.

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 (For more information see WATERpak 2.1 p141).

The potential crop water use (that you adjust given seasonal conditions) can then 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

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 (Figure 5.1). Irrigation scheduling decisions should take place when soil moisture is between field capacity and refill point, known as the readily available water (RAW).
- Seasonal farm water budgets help inform planting decisions and optimise production per megalitre of water.
- Record seasonal data 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.

RD&E in focus

Bankless irrigation in the north has lower slopes than traditional siphon designs, and with higher flowrates, the fast-moving large volumes in furrows has growers asking: "When is the best time to turn off water into my bankless?".

Research work by CAE at UniSQ has integrated commercial sensors into furrow irrigation using SISCOweb to automatically optimise irrigation by providing the best time to shut off inflow, while still targeting required irrigation depth. SISCOweb delivers an SMS to growers, an automated live update of Padman gate close times, and reports irrigation performance.

Now, this live surface irrigation optimisation tool has been adapted to bankless. SISCOweb in bankless automatically sends the head-ditch inflow shutoff time to growers, using just three commercial water advance sensors. Growers can now control where those large irrigation volumes move to under the crop canopy, down the length of the field. No other technology automatically offers that level of control over bankless irrigation. This overcomes the limitation of only using an end-of-row sensor, which cannot account for the fast-moving large volumes of water moving in bankless irrigation.

FIGURE 5.1 Plant available water capacity. (Source: WATERpak p149)

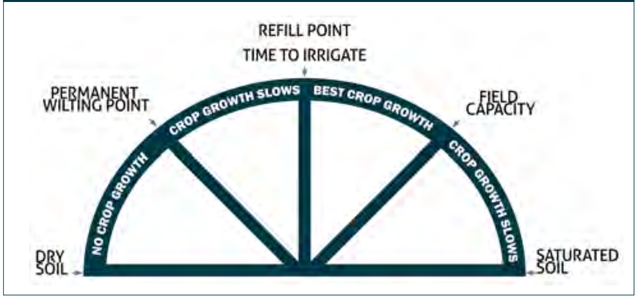


FIGURE 5.2 Nominal seasonal daily water use (mm/day) for cotton production. (Source: WATERpak Figure 2.1.3)

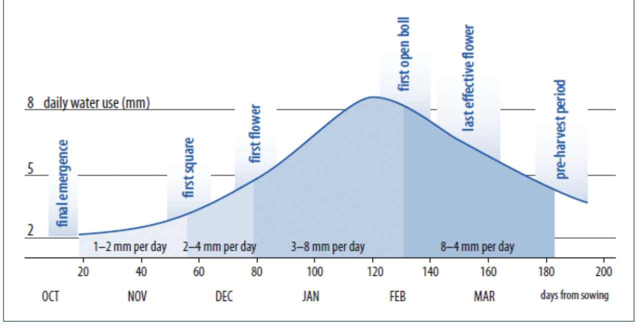


TABLE 5.1 Water requirements of crops. (Source: WATERpak Table 2.1.2)

Crop	Crop evapotranspiration requirement[1] (mm)	Peak daily water use (mm/day)			Critical irrigation periods
		ETo = 6 mm	ETo = 8 mm	ETo = 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. ETo = Evapotranspiration.
Sources: WATERpak.

or extraction limits. Investigation of rainfall records as well as historic and current climatic patterns will help predict what sort of season to expect. Refer to *Climate for growing cotton* chapter. The Bureau of Meteorology (bom.gov.au) or Australian CliMate (climateapp.net.au) provide information on climate and seasonal progress and can be used to complement local farm data.

An understanding of available water supply includes soil water levels, irrigation water allocations, rainfall runoff, total storage capacity and ability to trade water. You need to review available water supply and consider what area to plant and how much to irrigate.

Finally, an understanding of the irrigation system efficiency will be needed. You can estimate what proportion of the water across the farm is used by the crop. An Irrigation system efficiency of 64% would indicate that 36% of irrigation water is lost through deep drainage, in field leaching, evaporation or seepage from on farm storages and channels.

Water use efficiency...

Water use efficiency is a generic term that describes the optimisation of production per megalitre of water. The two most useful indices (that can be applied at a field or farm scale) are:

- Irrigation water use index (IWUI) relates total production to irrigation water applied. It does not account for rainfall or stored soil water and is therefore only useful for comparing between nearby fields or farms in the same season. It should not be used where there may have been differences in rainfall received, and care should be taken to reference it as irrigation water use to avoid misunderstandings.
- 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 water. Measuring soil water 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).

USEFUL RESOURCES:

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

IrriSAT – remote sensing determines site specific crop coefficients, providing local evapotranspiration (ETc) or daily crop water use – www.irrisat.app

GoField – 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 – goannaag.com.au/gofield

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

Australian Water Outlook – awo.bom.gov.au/products/historical/evapotranspiration-modelledPotential

Calculating the area to irrigate

The maximum area of crop that can be irrigated is determined by the annual crop water requirements, the water available, the irrigation system capacity and efficiency and factors specific to the location, farm and grower.

Area = Irrigation water available ÷ Annual crop irrigation water requirement x 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 4.5 ML/ha.

At planting, the grower has 300 ML in storage and 700 ML of available allocation, totalling 1000 ML. The grower estimates that another 500 ML will be harvested during the season. This means there is approximately 1500 ML of irrigation available. Assuming an irrigation system efficiency of 64%, the area (ha) that can be irrigated can be calculated:

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 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 –
cottoninfo.com.au/publications/water-preparing-water-budget

WATERpak Chapter 3.3 Water use efficiency, benchmarking and water budgeting, pp 18–21 – 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:

- Fully irrigate a reduced area.
- Deficit irrigate a larger crop area (See *Irrigation management* chapter).
- Include different crops that require less irrigation.
- Partially irrigate 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 range can help schedule limited irrigations to avoid water stress during peak flowering and boll fill (goannaag.com.au/gofield). Different crops have different seasonal ETc requirements and thus crop choice, maturity length and planting time can be used to make the most of limited water.

If the estimate of irrigation water supply is pushed below 5–6 ML/ha, then partially-irrigated skip row may be an option (WATERpak 3.3 p266). Skip row cotton provides an alternative to increase the area of cotton that can be grown, allowing an upside in production if conditions improve and less downside in potential fibre quality discounts if the season deteriorates.

FIGURE 5.3 Alternative row configurations.
(Source: 'Getting the most out of skip row irrigated cotton' by CSD)

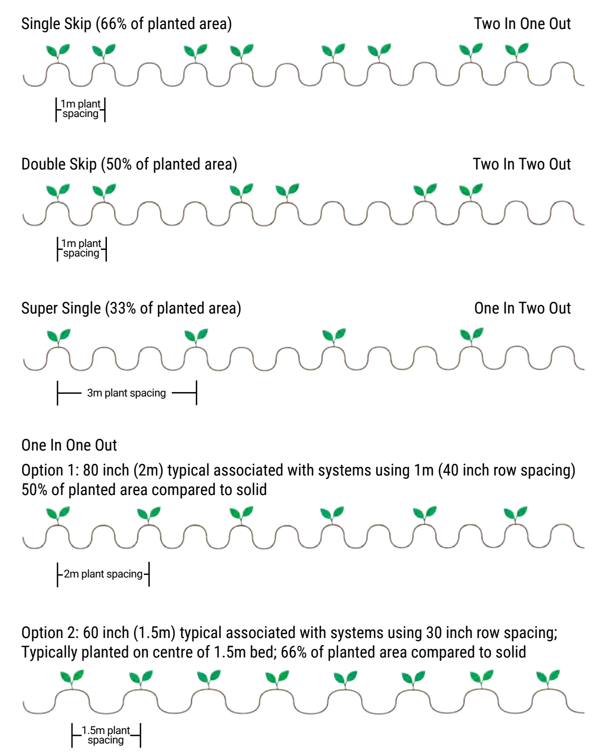
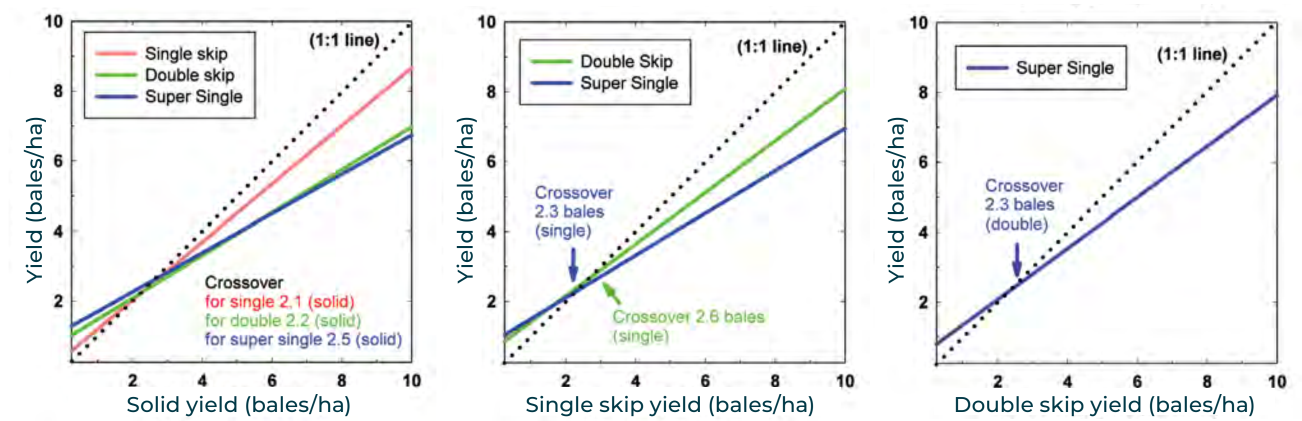


FIGURE 5.4 Average yield comparison. (Compiled by M. Bange 2012)

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

Cotton's vigorous tap root allows 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 water 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 and super single (Figure 5.3). 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. See *Dryland cotton* chapter.

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 take into account the following:

- **Single skip (two-in-one-out)** has the lowest risk of losing yield when conditions are favourable. It will, however, also use its moisture profile the quickest. It is best suited to heavier soil types with high plant available water capacity (PAWC) and more irrigation water availability.
- **Double skip (two-in-two-out)** provides more insurance against lower yields when compared to single skip, especially when conditions are less favourable. It is best suited to drier profiles and hotter environments. In better growing conditions, 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 widely spaced plant rows 3 m apart so 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 configuration (1.5 or 2 metres row spacing)** has shown yield potential similar to or slightly higher than the comparable configurations of single skip and double skip because of the equidistant row spacing. A more uniform growth habit can reduce lodging, allowing better spray penetration and defoliation 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 5.4 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 5.4, 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 webinar: What does it take to yield well with limited water – youtu.be/dOeM-Fl4Cjg

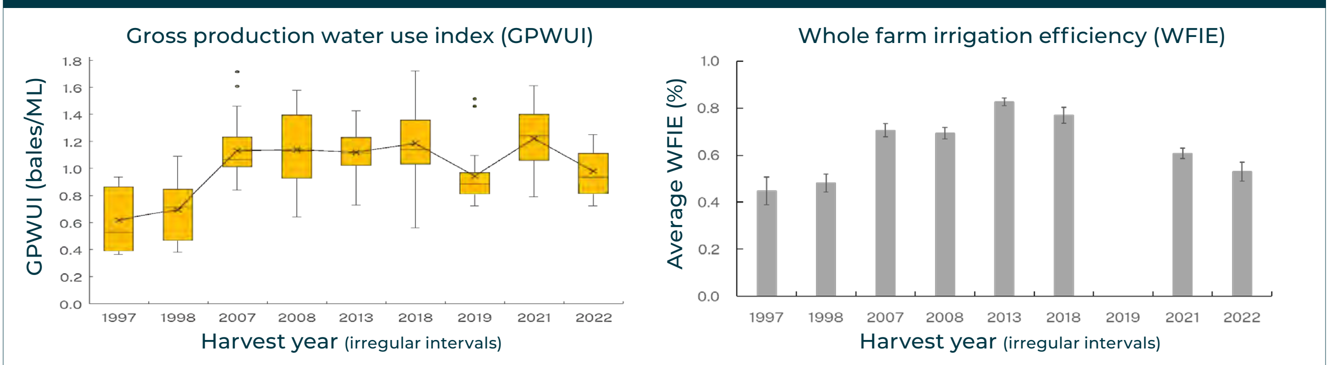
SIP2 podcast – smarterirrigation.com.au/plant-based-sensing-optimising-irrigation-timing-in-limited-water

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

CottonInfo Irrigation toolbox series – cottoninfo.com.au/search/node?keys=irrigation+toolbox

Choosing the appropriate row spacing and monitoring soil water will improve the efficiency of fully or semi-irrigated cotton. Lou Gall GVIA

FIGURE 5.5 The long-term trend of water productivity (1997–2021 cotton seasons) from the benchmarking studies.
(NSW DPIRD Water productivity benchmarking in the Australian cotton industry).
www.dpi.nsw.gov.au/agriculture/water/research-and-development/benchmarking-cotton-water-productivity



Measuring irrigation efficiency

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 several performance indicators including water use indices and irrigation system efficiencies.

Irrigation system efficiencies compare water output to water input at different points of the irrigation system of the farm, 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 5.2. 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 5.2). 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 components of the on-farm distribution system (such as individual storages or channels) and is discussed further in WATERpak Chapter 1.6.
- **Whole farm irrigation efficiency (WFIE):** Reflects the amount of total irrigation water used by the crop and 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.

TABLE 5.2 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	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

Water accounting

Water accounting tracks irrigation water and estimates the proportion actually used by the crop across the whole farm, providing 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 used the average value of gross production water use index (GPWUI) and whole farm irrigation efficiency (WFIE) in their analysis of the industry's water productivity and irrigation performance. The equations used in the project were:

GPWUI = Cotton yield ÷ (Irrigation water + Rainfall + Stored soil water change)

WFIE = (Crop water use (ETc) – Effective rain – Soil water) ÷ Total irrigation water used on farm

A high WFIE value generally indicates that the crop has used a higher proportion of the water brought onto the farm. The WFIE is influenced by rainfall and will be higher in dryer years when a greater proportion of crop water needs are met by irrigation.

The 2021 report found that GPWUI increased from 0.60 bales/ML in 1997 to 1.19 bales/ML in 2018, further increasing to 1.22 bales/ML in 2021. WFIE had improved from 45% in 1997, to 81% in 2018 (Figure 5.5). The wet 2022 year however saw it fall to 59%. Improvements in WFIE or GPWUI between 1997 and 2021 can be attributed to increased yield, reduced water inputs and increased irrigation efficiency. Reduced losses from storages and channels, better irrigation infrastructure, automation and management have contributed to the improvements in irrigation efficiency.

To help understand water use across your farm, develop a water account showing water inputs, crop water use, IWUI and GPWUI. Software packages such as WaterTrack can assist with this. Consultants like Aquatech Consulting can help develop a whole farm water balance and advise on the type of works and cost to reduce losses.

USEFUL RESOURCES:

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

Silo Climate Data: longpaddock.qld.gov.au/silo

BOM: bom.gov.au/watl/eto/about.shtml

WaterTrack: watertrack.com.au

Joe Foley on performance indicators: youtu.be/1RAAqK8i4H4

Ben Crawley on concepts and drivers: youtu.be/_QzQX_6eufo **and** youtu.be/GNS-uThiKR0

Storage seepage and evaporation: research.usq.edu.au/item/q1xy1/storage-seepage-and-evaporation-a-summary-of-the-results-from-the-measurement-of-seepage-and-evaporation-losses-from-136-on-farm-storages-across-the-cotton-industry

WATERpak 1.2 Water use efficiency benchmarking and water budgeting pg 4. cottoninfo.com.au/publications/waterpak

Benchmarking Water Productivity of Australian Cotton: www.dpi.nsw.gov.au/agriculture/water/research-and-development/benchmarking-cotton-water-productivity

Goanna Ag: goannaag.com.au

Irrigation systems

Surface irrigation systems such as siphon, bankless channel or siphon-less are the primary cotton irrigation systems in use. Pressurised systems such as overhead or drop are also used by the industry. These systems were compared in the grower-led Keytah System Comparison project at Moree, NSW, from 2009 to 2021. The comparison provides a commercial assessment of the yield and water use efficiency of these four irrigation systems as measured using gross production water use index (GPWUI) as shown in Figure 5.6.

GPWUI calculation includes stored soil water, 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 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 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.

Siphon irrigation

Siphon irrigation is the primary system used by the Australian cotton industry, but labour resourcing is forcing some growers to look at 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. 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.

RD&E in focus

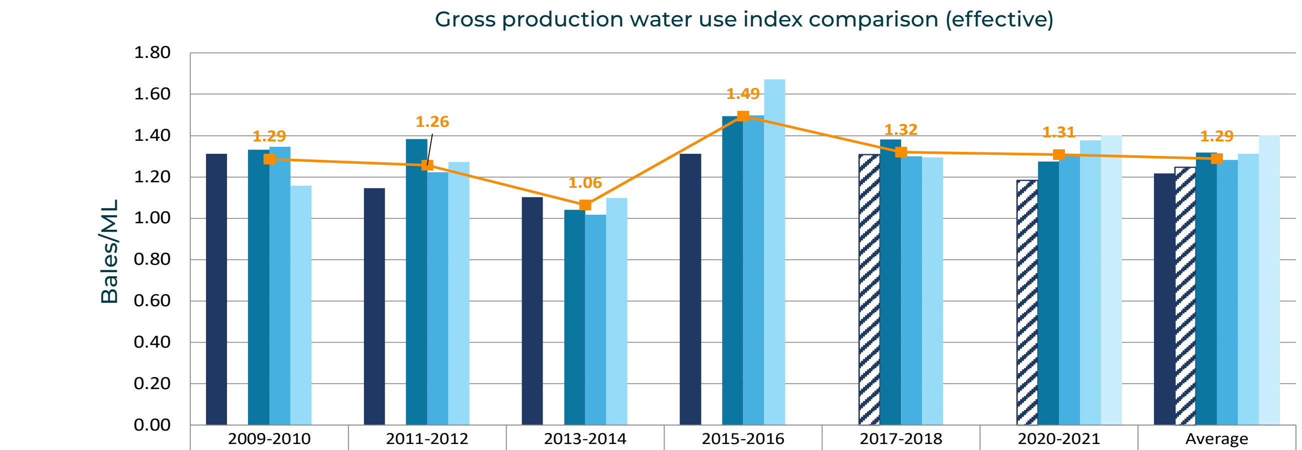
The growing availability of advanced technology for monitoring and remotely controlling surface irrigation has made it possible for more growers to automate furrow irrigation. This enables real-time optimization, reduces labor demands, and minimizes tailwater pumping.

The first step in implementing automated surface irrigation optimisation is converting existing manual siphon over bank irrigation to one of the forms of siphon-less irrigation; e.g. sPTB, bankless, or Smart Siphon.

Remote actuation of water flow into furrows is the next step in being able to use the time gained from tedious manual handling of siphons, to put toward irrigation application optimisation for a greater understanding of the target depth required with each irrigation, the depth actually applied each irrigation, and irrigation event control that limits the volume of tailwater being re-circulated around the farm.

Once this remote-control ability is in place for your siphon-less system, automated optimisation of surface irrigation events is then possible with SISCOweb implementation using these remote-control irrigation system actuators. There are now four manufacturers that have sensor systems interacting with the system to optimise irrigation events.

FIGURE 5.6 Keytah system comparison GPWUI summary.



	2009-2010	2011-2012	2013-2014	2015-2016	2017-2018	2020-2021	Average
Siphon	1.31	1.15	1.10	1.31			1.22
Smart Siphon					1.31	1.18	1.25
Lateral	1.33	1.38	1.04	1.50	1.38	1.28	1.32
Drip	1.35	1.22	1.02	1.50	1.30	1.31	1.28
Bankless	1.16	1.27	1.10	1.67	1.29	1.38	1.31
W567 Bankless						1.40	1.40
Average	1.29	1.26	1.06	1.49	1.32	1.31	1.29

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, and 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 to ensure even flow rates through the pipes for specific head heights. The three types of small PTBs still require rotobucks:

- **Small PTB:** The head ditch is split into sections, with each section filled from the supply channel by a gate fitted with automation.
- **Double head ditch small PTB:** 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 small PTB as at 'Waverley', Wee Waa.
- **Smart siphon:** small PTB are fitted with rotating elbows that are remotely controlled on or off in gangs of up to 150 siphons as at 'Keytah', Moree.

All small PTB 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:

SISCOweb: Cruise Control for Surface Irrigation

Part 1: Tools and Technologies: smarterirrigation.com.au/siscoweb-cruise-control-for-surface-irrigation-part-1-tools-and-technologies/

Part 2: Optimising the Irrigation event: smarterirrigation.com.au/siscoweb-cruise-control-for-surface-irrigation-part-2-optimising-the-irrigation-event/

Part 3: Practical Applications and Cost: smarterirrigation.com.au/siscoweb-cruise-control-for-surface-irrigation-part-3-practical-applications-and-cost/

CottonInfo:

Surface irrigation – Key factors to consider when improving furrow WATER: Evaluating furrow irrigation performance – cottoninfo.com.au

CottonInfo WATER: Calculating water use indices to benchmark water use efficiency – cottoninfo.com.au

CottonInfo YouTube:

Optimising furrow irrigation with SISCOweb – youtu.be/-saHo7ZdQhY

Moving to an autonomous irrigation system and automated small pipe irrigation system – youtu.be/bmltNZYXkMA

Siphon placement – youtu.be/wswKV4kSzn8

WATERpak:

Ch 5.2 Developing a surface irrigation system pg 355. Ch 5.3 Surface irrigation performance and operation pg 365. cottoninfo.com.au/publications/waterpak

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

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

CRDC:

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

Smarter Irrigation for Profit 2 – smarterirrigation.com.au/?s=sisco

– smarterirrigation.com.au/automated-broad-acre-irrigation-with-small-pipe-through-bank-sptb/

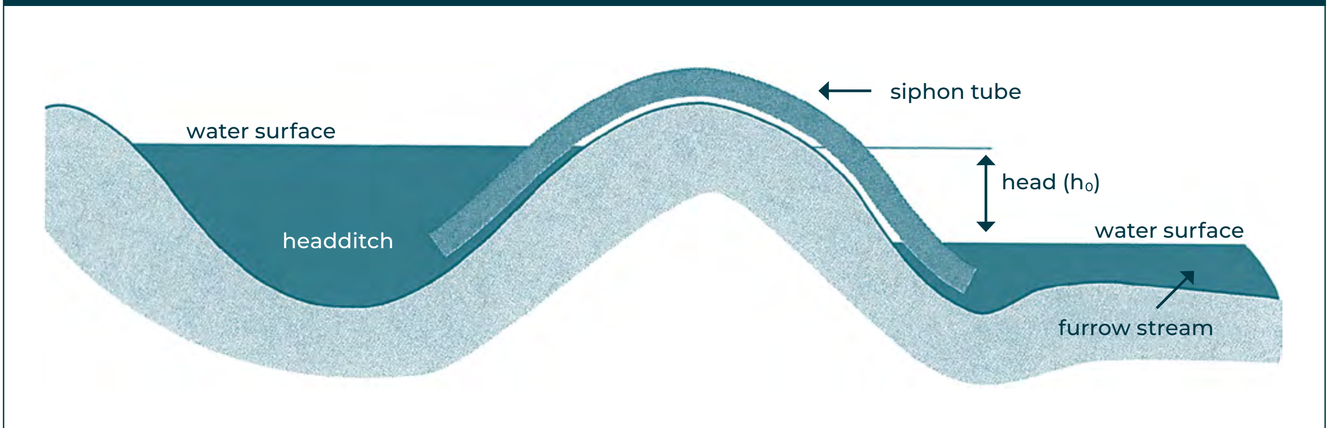
Bankless channel or siphon-less irrigation

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 reduces labour and enhances cultivation efficiency. There are many different designs so discuss your specific needs with an irrigation designer to ensure that the design chosen fits with management requirements, soil type and slope. It is critical that land levels are installed as precisely as possible; any inaccuracies in levels or deviations from design can have detrimental impacts on irrigation uniformity and efficiency.

Some of the common designs are:

- **Large PTB:** Hand siphons are replaced by a large diameter gated pipe this can include pontoon or bubbler designs. 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

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



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).

- **Rollover bays:** 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 with a furrow length of 400 m and width of 500 m. This 20 hectare 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:

Grower Case study: Irrigation Conversion at 'Lynbrae'
cottoninfo.com.au/publications/grower-case-study-irrigation-conversion-lynbrae

Consultant Case Study: Southern Irrigation Development
cottoninfo.com.au/publications/consultant-case-study-southern-irrigation-development

Grower Case Study: Irrigation Conversion at 'Bellevue'
cottoninfo.com.au/publications/grower-case-study-irrigation-conversion-bellevue

Grower Case Study: Irrigation Conversion at 'Norwood'
cottoninfo.com.au/publications/grower-case-study-irrigation-conversion-norwood

Siphon Irrigation Field Day 2019: cottoninfo.com.au/publications/irrigation-siphon-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:
youtube.com/watch?v=JRRC04aXDis&t=16s

WATERpak Chapter 5.4 Bankless Channel Irrigation Systems pg 388 – cottoninfo.com.au/publications/waterpak

CottonInfo Bankless channels – Turkey Lagoon case study:
cottoninfo.com.au/publications/water-case-study-bankless-channels

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

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

Consultants and designers:

Aquatech Consulting: aquatechconsulting.com.au
SMK Consultants: smk.com.au
PCTAg: 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

RD&E in focus

There are now options to apply irrigation water only to a particular distance down the bankless furrow length, helping growers to determine when to turn off their bankless so they don't end up with so much tailwater.

Automated SISCOweb messages to growers using three advance sensors provides that capability to 'collapse' that furrow irrigation water in the furrow at a set distance chosen by the grower. Given the existing ability of SISCOweb to control irrigation gates and valves this provides an automated way to control bankless irrigation. No other tech offers that capability, as current commercial advance sensors alone only give an indication to the grower of when the advancing water-front reaches a certain distance. The freight-train of water in the furrow still takes time to slow and stop advancing. Placement of an advance sensor near the taildrain will monitor in combination with higher flowrates per furrow which is usual in bankless, there ends up being significantly greater quantity of tailwater being pumped each irrigation. While SISCOweb used in this way cannot report application efficiency (as actual flowrates are not being measured) the uniformity of the water application is enhanced.

Best practice...

- Evaluate the full potential performance of your existing system before changing to alternative systems. Seasonal conditions impact irrigation performance more than system type.
- When assessing an alternative investment consider yield and price 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 between farms, regions and seasons. It relates total production (bales) to the total amount of water used, from all sources including irrigation water, effective rainfall and soil water.
- Successful integration of a new system will require a change in mindset and practices.

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 yields and water use efficiency.

It is, however, 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 for 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. If you are installing an overhead system, ensure you and your designer understand the system capacity requirements of you farm. Ensure the pump capacity and water supply are sufficient to match crop water requirements. 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.

When selecting the design consider the infrastructure and potential to automate gates to improve irrigation management.

Critical considerations:

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

USEFUL RESOURCES:

Centre pivot system capacity: how it's calculated and why it's important cottoninfo.com.au/publications/centre-pivot-system-capacity-how-its-calculated-why-its-important

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 – cottoninfo.com.au/publications/review-centre-pivot-and-lateral-move-irrigation-installations-australian-cotton

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

Surface and sub-surface drip irrigation

Surface and sub-surface drip irrigation (SDI) are low pressure, low volume systems 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 an annual or biannual basis (tape costs approximately $1,000/ha annually).

Drip systems can provide very good irrigation efficiencies but require different management in terms of agronomy, irrigation schedules and application volumes compared to surface or overhead irrigation. To ensure that drip irrigated cotton systems provide improvements in labour, yield and water use efficiency, the system must have the appropriate pumping and filter capacity to meet peak crop water requirements. A system setup with limited capacity will struggle to yield and hence achieve the desired GPWUI targets. Where permanent drip systems are being installed there must be 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. The manufacturers of drip systems typically have management systems to assist with irrigation scheduling.

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: insidecotton.com/sites/default/files/article-files/NEC6C_Final_Report.pdf

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

System changes

Before replacing an existing irrigation system, it is important to assess the performance and optimisation of the existing system, to be sure that changing systems 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 requirements.

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. The cost of installing any new design must consider the amount of soil to be moved, the number of and cost of the infrastructure needed for the design and how any new design will integrate with existing farm infrastructure and layout. Some rules to remember are:

Slope
For field slopes steeper than 0.300% (1:333), use siphons.
Flow rate
A supply rate of at least 24 ML/day is required.
Soil characteristics & variability
Soil with a very slow infiltration rate or significantly different soil types within a field 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 'with or without' financial assessment scenarios.
- 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 but should be balanced with potential labour savings.
- 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.

These systems can improve WUE when designed, installed and managed well.

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 5.3. Consider which aspects are most important for your operation and use them to guide your system decisions.

The Keytah system comparison project was 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 5.3 Advantages and disadvantages of irrigation systems.

System	Advantages	Disadvantages
Traditional siphon	▪ Lower capital set up costs. ▪ Dominant system that can produce high yields and GPWUI if optimised.	▪ High labour requirements. ▪ Potential for less uniformity if siphons are not placed consistently ▪ Potentially the person starting or stopping the siphon will not understand the importance of the starting irrigation on time and stopping irrigation on time.
Small pipe through bank	▪ Reduced labour requirements to traditional siphons. ▪ More uniform application and improved efficiency. ▪ Potential for remote control or automation.	▪ Increased cost compared to traditional siphon. ▪ Positioning rotobucks in line with pipes through banks.
Bankless channel and siphon-less	▪ Reduced labour and potential for automation. ▪ Improved machinery efficiency – no need for rotobucks or driving through ditches during spraying and picking. ▪ Less maintenance – tail drains are graded every 2–3 years. ▪ Potential to re-use tailwater and improve water use efficiency.	▪ Less suitable for paddocks with varying soil types. ▪ Need suitable slopes and can require significant removal of topsoil in some locations. ▪ Installation can involve significant earth works. ▪ Earth works at installation must be precise. ▪ Structures can be costly. ▪ Water use efficiency is less well understood.
Overhead irrigation	▪ Potential for improved yield and water use efficiency (GPWUI). ▪ Potential for increased rainfall infiltration. ▪ Reduced potential for runoff and deep drainage. ▪ Flexibility to fit a broad range of crops. ▪ Improved machinery efficiency. ▪ Potential to improve fertiliser use efficiency.	▪ High capital set-up costs. ▪ 'Just in time' irrigation system requires skilled labour for servicing and breakdown management. ▪ High energy costs to pressurise water.
Surface or Sub-surface drip	▪ Potential for improved water use efficiency. ▪ Potential to control runoff and minimise deep drainage. ▪ Potential to increase rainfall infiltration and reduce soil surface evaporation. ▪ Enhanced fertiliser efficiency.	▪ High capital set-up costs. Surface tape requires annual or biennial replacement. ▪ 'Just in time' irrigation system requires skilled labour for servicing and breakdown management. ▪ High energy costs to pressurise water. ▪ Additional care required with cultivation.

Siphon-less irrigation may be suitable on your farm. Discuss your needs with a designer. Lou Gall GVIA/CottonInfo

Healthy soils

Chapter coordinator:
Blake Palmer (CottonInfo/CRDC)

Acknowledgements: **Susan Maas** (CRDC), **Oliver Knox** (Cotton Seed Distributors) and **Nicola Cottee** (CRDC)

Soil, and especially a healthy soil, is the starting point for productive agriculture and the foundation of all terrestrial life. It underpins the fertility and productivity of a farming business, providing cotton plants with support and access to water, oxygen and nutrients.

Farming practices impact physical, chemical, and biological soil properties, which in turn impact the ability of soil to perform the functions needed for a cotton farm. These functions include nutrient cycling and storage, water infiltration and holding capacity, root exploration and resilience to weather extremes, pest and disease suppression and reducing erosion and runoff.

Soils for cotton growing

There are many aspects of soil properties (physical, chemical and biological) that should be considered when determining if a soil is suitable for cotton.

Soil structure – Crops are more likely to produce high yields when their roots can grow freely in well-structured soils. Cotton has poor tolerance of waterlogging. 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. The alluvial soil types, black earths and the better structured grey and brown clays – with their extensive cracking and vigorous root growth – typically provide favourable conditions. Soil types with dense, sodic subsoils have poorer profile permeability and drainage. Excessive traffic or tillage particularly at high moisture content will cause structural damage, which is likely to create soil compaction or smearing and produce large clods that also restrict permeability.

Best practice...

- Develop understanding of your soils, through soil sampling to determine physical and chemical properties, mapping of variability, and record keeping (including crop rotations and residual herbicide use).
- Aim to increase soil microbial diversity and ground cover through cover crops and rotation crops. Planning should consider stubble management, weeds, previous herbicide use, insects, disease, water use, soil health trends, and soil structural issues.
- Prevent or minimise erosion in susceptible areas and establish a monitoring plan to track progress.
- Incorporate controlled traffic and minimum tillage practices where possible.
- Avoid trafficking wet fields where possible – use the crop to dry soil down to well below plastic limit before harvest. 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 in the wheel lines is good as it allows access by machinery when the rest of the field is 'above' the safe moisture level.

Dryland cotton...

- 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, soil structure, weeds, insects, diseases and soil health.
- In dryland systems, cover crops have been shown to increase yield 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.

Plant available water capacity (PAWC) – The amount of water in the soil profile that can be extracted by plants is an important consideration when planning cotton. Structure will also influence the 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 irrigation events. Similarly, under dryland conditions, starting out with a full profile in these soil types can delay the onset of moisture stress in crops. In some high rainfall climates in parts of northern Australia, freely draining loam soils may have advantages over high PAWC clay soils.

Soil organic matter – While soil organic carbon is the primary component (~57%), soil organic matter also contains hydrogen, oxygen, and is an important source of nutrients. It supports:

- Biological functions: Supplies nutrients for plant growth and provides energy and nutrients for soil micro-organisms, that are important in many soil functions including nutrition cycling and disease suppression.
- Physical functions: Stabilises soil structure and promotes soil aggregation, which improves soil water storage and infiltration. Increased levels of soil organic matter can also increase soil resistance to machinery compaction.
- Chemical functions: Increases soil cation exchange capacity (especially in lighter textured soils), buffers soil pH, reduces effects of salinity and sodicity, and is a store of plant essential nutrients. Most of a crop's nutrient requirements are met from recycling soil organic matter and the nutrients released during the decomposition of this material (mineralisation). Inorganic fertilisers are required when the soil cannot meet a crop's nutrient demand and are critical in optimising production. Soil organic matter is a key source of the N mineralised during the cropping season. Fertiliser application at appropriate levels will help support nutrient cycling and ultimately aid in the delivery of nutrition from organic matter mineralisation in future seasons.

Nutrition – Cotton is typically grown in highly fertile soils. Refer to *Nutrition* chapter for nutrition requirements for cotton.

Soil constraints – (dispersion, sodicity, salinity, acidity, compaction) can impact soil structure, root growth and interfere with nutrient uptake. Refer to *Nutrition* chapter for more information on sodicity and salinity.

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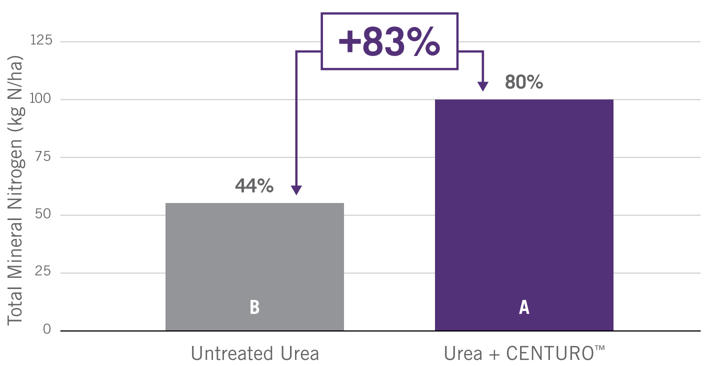
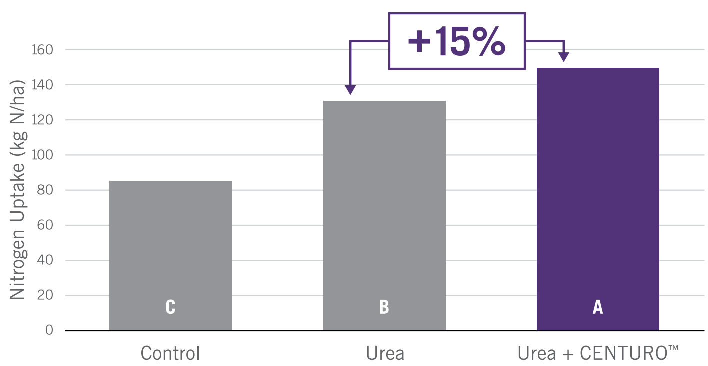
CENTURO™ increased soil mineral nitrogen





Bars with different letters indicate statistical differences (LSD 0.1)

Healthy soil principles

Healthy soil is a living, dynamic environment, full of microbial and macroinvertebrate life that help to recycle essential plant nutrients, improve soil structure, and control plant disease and pests. Soil health is the capacity of soil to function as a living system. A healthy soil is a resilient soil, capable of withstanding and quickly recovering from extreme events such as flooding or drought. This means the principles for improving soil health are to provide food and shelter to the living organisms within soil. The Australian cotton industry soil health framework (Figure 6.1) encourages greater adoption of practices that achieve these desirable outcomes.

Healthy soil practices

Maintain standing stubble

Standing stubble benefits go beyond many of the soil health benefits of rotation cropping, by improving the infiltration of water into the soil, slowing evaporation, and reducing soil surface temperature. An experiment in Narrabri showed that leaving standing wheat stubble gave better returns ($/ML of water) than wheat rotations incorporating the stubble, or cotton monoculture. Heavy stubble loads can present some challenges for both planting and pest and disease management. Legume stubble tends to break down quickly.

Although ground cover provides numerous benefits within a cropping rotation, crop residues need to also be managed based on best practice for any diseases present, and some consideration given to the potential for allelopathic effects on cotton. Refer to *Preventing pest problems* chapter for more information.

For information on managing cotton residues refer to *Post harvest pest and stubble management*.

Diversify

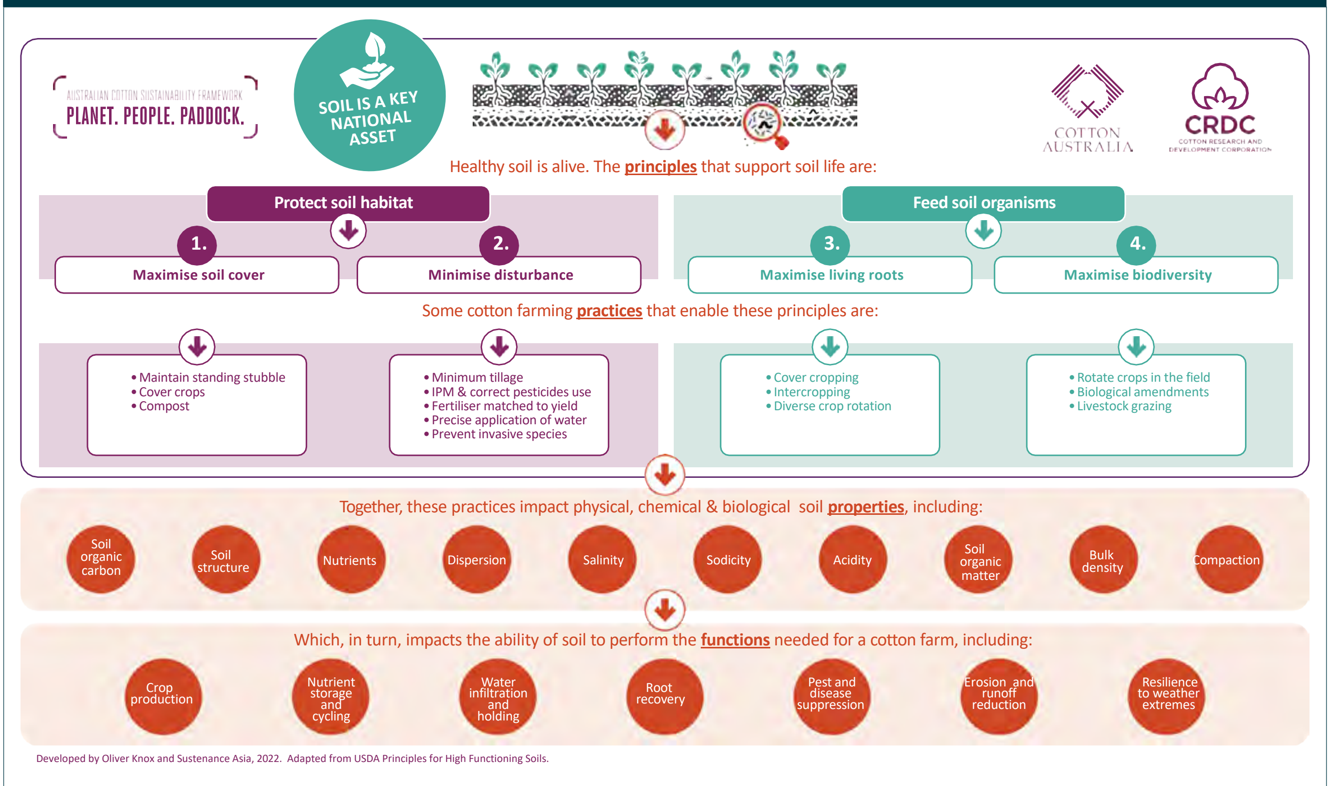
A diverse crop rotation that includes cereals and/or carefully selected green manure and cover crops can increase soil microbial diversity, supporting improved soil functionality, including nutrition cycling and disease suppression.

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 higher levels of 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.

Long-term field experiments have shown that legumes in rotation had a significant positive effect on N mineralisation and microbial diversity and activity when compared to continuous cotton. However, the use of legumes as green manure crops should be approached with caution in some fields, as they may pose an increased disease risk. In a cotton rotation, preferentially select crops that will not build cotton disease levels further.

Australian research has also assessed the role of crop rotations in disease suppression. Rotations with repeated or regular fallows could decrease pathogen inoculum levels and in turn reduce disease incidence, but regular fallows as part of the rotation cause a significant decline in overall microbial biomass and activity, in turn reducing disease suppression potential in cotton soils. Disease incidence was significantly lower following corn and sorghum compared to continuous cotton, and these crops are a good rotation option. Refer to *Preventing pest problems* and *Post harvest pest and stubble management* chapters for cotton disease implications of different crops.

FIGURE 6.1 Australian cotton soil health framework



Cotton can benefit from arbuscular mycorrhizal fungi (AMF), which form beneficial associations with plant roots and can act as agents in nutrient exchange. Bare fallow for more than 3 to 4 seasons or removal of topsoil (especially more than 40 cm), such as in the development of a bankless channel system, may result in a lack of AMF. A cereal or green-manure crop may restore sufficient mycorrhizal fungi.

Crop rotations and fallow can also 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. One of the difficulties with the use of alternative herbicides is that residual properties may be toxic to following crops and their breakdown can be weather and soil type dependent. 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. For more information refer to the *Managing pests in crop* chapter.

Cover crops, green manures and intercropping

In addition to rotation crops, it is also possible to plant and manage crops specifically to improve cotton cropping system and soils. Cover cropping is the process of growing cover during a fallow period, which helps increase water infiltration, slow evaporation, improve soil carbon, and protect the topsoil. Cover crops can also provide competition and reduce weed loads (refer to the *Preventing pest problems* and *Managing pests in-crop* chapters). Intercropping refers to the practice of growing two or more crops in close proximity and can be a way to incorporate cover crops into a system.

FIGURE 6.2 CRDC-supported research is seeking to develop regionally specific guidelines for cover crops.
Contact your CottonInfo REO to connect with this research.

Unless the cover crop is being grazed, 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 enough 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. Termination methods include rolling/crimping, herbicide application, mowing and incorporation. Incorporating the green residues (green manuring) is often used with legume crops to add nitrogen to the soil in addition to organic matter or with plants high in glucosinolates (brassicaceae family e.g., mustards, cauliflower, and broccoli) for soilborne pest and pathogen management (biofumigation). If incorporating green residues, be mindful that they can briefly elevate some diseases and pests, which can lead to emergence issues, so timing and conditions need to be factored into these decisions.

Collaborative research with Qld DPI, NSW DPIRD, 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.

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 N_2 fixation, and overall reduced microbial activity.

Integrating cover cropping into your farming system will need to consider lots of factors. CottonInfo have compiled grower experiences that provide good examples and considerations. Find here: cottoninfo.com.au/sites/default/files/documents/Cover%20crop%20case%20studies%202018.pdf

Biological amendments and compost

Biological products, such as manures, biosolids and composts, can be a good source of organic matter and nutrients. They should be spread and incorporated prior to planting. They vary in their chemical composition significantly in terms of major nutrients and trace elements and biologically-available biodegradable dissolved organic carbon (BDOC), and much of their nutrient load may not be available to the crop in the year of application. Biological amendments such as manure and composts have short-term effects on microbial activity and biological processes during the season, but repeated annual application can result in significant soil health improvements.

Composting of cotton gin trash needs to ensure that all material is cycled through the hot zone of windrows to reduce the risk of spreading pathogens, weed seeds and chemical residues.

Minimum tillage

Tillage systems have evolved from intensively tilled bare fallow systems with high soil losses, to reduced and no tillage with retained stubble systems that have improved soil structure, less soil erosion, and better fallow efficiencies. Reduced tillage systems increase soil organic matter and microbial activity, which are two of the main characteristics that influence soil health. Tillage contributes to carbon emissions both through the release of CO_2 from the ground as well as fuel usage for the operation.

The requirement in cotton for crop destruction and pupae busting, if other control options are not permissible, means that some cultivation is required. Strategic cultivation can also be a useful component of an integrated weed management strategy (see *Preventing pest problems* and *Managing pests in-crop* chapters), and may provide an opportunity to address subsoil constraints such as sodicity and re-distribute stratified immobile nutrients (e.g. phosphorus or zinc).

Controlled traffic and reducing compaction

The loss of soil structure due to compaction can significantly reduce cotton yields by restricting root growth and altering soil function, which in turn reduces water and nutrient uptake, cycling and holding capacities. Figure 6.3 provides an example of compaction symptoms. Some compaction is an inevitable consequence of machinery use throughout the season and compacted areas can remain from previous seasons and last for many years. 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). 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. 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. 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 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.

FIGURE 6.3 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.

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. While prevention is always better than cure and a dry harvest provides the widest range of options for preparation and improvement of cracking clay soils, in the event of significant rainfall between defoliation and picking, it may not be possible to avoid compaction to get the crop off. In these instances, compaction remediation strategies may need to be implemented. Strategies to remediate compacted soil may include tillage, however in wet clay soil this could cause further problems such as smearing and clodding and in a dispersive soil may exacerbate soil structural issues, without the concurrent application of gypsum. In shrink-swell clay soil compaction may self-remediate over time through multiple wetting and drying cycles. Previous research has indicated that growing rotation crops which dry the soil profile could fast track the shrink-swell induced self-remediation of the soil, and CRDC are currently supporting research to evaluate the most effective crop rotation system for this purpose under modern cotton farming practices.

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.

IPM and correct pesticide use

Pesticides can impact macro and microbiology of the soil, causing disruption to natural processes in a similar way to what can be observed when pesticides disrupt beneficials above the surface. Refer to chapters on *Preventing pest problems* and *Managing pests in-crop*.

Fertiliser matched to yield

Crop rotation and fertiliser management have a significant influence on the microbial community and biological processes involved in N and C cycling. Adopt a balanced approach to crop nutrition, especially with nitrogen and potassium. See *Nutrition* chapter.

Precise application of water

In addition to in-season irrigation management (see *Irrigation system choices* and *Irrigation management* chapters), field design and maintenance is important for management of water on and off fields. 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 is usually 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, be 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 further any compaction problems by trafficking wet subsoil in this situation as the ability to remediate deep soil will be limited. If subsoil is exposed to the surface under laser levelling conditions, both physical and chemical constraints need to be managed to limit any yield reduction. Ground truthing through soil coring before land forming takes place will give a better understanding of what to expect following the land forming event and what remediation practices may need to be implemented to manage the field for successful future crop production. Refer to the *Nutrition* chapter for information on how to manage soil nutrient constraints.

Prevent invasive species

In addition to new pathogens directly affecting soil health by changing the diversity of micro-organisms, new pests, diseases and weeds can impact soil health indirectly; for example limiting the types of rotation crops that can be incorporated and increasing the reliance on pesticides. 'Come Clean. Go Clean.', practices that ensure vehicles, equipment and people do not spread pests, weed seeds and pathogens onto the farm or between fields is one of the simplest yet most effective strategies for preventing introduction of invasive species.

Livestock grazing

A fully integrated system, that incorporates a pasture or dual crop component in a crop rotation can be used successfully to control weeds, build nitrogen and improve soil conditions, but there are pitfalls and the system needs to consider livestock (class of animal, ownership models, essential infrastructure) and the cropping operation (what and when to sow, when to graze and how to include fodder in rotation). It is critical that chemical residue risk is considered. Note that many pesticides used in cotton have restrictions relating to the feeding of cattle, harvesting and crop residues. A withholding period (WHP) is the minimum period from when a pesticide is applied to when the treated area is allowed to be grazed, cut for fodder or harvested. This period is to prevent the presence of inappropriate levels of chemical residues in the harvested crop or from developing in stock that graze the stubble or are fed by-products of the treated crop. Crop residues MUST NOT be fed to stock if any product that specifically prohibits grazing or cutting for stock food has been applied to that crop. Crops treated with a product that has a no grazing WHP specified should also not be grazed either before or after harvest. Always follow label directions and contact the relevant chemical manufacturer for advice where necessary. In most production systems cotton is unlikely to be suitable for grazing.

Field variability and history

Within-field production variability in Australian cotton farming systems cannot usually be attributed to any single factor. Every square metre of a paddock is unique, with a combination of varied production history and inputs, soil types and properties, topography, and weed, disease and insect burdens.

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. Recent research has shown that causal factors of yield variability could be identified by taking soil samples from neighbouring fields with historically contrasting yields. This investigative method can also be applied to high and low yielding areas within the same field. Overlayed with other information such as yield maps, this information can inform variable rate application and/or a decision to re-design a field. 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 particular areas. Bare earth satellite images can indicate soil change as well as the presence of old creek or riverbeds, which can affect a field's performance. Other digital tools, such as 'ConstraintID', can use satellite imagery of cereal crops to help plan soil sampling zones and there are other options that use NDVI, EM surveys and yield maps to provide similar guidance. Records of field history including previous crops and management information such as use of residual herbicides, can also be important for field selection and planning.

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

USEFUL RESOURCES:

CottonInfo case studies: cottoninfo.com.au/publications/cover-cropping-case-studies-growers-share-their-cover-cropping-strategies

Refer to the cotton rotation crop comparison chart. (see the *Post-harvest pest and stubble management* chapter)

Cotton Industry Sustainability Information including Snapshot on Soil Health and case study crdc.com.au/growers/sustainability

SOILpak: cottoninfo.com.au/publications/soilpak

***my*BMP soil health module:** mybmp.com.au/home.aspx

WaterPAK: cottoninfo.com.au/publications/waterpak

GRDC cover crop updates: groundcover.grdc.com.au/weeds-pests-diseases/weeds/weed-suppressive-cover-crops-identified

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

FIGURE 6.4 Research is investigating the value of Sunn Hemp (*Crotalaria juncea*) as a cover crop, particularly to reduce reniform nematodes.

Variety selection

By **Sam Lee** (CSD Extension Team) and the CSD E & D Team

What's new...

- New experimental lines containing Bollgard 3 XtendFlex technology will be included in CSD trials this season, some of which have improved fibre length and strength characteristics.

A wide range of cotton varieties 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. Over the past few seasons, CSD have supplied several varieties containing both Bollgard 3 and Roundup Ready Flex technology. Two varieties containing Roundup Ready Flex technology (non-Bollgard) and two straight conventional varieties have also been available. Four varieties containing Bollgard 3 and XtendFlex technology and one straight XtendFlex (non-Bollgard) variety were also commercially released for the 2024/25 planting season. The full range of cotton varieties available are outlined on CSD's website and will be updated accordingly for the coming season.

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.

Yield

In irrigated production systems, yield is the primary selection characteristic. Some varieties are widely adapted and can perform in a range of environments. Since 2016, growers have been planting the current suite of varieties with Bollgard 3 Roundup Ready Flex technology and have learned to manage them well. As we transition to the new varieties containing XtendFlex technology, growers must be aware that most of these varieties have been derived from new germplasm. This does not mean that there will be major differences in the way a new variety grows, but careful management will be needed to ensure that the best yields can be achieved.

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.

RD&E in focus

- Cotton Breeding Australia (CBA) undertaking plant breeding to develop new varieties containing ThryvOn® technology, which will assist in the management of sucking pests and have improved characteristics
- CSD investigating and implementing a new trials program that will seek to utilise precision ag technologies and spatial analytics. The intent of evolving this program is to provide varietal performance advice to crop managers in a more timely manner and help them to understand how varieties can be managed to achieve their potential. Part of this evolution has been the implementation of the 'Try Before You Buy' trials, which give growers more exposure to new varieties under their own management practices.

Currently, five varieties have been commercially named. Four of these varieties contain Bollgard 3 and XtendFlex technology, while one is a non-Bollgard variety, containing only XtendFlex technology - Sicot 724XF.

- **Sicot 724XF** is the non-bollgard variety containing XtendFlex technology, which is suitable as a refuge cotton option, or as a stand alone variety. It is a full season variety with an intermediate to strong growth habit.

The four new B3XF varieties will have a very good fit in irrigated production systems.

- **Sicot 619B3XF** is a normal seed density type that has performed well in both irrigated and dryland systems. It may also have a fit in Northern Australia, due to the ability to manage for earliness.
- **Sicot 743B3XF** is a full season variety which is broadly adapted and has overall performance similar to that of Sicot 748B3F. It also has a good disease package.
- **Sicot 761B3XF** has very high yield potential under irrigated conditions and is also resistant to cotton bunchy top.
- **Siokra 253B3XF** contains new germplasm and sees a return to an okra leaf variety in commercial production, while also being resistant to cotton bunchy top. This variety does have lower micronaire, which must be considered prior to planting, based on your conditions and season length.

TABLE 7.1 Summary of varieties containing Bollgard 3.

	Sicot 619B3XF	Sicot 743B3XF	Sicot 761B3XF	Siokra 253B3XF	Sicot 714B3F	Sicot 746B3F	Sicot 748B3F	Sicot 606B3F
Climate suitability	Cool/central	Central/hot	Cool/central/hot	Central/hot	Cool/central	Central/hot	Central/hot	Cool/central
Production	Irrigated, dryland	Irrigated, dryland	Irrigated, dryland	Irrigated, dryland	Irrigated, dryland	Irrigated	Irrigated, dryland	Irrigated
Maturity	Med/full	Full	Full	Full	Med/full	Full	Full	Full
Growth habit	Compact	Intermediate to strong	Intermediate	Intermediate to strong	Compact	Compact	Intermediate to strong	Intermediate
Seed density	Normal	Low	Low	Low	Normal	Low	Low	Low
Cotton bunchy top	Susceptible	Susceptible	Resistant	Resistant	Susceptible	Susceptible	Susceptible	Susceptible

A full summary of CSD's commercially available varieties including their physiological traits, fibre quality information and current disease ranks can be found on the Cotton Seed Distributors website - csd.net.au. This is kept up to date as new varieties and technologies become available to the Australian cotton industry.
Note - CSD plans to release a number of new commercial varieties this season, containing XtendFlex and Bollgard 3 technology. Information specific to these varieties will be updated on the CSD website as it becomes available.

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 619B3XF has been a standout performer under dryland conditions during trials over the past few seasons. This variety is a normal seed density type, which may aid establishment under dryland conditions.

New lines incorporating XtendFlex technology continue to be evaluated for their performance both in dryland and irrigated systems.

The relative performance of cotton varieties can be compared online at csd.net.au (membership may be required) 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 and management of the crop. 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% increase in average yield per year, so newly released varieties are often the best choice. New varieties will continue to deliver consistently better yields and quality due to improvements like increased fibre length and increased disease tolerance.

Fibre 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.

Some varieties 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.

Dryland cotton...

- Select varieties likely to achieve the best possible establishment under your dryland farming conditions.
- Select varieties that have a good fibre quality package.
- Select varieties that 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 that 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.

Disease

Breeding has provided the main method of managing our major diseases such as bacterial blight, verticillium and fusarium wilts. The industry has developed a ranking system (F rank for fusarium and V rank for verticillium) to allow a comparison of disease resistance of varieties. A standard ranking scheme has been developed to indicate 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 145 and a V rank of 115.

Breeding aims to improve the disease resistance over time and new varieties generally have improved F rank, however CSIRO breeders are working hard to develop better verticillium wilt tolerance, aiming to maximise yields by selecting varieties with the highest disease resistance in fields with significant disease pressure. In the case of Fusarium and Verticillium species, 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 csd.net.au/disease-ranks. Refer to the *Preventing pest problems* chapter for more information.

Okra leaf shape

There are currently two varieties with an okra leaf shape commercially available. One of these is a straight conventional variety, while the other is a new variety, containing Bollgard 3 and XtendFlex technology.

Biotechnology

Currently there are three broad classes of cotton biotechnology traits that are approved and available in Australian cotton varieties, providing either insect protection, herbicide tolerance or in varieties that are stacked with a combination of both traits. Bollgard 3 controls a range of lepidopteran pests including *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 that has allowed 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. Refer to the *Cotton Pest Management Guide* for more information on resistance management in Bollgard crops.

Roundup Ready Flex technology offers full season tolerance to glyphosate herbicides. The ability to use registered glyphosate herbicide products 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. 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).
- B3XF = Bollgard 3 stacked with XtendFlex.
- XF = XtendFlex (no Bollgard).

XtendFlex is the newest herbicide technology to be made available in Australian cotton varieties. This herbicide trait is stacked with tolerance to glyphosate, dicamba and glufosinate. A number of varieties were commercially released for the 2024/25 season.

Accessing biotechnology traits

Access to the various traits is governed by the technology company who develops and commercialises the technology via an annual license called a technology user agreement (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 practice, the licensing process is managed by Technology Service Providers (TSPs) on behalf of the technology company. TSPs are usually 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 and are aimed at supporting 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 *Preventing pest problems* chapter for more information.

Further information can be found at www.bollgard3.com.au **and** crop.bayer.com.au/products/biotechnology-traits/xtendflex-cotton

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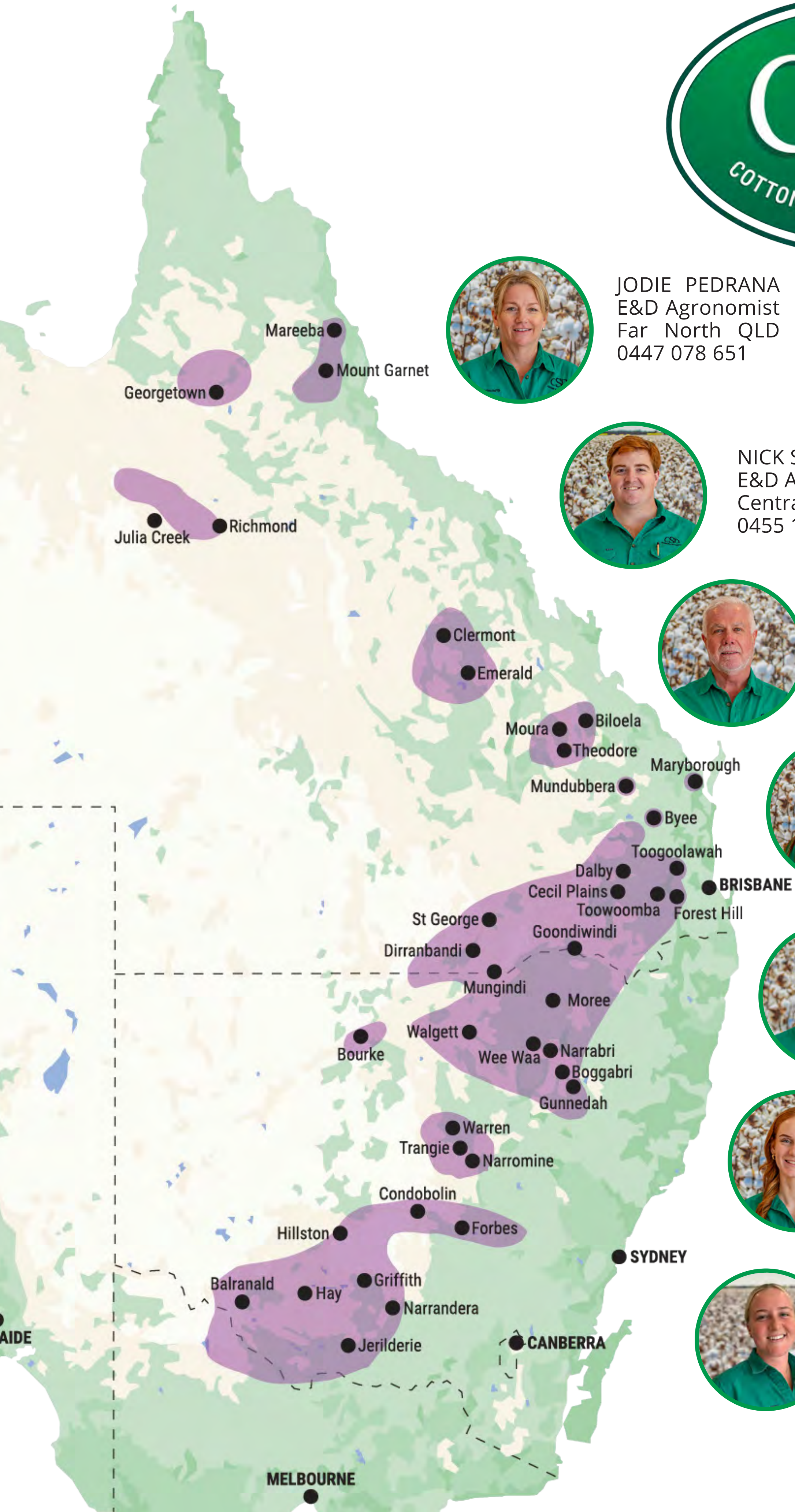
The CSD Extension team aims to deliver highly specific, targeted knowledge and information to cotton growers and industry which drives beneficial practice change to Australian cotton growers.
So, if you want to discuss your growing options, find out more information on our tools, get access to the latest trial data, or simply talk about all things cotton give your local Extension team member a call today.



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Nutrition

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

- 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 rainfed production).
- Soil physical condition.

Nutrient supply

Nutrient supply 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 indicates the fertility level of your soil at that point in time. For crop budgeting purposes, the ideal time of the year to soil sample is the cooler months of July and August when soil microbial activity is reduced. Once soil nutrient levels have been measured and seasonal nutrient tactics developed, fertiliser requirements for your crop can be accurately calculated. Crop 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 historical 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 8.1). 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.

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.

RD&E in focus

The use of enhanced efficiency fertilisers (EEF) in cotton systems provides a clear benefit for reducing nitrogen (N) losses and improving efficiency.

Read more at **crdc.com.au/publications/spotlight-magazine-summer-2024-25**

Nitrogen (N)

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 performed by micro organisms which convert organic N to plant available mineral N. Typically, around two thirds of the crop's N needs come from soil N while the remaining needs come from N fertiliser. Uptake of soil N is much more efficient than the uptake of fertiliser N. A farming system that incorporates legumes and cover crops increases soil carbon and available soil mineral N. A cotton 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 (xylem), with the final placement dependant on the nitrogen demand.

The method used to apply fertiliser N is critical to maximising production where soil sources cannot match crop demand. When fertiliser is applied to the soil, N will be cycled through to nitrate-N where the plant can take it up, remain in the soil, or be potentially lost to the atmosphere or from the field. 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 8.1). Irrigation management can also influence the amount of N – both soil and fertiliser N – that is lost from the system.

TABLE 8.1 Maximum nutrient uptake rate and timing of nutrients in whole crop.

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

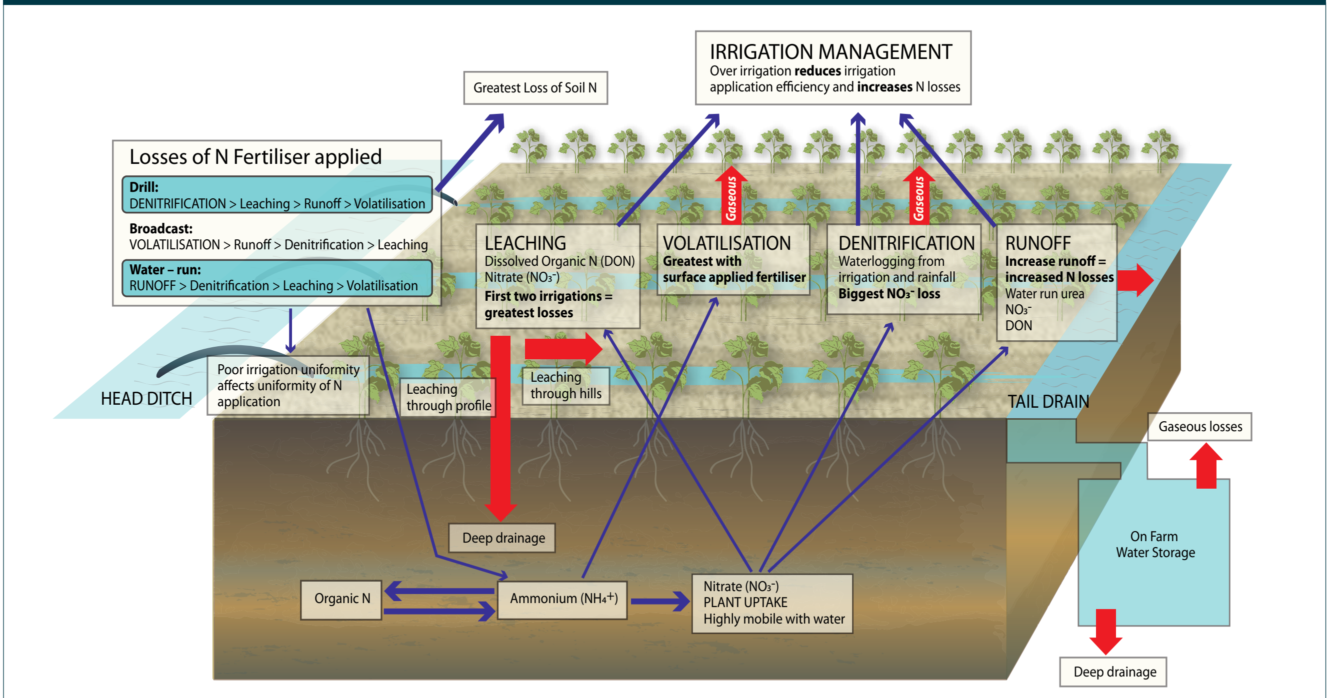
TABLE 8.2 Nutrient removal at various yield levels. Source: Rochester (2014)

b/ha	Macronutrients (kg/ha)							Micronutrients (g/ha)					
Yield	N	P*	K	S	Ca	Mg	Na	B	Cu	Zn	Fe	Mn
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	0.20	65	30	185	252	72
14	171	31	45	14	7	19	0.20	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

*New small seed varieties have reduced P removal by approx. 40% compared to published table.

Follow *my*BMP irrigation management recommendations 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 8.3). Insufficient nitrogen supply during this period will reduce yield. However, excess nitrogen can also have significant detrimental impacts on cotton and the environment. Rank vegetative growth, boll 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 associated with over-fertilising with N. 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 plant N uptake, soil N availability and/or N lost to the environment (Figure 8.1). 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, while ensuring optimum irrigation management.

FIGURE 8.1 Nitrogen and irrigation cycle highlighting the major loss pathways of N.



Right fertiliser

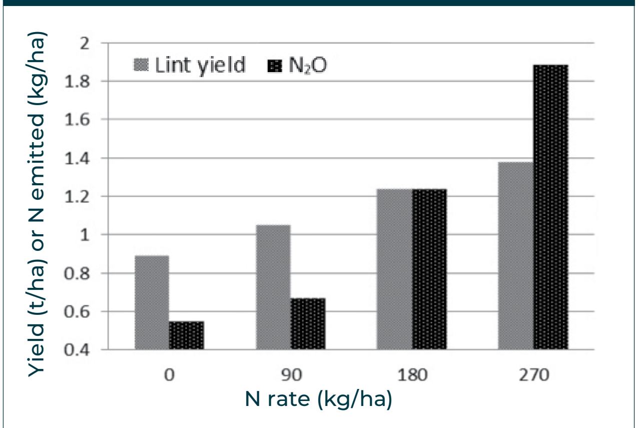
There are different chemical or physical forms of fertiliser that can be used to supply N to cotton, such as manures and composts, granular fertilisers, anhydrous ammonia (gas), and liquid fertilisers. Anhydrous ammonia (82% N) and urea (46% N) are the two major N fertilisers used in the cotton industry. 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. 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 90 cm for N).
- Calculate expected crop nutrient requirement taking into consideration expected yield, in-crop mineralisation, cropping history, cropping system and nutrient losses, crop N uptake efficiencies from the soil and fertiliser N, and the soil's 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) 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 take into consideration 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.

FIGURE 8.2 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)



- Monitor the crop through petiole (early season) and leaf analysis (flowering to defoliation) to determine if nutrient levels are sufficient or inadequate (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 8.2) 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 8. 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.

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 8.3). Research showed that in high-yielding cotton systems, the timing of N fertiliser influenced lint yield (Figure 8.4).

FIGURE 8.3 The pattern of plant N uptake and water use for an irrigated cotton crop. (Source: Chris Dowling, Back Paddock)

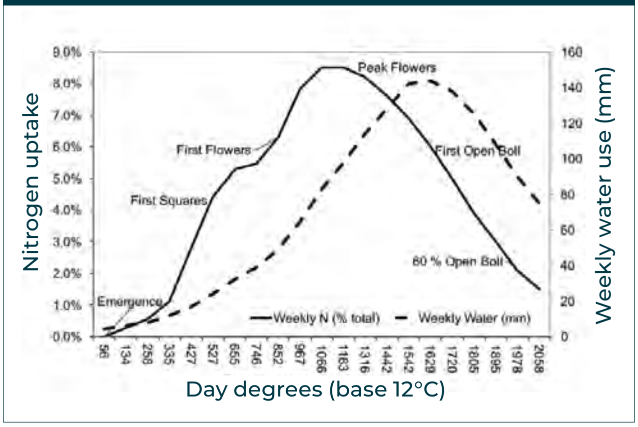
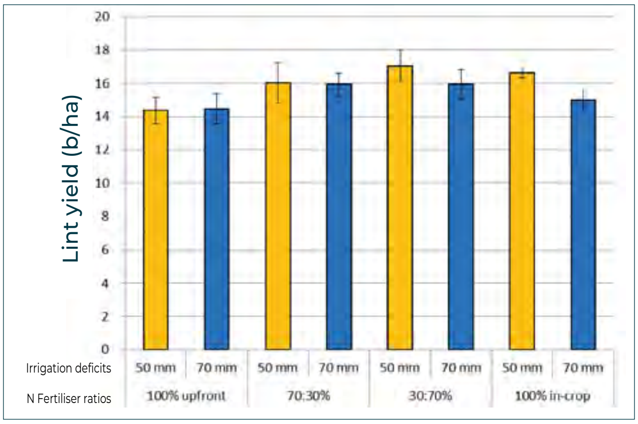


FIGURE 8.4 The influence N fertiliser timing on lint yield at Myall Vale (NSW) – 2017/18. (Source: Baird – 2018 Australian Cotton Conference)



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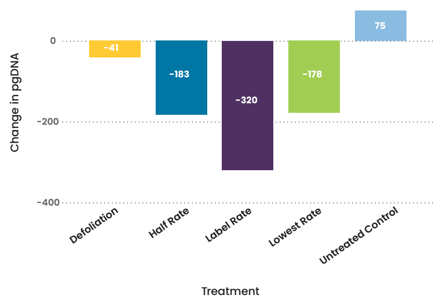
Broad sampled across 1 ha



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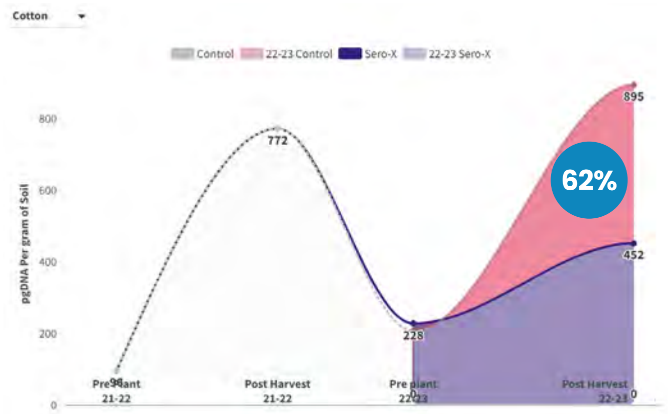
Sero-X Treated vs Untreated - DNA Abundance

Total pgDNA Verticillium Dahliae ie: Exposure to live and dead inoculum



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 seeding 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 the 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 the *Managing pests in crop* 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 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 salt or toxicity effects. Anhydrous ammonia should be applied deeper than 15 cm to reduce atmospheric losses.

Soil conditions will affect atmospheric losses, with N escaping from dry soils due to air spaces within the soils, while losses from wet soils occur back through the application furrow when it is not sealed correctly. 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 indicates it may be best to apply them even before the previous crop within the rotation due to the lack of mobility of these nutrients within the soil.

Foliar fertilisers can be an alternative source of nutrients, but the amount that can be applied is limited and the benefit is short term. Foliar fertilisers can help meet crop nutrient requirements when a nutrient has been identified as deficient, and the quantity of nutrient required is small. Foliars are not suitable for applying large amounts of nitrogen due to logistical challenges and the high demand for this nutrient.

Right irrigation management

In irrigated cotton, optimum irrigation management is 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.

Nitrogen losses

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 8.1) and must be considered within your system when preparing an N management plan. Ways N can be lost include:

- **Denitrification –** This is the most important loss pathway of nitrate-N in irrigated cotton systems, potentially accounting for over 50% of N losses, especially where excessive rates are used in an attempt to achieve yield targets or where poor field layout dictates long irrigations that result in extended waterlogging. Denitrification is a biological process that occurs under low oxygen conditions (such as during waterlogging) where nitrate N is converted into N and lost to the atmosphere. One of these gases is nitrous oxide, a noxious greenhouse gas that contributes to ozone depletion.
- **Leaching and runoff –** Early season irrigations can cause excessive N leaching from the planting hill, either out through the tailwater or down 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 it be 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; where soils contain low clay contents; soils are wet and drying; or conditions are hot and windy. Free lime (calcium carbonate) present in the soil can accelerate ammonia volatilisation where ammonia sulphate fertiliser is used and 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; note that water-run 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 this amount can be significant, particularly in high-yielding crops. Long-term budgeting should consider seed N removal after cotton harvest.

Reducing greenhouse gas (GHG) emissions

The application of N fertilisers can lead to high losses including high levels of GHG emissions. Current benchmarks suggest N fertilisers account for approx. 60% of cotton crop GHG emissions. As the industry strives to reduce our environmental footprint, optimising N fertiliser management is critical. Following the 5R's theory will aid growers reducing their footprint, but other options such as utilising enhanced fertilisers that protect nutrients before they are required by crops can be applied to help GHG reductions.

For growers investigating their nutrient performance, a simple measure to calculate nutrient use efficiency is nitrogen fertiliser use efficiency (NFUE).

NFUE = Lint produced (kg/ha) ÷ N Fertiliser applied (kg N/ha)

The current industry benchmark suggests that this should equate to about 13–18 kg lint/kg of fertiliser N applied. For many, this would seem very high and unattainable. However, the initial 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 realising that N is only one factor that determines the final yield. Addressing the other yield constraints 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 a single season of low NFUE but if long-term NFUE is below 10 and lint yield is below average 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.

Phosphorus (P)

The aim of phosphorus 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. The plant must have P to complete its normal production cycle because it 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 red/purplish in colour and stunted. 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 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 to allow the P 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 approach 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 these and 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 **Colwell P test** measures the 'labile' or 'sorbed P' (fast release) pool delivering P into the soil solution, as the plants draw solution P from the soil.

The **BSES soil P test** measures the slower release pools of P in the soil. This form of P contains the compounds formed in cotton growing soils from prior fertiliser application, e.g. calcium phosphate. This pool delivers P into the fast release pool and is the pool that is most likely to be depleted over time.

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 have low to moderate PBI, increasing P placement and timing options.

Measuring P's labile and slow-release pools 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 (indicated by decreasing Colwell P test results) 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 mycorrhizal 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. Low VAM populations can increase the risk of P deficiencies where:

- Soil P is low/marginal.
- There have been prolonged plant-free periods (crops/ weeds).
- Frequent and significant soil disturbance occurs across multiple wetting and drying cycles.

Potassium (K)

Potassium 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. While most soils have large amounts of K, only a small proportion (less than 2%) is in plant-available forms. These include freely available K in the soil solution, 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.

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, reducing the soil's ability 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 peak period 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. However, 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/or a triggering weather event is the most effective strategy to reduce the incidence and effect of premature senescence.

Other essential nutrients

Zinc (Zn): Zinc 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, and plant stunting. Zinc is best applied to the soil as a broadcast and worked in with cultivation, but can also be successfully applied to crops as a foliar spray to 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. Be aware of compatibility restrictions if mixing with early season crop protection products.

Iron (Fe): Iron 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, most of the iron in soils 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 Fe 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

Applying an amendment (such as chicken litter or feedlot waste) within a cotton system is an option if product and 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 which helps improve overall soil health. For example, chicken litter can provide relatively large amounts of N, P and Zn to the cropping system, reducing the reliance on inorganic fertilisers as a source of nutrients. A three-year study in southern NSW found that when poultry litter was applied at 16 m^3/ha, the cotton system allowed 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, seek independent analysis to guide you on application rates and nutrient budgets due to variations in these products.

MORE INFORMATION:

cottoninfo.com.au – **NUTRIpak, FIBREpak, SOILpak & NutriLOGIC**

mybmp.com.au

Fertiliser Industry Federation of Australia fertilizer.org.au

CottonInfo Nutrition video playlist youtube.com/cottoninfoaust

Monitor your soil

Achieving high yields requires healthy soil, which is why monitoring your soil's chemical and physical properties is essential. Conduct comprehensive soil tests in increments of 30 cm down to depths of 90 cm before the next cotton crop. Due to inherent soil variability within fields, soil samples must be representative of differences within the 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. Once collected, soil samples need to be sent to a laboratory for analysis as soon as possible. If samples are likely to sit for even a few days, they are best stored in a fridge (below 5°C) 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. For more, see *Healthy soils* chapter.

Soil organic matter

Importance of soil organic matter

Soil organic matter influences all three aspects of soil fertility:

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

Most of a crop's nutrient requirements are met from recycling soil organic matter and the nutrients released during the decomposition of this material. Inorganic fertilisers are required when the soil cannot meet a crop's nutrient demand, and are critical in optimising production. 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)

There are two ways of calculating in-season mineralisation:

1) Net N mineralisation =

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

Note: **a.** soil C:N ratio normally 10–12:1, **b**. 3–5% of N is normally mineralised

2) N mineralisation using soil %N directly =

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

The second method can be more accurate at estimating mineralised N than using the C:N ratio.

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Managing soil organic matter

Soil organic matter levels in many cotton fields have declined significantly since fields were developed for cultivation 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 healthy. 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:

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

In irrigated cotton systems, the decline in soil organic carbon levels can be reduced or stabilised with changes to conventional cropping systems. Losses can be reduced by changing management practices that promote healthy soil:

- Reduce tillage operations.
- Employ controlled traffic with permanent bed systems.
- Retain stubble and incorporate into the soil profile – avoid burning or baling crop residues.
- Optimise water and nutrient applications.
- Reduce fallow periods – increasing cropping frequency benefits microbial activity,

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, targeted tillage operations to incorporate stubble and control pupae can increase soil carbon. However, cultivation causes the loss of soil moisture and exposes the soil to erosion.

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, erosion of topsoil, crop stubble removal (silage, hay or burning), and high soil temperatures (bare fallow in summer).

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 an increase in sodicity levels, 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 (ESP) during a soil test. Table 8.3 provides a guide to the broad classification of sodicity within Australian soils.

TABLE 8.3 Sodicity classification for Australian soils.

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

As soil sodicity increases, several detrimental effects on the soil's physical properties influence plant growth and yield potential. Soil dispersion increases in sodic soils, reducing the infiltration rate, the hydraulic conductivity, and the plant available water capacity of the soil. So, in sodic soils, water cannot get in as fast, cannot travel within the profile, and the soil has 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 pH of the soil determines the best form of calcium to use. 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 (>30 cm) is difficult and expensive to manage as surface-applied ameliorant can have limited penetration and deep tillage is expensive and laborious.

Organic matter can reduce the effect of soil sodicity, as it helps hold the soil aggregates together, stabilises soil chemistry, reduces dispersion and improves soil structure. However, it is challenging to get sufficient organic matter deeper into the soil. Management of paddocks with sodicity 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. Soil salinity is measured by testing the soil solution's electrical conductivity (EC) (Table 8.4). Soil solution is the liquid in soils held between the soil aggregates. When the soil solution salt concentration exceeds that found in the plant roots, water flows from the roots back into the soil. In this situation, the plant cannot meet its water demands even though the soil is moist. Salinity occurs because of ground water rising close to the soil surface, or by irrigating with saline water, and/or by applying salts via fertilisers. Refer to the *Sustainable cotton landscapes* chapter for further information about assessing the suitability of water quality for irrigation. Alarmingly there have been reported studies that highlight cotton soils becoming saline or increasing in salinity.

TABLE 8.4 Saline soil classes based on different soil textures. (Adapted from NSW DPIRD's Diagnosis and management of soil salinity)

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

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 an increase in soil density and strength restricting root growth. It reduces the availability of water and nutrients to the cotton plant and can also increase denitrification, further reducing the availability of nitrogen. Some compaction is an inevitable consequence of using heavy machinery on soils, but by implementing good management practices, minimum tillage systems and guidance systems, the impact can be minimised or localised. Restoration can be difficult and expensive when compaction occurs at depth. Machinery operations on wet soil will exacerbate the problem.

USEFUL RESOURCES:

cottoninfo.com.au **and** mybmp.com.au
WATERpak, NUTRIpak & SOILpak
CottonInfo soils video playlist youtube.com/cottoninfoaust
Wet Picking and Soil Compaction Fact Sheet
cottoninfo.com.au/publications/wetpick-compaction

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. The critical value for petiole nitrate at first flower (750-day degrees from sowing) is 20,000 mg/kg. Below this value, nitrogen applications may be necessary. A greater certainty of N requirement can be gained from determining the slope of decline of two to three samples in the first couple of weeks of flowering.

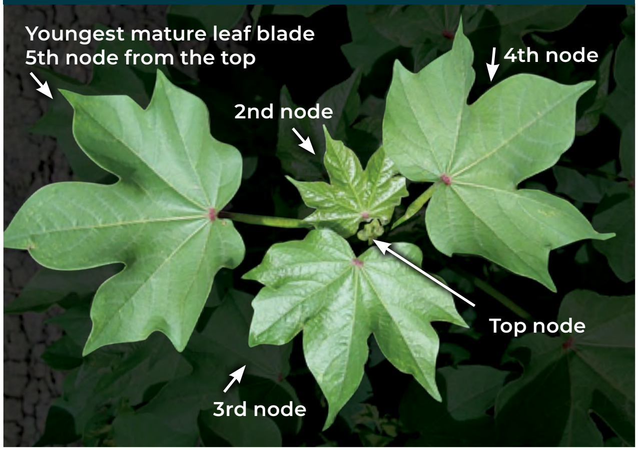
Leaf analysis can be used to monitor all nutrients including micronutrients. Sampling leaf tissue twice (at flowering and cut-out) produces the most useful information. Follow sampling directions carefully as results are only as good as the sample provided.

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 and transpiration is reduced.
- 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 (see Figure 8.5).
- 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.

NUTRIpak contains nutrient critical levels for both leaf and petiole analysis. The levels can be used to determine crop progress and help decisions on additional fertiliser requirements.

FIGURE 8.5 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.

USEFUL RESOURCES:

cottoninfo.com.au **and** mybmp.com.au
NUTRIpak, SOILpak & NutriLOGIC
Cotton Symptoms Guide
CottonInfo nutrition videos: youtube.com/watch?v=nC5E4zAvz3c&list=PLQy8KAPn-DyriETUnJxtJdij6HNWpp0hW

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 the 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.
- **Consider including cover crops in your farming system.** 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 by applying N fertiliser close to the crop. Once N is in the soil 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 said: "Stop treating your soil like dirt." Consider your soil, your rotation, the use of cover crops, and review and improve your nutrient management.

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 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.
- Applied N should be drilled/ incorporated 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 in the growing season due to ideal growing conditions, leading 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 extended 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 (including applying fertiliser prior to the previous crop) is recommend to improve distribution within the soil profile. Application rates should align with crop removal (refer to Table 8.2 for correlating nutrient removal rates to yield).

Planning for dryland cotton, including its nutritional requirements, starts well in advance of planting. Start considering cotton's nutritional requirements during earlier crops in the rotation.

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Energy use efficiency

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

Energy inputs are being increasingly scrutinised by policy makers and can also be a considerable cost to primary producers, particularly for cotton. Fuel, oil and electricity costs totalled $343/ha in the most recent Boyce and Co comparative analysis, second only behind crop nutrition ($482/ha) as the highest-cost line item in an irrigated cotton gross margin. Irrigated cotton growers can reduce energy costs in three ways: reducing demand by saving water; improving energy efficiency of machines/pumps; and substituting traditional grid power 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 and helping our product access export markets for sustainable cotton. To ensure best management practice, a number of steps can be taken to help you understand the range, costs and contributions of energy use to cotton production.

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:

- Measuring diesel and electricity use for all pumps: $/ML/m head. This is an easy first step to benchmark a pump against industry findings (refer to Best practice box for benchmarks).
- Reviewing your electricity bills and meter readings to ensure they 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) to achieve energy savings and high investment returns.
- Developing a buying strategy for liquid fuels that considers period of demand (to manage seasonal fluctuations), storage life of fuel and fuel quality.
- Using a heat wave prediction service to prepare the farm for high energy demands (maintaining inventory, servicing diesel motors).

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 using 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 or upgrading an existing one..
- Monitor tractor engine speed when undergoing heavy tillage. Throttling back and gearing up can reduce in-field fuel costs by 20%.

Water management to reduce energy costs

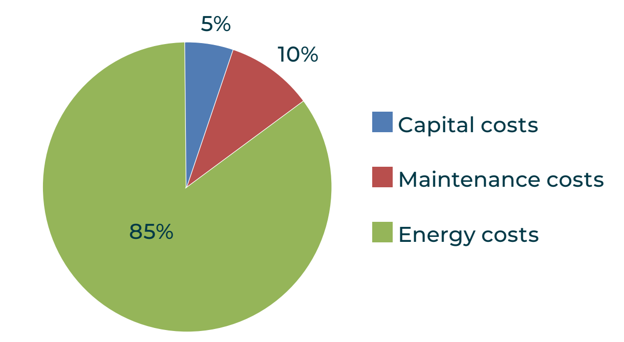
Reducing or optimising the amount of water pumped around the farm can substantially lower demand and energy costs. The CottonInfo website has resources with the latest research and knowledge on water use and management that range from collection through to field distribution. Measuring volumes of inputs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

- Use tools to schedule irrigations and monitor soil moisture levels.
- Estimate your soil's capacity to hold and store water (which will change with field and soil type). 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 as 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 using 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

FIGURE 9.1 The lifetime cost of an irrigation system.
(Source: 'Designing an Irrigation System.' McMullin, 2016)



our energy efficiency. From this research, it has been determined that 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. When investing in a pump station, capital costs need to be weighed against ongoing maintenance and energy costs.

Figure 9.1 illustrates the weighting of energy costs for each category throughout the life of an irrigation system. 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. However there is likely to be 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 others. Observations from previously conducted pump audits have 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 in pipelines 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 (see Figure 9.2). 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 air entrainment can 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 also decrease pump performance. Water velocities in a sump should be kept below 0.3 m/s. Keep in mind that one cubic meter of water weighs one ton, so significant energy is required to change the water direction.

FIGURE 9.2 Cotton trash can reduce pump performance by up to 30%. Phil Szabo

FIGURE 9.3 An industry first installation of a 55 kw submersible pump driven by combined 100 KW solar and 110 kVA diesel generator at the Gill family's 'Waterloo' Narromine, NSW. Jon Welsh

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.

Tractors and energy use

The field preparation and post-harvest phases 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. Therefore, under some agronomic circumstances, energy use can be lowered with a small 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 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 cottoninfo.com.au/publications/energy-ripping-depth-and-ground-speed.

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 9.3 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 or retro-fitted 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 employed. This may occur through pumping into storage in cooler months, operating grain drying equipment or (potentially) charging electric vehicles/machinery and replacing fossil fuels.

USEFUL RESOURCES:

cottoninfo.com.au/energy-use-efficiency

mybmp.com.au (Energy and Input Efficiency)

qff.org.au/wp-content/uploads/2016/11/Designing-an-irrigation-system-v2-Lex-McMullin.compressed.pdf

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

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

CottonInfo video: Integrating alternative energy solutions into irrigation farms youtu.be/y0wjOW-9RxM

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

Greenhouse gas emission reduction

By **Chris Cosgrove** (Sustenance Asia/CRDC)

Acknowledgements: **Aaron Simmons**, **Grace Griffiths**, **Jon Welsh** and **Nicola Cottee**

Greenhouse gases, carbon, nitrogen … what are we really talking about?

We're talking about climate change. A number of gases in the earth's atmosphere trap heat. The production of cotton mainly releases two greenhouse gasses (GHG):

1. **carbon dioxide (CO_2)**, mainly comes from fossil fuels used to manufacture fertiliser and operate machinery
2. **nitrous oxide (N_2O)**, comes from nitrogen fertiliser reacting with oxygen in soil or water, and the decomposition of crop residues.

Farms also remove GHGs from the atmosphere. This happens when vegetation takes in CO_2 in the natural photosynthesis process. If vegetation is big and perennial – like trees – the carbon in the CO_2 is permanently stored and is an important way to reduce total GHGs. If vegetation is small and annual – like crops – it breaks down fairly quickly and has no real impact on reducing total GHGs.

So when we talk about climate change, cotton farms can both release and store GHGs. Reducing the amount of fossil fuels, reducing excess N fertiliser, and increasing woody vegetation present all reduce the total emissions released on a cotton farm.

This is good news for you if the corporations you sell cotton to want to reduce their emissions, or are required by legislation to report GHGs in their value chain.

But it's also good news for you because using inputs like energy and N as efficiently as possible will increase your margins, and will most likely involve soil health practices that improve the resilience of your farm to seasonal extremes – such as storing more rainfall, and being less susceptible to erosion.

Market opportunities, and higher gross margins

Voluntary targets and climate change mitigation regulations are requiring companies worldwide to report the net GHG emissions associated with their business activities.

In Australia, organisations that meet certain criteria under the climate-related financial disclosure legislation are now required to report their supply chain GHG emissions and their strategies to manage emissions. The supply chain for companies that sell cotton or products that include cotton includes the GHG emissions associated with cotton production. Hence, even if your farm business is not required to report GHGs emitted or describe how you're reducing them, your customers almost certainly will now or in the near future.

This means there are market opportunities for farms who have the data needed to prove they grow low emission cotton, and risks for those who don't.

Even without direct financial rewards such as price premiums, growing cotton with a low carbon footprint is just increasing the efficiency of your inputs, if done correctly.

That's because by far the biggest source of GHG emissions in cotton production is the use of synthetic N fertiliser. The second biggest source is diesel followed by electricity for water pumping. So farmers who achieve yield targets with less N and less diesel will have higher gross margins and have lower GHG emissions per bale of cotton. Cotton growers are already focussing on efficiencies such as these to improve their profitability even if they are not targeting emission reductions.

How are emissions calculated?

GHG accounting is fairly new, but there are just a handful of concepts to understand.

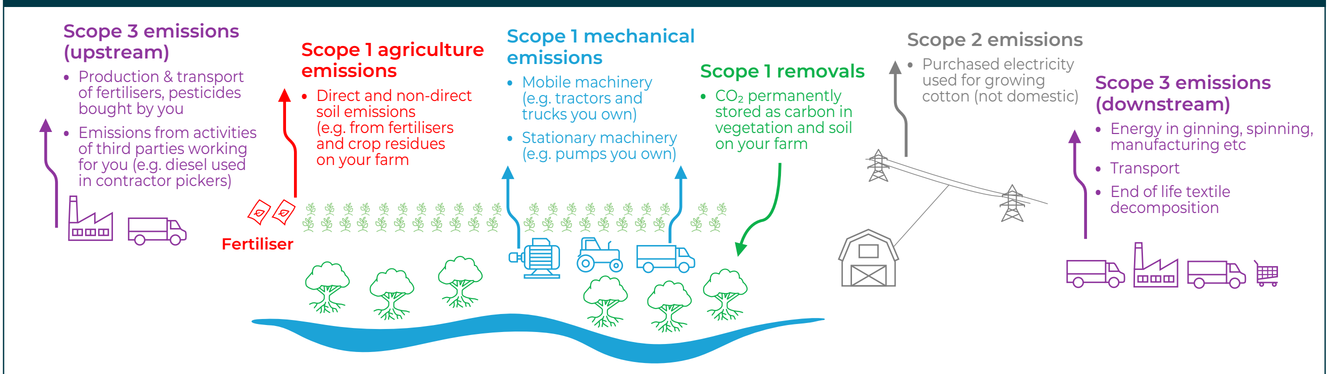
Firstly, GHG emissions are measured in carbon dioxide equivalent (CO_2e) to standardise the impact of different GHGs on the earth's climate. For example, one tonne of N_2O is equivalent to 273 tonnes of CO_2, so it is referred to as 273t CO_2e. This is referred to as the 100-year Global Warming Potential (GWP_{100}) of a GHG and it should be noted that the GWP_{100} of a GHG is determined by things that can vary over time such as the GHG's atmospheric concentration, so these values are re-calculated and change over time.

Secondly, GHG emissions are divided into three categories (Figure 10.1):

- **Scope 1: On-farm emissions from your direct actions**, like N_2O from the denitrification of nitrogen fertiliser in your soil and CO_2 from diesel combusted in machinery you use to produce cotton.
- **Scope 2: On-farm use of purchased fossil-fuel-generated electricity** in cotton production (e.g. for pumping irrigation water).
- **Scope 3: Emissions from third-party activities associated with growing your cotton**, such as GHGs emitted by the manufacture of fertiliser and the transport of inputs to farm.

And finally, GHG emissions are estimated by calculators that use equations and emissions factors (EF). The most robust calculators use equations and EF that are consistent

FIGURE 10.1 Sources of Scope 1, 2, and 3 GHG emissions for a cotton farming system.



with those Australia uses to calculate its GHG emissions for reporting to international climate change frameworks. These calculators require farm management data such as fertiliser type and use, diesel use, electricity use and crop yield to estimate GHG emissions associated with cotton production.

Therefore, to estimate your GHG emissions, you need to enter data like yield, fertiliser rates and diesel use into a cotton-specific emissions calculator, and the calculator tells you your scope 1, 2 and 3 emissions in CO_2e.

What does this mean for growers?

It's likely growers will be asked soon – if they aren't already – by merchants, gins, banks and others in the value chain for GHG emissions data so these companies can comply with the Federal Government's mandatory climate reporting.

To avoid being frustrated by being asked for similar information by multiple companies as their need for data increases, indicators from the cotton industry's PLANET. PEOPLE. PADDOCK. sustainability framework have been developed as a common language to meet the needs of all users (read more here: crdc.com.au/growers/sustainability). This means growers can either respond to requests for data separately several times during the year, or collect the right data once and have it in one place. In future, the cotton industry data platform will give growers the ability to automate this process, making it even easier to respond to information requests. Some growers are also producing their own voluntary sustainability reports.

What GHG emissions data should growers collect?

The cotton industry's aim is to have every agriculture sector and every business in the cotton value chain (farms, banks, agronomists, gins, merchants and others) all using the same sustainability language and indicators. That's the only way we can eliminate confusion.

Therefore, the cotton industry's revamped PLANET. PEOPLE. PADDOCK. Sustainability Framework indicators are being shared with other agriculture industries and the Australian Agriculture Sustainability Framework to work towards rapid harmonisation of sustainability indicators, including GHG emissions indicators, across Australian agriculture.

With so many people needing to have a say in harmonised reporting this is taking a lot of time to get right, and there may be more tweaks. Figure 10.2 outlines current recommendations for the GHG emissions indicators that every cotton grower will eventually need to report to allow companies in their value chain to meet their mandatory reporting requirements.

FIGURE 10.2 GHG metrics required by climate-related disclosure legislation.

GHG emissions

- Total scope 1, 2 & 3 emissions
- Removal of CO_2 in vegetation & soil
- Net GHG emissions
- Net GHG intensity (kg GHG per kg cotton)
- Nitrogen use efficiency
- Description of strategy to reduce Scope 1 emissions (i.e. on-farm emissions from fertiliser & energy)

How should growers collect GHG emissions data?

In the near future, participation in the cotton data platform will offer the best response to requests for sustainability data, including GHG emissions data, as it will enable automation of this process, saving time, effort and costs for growers. A grower's data can also be used to inform better management decisions, benchmark performance and ensure access to all markets is on the table.

CRDC and Cotton Australia will be meeting with growers and others in the industry during 2025 to explain the sustainability framework and indicators, and how growers can use the data platform to communicate GHG emissions data with merchants, gins or banks, as well as to hear from growers what they need to make the most of this in their farm business.

In the interim, the Australian cotton industry uses the Greenhouse Accounting Framework (GAF) calculators developed by the University of Melbourne; virtually every other agriculture industry like beef and grains also uses the relevant GAF tool for their sector. This calculator clearly lists the input data that need to be collected to calculate the cotton production emissions for your farm.

For farms with more than one commodity, the Agricultural Innovation Australia Environmental Accounting Platform (EAP) pulls together the GAF tools for each commodity into a single platform for a standardised approach.

You can access the calculators here to estimate your emissions:

- Cotton specific GAF: piccc.org.au/resources/Tools
- Cross-sectoral EAP: aiaeap.com

Reducing your on-farm emissions

Cotton production GHGs come mainly from nitrogen fertiliser and diesel fuel, and net emissions can be reduced by having non-remnant woody vegetation that sequesters carbon from the atmosphere and is only released when the vegetation decays naturally.

Under current GHG accounting rules, mature woody vegetation is deemed to be in carbon equilibrium: the amount of CO_2 a mature tree sequesters is the same as the amount of CO_2 it releases through leaves and branches that fall and decompose. For this reason, only new plantings currently count for offsetting GHG emissions.

It follows then, the key actions any grower can take right now to reduce emissions are to assess if you can:

- Increase input use efficiency, especially for key GHG sources such as N fertiliser, and improve soil health. For example, cover cropping with a legume may reduce synthetic N use and lower emissions.
- Reduce soil compaction and ensure field slope is well maintained to improve water use efficiency.
- Integrate renewable energy into groundwater pumps powered by diesel fuel and grid electricity. The declining cost of solar can offer fast paybacks in the current high-priced energy market.
- Maintain or increase the area of on-farm woody revegetation to store or remove carbon.

If you're doing all of these, you are off to a good start – but there may be additional options in the future. Technologies like green nitrogen, nitrogen inhibitors, and hydrogen-fuelled machinery might be years or decades away, and some of them are completely outside our control. Keep an eye out in CRDC's Spotlight on Cotton R&D magazine, CottonInfo publications, and local field days for emerging tools for reducing emissions in cotton farming systems.

But by having a credible plan to reduce GHG emissions as much as possible, our customers and investors will have more confidence in the industry, and growers can be confident industry research is aimed at supporting realistic actions growers can take.

Top tips for improving nitrogen use efficiency and reducing GHG emissions

The cotton industry has been investing in nitrogen use efficiency RD&E for 40 years. A significant contributor has been Jon Baird, who worked on CRDC-supported nutrition research via NSW DPI (now DPIRD) and CottonInfo for a decade, before recently moving to a new role with GRDC.

1. Minimise early-season fertiliser losses: Fertiliser losses during the first irrigation can be significant, sometimes upwards of 50 per cent of the applied amount.
2. Get the N where it's needed: The method of in-crop application is less important than ensuring the fertiliser is properly incorporated into the soil profile for better plant recovery and efficiency.
3. Ensure nutrient balance: While N is crucial for optimal yield, other macro and micronutrients are also important, especially during high-stress events like severe waterlogging.
4. Consider enhanced fertilisers: These can reduce losses, particularly early season, but their active lifespan must align with crop utilisation to be effective.
5. Harmonise irrigation and nutrition management: Timely water application and quick turnarounds on the field are vital for plant health and nutrient efficiency.

Chapter **11** sponsored by UPL OpenAg

Preventing pest problems

Chapter coordinator: **Tonia Grundy** (Qld DPI)

Acknowledgements: **Paul Grundy**, **Eric Koetz** and **Linda Smith**
Contributors: **Lisa Bird**, **Jamie Hopkinson**, **Linda Scheikowski** and **Murray Sharman**

Best practice...

- Knowledge is the key to effective management.
- Aim to prevent pest outbreaks using a year-round approach of good farm hygiene, appropriate agronomic practices, and conserving beneficial populations.
- Monitor for pests across the whole farm all year, and maintain awareness of beneficials, crop stage, crop growth rates and the weather.
- Before taking any action, consider its likely effectiveness, economic benefit, risk of resistance, legal requirements, and potential impacts on the cropping system or wider environment.

Management of pest insects, weeds and diseases needs to be a consideration year-round, not just in-crop. Two of the simplest ways to minimise weed competition, prevent carryover of pests, and encourage plant compensation post-damage are maintaining clean fields and growing a healthy crop.

An integrated management approach is the most effective method of dealing with the range of pests that occur in cotton systems as it implements a mix of pre-emptive and responsive pest management actions to reduce the risk of crop loss and improve the health of both the environment and ourselves. Knowledge and understanding of the pests, the crop, and the environment is used to reduce the likelihood of pest outbreak and the need for pesticide applications.

Options that could be considered include:

- **Cultural** – reducing pest establishment, reproduction, dispersal, and survival (e.g. planting windows, crop rotations, suitable varieties).
- **Physical** – excluding pests, making the environment unsuitable, or killing them directly without chemicals (e.g. Come Clean. Go Clean, cultivation to control weeds).
- **Biological** – utilising predators, parasitoids, pathogens or competitors to minimise pests and their damage (e.g. conservation or augmentation of natural enemies).
- **Chemical** (pesticides).

Dryland cotton...

- Good weed control during fallows is essential.
- Physical weed control options like cultivation may not be an option if conserving soil water.
- Adhere to herbicide resistance management strategies to ensure glyphosate remains effective.
- Ensure 100% crop destruction at the end of the season

For more information, see the dryland section at the end of this chapter.

RD&E in focus

The Australian Cotton Disease Collaboration (ACDC) is a partnership between the Cotton Research and Development Corporation (CRDC), the University of Southern Queensland (UniSQ) and the QLD Department of Primary Industries (DPI), delivering a comprehensive coordinated national disease program that will help understand the impact of disease, enhance foundational pathology resources and capability, and deliver tactical management and innovative technical solutions.
Find out more at **crdc.com.au/australian-cotton-disease-collaboration**

In many cases chemical options may not be available or feasible, or may have unwanted environmental impacts. Most non-chemical control options are proactive rather than reactive and can require long-term planning.

To improve system sustainability, only use pesticides when needed (and preferably in combination with other approaches). Choose products wisely and ensure your application is effective.

Occasionally, management options for specific pests will be incompatible with other pest or wider farm management objectives (such as cultivation for pupae busting or stubble/residue management resulting in a loss of soil moisture), and these need to be balanced in the context of the whole farming operation.

Refer to the *Cotton Pest Management Guide* for identification and management information about the most common insects, weeds and pathogens, along with the beneficial species that can occur in Australian cotton crops.

An integrated management system

While integrated management information is often categorised by the target pest type (IPM, IWM and IDM for insects/mites, weeds and diseases respectively), there are several key principles when combatting biotic pests:

- **Practice good farm hygiene.** Clean farms typically have fewer pest problems. Controlling cotton volunteers, ratoons and other weeds in fallow fields, field edges, roadways and drainage lines will also help limit the survival and spread of overwintering insects and plant pathogens. Control weeds before they set seed to minimise future weed populations. Use washdown facilities and limit movement between fields to minimise manually transporting pests onto and around your farm.
- **Plan ahead and optimise your production system.** Use agronomic tactics to disadvantage pests and start the season with a healthy crop. Avoid back-to-back cotton to limit season carryover and adjust crop planting dates where possible minimise exposure to pests of concern. Some weed seeds and pathogens can remain dormant in your fields for many years, so consider the long-term impact of your management decisions. Use seasonal forecasts to identify the risk of environment-related impacts on your crop.
- **Select and protect modern cotton varieties.** Choose varieties suited to local growing conditions. In areas where specific diseases are known to be a problem, use disease-resistant varieties if available. The ongoing ability of genetically modified crops to provide control of larvae or weed management advantages depends on the target pests remaining susceptible, so adhere to the industry's resistance management strategies.

- **Monitor regularly and effectively.** The crop's development stage strongly influences both its susceptibility to yield loss and if it can recover from pest damage without intervention. Tailor your monitoring program to the pests most likely to occur on your farm, and keep good records so that you can compare pest levels within and between seasons.
- **Know your friends and foes.** Know how to identify insect, disease and weed pests, natural enemies and abiotic damage (weather damage, herbicide drift, nutrient deficiencies or other physiological disorders). Be aware of the capacity of some insects to vector diseases. Consider life cycles and development times and identify when pests are most vulnerable to various control methods. For example, many herbicides may not effectively control large or stressed weeds.
- **Work out the potential for damage and most appropriate time for intervention.** Ensure that you are facing something that can actually be controlled (e.g. that square shedding was caused by insects rather than cloudy weather, and that they are still present). Balance effectiveness with future consequences when making pest management decisions. Where possible use economic thresholds as a guide to whether action is required, and follow-up afterwards to check the impact of any action taken. Leaving a small untreated area to allow direct comparison of the control method's effectiveness can often be useful.
- **Preserve pesticide usefulness.** Balance the product's effectiveness on the target pest against potential off-target impacts, target the appropriate pest stage, follow the label directions and consider both your application technique and environmental conditions to optimise chemical efficacy. Avoid unnecessary prophylactic sprays and adhere to stewardship programs such as resistance management strategies to ensure the ongoing effectiveness of available products.
- **Work with your neighbours.** Pests (and beneficials) do not recognise farm boundaries. Working together to better co-ordinate planting, farm hygiene and crop spraying can help manage pests on an area-wide basis. In some regions growers meet regularly at area wide management (AWM) meetings to discuss local issues and work towards shared solutions. Talk with your local CottonInfo Regional Extension Officer (REO) about any AWM groups in your valley. Check if there are any beehives or sensitive crops nearby using apps such as BeeConnected beeconnected.org.au and SataCrop satacrop.com.au.

For first-time growers, the easiest way to start is to employ the services of an experienced consultant to help guide you through the process of pest management decision-making and advise you on various management options that might be applicable to your situation.

Learning as you go is the key to success. When things change, be prepared to adapt what you are doing to overcome new challenges. Simple 'WHY' questions such as "Why is this pest's occurrence higher or lower than last season?" or "Why am I using this particular pesticide?" often provide insight into the best approaches for your management program. If you have unanswered questions, seek information and advice via your consultant, industry resources or your peers.

See CottonInfo's videos on IPM youtu.be/BdQRLx4hN5o and IWM youtu.be/AH3jwf0TY60

Being proactive in your pest management program, such as implementing good farm hygiene practices, active management of the weed seedbank, and reducing the pathogen load for the coming season will help prevent or minimise in-season problems, particularly against pests with limited mobility.

In recent years, interruptions to global supply chains have caused supply shortages of some pesticides. Consider the pests you commonly encounter during the season and plan ahead to ensure the products you are most likely to need will be available.

Preventing resistance

Resistance can occur when exposing pest populations to a strong selection pressure, such as repeated usage of pesticides with a similar mode of action.

Within pest populations, genes that confer resistance are often present but usually rare. However, when the population is exposed to a toxin, either from an applied pesticide or from a biotechnology trait, the preferential removal of susceptible individuals can increase the frequency of resistance genes. If selection continues repeatedly, the proportion of resistant pests increases until the toxin no longer kills enough of the population for effective pest control, resulting in control failure (for example Table 11.1 includes predictions of the length of time before resistance evolves to commonly used herbicide groups). Long-term management of pests depends on avoiding over-reliance on any one toxin-based control method and instead rotating chemistries and utilising cultural, physical or biological tactics. Keep good records of pesticide applications (including seed treatments) to help you avoid sequential use of products with similar modes of action.

The underlying frequency of resistant individuals within pest populations varies greatly with pest species and the pesticide's mode of action. The cotton industry has been seriously challenged by resistance (particularly to insecticides) in the past, and resistance management is at the core of an integrated approach, where the industry proactively generates pesticide use guidelines aimed to protect the longer-term efficacy and longevity of biotechnology traits and pesticide products.

In weeds, 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 and act, as options are much more limited if herbicide resistance is widespread before it is observed. Insects can be highly mobile, making it harder to recognise and contain emerging resistance.

The cotton industry invests in testing for resistance, and considering preventative measures. Each year herbicide, insecticide and Bt product performance and other relevant science is reviewed by the Transgenic Insecticide

TABLE 11.1 Years of herbicide application before resistance evolves. (Adapted from Glyphosate Sustainability Network data)

Group, examples	Years
2 (B) Glean, Ally, Hussar, Flame	4
1 (A) Verdict, Targa, Topik, Axial	6–8
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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Management Strategy (TIMS) advisory panels (through Cotton Australia) to ensure sustainable chemical control is underpinned by IPM and IWM-compatible resistance management.

The industry has also implemented science-based stewardship programs for the prevention or management of resistance that combine knowledge of the pest, resistance mechanisms and levels of field resistance, and consider how these factors might react in response to changes in product use.

Preserving the effectiveness of glyphosate

Herbicide resistance has been confirmed in 51 grass and broadleaf species in Australia, across 15 distinctly different herbicide chemical groups (www.croplife.org.au), with many reports of multiple resistance. As of January 2024, 19 weeds of cropping systems had developed resistance to glyphosate, and in cotton growing areas, the number of growers who are reporting glyphosate resistance is increasing.

The cotton industry's **Herbicide Resistance Management Strategy (HRMS)** currently emphasises glyphosate (Group 9/M) because of the strong reliance on this product in the current farming system and the increasing number of confirmed cases. An updated version of the HRMS (to be released later in 2025) focuses on a glyphosate, glufosinate and dicamba tolerant cotton system (XtendFlex® cotton), however other herbicides could also become at-risk for resistance if used more than once every year.

The HRMS's key message is to use at least two non-glyphosate weed control tactics in fallow and two non-glyphosate tactics in-crop and ensure that there are no survivors (2+2 and NO survivors). The aim is to drive down weed numbers and ensure no weeds set seed after herbicide applications, and use a diverse program of 6 modes of action every 2 years. The latest HRMS can be found in the *Cotton Pest Management Guide*.

See CottonInfo's videos on Minimising glyphosate resistance youtu.be/cke-mamGe2o and a visual demonstration of weed resistance youtu.be/y7Jj1IaiSLk

Bt technology and industry stewardship

A common soil bacterium, *Bacillus thuringiensis* (Bt) produces proteins that are toxic to some species of insects. Bt cotton has been genetically modified with genes that enable production of proteins that are specifically toxic to moth larvae like *Helicoverpa* spp.

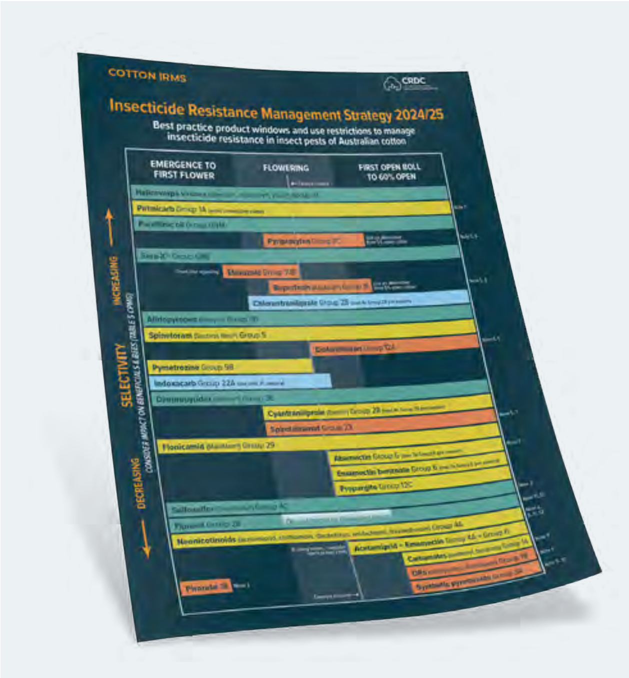
Bollgard® 3 cotton produces three different insecticidal proteins. This 'stack' contributes to resistance management as it is more difficult for the pest to overcome all three toxins in unison.

The success of Bollgard varieties in minimising the impact of helicoverpa, thus reducing both the need for early season chemical intervention and the overall pesticide load applied, underpins current insect management programs in cotton.

The Bollgard **Resistance Management Plan (RMP)** has been developed in conjunction with industry to help delay the development of resistance to Bt. A mandatory component of the licensing agreement (Technology User Agreement or TUA) that growers sign with the technology provider to grow Bollgard cotton, the RMP requirements (which may vary between regions) aim to:

- Limit the number of generations of *Helicoverpa* spp. exposed to the toxins (planting windows for temperate and tropical regions, controlling volunteer and ratoon cotton plants, limiting use of foliar Bt).
- Ensure that there is a population of susceptible moths that haven't been exposed to Bt during the season to dilute any resistant genes in the population (refuge type, area grown, agronomic management).
- 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 crop destruction, pupae busting).

Look for the early signs of resistance before large areas of survivors develop (like this annual ryegrass patch).
Graham Charles, NSW DPI



A strategy to minimise the risk of insecticide resistance is updated each year in the *Cotton Pest Management Guide.*

The interaction of all these elements should effectively slow the evolution of resistance. Commercial access to Bt transgenic varieties is conditional on 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.

YES/NO SELF-ASSESSMENT
for possible herbicide resistance.

1.	Was the herbicide rate 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.	Were weather conditions optimal at the time of spraying?
5.	Is there a potential incursion source (e.g., machinery or bought-in hay etc)?
6.	Were the plants present at application (i.e., not recently germinated)?
7.	Are the surviving plants in a different or unusual pattern compared to a spray failure?
8.	Are the weeds that survived in distinct patches in the field?
9.	Was control generally good on the other target species that were present?
10.	Have herbicides with the same MoA been used in the field several times before?
11.	Have results with the herbicide been disappointing before?
12.	Are higher rates needed each year to achieve the same level of control?

If you've answered yes to most of the questions above or 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

Dr Peter Boutsalis (seed test & quick test) 22 Linley Avenue, Prospect, SA 5082 Ph: 0400 664 460, Email: info@plantscienceconsulting.com

More information on weed resistance testing and how to collect samples is included in the *Cotton Pest Management Guide.*

Reducing the risk of insecticide resistance

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 avoid repeated use of products with similar modes of action.

The IRMS is designed to both delay resistance development and to manage existing resistance and advises how and when each insecticide or insecticide group is best used. Updated annually, it takes into account the levels of field resistance in pests and any relevant changes within the farming system. Adhering to the latest IRMS is critical to ensure the longevity of insecticides currently registered in cotton.

Insecticides are listed in the IRMS chart according to the order of their impact on beneficial insects and bees – the most selective are available for use early in the season while the broad-spectrum products are restricted to the end of the season. Delaying or avoiding the use of disruptive insecticides and miticides conserves natural enemies that can predate/parasitise surviving resistant individuals.

Spraying for one pest can simultaneously select for resistance in other pests present, so the IRMS includes all insecticide actives commercially available for use in cotton and should be consulted for every insecticide/miticide decision.

Resistance surveillance

As pests may also survive pesticide applications due to spray failure (that can be caused by a range of factors including product incompatibility, inappropriate calibration, non-optimal timing, equipment failure, or water quality issues) the industry has several monitoring programs in place.

INSECTS: Resistance surveillance on a range of arthropod pests is conducted each year, providing the foundation for the 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 are:

- Aphids, *Helicoverpa* spp., two-spotted spider mites, mirids and thrips: Dr Lisa Bird, NSW DPIRD 02 6763 1128.
- Silverleaf whitefly: Dr Jamie Hopkinson, Qld DPI, 0475 825 340.

WEEDS: Completing the Yes/No herbicide risk self-assessment will aid in determining if a weed's survival is likely to be due to resistance or other factors. 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 cottoninfo.com.au/glyphosate-resistance-toolkit

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

Biosecurity and farm hygiene

Pests do not recognise farm boundaries, and while some pests (such as winged insects) reach new areas relatively easily, small insects and mites, diseases and weed seeds can still be transported around and between farms by wind, water, people, vehicles or machinery.

Help protect your property from the entry, establishment and spread of pests that could impact production. Simple steps you can take include:

- Develop a farm biosecurity plan to assess the risk of pests, diseases and weeds entering the farm and identify practices that could minimise these risks.
- Ensure all staff, contractors and visitors are aware of your biosecurity requirements and adhere to 'Come Clean. Go Clean' principles before entering the farm.
- Provide a sign-posted designated parking area for visiting vehicles and contractor equipment that is away from fields and production areas. Keep a record of visitors and where possible, use farm vehicles to transport people around the farm.
- Ensure a wash down facility is available and that all machinery, vehicles and equipment are free of mud and plant debris before moving on and off the property. If fields are known to harbour diseases or pests that are not present on the remaining farm area, visit those fields last.
- Minimise spillage and loss when transporting modules, cotton seed or gin trash.
- Be on the lookout for pests that may gain entry in irrigation water, particularly during floods. If possible, pump flood water into a storage and allow to settle before applying to fields.

Maintain year-round vigilance for anything new or unusual. If you spot something that you suspect is exotic, contact the **Exotic Plant Pest Hotline on 1800 084 881**.

Come Clean Go Clean is one of the simplest yet most effective strategies for minimising the spread of weeds, diseases and pests. This fact sheet, available at cottoninfo.com.au outlines a 4-step best practice wash-down guide for machinery, vehicles and equipment.

It is important to remember that everyone on farm has an obligation to minimise biosecurity risks. For more information on biosecurity or exotic pests of particular concern to the cotton industry, refer to the *Biosecurity* chapter of the *Cotton Pest Management Guide*.

Insects

Field selection, avoiding back-to-back cotton production, adjusting sowing date and ensuring your farm is clear of weeds that could form a 'green bridge' are some of the tactics available to minimise pest presence pre-season. The *Cotton Pest Management Guide* has a seasonal activity plan summary that lists things to consider when planning a year-round insect pest management approach.

Conserving beneficials

Natural enemies can contribute significantly to keeping several of the major insect pests of cotton below threshold levels. Predators and parasitoids are most effective when present from the start of the season as their populations can take time to build to useful levels, so manage rotation crops carefully to avoid disrupting beneficial populations. Areas of native vegetation near fields can provide a refuge for natural enemies, including larger predators such as insectivorous birds and bats.

Establishment pests

Management tactics for soil and establishment pests must be implemented prior to planting, as there are no in-crop options available. Consider the paddock history and assess risk before planting. Use insecticide-treated seed or in-furrow applications if needed. Cotton has good compensation capacity and can grow out of early season damage if:

(i) the plants are not too severely affected, and

(ii) conditions are conducive to rapid recovery.

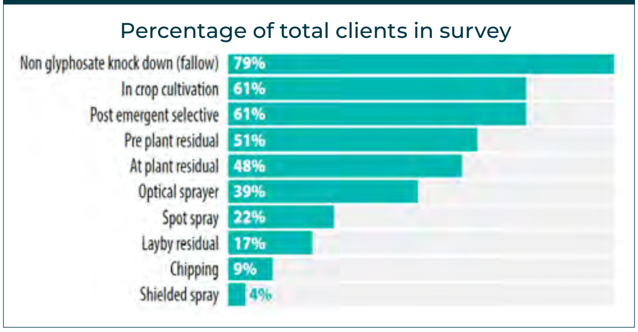
Make replanting decisions early based on plant stand losses. Also consider gaps, which can lead to delays in maturity in nearby plants. For more information, see the *Crop establishment* chapter in this manual.

More detailed information on specific early season insect pests of cotton and their management is available in the *Cotton Pest Management Guide*.

Weeds

Keep paddocks and other farm areas free of weeds (including volunteer and ratoon cotton plants) to minimise the carryover of both weed populations and any insect pests or pathogens they may be harbouring. If weeds germinate in rotation crops or fallows, control them before they set seed. Australia's cotton growers utilise a wide range of control tactics in their weed management programs (Figure 11.1).

FIGURE 11.1 A wide range of non-glyphosate options are used by growers to combat 'hard to kill' weeds.
(Source: 2022-23 CCA survey)



Keep good records of weeds present and your control measures for each field. Consider past records in this year's decisions, particularly in relation to rotating herbicide modes of action and safe plant-back periods for residual herbicides. Always refer to the Herbicide Resistance Management Strategy (HRMS; available in the *Cotton Pest Management Guide*) when selecting herbicides.

Monitoring and identification

Scouting fields and non-field areas well before the season starts enables weed control tactics to be matched to the species present. Continue monitoring regularly throughout the season 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 a reproductive phase in response to lengthening daylight hours.

If implementing a control measure, check afterwards to assess efficacy:

- Were there any survivors?
- Has control been better in some areas than others?
- Has there been good control but a subsequent germination?

Ensure you correctly identify weed species present before implementing control as similar species may respond differently. For example, the strong seed dormancy of cowvine (*Ipomoea lonchophylla*) make it less responsive to a tactic like a spring tickle than bellvine (*Ipomoea plebeia*) which has very little seed dormancy. Herbicide susceptibility can also differ between similar species.

Bellvine. 📷 Bruce Wilson, Qld DPI.

Cowvine 📷 Tonia Grundy, Qld DPI.

A summary of non-glyphosate options for weed management is updated each year in the ***Cotton Pest Management Guide***.

Timely implementation

Herbicides are most effective on rapidly growing small weeds. Cultivation may be more cost-effective to control large or stressed weeds, but avoid cultivating in-crop if the cotton is also stressed. Be prepared and implement controls at the optimum time.

To be effective in preventing resistance, weeds that survive an application of herbicide must be controlled by another tactic (double knock) before they are able to set seed. It is essential to check the double knock's efficacy post-treatment, especially if using a different herbicide as the second treatment, as some weed species can be resistant to multiple products.

Always follow label recommendations

Herbicide efficacy is highly dependent on the use of correct application techniques. Adhere to 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, and that you are using the appropriate water volume, water quality, droplet spectrum and operating pressure. Always consider the suitability of weather conditions, and if a WAND tower is located nearby use this information to help decision making when applying summer fallow sprays.

Stop seed set, and actively manage the seedbank

Seeds of some weed species can potentially survive for years dormant in the soil. It is essential to consider the weed seed bank in terms of both resistance risk and 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.

The primary objective of weed control and the HRMS is no survivors, however uneven spray coverage or missed areas due to blocked nozzles, inadequate tank mixing, or inappropriate operation of equipment can allow even susceptible weeds to survive. Insufficient coverage can also be due to high weed numbers, incorrect rates, dust on the weed's surface or interruptions by rainfall. 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 these survivors DO NOT set seed.**

If machinery (particularly of contractors) breaks down, closely monitor nearby areas as weed seeds (including species such as parthenium) are often inadvertently released when panels are removed during repairs. Whenever possible, ensure that all machinery maintenance occurs in a designated area so that any new weed incursions will be readily observed and managed.

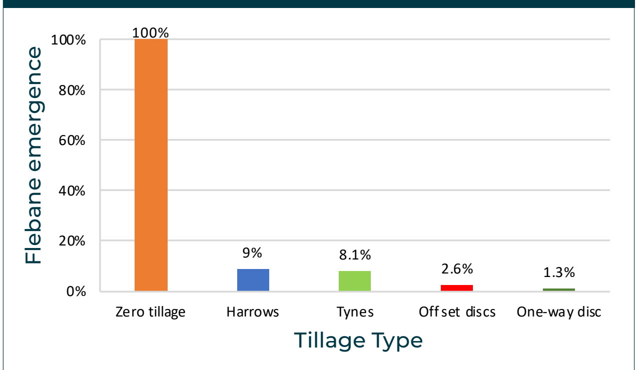
Non-cropping areas, such as roadways, channels, irrigation storages and degraded remnant vegetation can also be a source of infestation and can provide opportunities for newly introduced weeds to build up significant seed banks. Some of these weeds will also host pests and diseases.

CottonInfo YouTube video on sources of weed seed: youtu.be/TLSpFIZZaqU

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) and burying the seed will prevent its germination (Figure 11.2 shows the impact of different implements on fleabane). 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. However, avoid using this tactic too frequently as the seed may become dormant. For example, the seed longevity of common sowthistle and flaxleaf fleabane will be extended from around 12 months to about 30 months by seed burial, so a cultivation pass to bury surface seed could at the same time expose older but still viable seed buried in a previous operation.

FIGURE 11.2 Effect of tillage on emergence of fleabane.



Patch management

Intensive management of small patches of herbicide-resistant weeds allows the use of options (such as chipping, spot spraying or spot cultivation) that would be considered too expensive or intensive over a wider area. Patch management could be particularly effective for weeds such as awnless barnyard grass that are predominately self-pollinating, have a relatively short seed bank life and are not transported by wind. cottoninfo.com.au/barnyard-grass-understanding-and-management-bygum

Note the GPS coordinates of existing weeds and remove them before they flower. Monitor for subsequent germinations until the seed bank has been exhausted.

Optical spray technology (OST) weed detection systems provide an opportunity to utilise spot spraying across large areas of fallow. This can potentially reduce herbicide costs, while still ensuring robust label rates are applied to problem weeds. Limited brands are approved for use via this application method – check individual product labels for direction of use and application rates. For growers using technology such as See and Spray™, WeedSeeker® or Weed-IT®, check the APVMA website for additional use patterns. Be aware of longer plant-back periods when using higher rates.

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 as weeds need only be controlled if and when germinations occur so herbicide application can be timed to have maximum impact. The release of Xtendflex cotton varieties provides additional modes of action (MoA) for OTT application of non-selective herbicides glyphosate, glufosinate and dicamba. However, the use of other tactics to control any weed survivors will be critical to preserving the long-term value of these traits. Avoid using the same herbicide group to control successive generations of weeds. More information on herbicide tolerance is available in the *Cotton Pest Management Guide.*

Consider other aspects of crop agronomy

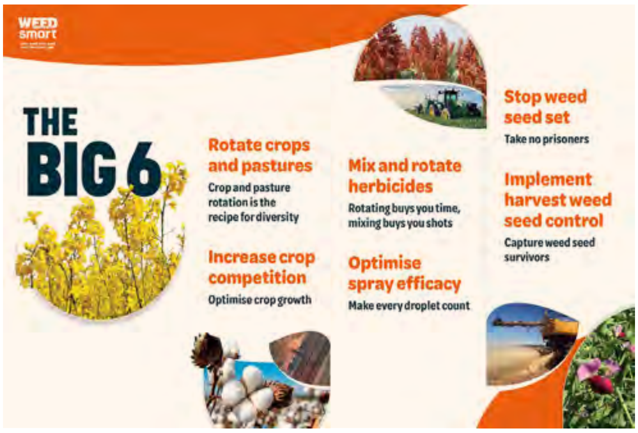
Most agronomic decisions for cotton have some impact on weed management. Cotton planting time, pre-irrigation versus watering-up, methods of fertiliser application, management of rotation crops, stubble retention and in-crop irrigation management all have an impact on weed emergence and growth. The influence 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.

WeedSmart Big 6

WeedSmart has developed a simple approach to managing weeds by increasing diversity of control tactics with the aim of disrupting the lifecycle of weeds to prevent seed set. weedsmart.org.au/big-6

The key points for a summer crop such as cotton are:

- Use diverse rotations.
- Optimise spray efficacy.
- Mix and rotate herbicides and tillage.
- Stop seed set in crop and fallow.
- Crop competition in grain crop rotations.
- Harvest weed seed control in rotational grain crops.



Understanding herbicides

Herbicides continue to play a vital role in weed management. Understanding how a herbicide works can help you improve its impact and sustainability. All herbicides are classified into groups based on their MoA in killing weeds (note that the herbicide MoA classifications in Australia have changed from letters to numbers to align with the international system).

Repetitive use of the same MoA group over time is closely associated with selection for herbicide resistance. Rotation of MoA 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 MoA, cultivation, chipping etc).

Rotate herbicide groups whenever possible to avoid using the same group on consecutive generations of weeds. 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.

Herbicide terminology

Residual herbicides remain active for an extended period (weeks or months), acting on successive weed germinations. They can be particularly effective in managing the earliest flushes of in-crop weeds, when the crop is too small to compete, and are a key component in prolonging the efficacy of glyphosate. Because they are applied in anticipation of a weed problem, their use requires knowledge of the type and amount of potential weed species present and a good understanding of seedbank dynamics.

Most residuals need soil incorporation for optimum activity. For some this is achieved through rainfall or irrigation, but others require 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 light cultivation to prevent 'shading' during herbicide application.

Utilising pre-emergent herbicides in grains and cotton cropping systems.
- Southern New South Wales cottoninfo.com.au/publications/utilising-pre-emergent-herbicides-southern-new-south-wales-grains-and-cotton-cropping
- Central Queensland cottoninfo.com.au/publications/utilising-pre-emergent-herbicides-central-queensland-grains-and-cotton-cropping

Herbicide persistence is determined by a complex range of factors including application rate, soil texture, stubble/ground cover and organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. For example, the length of time the soil is moist is more important than the volume of rain. Soil staying moist for a few days will contribute more to residual breakdown than a couple of storms where the soil dries out quickly. Refer to the product's label for more information, including plant-back limitations.

Check early if you have concerns about residual persistence. Look for the presence of susceptible weeds in the treated paddock or sow seed into soil potted up from treated and untreated areas and compare emergence. Where there may be a problem, consider planting an alternative crop that is tolerant of the herbicide. If sowing cotton, 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 capture and management of runoff water follows best practice.

Non-residual herbicides are usually applied to the foliage of young and actively growing weeds. Some herbicides from Group 14 may also provide short-term residual control of subsequent germinations, depending on the herbicide, weed and application rate combination. Cotton with XtendFlex technology provides an excellent opportunity to rotate the herbicide mode of action by using Group 10, 22 and 9 products OTT in-crop. Depending on the weed spectrum, more selective products from other MoA groups may also be used.

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

Translocated herbicides move within the plant's vascular tissues, and plant response can appear quite slow. How they are translocated influences their suitability for a situation. For example, atrazine is only translocated upwards in the xylem, and thus is not suitable for foliar application.

Selective herbicides have a limited range of target weeds and can help manage problem weeds under different scenarios. If using selective herbicides, consider how non-target weeds will be controlled. Follow label recommendations about appropriate adjuvants and avoid use in stressed crops.

Non-selective herbicides such as glyphosate, glufosinate or paraquat control a broad spectrum of both broadleaf and grass weeds. Despite being 'non-selective', 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 refer to application of the full label rates of more than one herbicide in a single operation, which can reduce application costs. Refer to the label or manufacturer to determine suitable mix partners, as some products are antagonistic (reducing weed control or damaging the crop when mixed together) or are physically incompatible (form a sludge).

Herbicide uptake varies with product but generally requires the weed to be actively growing. Refer to label directions for specific recommendations regarding additives such as ammonium sulphate, wetters and oils.

Application methods

A double knock is where two different weed control tactics are used on a single flush of weeds to stop any first application survivors from setting seed. When using two herbicides, apply a systemic herbicide, allowing sufficient time for it to be fully translocated through the weeds (generally 7-10 days), then return and apply a contact herbicide, from a different mode of action group, that will rapidly desiccate the above-ground material, leaving the systemic product to completely kill the root system. A physical control method such as cultivation can also be used as the second knock. When executed well (right products, right rates, right timing, right application) this tactic can provide up to 100% control of the target weeds. However, it is still important to monitor carefully after the double knock has been applied as any survivors from the double knock may lead to resistance in one or both of the herbicides used. Refer to the *Cotton Pest Management Guide* for some suggested intervals for common double-knock herbicide combinations.

A spring tickle uses shallow cultivation (1-3 cm) with lillistons or go-devils to promote early and uniform germination of weeds prior to sowing without sacrificing soil moisture. A nonselective knockdown herbicide (with a mode of action not used in the crop) is then applied to ease in-crop weed pressure. 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. Best results are achieved when the cultivation follows a rainfall event of at least 20 mm as 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.

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

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

Spot spraying is the chemical equivalent of manual chipping for controlling isolated weeds or weed patches. Optical spray technology (OST) weed detection systems can automate spot spraying across large areas of fallow.

Diseases

Cotton production systems have become more efficient in terms of nutrition, water, and pesticide use, but diseases continue to be a problem with very few 'quick fix' solutions available. Soil-borne diseases are particularly difficult to manage in-crop and require year-round and whole-farm system approaches.

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. 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 reduce the disease burden for subsequent crops and minimise the risk of diseases spreading within and between farms and regions. Use paddock histories and seasonal forecasts to help predict if any diseases are likely to be a problem in your next crop. For more detailed information on integrated disease management, refer to the *Cotton Pest Management Guide*.

Starting out right

Sowing in cool and/or wet conditions slows plant growth and favours disease development. The recommendations for planting cotton are soil temperatures of 14°C or above (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 perspective, it is best to wait until 16°C and rising if possible.

For best results:

- 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.

Vigorous crops may outgrow early disease damage. In fields with seedling losses, make replanting decisions based on plant stand gaps, relative yield potential of the remaining crop compared with a replanted crop, and the likelihood of further disease expression based on pathogen load and seasonal forecasts.

Varieties and seed treatments

Several cotton varieties have some resistance to verticillium wilt or fusarium wilt, with levels of resistance indicated by higher V rank and F rank, respectively.

Know the disease status of each field and consider the seedling vigour of your varietal options, particularly when pre-irrigating or planting early. When black root rot is present, use the more indeterminate varieties that have the capacity to catch up later in the season (if regional conditions allow).

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 available but must be chosen when seed is ordered. See the CSD website csd.net.au for more information. A couple of at-planting fungicides are also available for damping-off caused by *Rhizoctonia* spp.

Insect vectors of disease

Diseases caused by viruses and virus-like pathogens 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) relies on the virus from infected pollen entering plant cells through the feeding injury caused by thrips.

Consider IPM principles and resistance risks when targeting vectors. The control of aphids in cotton may be warranted if there is evidence of spread of CBT, however controlling thrips in-crop when TSV is observed is not likely to be as useful as thrips and TSV migrate into crops from nearby weeds, and the damage to cotton by TSV is negligible.

CBT can only survive within living plants or aphid vectors. Control of cotton ratoons and volunteers throughout winter will reduce pathogen levels within the immediate environment and lower vector insect populations, drastically reducing disease risk for the following season.

Pest management in rainfed (dryland) cotton

Cotton usually has similar pest (and beneficial) species present whether the crop is irrigated or not, and integrated management decisions and resistance management strategies are important regardless of where or how cotton is grown. However, a key IPM challenge for rainfed crops grown in minimum tillage systems is to ensure that crop destruction is 100%, as ratoon cotton or volunteers that emerge in a subsequent grain crop can provide a green bridge for cotton 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.

Weed management is also critical during fallows for moisture conservation and depleting the weed seedbank prior to a summer cotton crop. Weed control during fallows and in-crop herbicides can be a significant cost. About a quarter of rainfed cotton growers rely on glyphosate with only one other tactic for weed control, so it is particularly important in rain-grown crops to consider other products for knockdown applications. Rotate to Group 10 (glufosinate) or add 'spikes' to glyphosate such as Group 4 or 14 herbicides. Opportunities also exist in the winter crop rotation for weed control using different modes of action coupled with crop competition.

Incidence of wilt pathogens tends to be lower in rainfed cotton because consistent moisture from irrigation can create a more favourable environment for soil pathogens to thrive, while the variable moisture in rain-fed conditions can limit their spread. Foliar diseases that require humidity (such as ramularia and target spot) are also less likely to be prevalent in rainfed cotton, however moisture stress can exacerbate leaf spot diseases (including those caused by *Alternaria*, *Cercospora* and *Stemphylium* spp.) that are associated with low potassium levels.

Other considerations include:

- Incorporate layby residuals prior to boll fill or introduce residuals in the fallow phase. Aim to have residual overlap to maintain ongoing control of late germinations, but be aware of plant-back periods.
- Use strategic/targeted tillage: for example, after chickpeas or cotton when ground cover is minimal.
- Consider cover crops during the winter period to control weed emergence and preserve ground cover.
- Use chipping or strategic/spot spraying to control isolated patches without disturbing soil moisture.

USEFUL RESOURCES:

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 management of pests. The latest research findings are made available to growers and advisors via industry meetings and a wide range of information products:

The annually updated *Cotton Pest Management Guide* contains detailed identification, sampling and management information for insects, weeds and diseases commonly found in cotton. cottoninfo.com.au/publications/cotton-pest-management-guide

CottonInfo's Publications section also contains a range of factsheets and guides on various pests and their management, including the Cotton Symptoms Guide, Pest and Beneficial Insects in Australian Cotton Landscapes, and WEEDpak and its individual ID guides. cottoninfo.com.au

For weed ID on the go, download the Weeds of Australian Cotton App cottoninfo.com.au/weeds-australian-cotton-app

Cotton Seed Distributors (CSD) provide a variety guide that includes suitability for various scenarios and tolerance to fusarium and verticillium. They also maintain a Faststart™ soil temperate network (for members) to help plan your planting time csd.net.au

The *my*BMP program contains a wide range of information about planning for pest management mybmp.com.au

The CottonInfo YouTube channel youtube.com/cottoninfoaust **contains many videos on pest prevention and biosecurity topics.**

CottonInfo's technical leads for pest-management-related issues are listed in the inside back cover of this publication, or contact your nearest REO via cottoninfo.com.au/about-us**.**

A key IPM challenge for rainfed minimum tillage systems is to ensure complete crop destruction. Ratoon cotton (as pictured above) or volunteers that emerge in a subsequent grain crop can provide a green bridge for cotton pests and diseases.
Murray Sharman, Qld DPI

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, and 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.

RD&E in focus

- Maps identifying priority areas for improving riparian vegetation connectivity on farms- available on request **stacey.vogel@crdc.com.au**
- New grower case studies now live: 6 easy steps for success for revegetation in cotton landscapes. Read them here: **cottoninfo.com.au/publications/revegetation-grower-case-studies**
- Have your say in the development of Decision Support tool for managing riparian weeds – register interest in attending stakeholder engagement meetings in 2025 **stacey.vogel@crdc.com.au**

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. 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. The understory layer of grasses and herbs is most easily changed through management and season. The presence of livestock can result in species simplification if grazing periods are too long or there are too few watering points. Over 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 crops. 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.

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

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.
- Minimise pesticide impacts to the environment and neighbours (including apiarists).
- Control environmental weeds and volunteer crop plants that act as hosts for pest species.
- Monitor water quality and apply irrigation water efficiently.

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

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 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 vegetating 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 biodiversity on your farm.

USEFUL RESOURCES:

6 easy steps for success for revegetation in cotton landscapes: 3 grower case studies cottoninfo.com.au/publications/revegetation-grower-case-studies

Native Revegetation Guide for Australian Cotton growers cottoninfo.com.au/publications/native-revegetation-guide

Refer to the CottonInfo NRM webpage for more information: cottoninfo.com.au/natural-resource-management

CottonInfo video: Improving connectivity of habitat corridors and patches – an overview youtu.be/KifPZv2ny5c

Healthy rivers

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

Approximately 21% of the combined extent of cotton farms retains native vegetation (2019, Biodiversity assets of NSW & QLD cotton growing areas). of which 4% is manged for conservation and the remainder for grazing (2023 cotton industry survey).
Photo: Undertaking revegetation works along the Namoi River, Robyn Watson (Boggabri Grower), Stacey Vogel (CRDC) Alex Macintosh (ex-Cotton Australia)

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 in natural areas wherever you can.
- 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.
- Reduce entrainment of fish in irrigation pumps.

USEFUL RESOURCES:

Refer to the CottonInfo videos on Healthy rivers and Maintaining healthy riparian areas for more information.
Rivers – youtu.be/7I-fqMjJXSw
Riparian – youtu.be/VKbxXwGJpIs

Healthy soils

Whether in your field or in the natural areas of your farm, healthy soils 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.

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 (mybmp.com.au)

Also refer to the *Healthy soils* chapter.

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 is also an essential consideration in pesticide application.

TABLE 12.1 pH thresholds for irrigation water.

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

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 (refer to Table 12.1).

Electrical conductivity of water (ECw)

EC is the measure of a material's ability to transport electrical charge. When measured in water it is called ECw and reported in deciSiemens/metre (dS/m). Salts conduct electricity, so readings increase as salinity levels increase. Salinity can have major long-term impacts on production (see Table 12.2) 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).

TABLE 12.2 Tolerance of crops and pastures in different soil types to salinity in irrigation water.

	Water salinity limits for surface irrigation (in dS/m)					
Soil type	Well-drained		Moderate to slow draining		Very slow draining	
Yield reduction	< 10%	25%	< 10%	25%	< 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

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 lost 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 main consequence for areas that can't be pumped due to salinity or low flow rate is rising groundwater which leads to waterlogging and can bring salts present in the soil or groundwater to the surface (killing crops).

USEFUL RESOURCES:

The Australian Cotton Water Story WATERpak

DIY Groundwater Monitoring Fact Sheet are all available Cotton Soil and Water Quality Fact Sheet Ecosystem Services Fact Sheet are all available via cottoninfo.com.au **and** mybmp.com.au

Salinity Management Handbook – 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:

Gulf Savannah NRM – gulfsavannahnrm.org
Fitzroy Basin Association – fba.org.au
Southern Queensland NRM – sqlandscapes.org.au
New South Wales – lls.nsw.gov.au
Northern Territory – depws.nt.gov.au
Western Australia – agric.wa.gov.au

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

In season

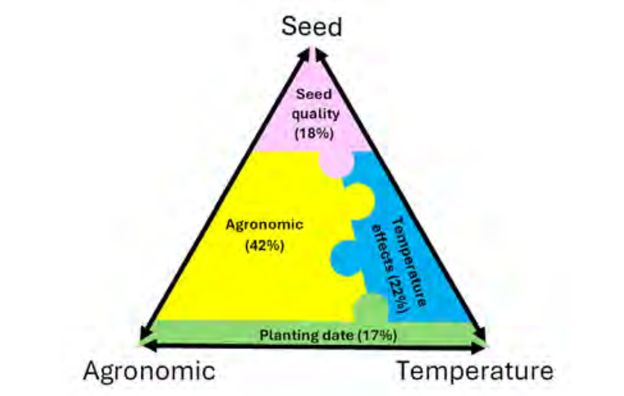
Crop establishment

By **Sam Lee** (Cotton Seed Distributors) and CSD E&D Team

Achieving even establishment is critical to getting 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.

A number of factors influence crop establishment. CSD recently interrogated their extensive trial data set and used machine learning to understand the weighting of these factors and how they interact with one another. Figure 13.1 illustrates the findings from this work and shows the relationship between the variables. A key understanding from this work is that many of the variables interact with each other to ensure good crop establishment. Furthermore, in the case where one or more of these variables are not ideal, it is necessary to compensate in other areas in order to achieve the desired establishment. This work can be read in full in an article in *the Australian Cottongrower* magazine June-July 2024 edition, on pages 58-60 cottongrower.com.au/read/137#60.

FIGURE 13.1 An establishment triangle, developed from computer predictions of the contributing factors to cotton establishment, derived from parameters in CSD's nine year trial data set.



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 rising.
- Aim to establish approximately 10–12 plants per metre in warm growing areas and 12 plants per metre in cooler growing areas.
- Varieties with lower seed density require careful management regarding 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 faststartcotton.com.au or via the QR code located on your bag of seed.

What's new...

FastStart™ Weather Network now incorporates the FastStart™ Field Forecast. This model predicts soil temperature for the proceeding seven days, to aid with planting decisions and to achieve desired establishment.

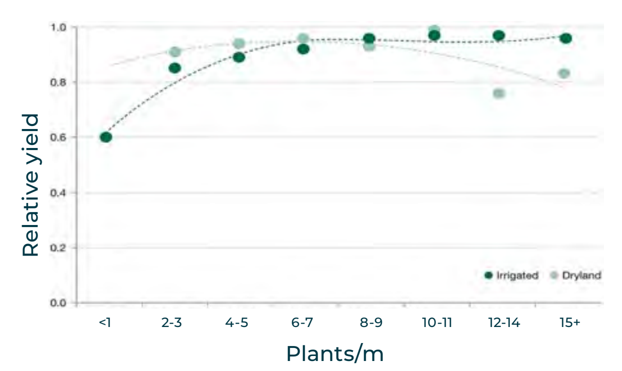
Plant population

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 from disease and insects.
- Rainfall and temperature (soil temperature and forecast air temperature).
- Row spacing.

CSD has conducted numerous plant population trials 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 13.2).

FIGURE 13.2 Summary of CSD plant population trials (21 irrigated and 9 dryland trials).



Dryland cotton...

In addition to the best practice recommendations:

- Aim to 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.

Current recommendations

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

- You normally grow a smaller plant size that cannot compensate well into gaps.

Early crop maturity is essential where crop compensation is limited, and diseases can have an impact (e.g. southern and eastern regions).

Planting rate

Factors to consider when determining your planting rate include:

- Variety.
- Field conditions.
- Disease levels of planting region and individual fields.
- Establishment method.
- Seed germination percentage.
- Soil temperature at planting.
- The seven day forecast.

Since all these factors will influence the seeding rate required to achieve an adequate plant stand, it is important that each field is treated as a separate operation. 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 12,000 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 by entering the AUSlot number (Figure 13.3) at CSD's website csd.net.au/auslots. Alternatively, scan the QR code on your bag of seed to directly access your statement of seed analysis.

FIGURE 13.3 Example of the seed variety information that is printed on the bag sticker.

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 of at least 40 mm and be free from abnormalities. 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 parameters but is conducted at a constant 18°C for seven days. CSD includes both warm and cool germination data on all AUSlots to provide 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.

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.

How to get accurate seed quality information

- View estimates on seed size at: csd.net.au/seeds-per-kilogram
- AUSlot information:
  - Each seed lot has a batch number on the label of each bag. This number can be used to access specific seed quality at tools.csd.net.au/auslots
  - Select your variety and treatment, enter your AUSlot number and select search – data includes warm and cool germination percentage, physical purity, mechanical damage 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 fully operational well before planting because breakdowns in the field cost time and allow surface soil moisture to further dry away:

- 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 filters to stop blockages when planting with herbicides or when in-furrow sprays are to be used.
- Regularly check seed depth and the condition of the soil around the seed during the planting operation – 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).

View a video on 15 steps for planter maintenance on CSD's website at csd.net.au/videos/planter-maintenance-15-tips-to-set-up-your-planter-units (membership may be required).

Planting depth

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 13.4). 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 difficulty emerging. Planting at depths of more than 5 cm can compromise establishment, even under ideal conditions (Table 13.1).

FIGURE 13.4 Checking planter depth using your knuckles (1 inch = 2.5 cm).

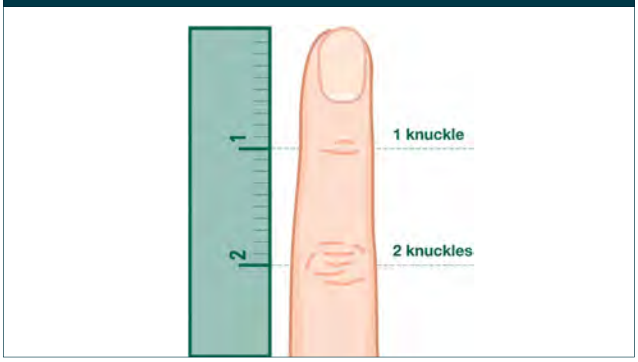


TABLE 13.1 Recommended planting depth based on establishment method.

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 apply starter fertiliser, insecticides or fungicides through various attachments. One of the keys to plant stand uniformity is planter speed. Aim 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, or slower than 8 km/hour - Ideal speed is likely to differ with newer technology planters e.g. John Deere's ExactEmerge™

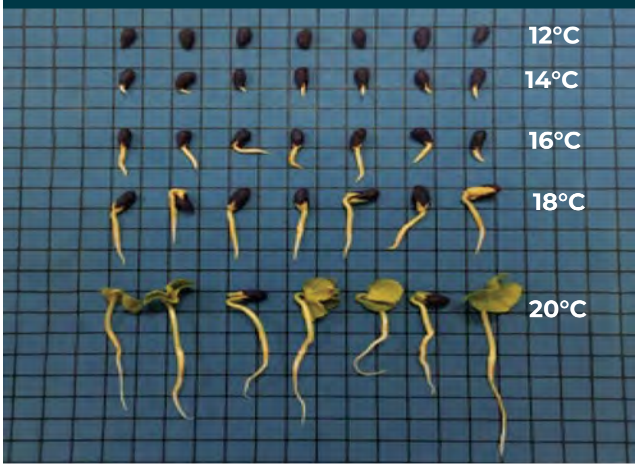
Planting time

The ideal planting time will vary between seasons and regions. Check the relevant Resistance Management Plan for the planting window specific your 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.

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 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 13.5 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.

FIGURE 13.5 Effect of temperature on germination (seeds from the same AUSlot after 7 days).



The slower the plant grows, the greater the chance of seedling death occurring through disease and insect damage. Figure 13.6 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

FIGURE 13.6 Cotton seed sensitivity to chilling injury through germination and establishment.
(National Cotton Council, 1996)

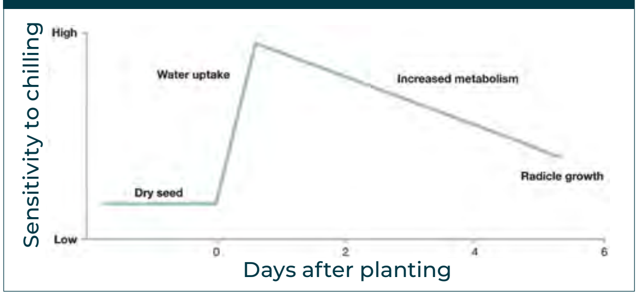
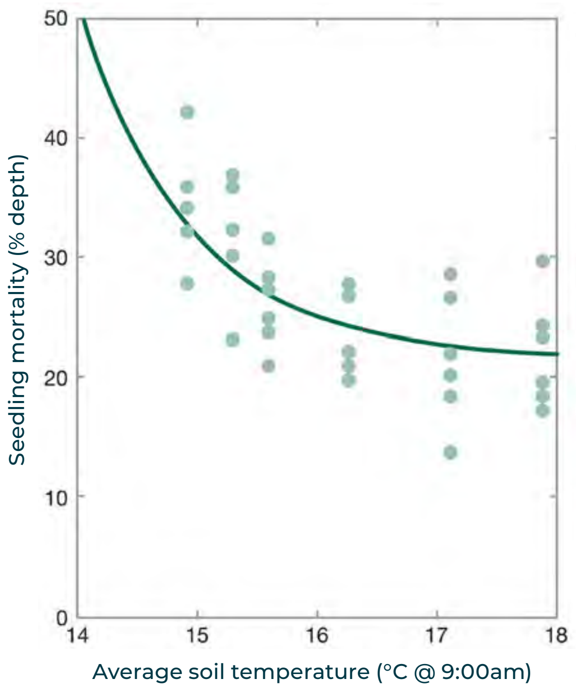


FIGURE 13.7 Impact of soil temperature on seedling mortality. Temperature is the average minimum soil temperature for the seven days after sowing.
(Nehl, NSW Department of Primary Industries)



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 13.7).

FastStart cotton tools

The FastStart™ Weather Network consists 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: tools.csd.net.au/agronomytools/weathernetwork. Many of these weather stations incorporate sensors that are a real-time measure of the soil temperature at 10 cm depth and can be used as a guide to whether conditions are suitable for planting cotton.

Visit faststartcotton.com.au/tools-and-calculators for other useful resources. A recent addition to these tools is the FastStart™ Field Forecast, which predicts average soil temperatures for the proceeding 7 days, to provide an assessment of the risk to seed emergence.

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 or a risk of volunteer cotton. Pre-irrigating is also beneficial when 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 that 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 can't tick 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!**

RED LIGHT **AMBER LIGHT** **GREEN LIGHT**

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, regularly check soil moisture levels in the seed zone – 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 you are more likely to achieve better results with the current planting or by replanting. It is desirable to have a minimum of 8 to 10 plants (10 to 12 plants in cooler areas) per metre of row, distributed along the row as uniformly as possible. It's important to note that potential yield declines as planting is delayed.

An inadequate plant stand generally results in a decline in yield, and also a delay in maturity of the crop. Cotton plants will compensate for gaps in 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.

Gappyness of plant stands is also a consideration that needs thought when making the decision to replant or not. A number of variables contribute to the degree of impact on yield in a gappy plant stand. CSD have interrogated their extensive trial data set to understand the relationship of these variables to one another, particularly in relationship to the number of gaps and the size of the gaps. A uniform plant stand is ideal.

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

Particularly when planting on rain moisture, be aware of uneven moisture throughout the bed which will cause variable crop development.
CSD

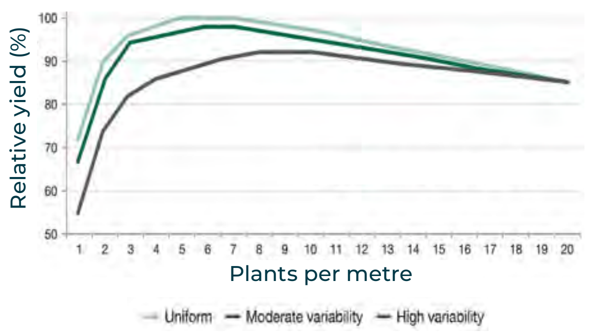
but you may not be able to mature the fibre. Visit www.faststartcotton.com.au/tools-and-calculators to access the Replant Calculator (requires CSD membership).

- 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 remaining 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 13.8 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.

Aim to avoid gaps greater than 50 cm – they have a large impact on yield. CSD

FIGURE 13.8 Relative yield potential at a range of plant stand uniformities (Constable, CSIRO, 1997)



The implications of replant

Replanting date: Relative yields decline in crops planted after a certain date, which will vary by region. Factor this reduction in yield potential into replant decisions, as a low population or gappy stand may have a greater yield potential than a 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 that 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.

If you choose not to replant

Sometimes sticking with the plant stand you have is a better option than replanting. However, there are some additional considerations when managing a low plant population:

Lower yield potential: If possible, prioritise resources to fields with 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.

USEFUL RESOURCES:

PLEASE NOTE: Membership may be required for CSD website.

FastStart™ Cotton website: faststartcotton.com.au

FastStart™ Cotton Establishment Guide: faststartcotton.com.au/downloads

Have you got the green light for planting? csd.net.au/green-light-for-planting

Statement of Seed Analysis: csd.net.au/auslots

FastStart™ Cotton Weather Network: tools.csd.net.au/agronomytools/weathernetwork

Crop establishment - by computer csd.net.au/knowledge_library/establishment/

CSD Replant Calculator: csd.net.au/replant-calculator

CottonInfo YouTube series – planting and establishment playlist youtube.com/cottoninfoaust

Temperature effects on seedlings video (CSD) - csd.net.au/wp-content/uploads/SHORT-FINAL-Thermogradient-Table-Video-2024-Hannah-Hartnett-SUBTITLES-2.mp4

Irrigation management

Contributing authors:
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Janelle Montgomery (CRDC/CottonInfo),
Michael Bange (Cotton Seed Distributors)

Effective irrigation strategies are important to maximise yield, fibre quality, and water use efficiency. Timing irrigation effectively will avoid crop stress and potential waterlogging. This chapter covers strategies and technologies that optimise the irrigation practices to avoid these stresses.

Water use by cotton plants

Plants lose water by transpiration through leaves. This helps to cool the plant and to move nutrients around the plant. Transpiration is influenced by crop stage and weather conditions; water lost to transpiration is replaced by water absorbed from the soil via the root system. Water is necessary for photosynthesis, cell expansion, growth, nutrient supply and turgor pressure (prevents plant from wilting and controls the stomatal openings).

Irrigation efficiency – plant response to water

Too little = water stress

Cotton is naturally a perennial plant. Under favourable conditions, leaves, new nodes, fruiting branches and squares continue to be produced and the number can increase rapidly. Prior to flowering, excess carbohydrates are produced (via photosynthesis), resulting in vigorous vegetative growth. As plant growth continues, the demand for carbohydrates by plant parts such as bolls increases, and production becomes more limited by environmental conditions as the season progresses. Boll

Best practice...

- Monitor the plant, the soil and the expected weather conditions, and schedule irrigations that meet crop demand and avoid plant stress.
- In irrigated cotton crops, avoid water stress during peak flowering and early boll fill stages.
- Plan the last irrigation to ensure that boll maturity is completed without water stress.

Weather stations provide additional information on local conditions. Lou Gall, GVIA

RD&E in focus

Defining water and nitrogen use of cotton in bankless channel irrigation systems

There are few reliable metrics for water and N use efficiency for different layouts and soil types in bankless channel systems. Typically, irrigation run-off from bankless bays is used on adjacent bays and discharged into on-farm recycle systems ensuring that over several sets of bankless channel bays, the crop is efficiently irrigated while final N residues are minimised.

This project, led by Deakin University and supported by CRDC, is monitoring water and nitrogen dynamics between bays on two farms in the Murrumbidgee Irrigation Area (MIA), with different layouts and nitrogen application methods.

Water metrics for an example irrigation cycle in early November 2024 that followed broadcast application of 200 kg urea-N/ha found:

- Water supplied and drained at individual bay scale indicated the total amount of water supplied to each bay ranged from 1.0-1.7 ML/ha. This represents the water used to refill a bay and is dependent on the accuracy of filling time dictated by gate opening and closure, crop growth and developmental stage and deep drainage.
- Water run-off ranged from 0.3-0.6 ML/ha.
- The amount of water available to the crop ranged between 0.7-1.1 ML/ha.
- N losses in Run off N were minimal ranging from 1.4-3.4 kg/ha.

Initial findings indicate that 'drain back' style bankless channel systems do have the potential to be efficient. However, a combination of nitrogen management and accurate control of irrigation together are needed to maximise both WUE and NUE. These systems also have the potential to be further enhanced by careful management driven by automation.

Monitoring and maintaining consistent channel head heights ensures more even siphon flow rates and more efficient irrigation. Lou Gall, GVIA

TABLE 14.1 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	0.7***

* Hearn and Constable 1984, ** Yeates et al. 2010, *** 14 days post cut-out

growth exerts a large demand for carbohydrates, and the balance between boll demand and leaf production restricts vegetative growth.

Water stress can restrict both vegetative growth and boll development. 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.

Like many crops, cotton is most sensitive to water stress during peak flowering. Table 14.1 illustrates the potential yield loss for cotton crops per day of stress for squaring, peak flowering, late flowering, and boll maturation.

USEFUL RESOURCES:

WATERpak Chapter 3.1 pg 239–247,Chapter 3.2 pg 248–263.
cottoninfo.com.au/publications/waterpak

Too much = waterlogging

Waterlogging reduces the transfer of oxygen between the roots and the soil atmosphere. Plant roots may become so oxygen deficient that they cannot respire. Therefore, root growth and absorption of nutrients is decreased, resulting in reduced 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.

Monitoring soil moisture and irrigation performance helps schedule irrigations. M Woods From SIP2

Cotton is most susceptible to waterlogging during the early stages of flowering when the plant is setting the fruit load that will dictate final yield. Waterlogging impacts are less severe once the fruit load is established, although plants exposed to rainfall-induced waterlogging may also suffer from the reduced sunlight 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. Waterlogging also tends to decrease the plant's ability to prevent excess sodium uptake. Although cotton is reasonably tolerant of salinity, exposure to increased concentrations may impact on yield potential. Irrigation strategies designed to avoid potential waterlogging events contribute towards improved yield and water use efficiencies and can also benefit crop nutrient efficiencies.

TABLE 14.2 Advantages and disadvantages of different options for irrigation at establishment.
(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. · In a heavy clay, water losses can be less than keeping it in an on-farm storage. · Soil temperature is less likely to drop after planting – meaning potentially less disease pressure. · 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. · Easier to plant, especially when beds are not 100% even. · Faster planting operation and less machinery needed. · Reduced potential for compaction because subsoil is dryer.	· Helps fix plant stand problems. · Can help 'boost' crops following a slow start.
Likely disadvantages		
· Soil drying out too quickly. · Dry rows in uneven fields. · Soil stays too wet when followed by rain. · Unable to capture rainfall before planting. · 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. · Pre-emergent herbicide damage more likely. · Side of beds might erode when flushing continuously over a long period of time. · Can germinate weeds at the same time as the crop. · Potential for waterlogging if rain occurs after flushing.	· Likely to use more water.

Optimised irrigation system design and management allow crops to be watered with optimal start and end times, and appropriate volumes. Efficient delivery of water to the field and drainage of tailwater from the field reduces potential exposure to waterlogging and minimises losses via deep drainage.

USEFUL RESOURCES:

CottonInfo video: Waterlogging in cotton youtu.be/08vnL2sT3io

WATERpak Chapter 3.4 cottoninfo.com.au/publications/waterpak

Monitor to manage – irrigation efficiency

Monitoring the conditions, the plant, soil moisture and weather will help you schedule irrigations to meet crop demands and avoid plant stress.

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.

It's also important to monitor crop growth. Monitoring node development, fruit number and nodes above white flower (NAWF) will help you keep track of how a crop is progressing compared to potential development when under stress. Knowing what stage the crop is at will help predict daily crop water use. This is most important during peak flowering when water demand by the crop is most critical.

Dryland growers can access tools such as climateapp.net.au or soilwaterapp.net.au. 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.

Scheduling irrigations

Pre-irrigate versus water-up

The decision whether to pre-irrigate or water-up the crop has to be made specifically to suit a particular farm and seasonal conditions. It may also be necessary to pre-irrigate to plant into moisture and then give the crop a quick flush. Every farm is different, and things to consider include: 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, and am I set up for dry or moisture planting? The likely advantages and disadvantages of pre-irrigation and water-up are summarised in Table 14.2. 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 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. waterschedpro.net.au

First irrigation

The first irrigation helps set the crop up for optimal future plant growth and fruit production, fibre quality and boll development. Its timing is perhaps the most difficult irrigation scheduling decision. It is a balancing act between ensuring stored water in the soil profile is fully explored by the developing root system and avoiding stressing the plant through either insufficient moisture or waterlogging.

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 or those with compaction that 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 – hot and dry, cool or wet weather near the time of first irrigation can be detrimental to crop growth and water use efficiency.
- Ensure actively growing roots are accessing moisture.

USEFUL RESOURCES:

CottonInfo: Timing first irrigation webinar – youtu.be/CdWJM8FDFIs

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

smarterirrigation.com.au/responsive-irrigation-management-with-canopy-temperature-stress-technology/

Subsequent irrigation scheduling

Once in-crop watering has started, aim to achieve a 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 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, avoid water stress during peak flowering and early boll fill stages. If irrigation water is limited, it should be utilised during flowering. Stress during peak flowering will result in greatest yield loss. The use of plant-based sensing with canopy temperature sensors (as found in GoField goannaag.com.au/gofield) 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 also help irrigation scheduling decisions. The inclusion of weather forecasts is important; for example, when the forecast is for low evaporative demand (reference evapotranspiration (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 (nodes, fruit production and NAWF) and general crop 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.

Assess your water requirements and know the amount of soil moisture remaining to calculate the best strategy with the remaining water. Consider stretching the second last irrigation, bringing the last irrigation forward (smaller deficit) so that less water is applied or skipping the last irrigation. End of season water requirements can be determined by:

- Estimating the number of days until defoliation.
- 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, while 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 time crop cut-out to ensure plants can realistically mature in suitable growing conditions, as well as estimating the number of days until defoliation in order to plan post cut-out irrigations. At cut-out, the plant's demand for assimilates (phtosynthesis products) exceeds supply and production of new squares and flowers virtually ceases, normally when the plant reaches 4–5 nodes above white flower (NAWF). It takes 493 day degrees (15_32 approach) for a flower to become an open, mature boll.

NACB can also be used to estimate the number of days until defoliation (assuming it takes about 62-day degrees for each new boll to open on each fruiting branch) using: Days to defoliation = (total NACB -4) x 3

If warm, sunny conditions prevail this is around three days per node. Mild an/or 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 before the boll set from the last effective flower matures. In cracking clay soils, plants can extract 125 to 150 mm of 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 14.1). Therefore, if water is becoming limiting, you can stretch irrigations after cut-out with less impact on yield.

Timing final irrigation

Measuring nodes above (last) cracked boll (NACB) is the 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 seriously affected by late water stress. Crops that come under stress before 60 to 70% of bolls are open – four nodes above cracked boll (4NACB) – can suffer yield and fibre quality reduction, especially micronaire. The degree of reduction 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 of water stress will be less at the end of the season.

USEFUL RESOURCES:

CottonInfo videos:
Late season irrigation management youtu.be/gVjv2IgUGCg
Timing your last irrigation youtu.be/uB0XSivwdXY

WATERpak, Chapter 3.2 cottoninfo.com.au/publications/waterpak

CSD Fact Sheets: csd.net.au/knowledge_library/flowering-is-a-critical-period-of-crop-development **(membership may be required) Flowering a critical period of crop development**

Scheduling with limited water

When water is limited, you may need to modify your 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 forecast using daily temperature data (day degrees). Monitoring of squaring nodes, fruit retention and 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 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. 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 can help predict how much water will be needed to refill the profile. The short-term forecast can help refine scheduling in predicting future crop water use.

Recommendations for limited water situations

- Aim to concentrate water applications during flowering (first flower to cut-out) and minimise stress during this period.
- Monitor your crop to determine how it 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, canopy temperature and weather forecasts.

USEFUL RESOURCES:

CottonInfo: WATERpak Chapter 3.1 and 3.2 cottoninfo.com.au/publications/waterpak

CottonInfo YouTube irrigation series: youtube.com/playlist?list=PLQy8KAPn-DyrDdVd--pzHPRBqMFa8Qnrv

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Developments in irrigation scheduling technologies

Moisture probes: Soil-based irrigation scheduling

A deficit approach to scheduling is a commonly used technique on irrigated cotton farms. About 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 evapotranspiration (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.

USEFUL RESOURCES:

IrriSAT: irrisat.app

CottonInfo video: Using IrriSAT for irrigation scheduling youtu.be/ccvJizT4Iw0

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 sensors are non-contact and non-invasive.

The Goanna Ag platform now also includes predictive canopy temperatures which enhances irrigation planning.

Using crop canopy temperature sensors will provides 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: smarterirrigation.com.au/responsive-irrigation-managementwith-canopy-temperature-stress-technology/

Podcast: smarterirrigation.com.au/plant-based-sensing-optimisingirrigation-timing-in-limited-water/

Factsheet: smarterirrigation.com.au/plant-based-sensing-for-cottonirrigation-2

CottonInfo Webinar: youtu.be/7Ap4744Y23w

CottonInfo Video: youtu.be/i2fPMCVG9dU

Goanna Ag: 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: cottoninfo.com.au/publications/cotton-irrigation-technology-tour-booklet

Crop canopy temperature sensors: scisoc.confex.com/crops/2014am/webprogram/Paper88636.html

CropWaterSched irrigation scheduling tool waterschedpro.net.au

Managing crop growth

By **Michael Bange** (Cotton Seed Distributors), **Sandra Williams** (CSIRO) and **Katie Broughton** (CSIRO)

Acknowledgements: **Greg Constable**, **Dave Kelly**, **John Barber**, **Bernie Caffery**, **James Hill**, **Brad Cogan** and **Steve Warden**.

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, 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, further fruit development 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, and growth regulators like mepiquat chloride may be required. When fruit is lost, such as shedding during prolonged cloudy weather, very high temperatures, or insect attack, the resources that were being used to develop that fruit become available for new 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 producing 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 excessive growth 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...

- Manage excessive vegetative growth by using mepiquat chloride to shorten internodes and reduce leaf area, restoring 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.

RD&E in focus

During the 2023/24 season, grower/consultant-led research trials overseen by Katie Broughton (CSIRO) and supported by CRDC and CSD's Richard Williams Initiative, aimed to develop a better understanding of crop growth and productivity responses to mepiquat chloride strategies across several cotton regions. The trials were hosted on four farms to demonstrate the effects of various alternative early season application strategies on cotton growth and yield.

Key research questions included:

- How early and 'hard' should we apply mepiquat chloride?
- Is there a difference in varieties and how we should use mepiquat chloride?

Experiments are underway to explore the use of mepiquat chloride, particularly managing crop growth to enhance resource use efficiency in a farming systems context. These experiments are supported by CSIRO and CRDC, and will continue over the next two seasons.

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. They play an important role in stimulating plant cell wall loosening to allow stretching of the wall by internal cell pressure. This is known as cell expansion and is one mechanism allowing a plant to grow larger. In addition to GA, cell expansion is driven by a number of factors including water availability, humidity and temperature. Mepiquat chloride can impact growth for up to 2 to 3 weeks post application, but is highly dependent on temperature, with reduced effects at higher temperatures.

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.
- - Good rainfall after a shedding event may result in lush vegetative growth. Keep a close eye on both this growth and weather forecasts.
- Using mepiquat chloride to aid crop cut-out is useful to help prepare a late or uneven crop for a timely harvest.

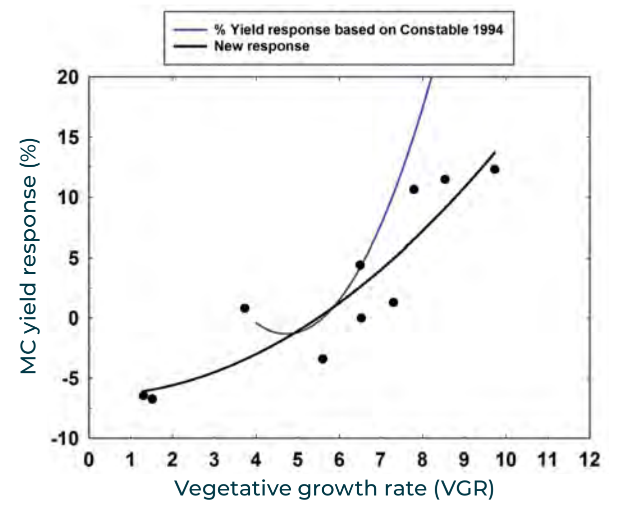
Impact on cotton growth

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 investigated the response between vegetative growth rate (VGR) at early flowering and percentage 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 15.1, these negative responses in Bt cotton have been more severe than previously measured on non-Bt cotton varieties before 1994.

FIGURE 15.1 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, causing the plant to approach cut-out and thus mature 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.
- 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 particularly important for shorter season and southern areas where adverse weather conditions can both occur earlier and be more severe. 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 to five 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, fields containing different 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. GA plays an important role in cell expansion, so preventing the plant's production of GA can be detrimental to plant growth, and 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 the causes behind any excessive growth. In assisting these decisions at early flowering, consider information on VGR, field history, fruit retention, irrigation scheduling, and current and future weather conditions.

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 the production of new nodes that are 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. VGR measures the rate of internode increase and is 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 or individual node length will not necessarily identify accurate mepiquat chloride response.

$$\text{VGR (cm/node)} = \frac{\textit{This week's height (cm)} - \textit{Last week's height (cm)}}{\textit{This week's node number} - \textit{Last week's node number}}$$

Start measuring VGR as the crop approaches first flower, normally late November for many regions, and the plant has roughly 12 mainstem nodes. Continue monitoring 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 Figure 15.2).

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, 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 during early 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 (particularly those in rainfed situations) 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. 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

Dr Katie Broughton measuring the height of a cotton plant.
CSIRO

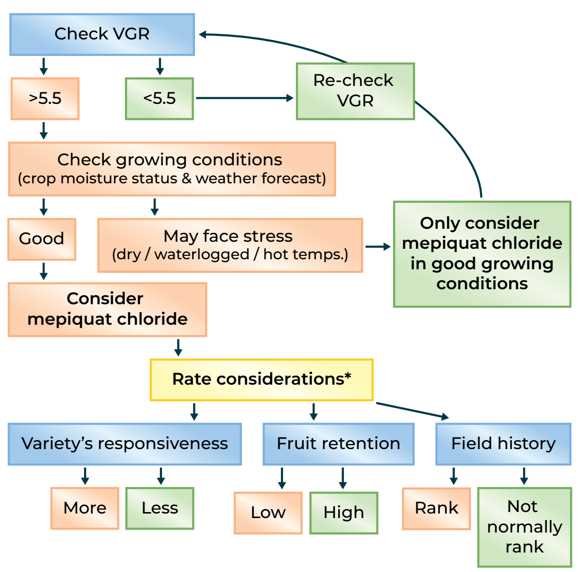
cases of severe stress (water, prolonged period of cloudy weather, or a period of very high temperatures) fruit loss may occur. In these cases, a symptom can be excessive vegetative growth once the stress has been removed. Crops should be monitored closely following these events.

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 the vegetative growth needed for continued fruit growth.

Variety

Varieties may vary in their yield response to mepiquat chloride. This could be due to determinacy (ability to regrow), rate of canopy development or fruit production, or because of differences in their architecture. Regardless of variety the crop still may require mepiquat chloride, so monitoring their VGR and considering other factors remains important.

FIGURE 15.2 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 15.4 for assisting with decisions regarding mepiquat chloride rates.

FIGURE 15.3 Cut-out Decision Tree – This cut-out chart is designed to help with late season decisions to apply mepiquat chloride.

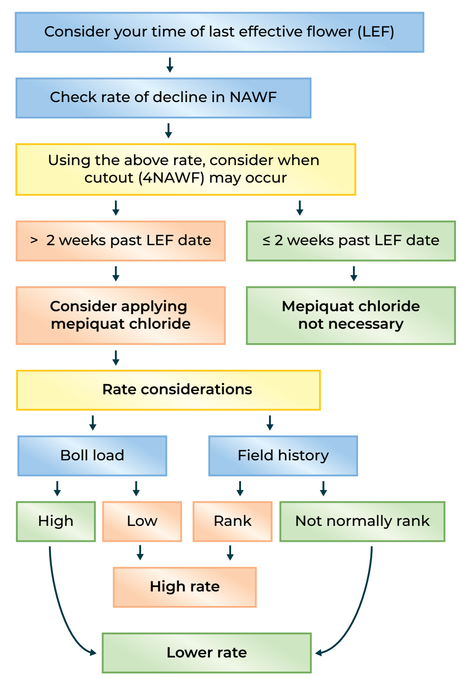
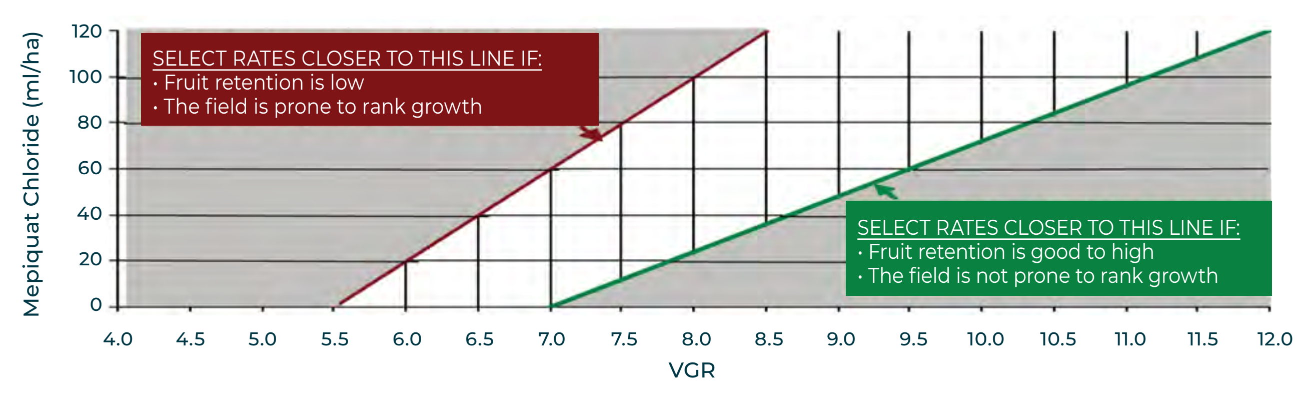


FIGURE 15.4 Mepiquat chloride requirement graph incorporating VGR and other factors. Rates assume mepiquat chloride formulation of 380 g/litre. (Source: CSD)



Rate considerations at early flowering

Figure 15.4 has been designed to consider all factors when deciding on the rate of mepiquat chloride. The following examples 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 15.4 the application rate may be at a higher rate (for example 60–100 mL/ha; based on 380 g/L active ingredient concentration).

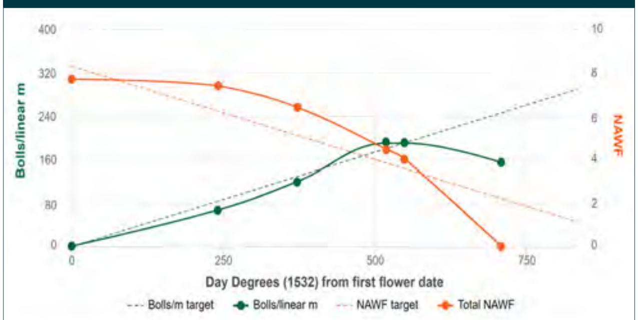
Example two: A crop has a VGR of six, good fruit retention, the field has no history of rank growth and the variety is not greatly responsive to mepiquat chloride, therefore using Figure 15.4 applying mepiquat chloride may not be a benefit, although monitoring should continue.

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.

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 Figure 15.3). These decisions are generally made in late January for most regions or about three weeks before the last effective flower (LEF) date.

FIGURE 15.5 An example of using CSD's CottonTracka tools to monitor nodes above white flower (NAWF) decline and boll development, both which can be used to assist in the timing of cut-out (NAWF of 4-5). www.csd.net.au



Monitoring NAWF – late season

An effective technique 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. Where there is a slow rate of NAWF decline and the forecast cut-out (four NAWF) is beyond the LEF (See Chapter 19, *Preparing for harvest*), then applying a cut-out rate of mepiquat chloride should be considered. The NAWF measurements provided as an example in Figure 15.5 indicate a relatively rapid rate of decline and in this case, an application may not have been necessary.

USEFUL RESOURCES:

CottonInfo YouTube video on vegetative growth rate in cotton youtu.be/cDh0ezLwnH4

cottoninfo.com.au and mybmp.com.au

FIBREpak 2nd Edition (available from cottoninfo.com.au)

CSD Growth and development team (2024/25, December, January). Beyond the seed: Managing the crop canopy with mepiquat chloride. The Australian Cotton Grower Volume 45. pp 62-63 cottongrower.com.au/article/3270

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.

Revaluating mepiquat chloride use in Bollgard II. The Australian Cottongrower 36, 16–21.

Get the latest information on Australian cotton varieties at csd.net.au

Managing pests in-crop

Chapter Coordinator: **Tonia Grundy** (Qld DPI)

Acknowledgements: **Paul Grundy**, **Eric Koetz** and **Linda Smith**

Contributors: **Lisa Bird**, **Jamie Hopkinson**, **Dinesh Kafle**, **Linda Scheikowski,** and **Murray Sharman**

What's new...

Disease collection form: The submission form for disease samples has been revised into an interactive pdf that can be completed on-screen. Print out and enclose with the sample, and/or email the form to your state pathologist. Now available at **cottoninfo.com.au/disease-management**

As the crop grows and the canopy expands, physical access to the plants and rows becomes increasingly difficult, and the crop's potential to compensate for damage reduces as the season proceeds.

In-crop management is therefore predominantly chemical, although physical options for weed control, such as inter-row cultivation or chipping are still an option depending on accessibility. Agronomic adjustments such as timing irrigations to reduce crop stress or assist recovery from damage may also be available. Maintain farm hygiene and biosecurity programs throughout the season.

The Australian cotton industry has set a draft target to reduce the environmental impact of pesticides by 5% every 5 years. Environmental Toxic Load (ETL) for bees and algae is being used as an indicator to assess the average toxic pressure from one hectare for insecticide and herbicide hazards respectively.

Reduce your ETL by choosing products with lower toxicity and reducing the overall volume of pesticides used. For more information visit crdc.com.au/growers/sustainability

Best practice...

- Understand your crop's developmental stage, yield potential and susceptibility to damage.
- Be confident that your monitoring is providing an accurate picture of what is present.
- Aim to prevent the build-up of pest populations to damaging levels.
- Use non-chemical tactics where possible to reduce reliance on pesticides.
- Select products carefully to avoid or delay the development of resistance and minimise the impact on beneficial populations.

The Cotton Pest Management guide is updated annually and includes detailed information on in-season sampling and management information for insect, weeds and diseases commonly found in cotton as well as information about biosecurity, pesticide stewardship and the annual industry strategies for resistance (IRMS, HRMS and Bollgard 3 RMP). The latest edition is available on the CottonInfo website (**cottoninfo.com.au/publications/cotton-pest-management-guide**), and a copy is posted out with the spring edition of CRDC's Spotlight magazine.

RD&E in focus

The science behind managing square retention

Exciting research from Qld DPI and CottonInfo published in the prestigious US journal 'Crop Science' identifies some critical findings:

- Pre-flowering square loss in Bollgard 3 cotton in Australia has minimal impact on yield, quality, and crop maturity.
- Negative impacts only arose when square loss occurred after flowering commenced or when square loss during flowering compounded earlier losses.
- The crop naturally compensates for pre-flowering square loss without management intervention.

The retention guidelines in the *Cotton Pest Management Guide* are based on this work.

Read the full research paper at **acsess.onlinelibrary.wiley.com/doi/10.1002/csc2.21429**

Be aware of what is there

Efficient and effective monitoring is essential, but not all symptoms are caused by pests. Be aware of the crop's growth stage, its nutritional and moisture levels and recent environmental conditions, and do enough sampling replicates to be confident that you know what pests (and beneficials) are present in your field.

Before taking any management action, be certain that:

1. you have correctly attributed the cause of any visible damage or symptoms
2. any pests present have been correctly identified and are likely to cause future economic damage
3. the benefits of the action outweigh possible future adverse consequences (e.g. secondary pest flaring, impacts on pollinators, drift issues, and the potential for spreading the target pest or other pest species).

Good record keeping will help you to develop appropriate management strategies. Consider the records from past years and earlier in the current season in your decisions, particularly in relation to identifying likely pest pressure, checking pest population increase or decline, rotating modes of action to reduce resistance risk, and safe plant-back periods for residual herbicides.

If you spot something unusual that you suspect is exotic, contact the **Exotic Plant Pest Hotline on 1800 084 881**.

Instructions on how to conduct your own disease surveys are included later in this chapter.

CottonInfo HELPING YOU GROW

IF YOU THINK YOU'VE FOUND SOMETHING UNUSUAL CALL THE EXOTIC PLANT PEST HOTLINE

1800 084 881

Vegetative branch: no square or abscission scar opposite the subtending leaf.

Fruiting branch: a square is present opposite the subtending leaf.

Fruiting branch: a scar (following the loss of a square) is visible opposite the subtending leaf.

Insects and mites

Important pests of cotton include helicoverpa, mirids, silverleaf whitefly, mites, thrips, and aphids.

Some pests (including mites, aphids, mealybug and whitefly) can reproduce quickly to generate large populations, particularly when natural enemy populations have been disrupted by applying broad-spectrum insecticides early season.

Assisting biological control by conserving natural enemy populations is a major tactic for some insect pests. Some beneficials are also commercially available for augmentative release – check with your advisor regarding the suitability and economic viability of this option for your situation.

Using thresholds

Action thresholds (based on a 'break even' point, where the benefit of action equals or exceeds the cost of control) are available for many of the common insect pests of cotton. They vary for each pest and can be based on insect numbers, population increases or damage levels.

It is important to understand the critical crop stages where pests will have the most impact on yield and/or lint quality, and remain aware of what growth stage your crop is at when assessing damage. For example, if the crop has not yet produced fruiting branches, the lack of squares may wrongly be assumed to be low retention from insect damage (refer to photos above).

Product selection and application

The choice of insecticides (or miticides) is a balance between cost, efficacy on the target pest, possible off-target impacts, and the potential for the development of resistance. A more expensive selective product (reducing the risk of flaring secondary pests that then require additional sprays later in the season) may be a more cost-effective choice overall.

Don't add an insecticide when doing an 'over the top' herbicide application if your primary reason for doing so is to save on application costs. Avoid in-season prophylactic sprays for insects where possible as they are more likely to create problems than solve them.

Be aware of the resistance profile of not only your target pest/s but also any other pests present at below-threshold levels. Refer to the industry's Insecticide Resistance Management Strategy (IRMS) and Resistance Management Plan (RMP – if using Bollgard® technology) for application windows or restrictions.

As crops mature, carefully check the withholding periods of products before use. Always read and adhere to each product's label directions.

Conserving beneficials and protecting pollinators

In-crop support for natural enemies focuses on not disrupting populations with early season application of broad-spectrum products. Some predator and parasitoid species are commercially available – the economic viability of augmentative release would depend on individual circumstances.

Look for bee activity when monitoring for insects. Bees can collect nectar from both flowers and cotton's extra-floral nectaries (on the underside of leaves), so they can be present in the crop throughout the season. Individual bees and bee colonies can be affected by insecticides though direct contact with spray or residues, airborne drift, or an accumulation of chemical brought back to the hive.

Always consider the impact of your pesticide choices on non-target organisms. The *Cotton Pest Management Guide* includes a table ranking the impact of registered insecticides on beneficial species, including bees. Products that are particularly hazardous to bees will include a statement on the label.

Weeds

The weed species you see during the season will largely depend on the effectiveness of year-round control methods, whether resistant individuals are present, and the contents of your local weed seed bank (some seeds can survive dormant for years in the soil before germinating). Preventing weed seed set is just as important as preventing yield loss when controlling weeds. Consult the industry's Herbicide Resistance Management Strategy (HRMS) when making management decisions, and ensure your equipment and application methods are appropriate (see the *Effective spray application* chapter for more details).

Crop competition

After planting, target and manage weeds in a timely manner to prevent yield loss, as young cotton is not a strong competitor. Yield can be impacted by broadleaf weeds when cotton is at the 1-2 true leaf stage, and by grass weeds even earlier. The higher the weed population, the longer into the season weed control is required. Plant weedy fields last so you have more time to control weeds that emerge prior to planting and better conditions for cotton emergence and early vigorous growth.

An evenly established, vigorously growing cotton crop can compete strongly with weeds, especially later in the season. Canopy closure in irrigated cotton maximises light interception for optimum cotton yield but also significantly reduces 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. Factors such as uneven establishment (gappy stands) and seedling diseases can reduce crop vigour and increase the susceptibility of the crop to competition from weeds.

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 prior to cotton establishment. Each irrigation during the season will promote a weed flush, providing another opportunity for a planned control tactic, as well as reducing moisture stress for existing weeds, making them more easily controlled by herbicide applications.

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. However, soil that is too dry will result in poor implement penetration, bring up clods, require more horsepower and wear out equipment faster.

Over the top herbicide applications

Cotton varieties incorporating herbicide tolerance are commercially available, allowing herbicide applications to be made over the top (OTT) of the growing crop. Only products specifically registered for this application can be used and application limits apply.

Selective spraying – spots and bands

Spot spraying may be used as an alternative to manual chipping for controlling low densities of weeds in-crop. Ideally, use a relatively high rate of a herbicide from a different herbicide group to those 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 on non-field weeds that are difficult to access such as roadside culverts. Ensure your application equipment and method will not drift product onto the growing crop.

Band spraying in row crops reduces the amount of wasted spray by applying the product in targeted parallel bands rather than evenly across the whole paddock area. If used in the interrow, spray shields can be utilised to further protect the crop. See the *Effective spray application* chapter for details on how to calculate banded spray rates.

Manual chipping

Chipping (manual hoeing of weeds) can be a useful means of preventing survivor seed set within the crop row when weed densities are low. Historically an important supplement to interrow cultivation or spraying, it is no longer widely used in current cotton farming systems, particularly since the advent of herbicide tolerance technology and optical weed detection systems.

Seed heads of windmill grass in cotton. T. Cook NSW DPIRD

Diseases

Disease management in cotton focuses on prevention and suppression as once disease symptoms are visible, in-crop management options are relatively limited.

Fungicides

All cotton seed in Australia for planting is treated with a standard fungicide for broad-spectrum disease control. Some other seed treatments, including biostimulants and fertilisers, can also assist with early vigour and suppression of seedling diseases. In-crop foliar sprays of registered/permitted products can be used in conjunction with other options to manage some diseases.

Agronomic management

A healthy crop is better able to express its natural resistance to disease.

High planting rates can compensate for seedling mortality, but a dense canopy favours the development of bacterial blight, alternaria and other leaf spots, sclerotinia and boll rots. Optimise nutrition/irrigation and consider using growth regulators if growth is excessive.

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).

Irrigation or rainfall lowers the soil temperature, increasing the risk of disease. Pre-irrigation (provided the hills or beds sub-up adequately) may provide better conditions for seedling emergence than watering-up by avoiding an early cold shock. If the root system has been weakened by disease early season, watch for signs of water stress 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 increase the incidence of verticillium wilt.

Manage tail water to minimise the risk of disease spread. If possible, apply water to the least infected fields first. General traffic, sprays, and picking should also follow the same order as much as possible.

Adopt a balanced approach to crop nutrition, especially with nitrogen and potassium. Both fusarium and verticillium wilts 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; for example, leaf spots caused by *Alternaria*, *Cercospora* or *Stemphylium* spp. are often more severe when potassium is deficient. Refer to the *Nutrition* chapter for more information.

Conduct your own in-field disease survey

Be aware of what diseases are present, where in the field they occur and whether the incidence and severity is increasing. Monitor and record disease throughout the season to allow a comparison over time. Train farm staff to look for and report unusual symptoms. Contact your state department cotton pathologist for assistance in identifying suspected disease and to confirm the pathogen's strain. Some abiotic stresses may cause similar symptoms, so if the disease diagnostics are negative, consider the possibility of nutritional or environmental factors.

Refer to cottoninfo.com.au or the *Cotton Pest Management Guide* for instructions on how to send a sample. Sample healthy plants along with those suspected of disease. Use the interactive submission form (available at the CottonInfo website) if sending the sample to a pathologist for diagnostics. Watch the CottonInfo video on how to take stem and leaf samples for disease diagnosis: youtu.be/4mCk2883IO0

Alternaria spp. is not the only cause of leaf spots in cotton. Look out for high incidence of spots in the canopy or different leaf spot symptoms and send in leaf samples for diagnosis if you notice anything unusual.

Start early season disease surveys from the two true leaf stage. Examine multiple plants at multiple locations as diseases are often unevenly distributed. Look for signs of poor vigour or unusual symptoms. Examine roots by digging up the seedlings – DO NOT pull seedlings out as this may remove characteristic symptoms on the roots or leave behind the infected parts. Compare the number of plants established per metre with the number of seeds planted, and refer to the *Crop establishment* chapter if considering replanting.

Continue conducting disease surveys frequently during the season. Look for individual plants or patches that show unusual symptoms, have poor vigour, or have died, that could indicate a pathogen or insect hotspot. Cut plants in several places, especially along the lower stem, and look for discolouration. Also sample plants that appear healthy, as plants with internal discolouration indicating verticillium or fusarium wilts may show no external symptoms. A high F rank can also mask fusarium wilt infection.

Perform a final disease survey after the final irrigation but before defoliation to give an indication of the disease burden the field has been under and the potential for inoculum carryover to the following season.

USEFUL RESOURCES:

The annually updated *Cotton Pest Management Guide* cottoninfo.com.au/publications/cotton-pest-management-guide contains detailed information on in-crop management of insects, weeds and diseases.

The CottonInfo website contains a range of factsheets and guides on various pests and their management, including the Cotton Symptoms Guide, Pest and Beneficial Insects in Australian Cotton Landscapes, and WEEDpak and its individual ID guides. cottoninfo.com.au

For weed ID on the go, download the Weeds of Australian Cotton App cottoninfo.com.au/weeds-australian-cotton-app

The CottonInfo YouTube channel www.youtube.com/cottoninfoaust contains many videos on pest identification, sampling and management topics.

Check current registrations or off-label permits at APVMA's PubCRIS website portal.apvma.gov.au/pubcris

If you spot something unusual that you suspect is exotic, contact the Exotic Plant Pest Hotline on 1800 084 881.

CottonInfo's technical leads for pest-management-related issues are listed in the inside back cover of this publication, or contact your nearest REO for more information.

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Figure 1. Fusarium wilt can cause some leaves to develop a yellow mottle.

Figure 2. A key feature of **Fusarium wilt** is the brown discolouration in the woody part of the stem.

Figure 3. Fusarium wilt can cause plants to die back from the top and may regrow back from the base later in the season.

Figure 4. An early symptom of **Verticillium wilt** is leaf wilting and mottling.

Figure 5. Verticillium wilt causes a speckled vascular discolouration throughout the stems.

Figure 6. Severe **Verticillium wilt** infection may cause defoliation.

Figure 7. Reoccurring wilt causes plants to wilt and suddenly die with dead leaves remaining on the plant.

Figure 8. Reoccurring wilt causes root decay i.e. if plants are pulled out of the soil, the taproot snaps due to a dry rot, and reddening of the vascular tissue.

Figure 9. When the stem or tap root is cut horizontally, infected tissue may have a wedge-shaped discolouration **(Reoccurring wilt)**.

Figure 10. Reoccurring wilt causes blackening of the stem.

Figure 11. Sudden wilt (right plant) can cause plants to suddenly wilt and die. Does not re-occur in the same place.

Figure 12. Lightning strike can cause circular or irregular patches of dead or damaged plants.

Photo acknowledgements: Duy Le (NSW DPIRD), Linda Smith and Linda Scheikowski (Qld DPI).

Living in harmony with bees

Honey bees are essential for the pollination of fruit and nut orchards, which are becoming more abundant in parts of the Murray Darling Basin. Bees use cotton as a source of pollen and nectar, particularly when 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.

Bees can also be active in cotton crops before and after flowering, as they 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. Insecticides that are toxic to bees are identified on the label. 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, is highly toxic to the Hymenoptera family of insects (ants, bees and wasp parasitoids) when freshly applied.

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 that can be detrimental to the developing brood via contact or feeding. These effects can also occur when insecticide drifts over hives or over neighbouring vegetation that is being foraged by bees.

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 cotton growing areas. When heavy budding occurs, beekeepers often move large numbers of hives into cotton growing areas for honey production. Budding and flowering 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.
Susan Maas, CRDC

Reduce the risk to bees:

- If beehives are in the vicinity of crops to be sprayed (bees can travel up to 7 km in search of pollen and nectar), provide the apiarist at least 48 hours' notice to allow removal of the hives before spraying.
- Inform contract pesticide applicators operating on the property of the locations of apiaries.
- Always read and comply with label directions. Look for special statements on the label such as 'Dangerous to bees'.
- Ensure all components of your spraying operation are contributing to reducing the risk of drift, including paying particular attention to wind speed and direction, air temperature and time of day before applying pesticides.
- Use buffer zones to reduce the chance of spray drift or overspray reaching vegetation used by bees and avoid contamination of surface waters where bees may drink.

The *Cotton Pest Management Guide* provides additional information about bees, including how to notify hive owners and the relative toxicity risk of various insecticide and miticide actives registered for use in cotton.

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.

CottonInfo video 'Bee aware': youtu.be/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 beeconnected.org.au

BeeConnected

Effective spray application

By **Susan Maas** (CRDC)

Acknowledgements: **Nicola Cottee**, **Graeme Tepper**, **Bill Gordon** and **Mary O'Brien**

Best practice...

- Always follow label instructions when handling and applying chemicals.
- Make a spray plan before the season starts
- Establish clear communication processes for staff, agronomists, spray applicators and neighbours to manage safety and reduce risks.
- Keep comprehensive records.
- Select pesticides appropriate for the target and other aspects of your local situation.
- Use the correct application equipment and techniques, and ensure equipment is well-maintained.
- Ensure spray application only occurs during appropriate weather conditions.
- Ensure chemicals are transported, handled and stored appropriately and that unwanted chemicals and chemical containers are correctly disposed of.
- Participate in spray application training and field days to ensure your skills and knowledge are up to date.

No one wants spray drift. Pesticides that don't hit their target are ineffective. Ineffective pest control increases the cost of growing a cotton crop, threatens crop productivity, accelerates the evolution of pesticide resistance, increases the risk for environmental damage and damages agriculture's reputation locally, nationally and internationally. Everyone has a responsibility to understand their obligations in managing spray drift and ensuring agriculture maintains its social license for ongoing access to crop protection products.

Ensuring correct set up (nozzles, tank mix, water rates and ameliorants) and operation (weather conditions, speed, pump pressure, boom height) will improve efficacy, reduce costs and reduce the risk of off-target damage.

Indications of strongly stable and hazardous conditions with aerosols concentrated in thin layers. Nicola Cottee

RD&E in focus

The GRDC '*GrowNotes™ - Spray application manual for grain growers*' has a new HTML version, published in January 2025 that includes significant changes across many of the Modules. Relevant to spray operators in both cotton and grains, the manual provides information on how various spraying systems and components work, along with factors that the operator should consider to ensure the sprayer is operating to its full potential.

grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual

The WAND system **www.wand.com.au** provides free real-time and 'nowcast' (2 hour forecast) weather data, updated every 10 minutes, and is able to distinguish between hazardous and non-hazardous surface temperature inversions.

Additional functionality including 24 hour forecast is available through subscription.

Plan ahead

Spray application is complex and planning is important to ensure all necessary factors are considered. Developing 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 spray plan such as a PAMP in place helps ensure that everyone involved in pesticide application has a clear understanding of their responsibilities.

The spray planning process should include discussing cropping intentions and communication proccesses with neighbours, consultants and spray contractors. Plan your crop layout to reduce risk to sensitive areas. Be prepared to leave unsprayed buffers when the label requires. Check with your reseller to ensure there is sufficient stock of products you commonly use, and ensure your equipment is well-maintained.

Using pesticides safely not only involves the application process. Planning should ensure there are appropriate transport and storage facilities available, and high quality personal protective equipment in good condition. Ensure operators are adequately trained for pesticide handing and application.

USEFUL RESOURCES:

***my*BMP Pesticide Management module –** mybmp.com.au

GrainGrowers spray application video series, including examples of spray plans for specific equipment (Hardi 5030, Jon Deere Exact Apply, Goldacres 3TS, camera spraying): graingrowers.com.au/graingrowers-spray-drift-resources-hub/spray-application-and-drift-management-video-series

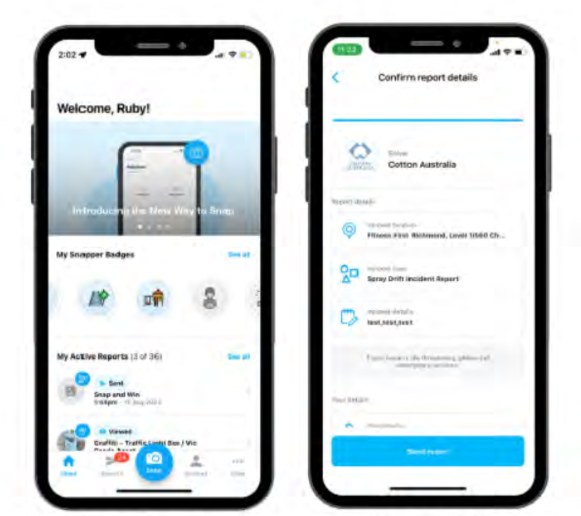
Bayer XtendFlex Applicator training videos: Spray Planning – youtu.be/HMSz-8DRLPU

Report spray drift in a Snap

The Cotton Australia Snap Send Solve platform helps cotton farmers to photograph and report drift incidents so other growers and industry stakeholders can be alerted as quickly as possible. Download the App and then sign into the Cotton Australia group.

Once you are signed in, you can take a photo of spray drift damage or other evidence and send it to Cotton Australia for appropriate action. You can also give approval for Cotton Australia to refer the incident to the relevant authority for investigation.

It allows Cotton Australia to provide the relevant authorities real-time mapping of spray drift incidents so that they can take appropriate action to prevent further drift incidences.



The Snap Send Solve Spray Drift app interface

Download the app at snapsendsolve.com

The step-by-step user guide is available on the Cotton Australia website (the password/code is Cott123).

Understand your legal requirements

Start with the label or permit when handling and/or applying chemicals. Product labels specify certain legally-binding conditions, including spray quality, weather conditions (temperature, humidity, wind speed) and buffer zones for sensitive areas. 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. 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.

USEFUL RESOURCES:

Cotton Pest Management Guide has additional information and links crdc.com.au/publications/cotton-pest-management-guide

APVMA has a database of registrations and permits. portal.apvma.gov.au/pubcris/

Neighbour communication

Good communication between the grower, the applicator, the consultant, farm employees and neighbours (including apiarists) is required both pre-season and during the season. Having a PAMP in place helps ensure that everyone involved in pesticide application has a clear understanding of their responsibilities by:

1. Identifying the farm-specific risks associated with pesticide applications and the appropriate practices to minimise those risks.
2. Establishing good communication with everyone involved in the application of pesticides.
3. Establishing the application techniques and procedures that are to be used on your farm.

Farm maps that highlight sensitive areas can be useful. Refer to satacrop.com.au for sensitive crops near you and to include your cotton crop on the map..

BeeConnected can help identify if hives are located nearby and facilitate communication between spray applicators and beekeepers 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, and any other requirements specific to your State or Territory government. This should include detailed information about:

- ☐ Who applied the pesticide and when (date and time);
- ☐ Details of the product/s and amounts used;
- ☐ Where the pesticide was applied including 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).

Product and tank mix

Selecting the most appropriate active ingredient(s), mode of action and formulation is important to achieve maximum efficacy against the target pest, and should also consider the off-target risk to susceptible crops and vegetation, as well as beehives and natural habitats. Adherence to the industry resistance management strategies, and good application practices to ensure full dosage to the target, will reduce the risk of resistance developing.

Before mixing it is important to check that products and adjuvants are physically, chemically and biologically compatible. Products that are not compatible can result in undesirable interactions (e.g. ineffective active, or equipment blockages). Correct mixing order reduces the risk of products interacting in a way that reduces their efficacy or stability in the tank mix.

It is important to check that the different modes of action will not conflict within the plant and reduce efficacy. For example, 'fast acting' herbicides (e.g. glufosinate, Group 14) damage cells quickly which then reduces the ability of slower acting herbicides (e.g. glyphosate, haloxyfop, clethodim) to fully translocate around the plant.

Refer to manufacturer information (label, tech notes, product guide) or discuss with your supplier to ensure that you avoid incompatible tank-mix partners and modes of action.

Volatility refers to the likelihood that the pesticide will become 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

Ultimate control

The G6 Crop Cruiser Series 2 is smarter, faster & stronger.

Fast Fill

Simplified controls and increased capacities.

The operator workstation area and fill system has been designed to dramatically reduce sprayer refill times with a 3” product tank filling point with auto shut-off.

60L chemical induction hopper provides chemical transfer rates of up to 120 l/min.

G-Hub

Intuitive & easy to use system with on-board diagnostics.

The G-Hub system comprises of a cabin display, external display, PLC, I/O modules, sensors and switches. This system controls and monitors all critical drivetrain and machine functions, packaged into one easy to use fully integrated system.

GOLDACRES

Delivering the perfect blend of capacity & weight with a 6000L product tank and boom sizes up to 48 meters, while maintaining the lightest tare weight in its class.

Check out why more Aussie farmers are turning to Goldacres for sprayers.

TriTech RivX / TriTech V boom

- **RivX boom** – 36-42m symmetrical inners / aluminium / steel riveted construction / hydraulic bi-fold.
- **TriTech V** – 48m boom / 3 working spray widths 20, 36 & 48m.
- **Plumbing** – 1" plumbing in perfect alignment.
- **Raven XTR** – Radar height control.
- **Spray Technolgy** – RapidFire / RapidFlow / 3TS / 3TS-Pro / Raven Hawkeye.
- **Weedetect** green on brown & green on green camera technology.

goldacres G6

choosing actives/formulations with low volatility. However, even products with very low volatility are still susceptible to droplet and particle drift.

The inclusion of adjuvants can also change the drift potential and/or volatility of some compounds (see the 'Operate efficiently' section later in this chapter).

Suitable water volumes and quality

Water is the largest component of any spray operation and water quality can impact efficacy and driftability of products. Conduct regular water testing of pH (including bicarbonate levels), total dissolved salts (TDS) and electrical conductivity (EC). 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. The CottonInfo YouTube channel youtube.com/cottoninfoaust contains demonstration videos on tank mixing and water quality.

USEFUL RESOURCES:

GRDC Spray mixing requirements fact sheet grdc.com.au/resources-and-publications/all-publications/factsheets/2019/mixing-requirements-for-spraying-operations

GRDC Spray water quality fact sheet grdc.com.au/GRDC-FS-SprayWaterQuality

Bayer XtendFlex Applicator training videos: The impact of water quality: youtu.be/3ub5VkvTmL4

Spray conditions and application timing

Pesticides often require specific conditions or need to be targeted to work optimally. Always check the label, particularly the general instructions and critical comments sections, for recommendations and cautions.

Targeting pests

Pesticides can be significantly more (or less) effective depending on the specific parameters at the time of spraying. Many herbicides require healthy actively growing foliage to work effectively. Insect growth regulators and fungicide products often only affect specific life stages of the target insect or disease.

Weather conditions

Weather conditions are not only a primary influencer of efficacy; they determine whether the spraying operation should proceed, be delayed, or be aborted.

Regularly monitor and record weather conditions including temperature, humidity, wind speed and direction, and hazardous surface temperature inversion conditions during spray applications. This means continual visual observations and actual measurement at least every 20-30 minutes. Some labels require measurement of weather parameters at the site of application. This can be done with handheld equipment (such as Kestral weather meters or equivalent). 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.**

There are a number of online resources to help with planning and decision making for timing spray application (wand.com.au, spraywisedecisions.com.au and crop.bayer.com.au/tools/weather-inversion)

Rainfall

Rainfall occurring too soon after application will reduce the efficacy of some products. Always check the label for warnings about rain-fastness or reduced effectiveness of the product after rainfall or heavy dews.

Temperature and humidity

For some products, efficacy can be affected when plants are stressed due to high temperatures. High ambient air temperatures and lower relative humidity conditions can also increase evaporation rates (Figure 17.1).

A Delta T between 2 and 8 is ideal for spraying. An operator needs to decide whether to stop spraying or to continue using a larger droplet size and water rate when Delta T is between 8 and 10.

Wind

Spray when wind is steady and ideally between 5 and 15 km/h. It is important to apply pesticides when the wind is blowing away from sensitive areas and crops. Still or very light winds (less than about 5km/h) frequently accompany two of the most adverse spraying conditions: strong thermals and hazardous inversions. Avoid calm, variable or gusty wind. A wind speed drop at night is likely to indicate the formation of an inversion – stop spraying immediately and confirm whether hazardous inversion conditions are present. 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.

Hazardous surface temperature inversions

Pesticide applications during hazardous surface temperature inversions can lead to spray drift causing severe damage up to several kilometres off target. Current regulations prohibit spraying of agricultural chemicals when hazardous temperature inversions exist. Hazardous inversions have only recently been defined and methods to detect and forecast them specified (Grace and Tepper 2021 journals.ametsoc.org/search?f_0=author&q_0=Graeme+Tepper).

FIGURE 17.1 Delta T is used to indicate evaporation rate and droplet survival. Spraying operations are best conducted when Delta T is between 2 and 8.
Source: GRDC weather essentials

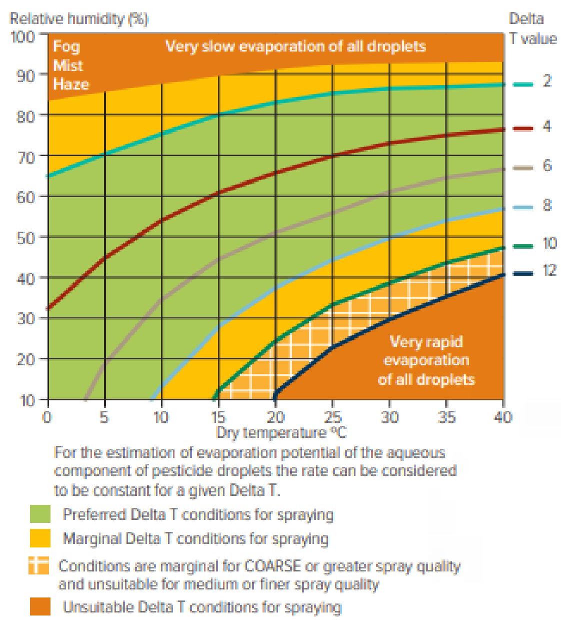
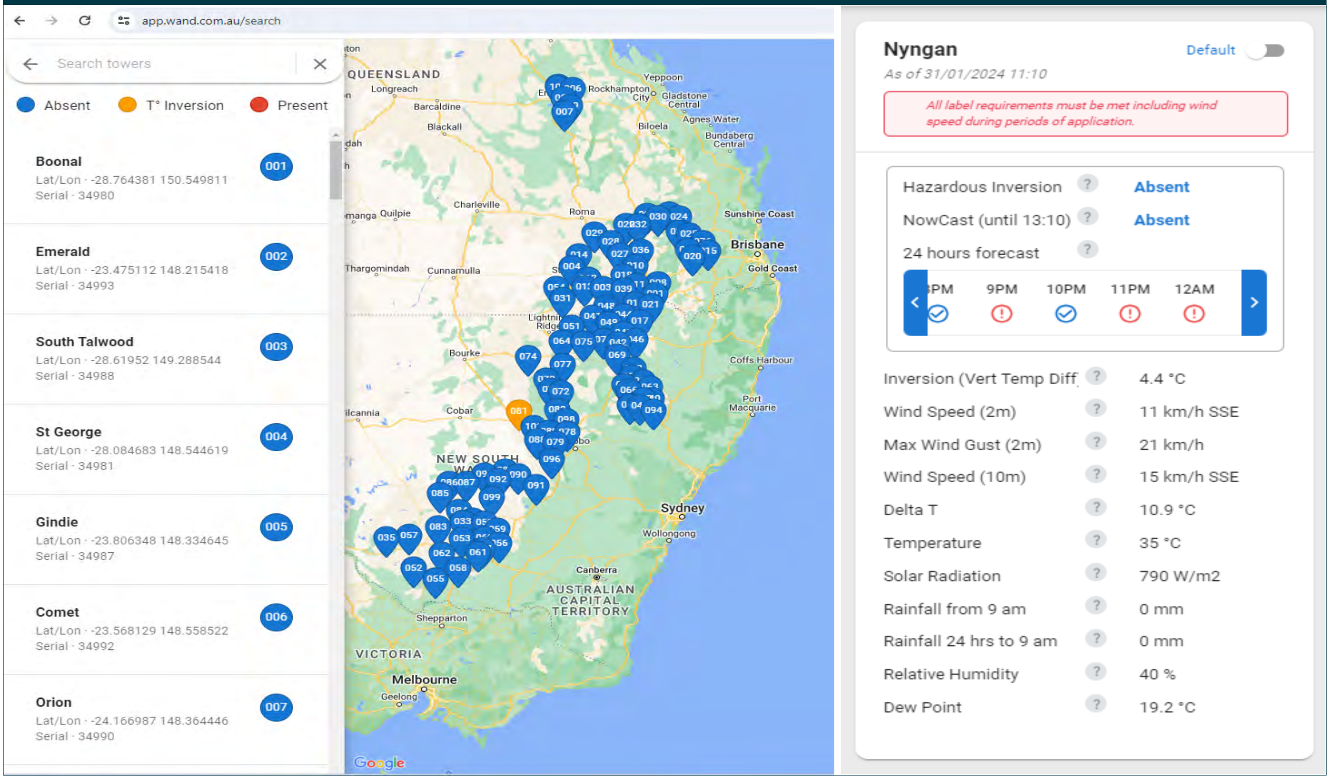


FIGURE 17.2 Example of the information available through the WAND system.

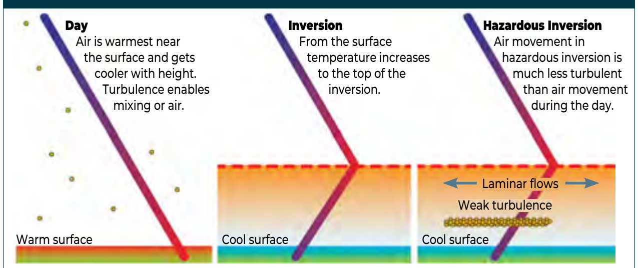


A surface temperature inversion occurs when the air temperature increases with height from the ground surface, which is the opposite of what normally happens (i.e. the temperature profile is 'inverted'). This results in a layer of cool dense air being trapped close to the surface below warmer air. Not all surface temperature inversions are hazardous, but they must be considered as such, unless recognised instrumentation exists to identify them.

Growers and spray contractors can use the WAND (Weather and Networked Data) spray drift hazardous inversion system to obtain real-time information about the presence or absence of hazardous temperature inversions. You can access WAND, free-of-charge, by registering at wand.com.au

For areas not covered by WAND, all inversions must be considered hazardous and must be monitored in the paddock of operation. Refer to GRDC's Hazardous inversion Fact Sheet for more information: grdc.com.au/__data/assets/pdf_file/0033/579390/hazardous-inversion-grdc-20250109.pdf

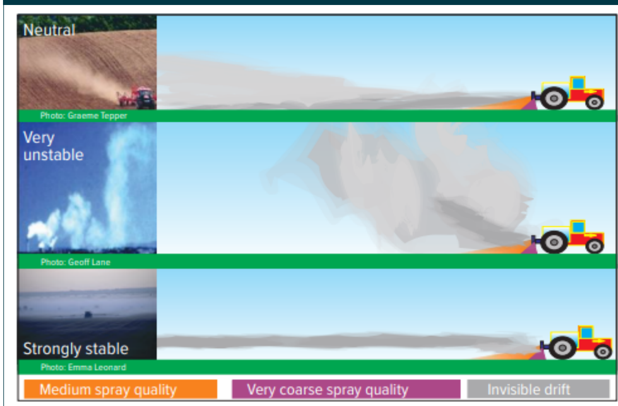
FIGURE 17.3 What is a hazardous inversion?



Typical vertical temperature profiles for normal, inversion and hazardous inversion conditions. Blue represents cooler air, red represents warmer air and yellow dots represent spray droplets.
Spray applied during a hazardous inversion can become trapped in the cool air layer where there is insufficient turbulence to either deposit or disperse the suspended spray droplets. This lack of turbulence results in the transport of drift over long distances in localised laminar air flows. Not all inversions are hazardous, but they must be considered as such unless recognised instrumentation (e.g WAND) exists to identify them.

When a hazardous inversion has established, it acts like a barrier, isolating the inversion layer from the normal weather situation, especially the normal wind speed and direction. During a hazardous inversion, air movement is much less turbulent than during the day (Figure 17.3). Sprays applied in these conditions can become trapped in this cool air layer where there is insufficient turbulence to either deposit or disperse the suspended spray droplets (Figure 17.4). This lack of turbulence results in the transport of drift over long distances in localised laminar air flows that glide smoothly down slopes, deviate around obstacles, flow parallel to contours and generally flow towards low-lying areas where they converge and concentrate; all the while transporting airborne material such as spray drift.

FIGURE 17.4 Three common states of atmospheric stability and their relationship to spray application and drifting sprays.



Neutral conditions favour drifting plume deposition to the near surface but some percentage will also be transferred to the wider atmosphere.
Strongly unstable conditions promote vertical dispersion and widespread dispersion of plumes into the atmosphere.
Strongly stable conditions (hazardous inversions) cause high concentration of drifting plumes near the surface in contained layers.

Operate efficiently

Droplet size, nozzle choice and pressure

Nozzle selection and droplet size

You will need a range of spray nozzles to use with different types of spray applications. There is no 'one-size-fits-all' when it comes to nozzles. Certain herbicides require the application of ultra-coarse droplets, whereas other herbicides and insecticides will need to be applied using a medium size droplet. The product label specifies the optimum droplet size required, and you should select the nozzle type and operating pressure that allows you to apply droplets in that range.

Nozzle selection should consider the target situation so that flow rate, spray quality, fan angle and nozzle type will generate an appropriate spray output that ensures both control efficacy and label-specified environmental obligations.

Spray quality refers to the standard range of droplet sizes produced by a nozzle at a particular pressure according to that nozzle classification standard being used. These are extremely fine, very fine, fine, medium, coarse, very coarse, extremely coarse and ultra-coarse. Select a nozzle that complies with the label and will produce the coarsest spray quality without compromising efficacy.

Fan angle determines the width of the spray pattern. It is important to set the boom at the minimum practical height to achieve the correct spray pattern for the nozzles. Be aware that pulse width modulation (PWM) spraying systems require specific consideration for setup and operation to perform accurately.

USEFUL RESOURCES:

GRDC nozzle selection chart to determine the best nozzle for your situation. grdc.com.au/__data/assets/pdf_file/0023/614147/nozzle-selection-guide-50-cm-38-1-cm-grdc-241126.pdf

GRDC Spray application manual - module 3. grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual

Information regarding nozzle classification and selection is available on the GrainGrowers website. graingrowers.com.au/graingrowers-spray-drift-resources-hub/spray-application-and-drift-management-video-series

GRDC Module 17. Pulse-width modulation systems: how they work and set-up considerations. grdc.com.au/resources-and-publications/all-publications/factsheets/2023/pulse-width-modulation-sprayers

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. Ammonium sulfate, ammonium-based additives and ammonium-based products must not be used in applications that include XtendiMax® 2 Herbicide with VapourGrip® Technology. 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 choosing 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 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 operating pressure. Where automatic rate controllers are fitted to the machine, carefully consider the true range of speeds the machine is likely to operate at, 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.

Boom height

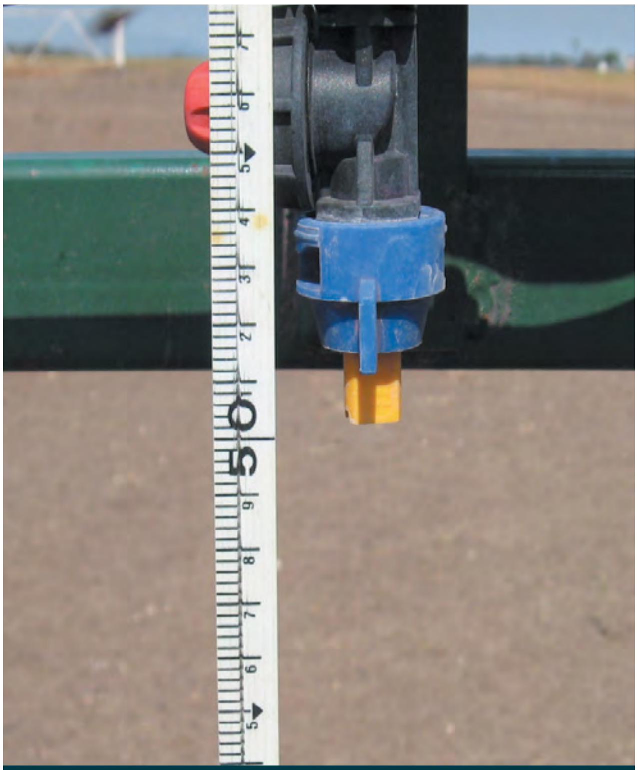
Setting appropriate spray release height

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 by tuning the boom suspension and matching travel speed to release height. Alternatively, consider fitting an auto boom height system.

Auto boom height devices use ultrasonic sensors to detect the height of the boom above the target and adjust the boom hydraulically to maintain the nozzles at a constant height above the target. These systems require a machine with good hydraulic capacity to allow consistency of boom height at higher travel speeds.

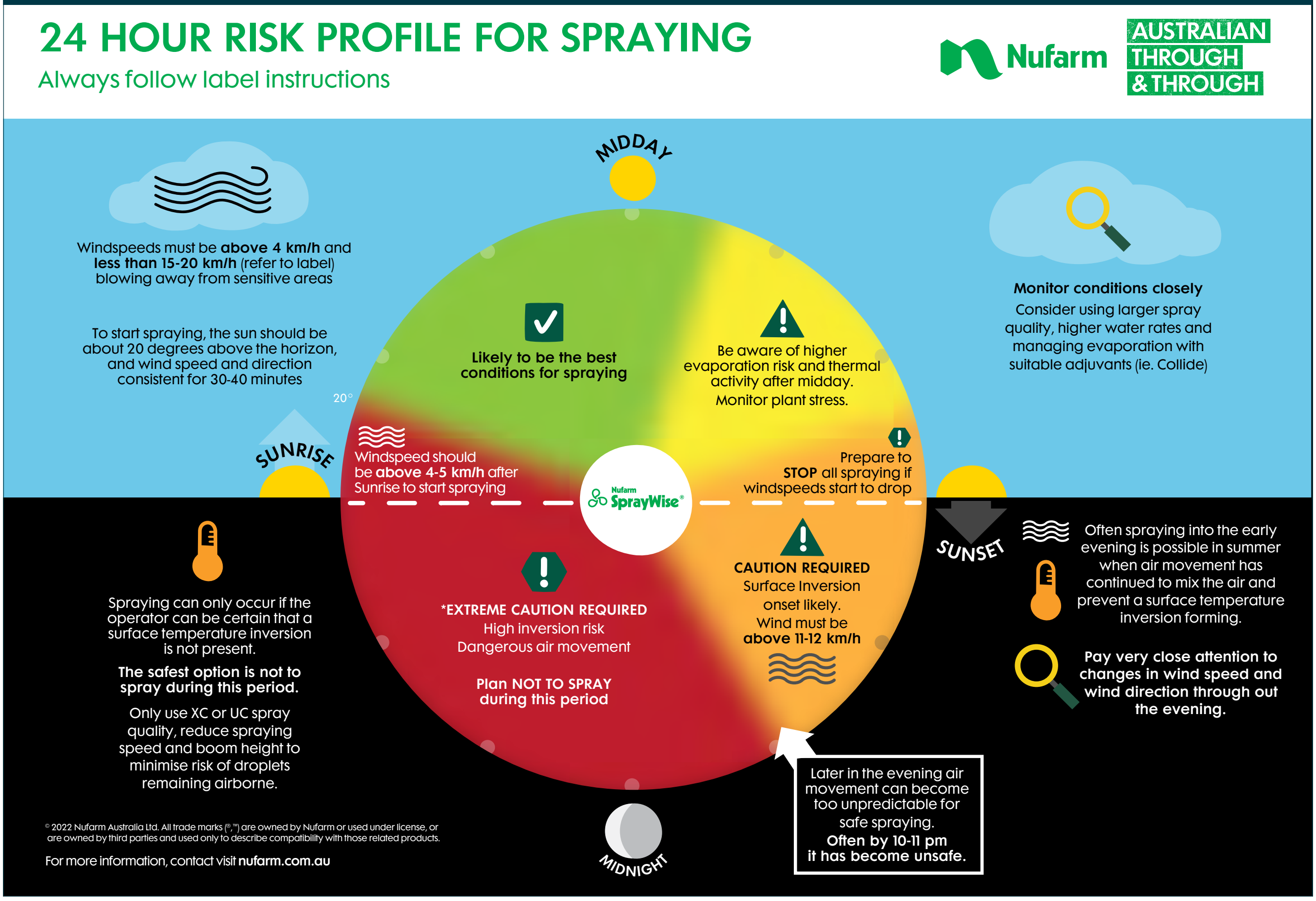
Travel speed for ground rigs

Avoid high travel speeds. Spraying speeds of more than 16 to 18 km/hr with trailing rigs and more than 20 to 22 km/hr with self-propelled sprayers greatly increases losses due to the effects at the nozzle and the aerodynamics of the machine. Higher speeds reduce deposition of spray droplets in the wheel tracks and behind stubble, and also increase the drift potential due to droplets being drawn in the machine's wake.



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 17.5 Guidelines for temperature inversion risk (if access to a WAND tower is not available). Developed by Nufarm.



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. Be aware that however much time is spent decontaminating the equipment there is always a risk of herbicide residues causing a problem.

Disposal

Unwanted pesticide and containers must be disposed of legally and responsibly. Agsafe www.agsafe.org.au operates stewardship programs focusing on the safe handling, storage, transport, and disposal of agricultural chemicals. Programs include:

ChemClear provides Australian agricultural and veterinary chemical users with a collection and disposal pathway for their unwanted chemicals.

drumMUSTER provides chemical users with a recycling pathway for eligible empty pesticide containers.

Optical sprayers

Optical sprayers such as See & Spray™, WeedSeeker® and WEED-IT 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, conditions are appropriate and that equipment is 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, such as only spraying inter-rows with herbicide or directing insecticides onto crop rows. This uses less chemical overall compared to broadcast spraying, but still applies the equivalent per hectare rate to the target area. It is important to get calculations correct to avoid costly errors.

Check the pesticide label for registered rates and recommended water volumes of formulated product per hectare. The proportions of active and adjuvants within the tank mix remain the same. What changes is the total volume of formulated spray needed for the paddock area.

Ensure you keep units consistent (e.g. convert cm to m where appropriate).

Determine the required band width

The width of the bands you use will depend on your farming system and target pest. Band width should be measured along the top of plants for post-emergence products and at ground level for soil applications.

Take a note of any other constraints involved in the spraying process:

- Can the band width be achieved with a single nozzle?
- Can your boom height be adjusted to achieve the desired output width?

If spraying herbicide into inter-row areas, a single nozzle is likely to be sufficient in solid plant, but several nozzles may be required for wider inter-rows or if directing spray from multiple angles onto the crop row.

Application rate

When band spraying, the application rate to the target is the same as normal spraying but the total amount applied is a proportion of the broadcast (non-banded) amounts. For example, if the sprayed bands covered half the paddock area, the total volume (including actives and adjuvants) applied would be half that of an equivalent broadcast spray (a full tank could treat twice as much crop).

Actual sprayed area

The actual area sprayed is a proportion of the paddock, calculated using the size of your band width compared to the row spacing (refer to Figure 17.6).

Actual sprayed area = (Band width ÷ Row spacing) x Total planted area

For example:

In a 50 hectare field with solid plant cotton (1 metre row spacings), a 70 cm wide band would cover 70% (0.7 m ÷ 1 m) x 50 ha = 35 ha.

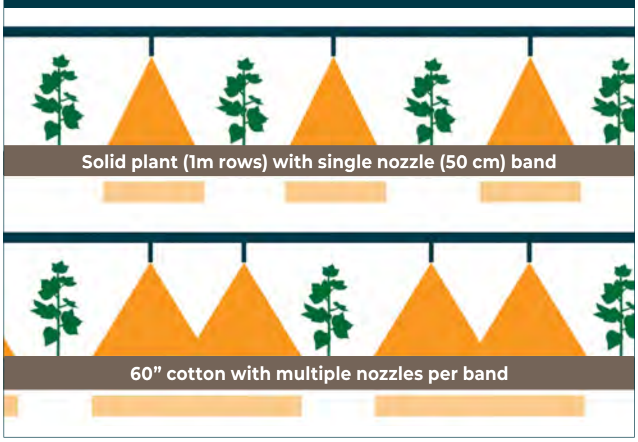
In a 50 hectare field with 60 inch cotton (1.5 m rows), a 1 metre band width would cover two thirds (1 m ÷ 1.5 m) x 50 ha =33.3 ha.

Nozzle selection and output

Work out the volume applied in litres per minute based on the label recommended rate, the band with, and the rig's travel speed (with an adjustment factor of 600 to change km/hr into m/min):

Band output (L/min) = Band width (m) x Label volume rate (L/ha) x Travel speed (km/hr) ÷ 600

FIGURE 17.6 Examples of banded spraying applications and the relative amount of ground covered.



If multiple nozzles are being used per band, divide the band's output by the number of nozzles to give an average output in L/min for each nozzle:

Average nozzle output (L/min) = Band output (L/min) ÷ Number of nozzles

Refer to manufacturer's specifications to select nozzles that will apply the desired spray quality and volume in L/min over the band width when operated at the middle of their advertised pressure range. Adjust boom height if required to achieved desired band width while keeping within 50 cm of the target to reduce drift risk.

Working out sprayed and total hectares

You can calculate how much chemical and water is needed by multiplying the proportion that requires spraying by your normal broadcast volume (for example if your banded area is 50% of the field, you will need 50% of your normal application volume and chemical additives).

To calculate how many paddock hectares a full tank will cover when banding:

Litres per sprayed hectare = (Band width ÷ Row spacing) x Label volume rate/ha

Sprayed hectares per tank = Tank size (L) ÷ Litres per sprayed hectare

Sprayed litres per hectare = Band output (L/min) ÷ 600 ÷ Speed (km/h) ÷ Band width (m)

To calculate the total paddock area (including unsprayed bands) that can be covered by a single tank, divide the sprayed hectare per tank by the band width.

Total paddock area per banded tank = Sprayed hectares per tank ÷ Band width

If not spraying a solid configuration on a 1 m row spacing, adjust for band width, boom width and row width (all in metres) and number of planted rows covered:

Total paddock area equivalent per banded tank = Sprayed hectares per tank ÷ Band width x Boom width ÷ Row width ÷ Number of planted rows under the boom

Example

You plan to spray for grass weeds using clethodim 360 in the inter-rows of a 120 ha field with solid (1 m) row spacing at about the 5 leaf stage. The label ground application rate is 100 L/ha, and you're using a sprayer with a 4000 L capacity driven at 8 km/hr. Your boom is set up to provide a shielded band width of 75 cm.

If broadcast spraying, you would be applying 100 L/ha, for a total spray volume of 12,000 L (3 tanks at 40 ha per tank).

When band spraying:

- Actual sprayed area is (0.75 ÷ 1) x 120 = 90 ha
- Band output is 0.75 x 100 x 8 ÷ 600 = 1 L/min
- Litres per sprayed hectare is (0.75 ÷ 1) x 100 = 75 L
- Sprayed hectares per tank is 4000 ÷ 75 = 53.33 ha
- Sprayed litres per hectare is 1 x 600 ÷ 8 ÷ 0.75 = 100 L/ha*
- Number of tanks to band spray the field is 120 ÷ 53.33 = 2.25

***Note: the sprayed litres per hectare should be the same as your label application volume rate, allowing a quick cross-check that the calculations are correct.**

Double-check your figures when calibrating the sprayer

Check that the nozzles are putting out the appropriate volumes, and that the boom is set to the appropriate height from the target to achieve the band width you need.

Always remember to check the spray quality produced to ensure it is consistent with what is required by the product label.

Adding chemicals

The rate of active per sprayed hectare does not change, only the volume (number of full spray tanks) required to treat a field. Add active ingredients and adjuvants to the tank at the same rates and order you would for broadcast spraying. For the above example, assuming label rates of 250 mL/ha of herbicide and 1 L of adjuvant per 100 L, a 4000 L tank would require 10 L of herbicide and 40 L of adjuvant, mixed with 3950 L of water.

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 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.

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 local groups, such as Stop Off-target Spraying (SOS) in your region sos-nsw.com.

USEFUL RESOURCES:

GRDC Spray Application Manual grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual

GRDC Spray drift hub grdc.com.au/resources-and-publications/resources/spray-drift

Pesticide input Efficiency – cottoninfo.com.au/index.php/pesticide-input-efficiency

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

The CottonInfo YouTube channel contains many videos on pesticide application topics – youtube.com/cottoninfoaust

***my*BMP has a Pesticide Application module –** mybmp.com.au

Bayer's XtendFlex Spray Applicator training video series – youtube.com/playlist?list=PLmB7Kj95nhq2Sh2rUxRKggcG71iIA321Q

Stop off-target spraying community groups – sos-nsw.com

APVMA's using chemicals section – apvma.gov.au/node/10811

Making and keeping records of agricultural chemical applications (Qld Government) – business.qld.gov.au/industries/farms-fishing-forestry/agriculture/sustainable/chemical/use/record

Avoiding pesticide spray drift (NSW Government) – epa.nsw.gov.au/your-environment/pesticides/preventing-pesticide-misuse/reducing-conflict-avoiding-spray-drift

TOOLS:

WAND: provides real time guidance on hazardous inversion conditions – wand.com.au

SataCrop: a Cotton Australia and Precision Crop Technologies (PCT) initiative designed to highlight the location of cotton fields. satacrop.com.au

Syngenta's weather website: provides forecasts of conditions for spraying up to 10 days in advance. syngenta.com.au/weather

Through Agsafe, ChemClear provides a collection and disposal pathway for unwanted chemicals and *drumMUSTER* provides chemical users with a recylcing pathway for eligble empty pesticide containers agsafe.org.au

Bayer's The Spray App helps plan sprays more effectively by providing weather forecasts including inversion risk probability – crop.bayer.com.au/tools/weather-inversion

Snap Send Solve app: for documenting spray drift incidents and reporting to Cotton Australia. cottonaustralia.com.au/spray-drift-app

There are a range of manufacturer and educational apps on nozzle selection, pesticide mixing, sprayer calibration and modes of action. See Apple's App Store or GooglePlay for what is currently available.

Managing for fibre quality

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

Acknowledgements: **Rene van der Sluijs**, **Greg Constable**, **Sandra Williams**, **Stuart Gordon**, **Robert Long** and **Geoff Naylor**

RD&E in focus

Cotton Seed Distributors along with CSIRO are currently evaluating a decision tool that will assist in predicting in-season fibre micronaire from flowering onwards based on weather and management insights. This model has been built from CSD's extensive agronomic dataset using machine learning approaches. It is currently being validated, and will be implemented in CottonTracka® to assist with end of season management decisions such as timing of defoliation and harvest.

Importance of quality fibre

Australian cotton holds a reputation for producing high quality cotton that usually attracts a premium, and so the consequences of producing poor fibre quality can be substantial (see Table 18.1). 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 *Variety Selection* chapter for information on variety-specific fibre characteristics.

Crop management for improved fibre quality

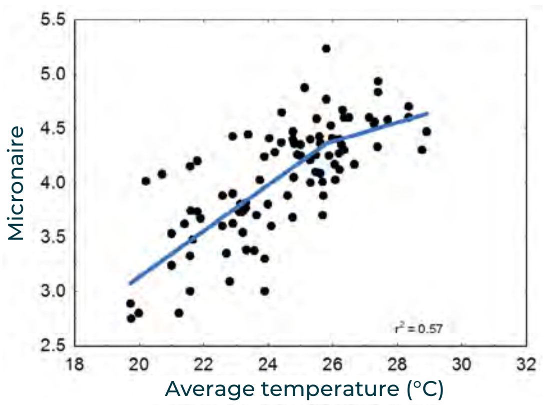
Most crop management factors that increase/optimise yield also optimise fibre quality. One exception may be instances of high yielding crops with undesirable high micronaire cotton. Fibre length and micronaire are significantly affected by agronomic and climatic effects, but fibre strength is more influenced 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 chapter, 'fibre elongation' refers specifically to the elongation of a fibre in length during its growth. In terms of fibre quality characteristics, fibre elongation can also refer to the elongation in a fibre before it breaks

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.

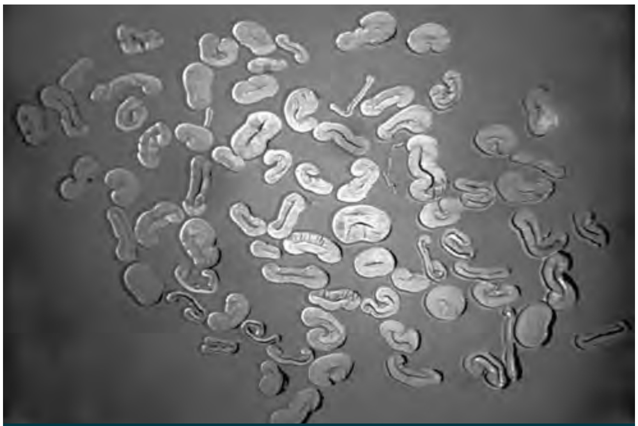
FIGURE 18.1 The response of micronaire to daily average temperature during fibre thickening taken from planting time studies. Varieties used in this study had an average micronaire of 4.05 generated at an average daily temperature of 24.4°C.
Adapted from Luo, Bange and Johnston (2014)



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 and/or cloudy weather, leading to lower 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 18.1 shows the influence of average daily temperature on micronaire during the phase when most bolls have their fibres thickening. Recent research is showing that the effects of growing conditions during boll filing are the predominant factor influencing micronaire (reflected mostly in the size of bolls). Leaf area at flowering also has an impact (lower leaf area = lower micronaire), but this effect is less when growing conditions during boll development are optimal. Early crop defoliation or leaf removal can cause substantial reductions in fibre micronaire due to the cessation in carbohydrate supply for fibre thickening.

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. Where nutrient deficiencies are not the major factor in a production system, nitrogen or potassium fertiliser treatments will not necessarily improve



Cross section of a cotton yarn showing the packing and interaction of individual fibres. Changes in micronaire affect how many fibres make up the cross section of the yarn, affecting its strength and dye uptake. CSIRO fibre length. 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 contributing to trash contamination.

Cotton's indeterminate growth habit also leads to many secondary (indirect) impacts of climate and management on fibre properties. Any circumstances that delay 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.

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 18.2). The issues to consider for each crop management phase are summarised in Table 18.2.

USEFUL RESOURCES:

Resources and tools are available at cottoninfo.com.au and mybmp.com.au

CottonInfo video 'Factors affecting fibre quality': youtu.be/q3erKghtGb0

FIBREpak 2nd Edition (available from cottoninfo.com.au)

Bange, M.P., Long, 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. DOI: 10.1002/csc2.20679

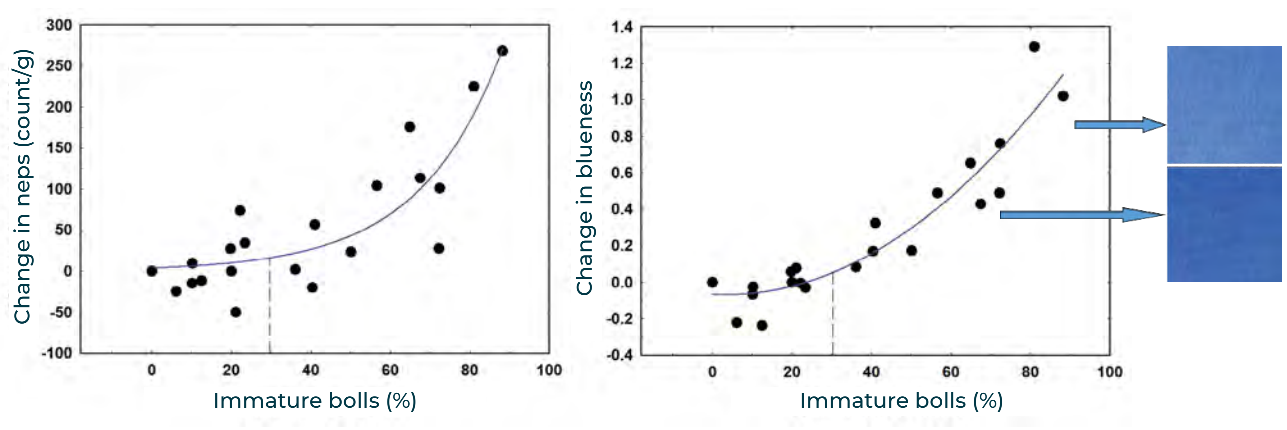
TABLE 18.1 Consequences of poor fibre quality.

Fibre trait	Trait description	Ideal range	Consequences of poor fibre quality (pricing)	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 inches or 36/32nds. For premium fibre 1.250 inches 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	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, 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 and a deterioration in processing performance and yarn quality.
Micronaire	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.	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	Describes the colour and 'preparation' of cotton. 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)	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 honeydew produced by 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.
Neps	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.
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.	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.
Contamination	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.	Can lead to the downgrading of yarn, fabric or garments to second quality or even the total rejection of an entire batch.

TABLE 18.2 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 greater than 29% immature bolls as defined by boll cutting (see Chapter 19) 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 *Cotton Pest Management Guide* for aphid, mealybug and whitefly management. Consider defoliating earlier if crop shows signs of maturing rapidly.	Harvest at moisture levels of ≤12%, ensure that the harvester is setup according to the operator's manual and that regular cleaning and servicing of the harvester is conducted before, during and after harvesting.
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; make all workers aware of the consequences of contamination. Take care when transporting and staging modules to prevent damage to the module wrap.

FIGURE 18.2 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**, **Sandra Williams**, **Greg Constable**, **Stuart Gordon**, **Rob Long** and **Geoff Naylor**

Timely and effective cut-out

The timing of cut-out at the end of the season must balance the opportunity of further fruit production (yield) with potential losses in fibre quality and harvesting difficulties associated with potential cold and/or wet weather. The cut-out date should aim to have all bolls on the plant mature ready for defoliation.

Best practice...

- Avoid management practices that delay maturity as they can lead to reduced micronaire.
- Timing of harvest should strike a balance between further boll development and potential losses (from adverse weather and immature fibre).
- In addition to timing of harvest aids, it is important to consider product, rate and application issues.

RD&E in focus

Recent research undertaken by the CSD Extension team have re-evaluated the boll period. Using an updated definition of when fibres are mature in a boll, the team was able to establish that fibres are mature in the boll at 404 day degrees (15_32 DD). This is less than the previously used definition of 493 (15_32 DD) which was from a flower to an open boll. This new boll period has been used in this chapter to estimate the time of Last Effective Flower/Cutout for the various regions.

Management tips

During flowering, monitor cut-out at least weekly using the nodes above white flower (NAWF) technique. A NAWF of 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 that promotes new growth such as more frequent irrigation or increased nutrition to raise NAWF. To time cut-out appropriately consider how much time is left in the season by estimating the date of the last effective flower (see Table 19.1). Crops approaching cut-out too slowly can indicate a loss of fruit and/or ample access to water and nutrition. If crops are continuing to grow and the time of last effective flower (optimal cut-out date for your region) has passed, consider extending irrigation intervals and using a late season,

TABLE 19.1 Average date of last effective flower (optimal cutout date) for various locations based on a desired date for the crop to be finished (last harvestable boll). Included are the dates when first frost incidence occurs in each location for comparision. Ideally the last harvestable boll should mature before the first frost.

Location	Date of Last Effective Flower (LEF) — Desired date for crop to be finished (Last Harvestable Boll - LHB)								First Frost Analysis				
	14-Mar	21-Mar	28-Mar	7-Apr	14-Apr	21-Apr	28-Apr	7-May	Average Frost Date	Earliest Frost Date	20th Percentile Frost Date	80th Percentile Frost Date	Latest Frost Date
Jerilderie LEF Date	15-Jan	20-Jan	24-Jan	29-Jan	1-Feb	4-Feb	7-Feb	10-Feb	**17-May**	22-Apr	5-May	30-May	20-Jun
Griffith LEF Date	17-Jan	22-Jan	26-Jan	31-Jan	31-Jan	11-Feb	10-Feb	13-Feb	**16-May**	22-Apr	2-May	30-May	20-Jun
Hay LEF Date	17-Jan	21-Jan	25-Jan	31-Jan	3-Feb	6-Feb	9-Feb	13-Feb	**16-May**	13-Apr	1-May	30-May	13-Jul
Hillston LEF Date	18-Jan	23-Jan	27-Jan	2-Feb	5-Feb	9-Feb	12-Feb	15-Feb	**15-May**	22-Apr	4-May	30-May	18-Jun
Warren LEF Date	19-Jan	24-Jan	29-Jan	4-Feb	8-Feb	11-Feb	15-Feb	18-Feb	**31-May**	22-Apr	13-May	14-Jun	18-Jul
Narromine LEF Date	17-Jan	22-Jan	27-Jan	1-Feb	5-Feb	9-Feb	12-Feb	15-Feb	**17-May**	22-Apr	7-May	27-May	18-Jun
Bourke LEF Date	23-Jan	28-Jan	2-Feb	8-Feb	12-Feb	16-Feb	19-Feb	23-Feb	**1-Jun**	30-Apr	15-May	13-Jun	27-Jul
Walgett LEF Date	20-Jan	26-Jan	30-Jan	6-Feb	10-Feb	14-Feb	17-Feb	21-Feb	**23-May**	30-Apr	9-May	31-May	18-Jun
Wee Waa LEF Date	19-Jan	24-Jan	29-Jan	5-Feb	9-Feb	13-Feb	16-Feb	20-Feb	**23-May**	28-Apr	9-May	4-Jun	18-Jun
Narrabri LEF Date	18-Jan	23-Jan	28-Jan	4-Feb	8-Feb	12-Feb	15-Feb	19-Feb	**19-May**	22-Apr	6-May	29-May	24-Jun
Gunnedah LEF Date	15-Jan	20-Jan	25-Jan	31-Jan	4-Feb	8-Feb	11-Feb	15-Feb	**14-May**	12-Apr	4-May	24-May	18-Jun
Quirindi LEF Date	13-Jan	18-Jan	22-Jan	28-Jan	1-Feb	4-Feb	8-Feb	11-Feb	**7-May**	5-Apr	26-Apr	20-May	28-May
Burren Junction LEF Date	20-Jan	25-Jan	30-Jan	5-Feb	9-Feb	13-Feb	17-Feb	21-Feb	**24-May**	30-Apr	10-May	6-Jun	18-Jun
Spring Ridge LEF Date	15-Jan	19-Jan	24-Jan	30-Jan	3-Feb	7-Feb	10-Feb	14-Feb	**12-May**	12-Apr	5-May	23-May	18-Jun
Moree LEF Date	19-Jan	24-Jan	29-Jan	5-Feb	9-Feb	13-Feb	17-Feb	21-Feb	**26-May**	23-Apr	14-May	11-Jun	27-Jun
Mungindi LEF Date	21-Jan	26-Jan	1-Feb	7-Feb	11-Feb	15-Feb	19-Feb	24-Feb	**5-Jun**	1-May	16-May	25-Jun	10-Jul
St George LEF Date	21-Jan	26-Jan	1-Feb	7-Feb	12-Feb	16-Feb	20-Feb	24-Feb	**3-Jun**	1-May	16-May	15-Jun	21-Aug
Goondiwindi LEF Date	19-Jan	25-Jan	29-Jan	5-Feb	10-Feb	14-Feb	18-Feb	22-Feb	**26-May**	28-Apr	14-May	8-Jun	30-Jun
Dalby LEF Date	15-Jan	20-Jan	26-Jan	1-Feb	6-Feb	10-Feb	15-Feb	19-Feb	**20-May**	28-Apr	8-May	29-May	26-Jun
Forest Hill LEF Date	11-Jan	17-Jan	22-Jan	29-Jan	3-Feb	8-Feb	12-Feb	17-Feb	**14-Jun**	9-May	31-May	27-Jun	18-Jul
Murgon LEF Date	11-Jan	17-Jan	22-Jan	29-Jan	3-Feb	8-Feb	12-Feb	17-Feb	**28-May**	1-May	15-May	9-Jun	26-Jun
Maryborough LEF Date	14-Jan	19-Jan	25-Jan	1-Feb	7-Feb	12-Feb	16-Feb	22-Feb	**14-Jul**	10-Jun	29-Jun	1-Aug	26-Aug
Theodore LEF Date	18-Jan	24-Jan	29-Jan	6-Feb	11-Feb	16-Feb	20-Feb	26-Feb	**7-Jun**	10-May	20-May	24-Jun	4-Jul
Emerald LEF Date	20-Jan	26-Jan	1-Feb	9-Feb	14-Feb	19-Feb	24-Feb	1-Mar	**11-Jul**	30-May	20-Jun	9-Aug	20-Aug

***** 30 year historical record mean data***

Last Effective Flower date estimated using a development rate function and SILO dataset.
This is the estimated date, that on average, when analysing the climate record, indicates the date of the last effective flower for desired date of crop maturity.

 # Climate observation data obtained via the State of Queensland SILO patched point dataset.

***** 30 year historical record data***

Historical record dates of average first frost, earliest recorded, 20th and 80th percentile and latest recorded as analysed via the SILO dataset.

20th percentile indicates 80% of the time first frost occurred after this date, yet has occured 20% of the time prior to this date

80th percentile indicates 20% of the time first frost occurred after this date, yet has occured 80% of the time prior to this date

FIGURE 19.1 Tagging flowers around cut-out will assist in identifying bolls that are most likely to be mature at harvest. Jane Caton, CSIRO

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 use of growth regulators to manage timing of cut-out can also reduce the risk of providing a late season food source for insect pests. Use of growth regulators around the time of cut-out may consider the following:

- Target boll numbers have been achieved.
- Resumption of unnecessary late vegetative growth or fruiting.
- LEF date for the region has been reached .
- 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.

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 should be removed before harvest to reduce harvest trash) that produced the last effective flower (Figure 19.1). 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.

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. Ineffective leaf removal 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.

An ideal system to attain the highest quality cotton would be 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 that 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 impact 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 that 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 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 include:

- Days to defoliation.
- Boll maturity.
- Crop water use.
- Plant available water – a crop's ability to extract water below a 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. Only count nodes that contain harvestable bolls.
- Allow for it to take 62 degree days (15_32 approach) (around three days; up to four days in cooler regions) for each new boll to open on each fruiting branch.
- Use this calculation to generate days to defoliation = (Total NACB - four) x three.

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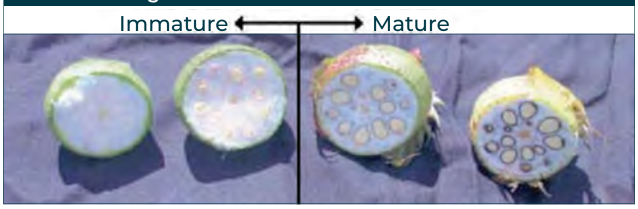
FIGURE 19.2 Bolls that have mature fibre have seed coats that begin to turn brown. CSD



Monitor crop maturity to avoid early crop cessation and ensure timely defoliation

To determine crop maturity and have a timely defoliation, monitor plants that are representative of the crop. Methods include:

- **Boll cutting –** The most effective method to determine if bolls are mature or immature. It can be used when crops are not uniform (e.g. tipped out plants or 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 19.2); and fibre pulled from the boll is stringy (moist but not watery).
- **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 method on crops that are uniform in growth, and is less time consuming than other approaches.

Monitor and manage sucking insect infestations to avoid sticky cotton

A significant proportion of lint stickiness isattributable to honeydew generated by the silverleaf whitefly (SLW; *Bemisia tabaci*), cotton aphid (*Aphis gossypii*) or mealybugs (*Phenacoccus solenopsis*). The sugar exudates from these insects (particularly SLW) 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 combination of fungal spores and 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 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

Severely weather-damaged cotton 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. 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. As cotton weathers it loses reflectance, becoming grey due to moisture from both humidity and rain, exposure to ultraviolet radiation (UV), and from microorganisms that grow on the lint or wash off the leaves. Under very humid conditions fungi can multiply on the lint causing 'hard' or 'tight lock' bolls that 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, as injury to moist boll walls from frost damage releases gossypol which stains the cotton yellow. Plan to have the crop defoliated before first frost (see Table 19.1). While preparing for harvest examine your harvest capacity, regional weather patterns, and monitor crop development to avoid excessive weathering.

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. Harvest aid 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 a 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 depends 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 19.3), micronaire and increase neps (Figure 19.4).

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.

Types of harvest aids

Categories of harvest-aid chemicals include herbicidal and hormonal defoliants, boll openers, and desiccants each with a different mode of action.

Defoliants (thidiazuron, diuron) – 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. 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).

FIGURE 19.3 Effect of early application of harvest aids on lint yield (adapted from Bange et al. 2009). Yield is reduced if defoliation occurs where there are more than 29% immature bolls.

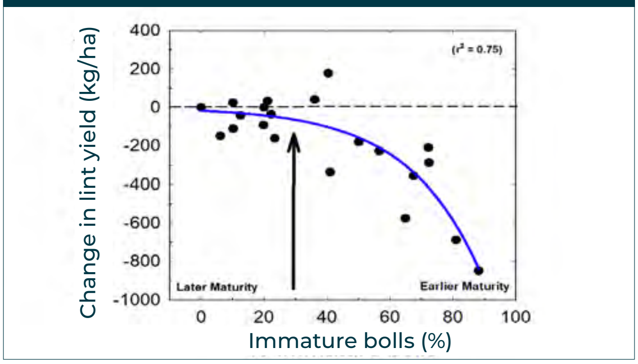



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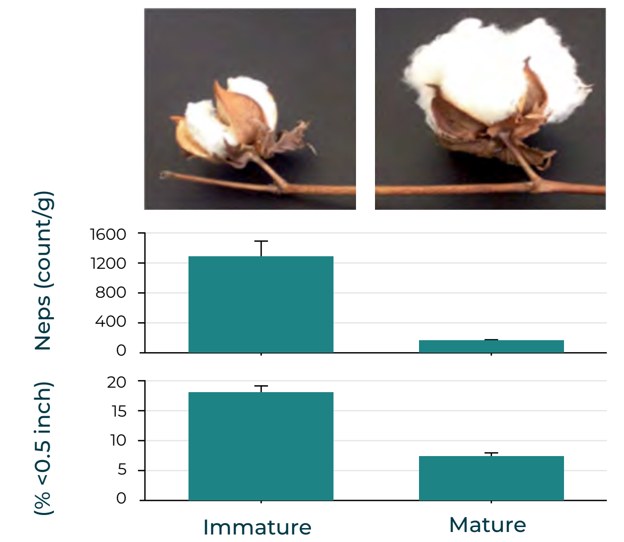
FIGURE 19.4 Pursuing late bolls may put fibre quality at risk. Un-fluffed immature bolls contribute little to yield but significantly increase neps and short fibres. (Rob Long, CSIRO)



Herbicides can also used as defoliants when used at rates that injure or stress the plant into increasing ethylene production (similar to waterlogging or drought effects). Although if the herbicides are applied at too high rates then the plant material may die before releasing enough ethylene to cause defoliation resulting in leaf dessication (leaf death) - see herbicides below.

Boll openers/conditioners (ethephon, Amino meth dihy tetras (urea)) – 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, glyphosate, diquat, paraquat, carfentrazone-ethyl) – Contact chemicals that cause disruption of leaf membrane integrity, leading to rapid loss of moisture, which produces a desiccated leaf. Desiccants should be avoided if possible 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. At high rates, some defoliants can act as desiccants.

Timing the application of harvest aids

The type of defoliation product is unlikely to impact fibre quality if timing is correct, but early defoliation can cause a significant reduction in all desirable fibre properties, increasing the number of harvested bolls (often from the top of the plant) that have immature fibre 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 harvest aids where there are more than 29% immature bolls may reduce micronaire and increase neps. In crops that have non-uniform maturity aim for no more than 29% immature bolls (of total boll number), as defined using the boll cutting technique, to avoid increasing neps.

Key issues when using harvest aids

- Ensure defoliation occurs before the onset of frost.
- Aim to have soil moisture at refill points at defoliation. Defoliants will not act effectively in severely water-stressed crops.
- Applying boll openers/conditioners before boll maturation may cause bolls to shed and reduce yield.
- Boll openers/conditioners should only be considered if the bolls that will be forced open are mature.
- Avoid applying defoliants when rainfall predicted shortly after. Some defoliants are taken up slowly by the leaves and will wash off, resulting in incomplete defoliation.
- To avoid regrowth issues, do not defoliate an area bigger than can confidently be harvested within two weeks.

Selecting chemicals and rates

- Older leaves are most susceptible to defoliant. Higher rates of defoliant are needed for young healthy leaves. However, young leaves may 'freeze' on the plant if the weather is too warm.
- 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 minimum temperatures for defoliant performance. Hormonal defoliants and boll conditioners have a higher optimal minimum temperature (around 18°C) compared with herbicides (13 to 16°C). Higher rates are often needed to offset the effects of low temperatures.
- Varieties may differ in their defoliation needs, depending on their concentration of plant hormones and the quantity of wax on the leaf surface.
- Chemical effects are usually complete seven days after application.

Applying harvest aids

- 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 if using ground rigs. 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 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.

USEFUL RESOURCES:

FIBREpak 2nd Edition, *Cotton Pest Management Guide*, *Defoliation booklet* – cottoninfo.com.au

***my*BMP –** mybmp.com.au

Related videos can be viewed at: youtube.com/cottoninfoaust

Impact of harvest aid timing and machine spindle harvesting on neps in upland cotton MP Bange, RL Long – Textile Research Journal, 2013

Optimising timing of chemical harvest aid application in cotton by predicting its influence on fiber quality MP Bange, RL Long – Agronomy journal, 2011

For more information access the **CottonInfo Defoliation Booklet** via the QR code.

Harvesting

By **René van der Sluijs** (Textile Technical Services and CottonInfo)

What's new...

Take into consideration the duration of storage (both on farm and at the gin) and method of transportation, when choosing the type and manufacturer of wrap. This being especially important as the quality of the round module wrap plays an important role in preserving fibre quality and minimising contamination.

Preharvest preparation and harvesting play important roles 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, harvesting is done by either spindle pickers or cotton strippers. Irrespective of the mechanical harvesting method, the set-up 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 correctly set-up

The bulk of the Australian crop is harvested with spindle pickers, that use rotating tapered, barbed spindles to selectively pull seed cotton from opened bolls into the machine. Pickers are large and complex machines that are expensive to purchase, costly to maintain and require precise set-up, adjustment, and trained and skillful operators to obtain the maximum yield and income per hectare. Proper maintenance and correct set-up will help to ensure a clean and effective pick. Your best source of information about maintenance and set-up is your harvester operator's manual.

The other type of machine is the cotton stripper, a non-selective harvester that uses brushes and bats to strip seed cotton from bolls. These harvesters are predominately used in 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...

- Ensure harvesters are correctly set up and regularly maintained.
- Check moisture levels of seed cotton prior to and during harvesting and in modules.
- Stage the modules in the sequence that they were harvested to reduce variability and assist in efficient ginning.
- 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. René van der Sluijs

Agronomic and management decisions 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. Keep row ends 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 picked and 0.8 m for cotton that is to be stripped.

As Australian cotton is primarily harvested using spindle pickers, 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. Give special care to the spindles, moisture 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.
- Ensure all spindles turn when the row unit is rotating.
- Doffers need to be ground and reset properly as required. Replace when damaged.

The picker uses spindles, doffers and pads to pick cotton from bolls. René van der Sluijs

- 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.
- 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.
- Grease picker heads 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.
- Check doffers daily and throughout the 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).
- Check spindles and bushes regularly for wear, especially the ones near the ground, and replace worn parts.
- Keep spindles 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.

Round bales in module yard. LDC

- 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, set pressure doors to light to medium and ensure all grid bars are in position.
- Harvest seed cotton at moisture levels of ≤12% to prevent downgrading of fibre and seed.

Module placement, construction, 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) rectangular modules that can weigh 12,000–16,000 kg, producing an average of 24 bales. In contrast, harvesters with on-board module building capacity produce round modules that have a diameter of up to 244 cm and weigh 2200 to 2800 kg. These round modules can produce an average of four bales for spindle pickers and three bales for stripper harvesters. The newer 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:

- Allow enough space for easy access for the equipment and trucks.
- Choose well-drained field road and avoid areas where water accumulates.
- Ensure the surface of the site is free from gravel, rocks, stalks, and debris such as long grass or cotton stalks.
- Aim for a smooth, even and firm compacted surface that allows water to drain away.
- Ensure access to transport and inspection in wet weather.
- Locate it away from heavily travelled and dusty roads, and other possible sources of fire and vandalism.
- Ensure it is clear of overhead obstructions, especially power lines.

Round modules

John Deere harvesters with on-board module-building capacity offer significant 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 now harvest the majority of the 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 these advantages, 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 does not need to stop to unload, the operator must 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.

Plastic wrap

The quality of the round module wrap plays an important role in preserving fibre quality and minimising contamination.

Take into consideration the duration of storage (both on farm and at the gin) and method of transportation, when choosing the type and manufacturer of wrap. This is especially important as more wrap producers are entering the market with, at times, inferior product.

Staging (method used to place modules together for transport)

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. The staging tractor must be sufficiently large to cope with the module's weight (up to 2800 kg).

Other considerations:

- Keep transport speed of the tractor with a module on the handler to a safe speed that suits current conditions (and do not exceed 16 km/h).
- When transporting modules through harvested rows, carry the module high enough to minimise contact with those rows.
- Keep the gap between the underside of the module and the ground sufficient (no less than 15 cm) during module staging to prevent drag and tearing of the underside of the wrap.
- Stage modules 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.

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.
René van der Sluijs

- Stage modules on a high, flat surface (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. Align the modules 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.
- Repair significant wrap tears in the field before module truck pickup to prevent further wrap damage and ginning problems.
- Secure loose outer tails with a high strength spray adhesive (3M™ 90) or lint bale repair tape.
- Consider purchasing emergency module recovery tarps.

Conventional modules

Module construction

A tighter module sheds moisture better on the sides and less cotton is lost during storage, loading, and hauling. It also helps reduce freight costs.

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.

Cotton 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

It is important to use a high-quality tarpaulin on modules to both avoid moisture-related quality impacts and prevent 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.

When choosing tarpaulins, consider 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. Avoid centre seams (unless heat sealed) as it is a potential weak point that may 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.

Tama
FARM GROWN SOLUTIONS

PREMIUM COTTON WRAP

FOR PREMIUM AUSTRALIAN COTTON

TamaWrap+® TamaWrap+® TamaWrap®

Leading the way in cotton wrap recycling: a global commitment to sustainability

For decades, Tama has been at the forefront of the cotton industry, not only by engineering premium cotton wrap tailored specifically to Australian cotton-growing conditions but also through a deep commitment to sustainability. Our dedication to responsible environmental practices spans the globe, and now, we are bringing this focus even closer to home with a groundbreaking initiative in Australia all driving towards achieving our main objective – reducing our carbon footprint.

In September 2024, we commenced Australia's first onshore cotton wrap recycling trial, a major milestone in our journey towards a circular economy. Through this trial, used TamaWrap+ and TamaWrap Blue was successfully processed back into a pelletised state, with samples sent to our global head office for further research and development. This initiative is driven by a singular vision: to return this recovered material back into the production of cotton wrap, creating a product that contains Post-Consumer Recycled material. Tama is driven to be at the forefront of closing the loop in cotton wrap production, and this trial represents a tangible step toward achieving that goal.

The challenges for closing the loop and being able to manufacture cotton wrap from recycled raw material are complex. One of the primary issues is the colouring of raw materials, which can affect the final product. Additionally, quality concerns such as the presence of small holes in the film can impact performance. However, Tama has worked closely with Polymer Processing for years to overcome these barriers. Together, we've ensured that the machinery used in recycling can produce film to the highest possible standard, giving every opportunity for it to be utilised as PCR (Post-Consumer Recycled).

For years, used wraps have been recycled, but typically they have been downgraded and used to manufacture lower value products such as builders film. This trial is set to break that pattern by returning raw materials directly to Tama for use in the manufacture of new cotton wraps, effectively clo-sing the loop for the first time in this product category.

Tama's commitment to reducing our carbon footprint goes back five years ago to the launch of a pilot program focused on core reuse. This program provides stillages and the opportunity for growers and contractors to return used cores. It marks another important step in our broader mission to promote and support carbon footprint reduction across the cotton industry.

This project is not just a singular achievement; it represents the culmination of years of research and development. Across our global operations, sustainability and innovation go hand in hand. Our continuous investment in R&D has enabled us to pioneer advancements that redefine industry standards, and this recycling initiative is a testament to that ongoing effort.

We recognise that achieving a successful, high performing recycled cotton wrap is a complex, multi-year endeavour, requiring rigorous testing, refinement, and collaboration. However, we are unwavering in our commitment to seeing this vision come to fruition. By leading the charge in cotton wrap recycling, we aim to set a new benchmark for sustai-nability in the cotton industry—one that ensures a greener, more responsible future for growers, manufacturers, and the broader agricultural sector.

Our ongoing gratitude to all Australian cotton producers who work with Tama as an R&D partner supporting these research ventures. Tama is proud to work with the leading cotton producers in Australia to help them reduce their car-bon footprint and by that increase the value of their cotton as the most clean and sustainable cotton in the world. Together, we can create a lasting impact, shaping the future of cotton packaging for generations to come.

Keeping good module records

Identifying when and where each module was produced can help produce 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 and 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. Use permanent marker pens on cards attached to modules in a sealable plastic bag. Round modules have radio-frequency identification (RFID) tags embedded in the module wrap 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 prevent damage to property. Conventional modules are generally transported by flatbed trucks and trailers. Round modules are transported to the gin on either flatbed trucks and trailers, which can carry four to six modules or with specialty trailers that can transport up to 24 modules over long distances. Cotton Australia's *Module Restraint Guide* cottonaustralia.com.au/transport 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.

Work health and safety at harvest

It is vital that all contractors and farm staff complete a safety induction before harvest commences. The key to managing farm safety 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 for how the harvesting operation should progress will ensure that everyone is aware of the correct and safe operation of equipment. For example:

- 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.
- Wear appropriate clothing and use protective equipment where necessary to reduce the risk of an accident occurring.
- Be careful when climbing up or down the access ladder (one of the most common causes of injury on pickers is falling off the ladder).
- 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 refer to *People management* chapter.

Quality issues

Moisture considerations

Harvesting wet cotton 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. Doffers and moisture pads on harvesters can also be damaged.

Seed cotton moisture has a significant influence on fibre quality. Increased moisture results in microbial/bacterial action that leads to colour degradation (spotting) and discolouration which affects the colour grade; the fibre becomes 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 emitting a strong unpleasant odour and/or self-combusting. 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 more mechanical damage to the seed, resulting in an increase in the quantity and weight of seed coat fragments and motes. 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 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 done more frequently at the end of each 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%

A round module with moisture contamination.
📷 René van der Sluijs


SAMUEL


P600

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 responding to rapidly changing moisture levels impacts their ability to gin efficiently. Round modules are very compact and wrapped in plastic, which is impractical and difficult to remove and replace. This limits the rate of moisture transfer to the atmosphere and 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.

During storage on-farm and at the gin, monitor modules 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 the module should be ginned as soon as possible.

If temperatures rise to 43°C, the module needs to be ginned immediately. Modules harvested at safe storage moisture levels will not increase in temperature 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.

Assessing moisture content

Some rules of thumb relating to moisture when harvesting cotton 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 readings 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 between 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.
- Suitable harvesting conditions late into the night are rare.
- Notify your ginner of modules that may have high moisture so that they can be ginned first, or at least prioritised for monitoring 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.

Round module plastic wrap in cotton bale.
René van der Sluijs

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, string made from plastic film and woven plastic, and are mainly from round module wrap and to a lesser degree conventional module tarpaulins.

Other contaminants include:

Natural – Rocks, wood, leaf, bracts, bark, green leaf, burrs, and grass. Also sticky honeydew produced by aphids, mealybug and whitefly 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 that can be avoided with an inspection. Train workers 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:

cottoninfo.com.au/publications/fibre-quality-managing-contamination-cotton

***my*BMP:** mybmp.com.au

FIBREpak: cottoninfo.com.au/publications/fibrepak

Fibre quality videos: youtube.com/CottonInfoAust

Fibre quality podcasts: Search 'CottonInfo Crop to Top' via your preferred podcast platform or access via Buzzsprout buzzsprout.com/1857956

Ginning

By **René van der Sluijs** (Textile Technical Services and CottonInfo)

What's new...

There are several post-farm gate BMP programs in Australia. For example, members of the Australian Cotton Ginners' Association must comply with their BMP and consent to annual scheduled audits during the ginning season. This is to ensure that all critical issues are complied with. During the 2024/25 season 91% of operating gins were audited and certified.

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 remove trash and 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 (Table 21.1).
- To produce a fibre with minimum damage to satisfy the demand from the spinner and the consumer.

Best practice...

- The main concerns during the ginning process are to maintain quality, optimise lint turnout and contain the costs of ginning.
- Appropriate handling and ginning of round modules to minimise the possibility of contamination will help maintain the industry's reputation for high quality cotton.
- Effective communication between growers and ginners is a key factor in assisting this process.

TABLE 21.1 Summary of key post-harvest decisions for optimising fibre quality.

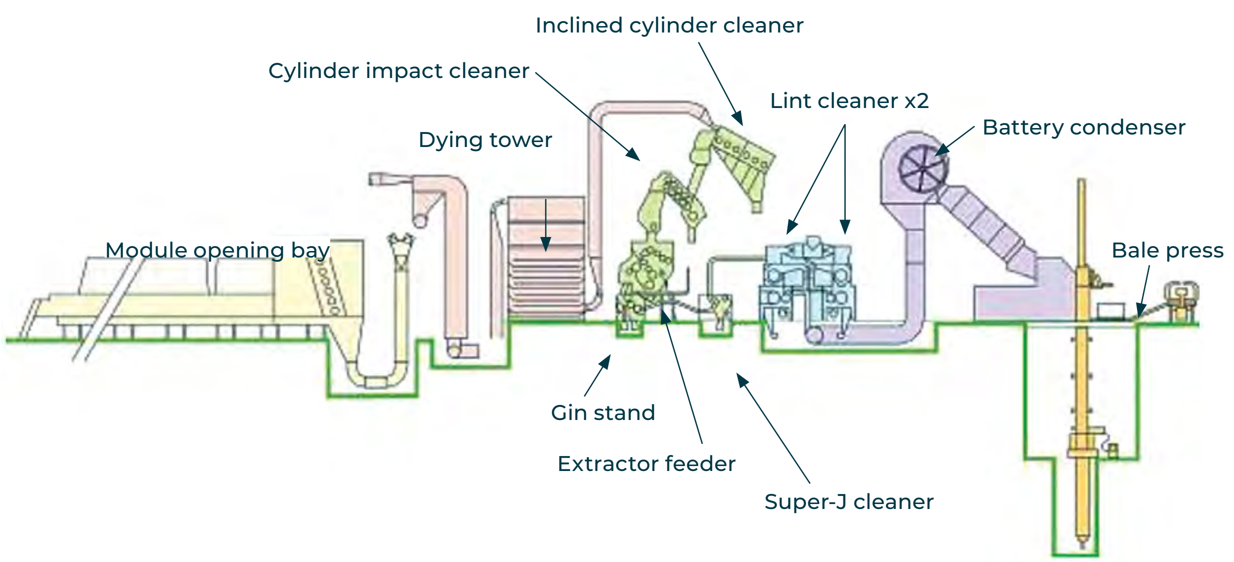
Objectives	At the gin
Maintaining fibre length	In the gin, fibre length can be preserved and short fibre and nep content reduced by reducing the number of lint cleaner passages (depending on quality of seed cotton) and ensuring fibre moisture at the gin and lint cleaner does not exceed 7%. Lower combing 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.

Ginning is, therefore, an essential link between the cotton grower and the cotton spinning mill. However, the gin 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 (lint turnout), production speed and the effects that the various cleaning and ginning components have on the fibre quality.

FIGURE 21.1 Gin flow diagram shows cross-sections of machines used in a modern gin to process spindle-harvested cotton.

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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 fibres can seriously affect 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 turnout. Therefore, 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 lint turnout 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 this balance between lint turnout and grade that maximises the return to the grower. It is therefore essential that growers seek to:

- Ensure nutrition, defoliation and harvest practices limit trash.
- Limit contamination.
- Limit moisture during harvesting and ensure moisture in the module is ≤12%.
- Control silverleaf whitefly, mealybug and cotton aphid to minimise sticky cotton, particularly as bolls open.
- 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 lint turnout 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 (this is especially the case for stripper cotton) from the cotton that would significantly reduce the value of the ginned lint. Figure 21.1 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 incurring significant damage (neps and short fibres). Cotton that is too dry (<5.5% moisture content) is more likely to be damaged during the lint cleaning process.

USEFUL RESOURCES:

CottonInfo video on ginning youtu.be/QQQGkmX-ul8

Australian Cotton Ginning Association
australiancottonginning.com.au/

Classing

By **René van der Sluijs** (Textile Technical Services and CottonInfo)

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 that variations in fibre properties have on processing performance, cost, and product quality, it is important that these variations 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. These are then put together (with bale number and barcode of bale) and rolled up in groups of 50-60 with consecutive bale numbers and sent to the classing facility for classification. Originally, but still conducted today, cotton is 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.

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, length and micronaire do not lend themselves to visual assessment, so a number of instruments were developed to 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, while 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) is still assessed by visual determination.

Cotton quality can be expressed by several different measurements performed by cotton classing facilities. These measurements are described in a wide range of grades (Figure 22.1) and affect the final price that is paid for a bale of cotton. This price depends on the quality of each bale. Cotton prices are quoted for 'base grade' 31-3-36, G5 (refer to Figure 22.1).

Best practice...

To provide accurate, reliable and consistent results classing facilities conduct the following activities:

- employ trained classers
- use calibration cottons and tiles to calibrate and verify their instruments.
- qualify their instruments prior to the season.
- participate in international Round Trials

TABLE 22.1 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

FIGURE 22.1 Interpretation of Australian base grade for Upland cotton: 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

Base grade refers to the grade of cotton that is used by cotton merchants as a basis for contracts, premiums and discounts. Premiums and discounts apply for higher and lower grades respectively. These pricing adjustments reflect the change in suitability for the spinning and dyeing process (refer to *Managing for fibre quality* chapter, Table 18.1, *'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.

Colour

Colour can be classed either visually by a trained cotton classer or by HVI. When cotton is classed visually, the classer compares the sample to a standard lint sample of a known grade provided by the 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 (see Table 22.1).

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), from which the colour grade is calculated.

Leaf

Also known as trash, is a measure of the amount of leaf material remaining in the cotton sample. Whilst the gin removes most of the trash, some remains in the sample and 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 largely measured by HVI by passing a beard of parallel fibres through an optical sensing point and is reported in 100ths and in 32nds of an inch (Table 22.2). 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 22.2 Upland fibre 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 also 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 is 3.8 to 4.2 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 rates.
- 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:

- Variety.
- Poor boll set.
- Small boll size due to hot weather or water stress.

Ginning has little or no effect on micronaire although low micronaire cotton is more susceptible to buckling and entanglement, creating 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 producing high micronaire. Late planted crops are susceptible to low micronaire (and potentially heavy discounts).

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 Institute confirmed that defoliating before 60% bolls open lowers micronaire (reduced fibre maturity) and increases neps.

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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 including (but not limited to):

- Grass or bark in the sample.
- Contamination.
- Stickiness (honeydew).
- Neps.
- Seed coat fragments (SCF).

Several other fibre characteristics measured by HVI instruments are of increasing importance to spinners but do not have a direct impact on price include:

- Length uniformity index (UI%).
- Elongation.
- Short fibres (SFI%) (<12.7 mm).

Cotton grade and price

The price received for cotton is depends on the quality of each bale. Cotton prices are quoted for 'base grade' 31-3-36, G5 (refer to Figure 22.1). 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 while the adjustments are generally quite similar, 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, when 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 for the exact exchange rate applicable).

For example:

A total discount of 800 pts/lb = -$0.08/lb

$$= \frac{-\$0.08 \times 500}{0.74} \text{ (exchange rate is highly variable)}$$

= AUD -$54.05/bale

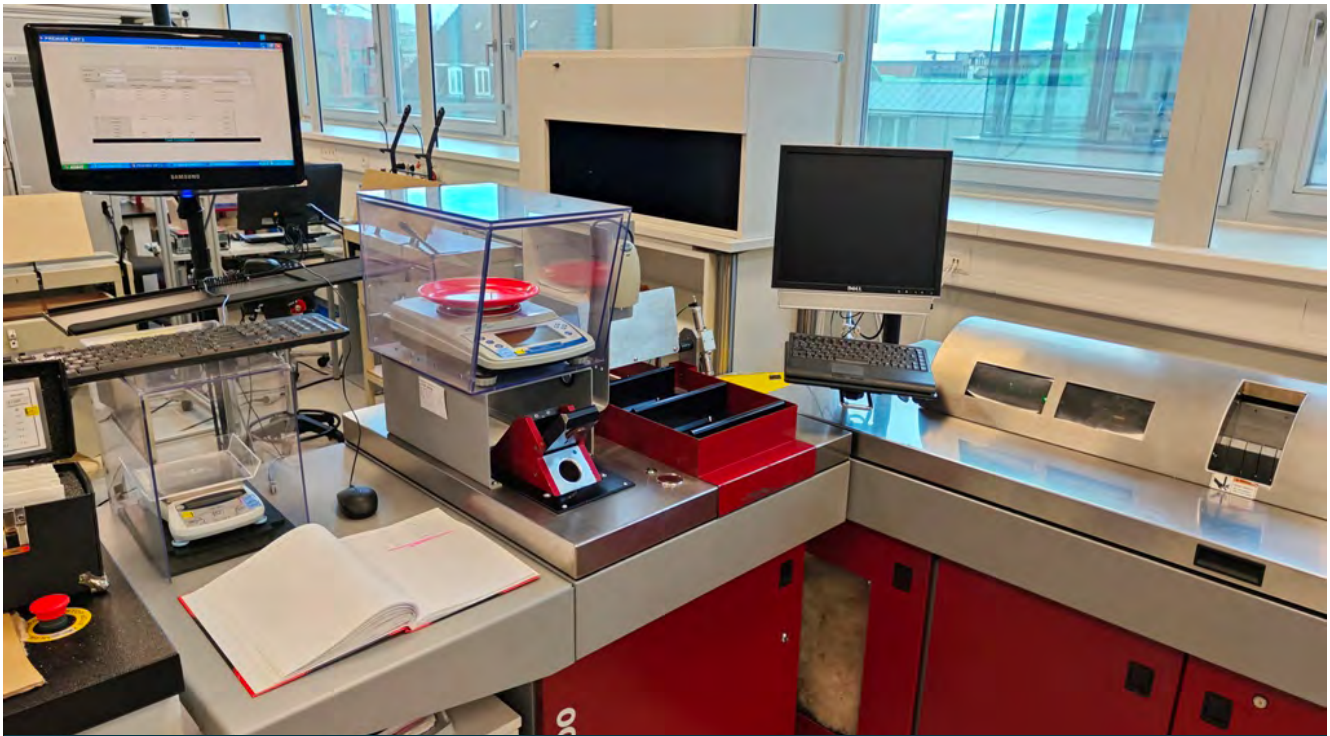
Multiple adjustments may apply to one bale of cotton. One adjustment for colour – leaf – staple length, while all other characteristics have their own adjustments.

USEFUL RESOURCES:

Australian Cotton Shippers Association austcottonshippers.com.au

FIBREpak cottoninfo.com.au/publications/fibrepak

CottonInfo pricing guide cottoninfo.com.au/publications/basic-guide-cotton-pricing-and-quality



Rene van der Sluijs

Post-harvest pest and stubble management

Chapter coordinators: **Tonia Grundy** (Qld DPI) and **Sharna Holman** (Qld DPI & CottonInfo)

Acknowledgements: **Linda Smith**, **Linda Scheikowski** and **Dinesh Kafle**.

Once the lint has been harvested, the pest management focus turns to stopping cotton regrowth, managing the cotton stubble/residues, and preventing carry-over of pests between seasons. Some post-harvest management strategies are legal requirements of Technology User Agreement (TUA) contracts or specific recommendations for avoiding pesticide resistance.

After harvest, the cotton plant is usually still alive, capable of regrowth, and will become a ratoon plant if sufficient moisture is available. Ratoon cotton can support additional pest generations, adversely impacting resistance management strategies, so preventing post-harvest regrowth is essential.

Ensure complete crop destruction and manage plant residues

Successful crop destruction is the first step in preparing a field for the next crop, as well as fulfilling a core requirement of the Bollgard 3 Resistance Management Plan (RMP).

Ratoon cotton (regrown from leftover root stock) and volunteer cotton plants (cotton that has established unintentionally) need to be removed from all fields irrespective of what is subsequently being grown. These plants 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. Watch the CottonInfo video on effective end of season crop destruction youtu.be/rO-JAX7s7jg

Root cut and mulch is the industry-preferred option for crop destruction – mulching the stalk above ground and cutting the root below cotyledon height (at least two to five centimetres below the top of the bed) with a set of powered discs on the back of the mulcher. The root system that remains has no vegetative buds and therefore cannot reshoot and become a ratoon plant. Depending on the depth of the root cut, some preliminary control of pupae can also be achieved.

Root cutting controls plants within or near the plant line only, and while using GPS systems can improve planting accuracy and minimise the number of ratoon escapes, a secondary control step (such as herbicide or additional tillage) will still be needed to control volunteers that have germinated in the interrow.

Mulched crop residues are incorporated into the soil to improve the amount and quality of organic matter and avoid issues in future cultivation/planting operations. Cotton stalks are woody and large pieces can block cultivation equipment or irrigation channels. The root cut and mulch method retains the existing hill or bed in situ, but the ability to work the mulched stubble can be variable depending upon the soil type and moisture conditions. Stubble is particularly difficult to incorporate in light, dry soils and tends to 'float' to the top of the hill. Further trash management passes/implements may be needed in some situations.

Dryland cotton…

- Volunteer cotton can present a weed management challenge in some rotation crops.
- Consider the use of herbicides for control of volunteers and ratoon cotton plants in fallow, to conserve soil moisture.

Best practice…

- Ensure complete crop destruction.
- Manage crop residues to minimise disease risk.
- Manage weeds and cotton volunteers/ratoons to prevent green bridges and reduce resistance risks.
- Pupae bust as recommended in the RMP and/or resistance management strategies.
- Consider incorporating suitable rotations or cover crops into your farming system.
- Where possible, perform all in-field operations (including picking) when soil is dry to reduce compaction risk.

The top photo shows how a field's trash content should look. The large piles of trash left on the field in the bottom photo can cause blockages and other management issues.

Another technique used in regions where pupae busting is a requirement of growing Bollgard is to mulch the stubble then remove the stub plant with tillage. Full disturbance of the profile to a depth of about 10 cm is required to pupae-bust effectively.

Other (not generally recommended) approaches:

- Pull, rake and burn (where plants are uprooted using a rubber tyre stalk puller, raked into windrows and burnt) was widely used in the 1990s for cotton crop residue management, but is now limited to fields that need laser levelling, as it removes or shifts nutrients and organic matter out of the plant line, potentially spreads pathogens, and can create field access issues if trash burns are delayed.
- Standard slashing or mulching without stalk cutting or removal creates ratoon issues and should only be considered if going into a fallow or cereal rotation crop where broadleaf herbicides can be used to kill the ratoon cotton that emerges from the standing stalk.
- Ploughing (or off-set discs) incorporates standing stubble and provides the opportunity to include a pupae bust in a single pass, but the roughly cut stalks do not break down quickly, and soil moisture content must be low to minimise smearing and compaction. This methods destroys hills/beds, and the re-hilling process risks moving the new plant line into a previous furrow, potentially creating compaction issues.

Where possible, conduct all machinery and tillage operations at an appropriate moisture level for the soil type to avoid compaction. Detailed information on soils and their management is available in SOILpak (available from the CottonInfo website).

Retaining and returning cotton stubble to the soil improves overall soil health by increasing soil organic matter, improving water infiltration and enhancing nutrient cycling. The incorporated stubble provides a source of energy for microbial organisms, that in turn help with stubble breakdown supplying nutrients back to the crop.

Some cotton pathogens are saprophytes (feed and grow on dead organic material) and can survive and even multiply in the residues of cotton and other crops. Correct diagnosis of the pathogens in your field is essential, as crop residue management recommendations to reduce pathogen inoculum vary with the species present.

While weedy fallows and high stubble loads usually promote soil pests, stubble and crop residues can also increase the diversity and abundance of other soil fauna, including beneficial species. Keep good records of soil pest incidence and stubble loads from previous seasons to inform your management decisions.

Prevent pest carryover between crops

Prevent late season weeds from setting seed

Some weeds will be present 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 chance of these weeds setting seed, it is important to destroy crop residues and control weeds as soon after picking as possible. Watch the CottonInfo video on late season weeds youtu.be/4gqLpEu5uTE

Manage crop residues to reduce pathogen inoculum levels

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, retain slashed/mulched residues on the surface for at least one month prior to incorporation (ideally until the stubble bleaches from pale brown to grey), to disinfect the stalks through UV light exposure. For verticillium wilt and other diseases, incorporate crop residues as soon as possible after harvest.

Avoid green bridges

Removing alternative hosts, especially ratoon or volunteer cotton, will help:

1. reduce the risk of harbouring the less mobile insect species (such as aphids, mites and mealybug) between seasons
2. prevent build-up of pathogen inoculum, reducing disease persistence between seasons
3. minimise the spread of insect-vectored diseases.

Having a host-free period is particularly important for cotton bunchy top as it cannot survive outside the living host or aphid vector.

Many cotton pathogens can also infect other crops and common weeds found in cotton growing areas (see the 'Weeds as hosts of cotton pathogens' table in the *Cotton Pest Management Guide*. Note that some alternative host species may not display any obvious signs of disease.

Continue to monitor for and manage weeds (including crop volunteers and ratoons) throughout the year. Check both field and non-field areas (roadsides, fence lines, channels, and around buildings). Use the off-season to rotate herbicide modes of action and explore alternate mechanical means of weed control.

Cotton trash after 140 days solarisation. The colour of trash can be used to determine when to incorporate fusarium infested fields. Scott Brimblecombe

TABLE 23.1 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	Reniform nematode
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.	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.	Anything that moves contaminated soil.
Survival	N/A	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 (living or dead/dying plant tissue).	Volunteer cotton and other living crop/weed hosts. Repeated use of non-hosts in rotations may decrease incidence.	Can survive in soil organic matter or the rhizosphere of some crops/weeds without causing symptoms.	Can survive in soil, volunteer cotton and other living crop/weed hosts.	Survives in the soil for many years. May also survive in infected crop residues.	Can survive at least two years without a host in dry soil.
Canola	Increases risk	Host of *Rhizoctonia* and *Pythium* species.	Non-host	Decreases risk	Non-host; may be a biofumigant when incorporated	Crop residues increase risk – incorporate infected residues early	Increases risk	Increases risk	Non-host
Chickpea	Avoid planting into freshly incorporated, unweathered residues	Host of *Pythium sp.* and *Rhizoctonia solani*. Incorporate infected residues early.	Non-host	Decreases risk	Increases risk	Crop residues increase risk – incorporate infected residues early	May increase risk*	Increases risk	Increases risk
Cotton (i.e. back-to-back)	Decreases risk	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.	Higher risk in fields with a history of Verticillium; overall risk depends on inoculum level and environmental conditions	Increases risk	Increases risk (no resistant varieties available)
Faba bean	Avoid planting into freshly incorporated, unweathered residues	Host of *Pythium sp.*	Non-host	Decreases risk	Increases risk	Crop residues increase risk – incorporate infected residues early	May increase risk*	Increases risk	Decreases risk when resistant varieties are grown
Long fallow# (see note below)	None	Decreases risk if previous 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
Maize/corn	Decreases risk	Host of *Pythium sp.* and *Rhizoctonia solani*	Non-host	Decreases risk	Non-host	Crop residues increase risk – incorporate infected residues early	Reported internationally as a potential asymptomatic host. Research in Australia suggests it reduces risk	Non-host	Non-host

Mungbean	Avoid planting into freshly incorporated, unweathered residues	Host of *Rhizoctonia solani*	Non-host	Decreases risk	Increases risk	Crop residues increase risk – incorporate infected residues early	May increase risk*	Increases risk	Increases risk
Pigeon pea	Avoid planting into freshly incorporated, unweathered residues	Host of *Pythium sp.*	Non-host	Decreases risk	Increases risk	Crop residues increase risk – incorporate infected residues early	May increase risk*	Increases risk	Increases risk
Safflower	Avoid planting into freshly incorporated, unweathered residues	Host of *Pythium ultimum*	May increase – listed as a host in Qld and WA	Decreases risk	Non-host	Crop residues increase risk – incorporate infected residues early	Increases risk	Increases risk	Non-host
Sorghum	Increases risk	Host of *Rhizoctonia solani*	Non-host	Decreases risk	Non-host	Crop residues increase risk – incorporate infected residues early	Non-host	Non-host	Non-host
Soybean	Decreases risk	Host of *Pythium ultimum*. Only some strains of *Rhizoctonia* solani infect soybean. Incorporate infected residues early.	Non-host	Decreases risk	Increases risk	Crop residues increase risk – incorporate infected residues early	May increase risk*	Increases risk	Decreases risk when resistant varieties are grown
Sunflower	Increases risk	Host of *Pythium sp.* and *Rhizoctonia solani.*	Non-host	Non-host	Non-host	Crop residues increase risk – incorporate infected residues early	Choose resistant varieties	Increases risk	Increases risk (unless resistant varieties become available)
Vetch	Avoid planting into freshly incorporated, unweathered residues	Host of *Pythium sp.*	Non-host	Decreases risk	Non-host	Crop residues increase risk – incorporate infected residues early	Asymptomatic host that may increase risk	Increases risk	Increases risk
Winter cereals	Avoid planting into freshly incorporated, unweathered residues	All major grain crops in Australia can host *Pythium* species. For hosts of *Rhizoctonia solani*: oats are most tolerant followed by triticale, wheat and barley	Non-host	Decreases risk	Non-host	Crop residues increase risk – incorporate infected residues early	May increase risk*	Non-host	Non-host

RED = Potential disadvantage. GREEN = Generally positive interaction. YELLOW = Cautionary note (reported in international literature but not yet confirmed in Australian climates and conditions; hosts in glasshouse trials when tested against Australian Verticillium isolates indicated with *).
#Note that long fallows also reduce overall microbial diversity and so may not actually decrease the disease risk in the following season. Research suggests a suitable rotation crop is more beneficial than long fallow.

Out of season cotton is a preferred green bridge for cotton pests and should be controlled as part of an integrated weed management strategy. Ratoon and volunteer cotton can:

- Extend the amount of time *Helicoverpa* spp. are exposed to Bt proteins outside the growing season, imposing additional resistance risks.
- Provide the ideal host plant for insect and disease survival during winter, increasing the risk of earlier infestations in the subsequent crop (around 40% of volunteer cotton on roadsides in cotton growing regions harbours cotton bunchy top).
- Provide a source for soil disease inoculum build-up.
- Pose a biosecurity risk as a potential point of establishment for exotic pests.

Reducing the amount of lint and viable cotton seeds remaining in the field at the end of the season can help prevent the establishment of cotton volunteers. Focus on achieving a clean pick and clean up after module spillages.

The two most common methods of controlling volunteer cotton are cultivation and herbicides. Planning in-field volunteer management is particularly important where back-to-back cotton is grown. Also monitor for and control volunteers located outside of the field, including roadsides, fence lines, channels, culverts, and 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. Several herbicide options (including for optical booms) are available for the control of large volunteer or ratoon cotton amongst stubble or in fallow, enabling soil moisture conservation. Refer to the Comet 400® label for further information and always follow label directions.

Manage diapausing pupae

Pupae destruction is a key recommendation for cotton crops under the Insecticide Resistance Management Strategy (IRMS). It is also a legal requirement in the TUA for Bt crops with a high risk of overwintering populations. Bollgard 3 provides growers with more flexible pupae busting requirements depending on crop location and timing of defoliation. For further details, refer to the Bollgard 3 RMP for your region bollgard3.com.au.

Utilise crop rotations and cover crops

Successive crops of cotton (or other susceptible hosts) can contribute to increased 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 23.1 for potential disease implications 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. However, using legumes as green manure crops may pose an increased disease risk. Only crops that are non-hosts to cotton diseases should be used in rotation with cotton.

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

Rotation crops also provide an opportunity to introduce a range of different weed management 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 the *Healthy soils* chapter and the *Preventing pest problems* and *Managing pests in-crop* chapters.)

The cotton rotation finder can assist with developing a rotation strategy cottoninfo.com.au/cotton-rotation-tool.

USEFUL RESOURCES:

The Cotton Pest Management guide is updated annually and includes further information about volunteer and ratoon control as well as the Bollgard 3 resistance management plan.
cottoninfo.com.au/publications/cotton-pest-management-guide

The CottonInfo YouTube channel (youtube.com/cottoninfoaust**) contains many videos on post-harvest topics.**

CottonInfo cottoninfo.com.au

myBMP mybmp.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 tailored to your situation see your accountant or agribusiness manager.

It has been said that 'farm profits are made in the office, not in the paddock'. This chapter summarises some of the key business aspects of growing cotton including budgeting, marketing, finance and insurance, and 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.

Fixed costs are usually discussed at a business level, as they are costs that must be met regardless of enterprise size or crop mix. 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 impact on expected profitability.

A pre-season gross margin budget can assist with deciding 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 24.1 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: cottoninfo.com.au/publications/australian-cotton-industry-gross-margin-budgets

Best practice...

- Prepare your own gross margin budget using published budgets as a guide.
- Understand your production and price risk. Test your budgets for sensitivity to reasonable changes in yield, price, and input costs.
- Manage your production and price risk by understanding your available marketing options and choosing a merchant and product that suits your particular needs.

RD&E in focus

Ag Econ, with support from CRDC, undertakes economic analysis for the cotton industry to support improved business decisions. Recent and upcoming analysis includes:

- Updating the CottonInfo Gross Margins every two years. These are available on the CottonInfo website. Keep an eye out for the next update in August 2025.
- Developing fact sheets and case studies including:
  - Centre pivot system capacity: how it's calculated & why it's important
  - Economics of Irrigation Management
  - Variable yield maps: making the most of data
  - Consultant Case Study: Southern Irrigation Development
  - Grower Case Study: Irrigation Conversion at "Lynbrae"
  - Grower Case Study: Irrigation Conversion at "Bellevue"
- plus other mini-analyses published via the CottonInfo e-news - make sure you're subscribed!

You can access all documents via **cottoninfo.com.au/publications-and-media**

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 seasonal conditions, but also by the individual farm or field characteristics such as soil type, crop rotation and management decisions.

Enterprise gross margins are sensitive to variations in yield, price, and input 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, price and input costs have on the GM. The industry GM budgets include sensitivity analysis for key GM variables. Cotton pricing is discussed in detail below, along with price and production risks.

Create gross margins using recent crops as an indication of operations and the most recent published budgets as a guide for costs. If new to cotton, your agronomist can help outline expected operations for the season.

Dryland cotton...

- A gross margin budget is essential for dryland crops.
- These budgets do not take risk into account, so 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.

TABLE 24.1 Example gross margin budgets for Bollgard® 3, Roundup Ready Flex®.

Yield	Irrigated 12 bales/ha	Dryland (double skip) 3.2 bales/ha
Income	$/ha	$/ha
Bales lint/ha @ $610/bale	7320	1952
Cotton seed @ $100/bale	1200	320
(Combined lint and seed price $695)		
Less lint quality discount	0	0
TOTAL INCOME (A)	8520	2272
Variable costs	$/ha	$/ha
Fallow management	61	59
Pre-plant operations	47	0
Nutrition	820	45
Planting & in-crop farming	132	66
Irrigation 8.8 ML (C)	568	0
Insurance	304	88
Crop protection, application & licence fee	876	347
Defoliation	156	53
Picking, cartage & ginning	1317	443
Farming: Post-crop	118	78
TOTAL VARIABLE COSTS (B)	4399	1179
GROSS MARGIN/HA (=A-B)	4121	1093
GROSS MARGIN/ML (=(A-B)/C)	468	NA

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, and thus incorporates production and price risks. Each marketing method balances production and price risks differently, so growers should seek advice from an independent broker or 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 (or planting) 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 regarding both the area to be harvested (due to seasonal conditions) and the yield that will be achieved. Production 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 they may be obligated to fill the contract at market rates, which could result in a financial loss to the grower.

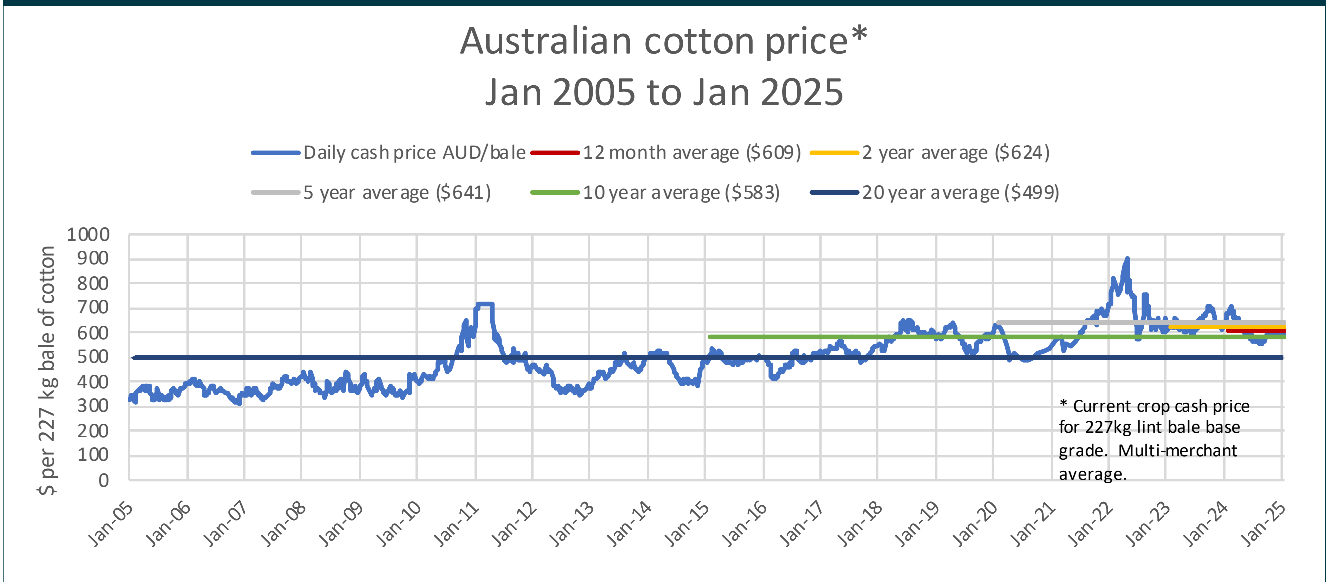
Production risk is a particularly important consideration for dryland growers. Soil moisture, seasonal climate outlook and crop price at planting are the main factors for farmers who dryland crop. The *Climate for cotton growing* chapter provides a comprehensive overview of climate indicators. Given 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 that 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 24.1) 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 used. A brief overview of crop finance options can be found later in this chapter.

Industry resources are available to manage production risk including CSD member resources and the Bayer Cotton Choices Program®. These programs can make the decision to plant with limited water or dryland production 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

FIGURE 24.1 Australian cotton price AUD/bale. The lint price remains above long-term averages, supported by positive fundamentals.



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).

Engage a broker or 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 pre-sold and the grower is exposed to a potential decrease in the spot 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.

1. ICE Cotton Futures.
2. The basis.
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 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

$$\text{AUD cash price per bale} = \frac{(\text{USD\$/lb Cotton Futures} + \text{USD\$/lb Basis}) \times 500\,\text{lbs}}{\text{AUD/USD exchange rate}}$$

Converts price from USD/bale to AUD/bale

$$\text{An example of pricing elements for AU\$600/bale} = \frac{(0.81 + 0.03) \times 500}{0.70}$$

All three price elements change daily. The price of cotton in AUD terms is therefore subject to daily volatility. The major merchants in Australia communicate their prices via email and SMS, which you can subscribe to. Refer to Figure 24.1 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, allowing 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 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 24.1). This is a forward contract for delivery of a fixed number of bales of a given crop year (e.g. 2023–24) 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 a financial penalty if a grower is unable to deliver the specified number of bales in the correct delivery period.

USD fixed cash price 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 the AUD is going to weaken against the USD.

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 also affect your ability to deliver in contracted months.

Basis on-call 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. This option is mainly advantageous if the grower thinks 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 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, with potential (but limited) upside benefit. 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 are where the grower commits a particular production area, 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 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 come with fixed payment timings and percentages (e.g. 70% July, 10% September, 20% 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 and 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 produced in the ginning process of one bale, and depending on variety, this varies between 220–300 kg seed/bale. Currently, most gins work on a yield between 240–260 kg seed/bale.

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. $640/t of seed), and as little as $40/bale (approx. $160/t). A price closer to $90/bale (approx. $360/t) has been more common in recent years. When seed is priced at the same level as the cost of ginning (approx. $72/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'. This means the difference between the ginning cost/bale and the seed price/bale is either payable to the grower, or paid by the grower. Talk to your preferred ginning organisation about current cotton seed pricing.

For further information on marketing your cotton, talk to an independent broker or a merchant. You can also find comprehensive marketing notes at the Australian Cotton Shippers Association website:
austcottonshippers.com.au/downloads/Grower_Marketing_Risk_Handbook.pdf

Want more advice? Independent brokers have in-depth market understanding and closely monitor 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 capacity 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.
- 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 tailored advice on how these measurements impact your individual business financial assessment.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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, who may require 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 distribution channels:

- Directly with the insurer or via their agents.
- Indirectly through 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 will compare those products and make more meaningful recommendations to their clients. Agents only access a single insurer and the products they provide. Seek expert advice in determining what insurance products you require and how they will respond in the event of a loss.

TABLE 25.1 Types of losses vs timing.

Timing of the loss	Types of yield losses	
	Partial losses	Total losses
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
Losses 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

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 financial requirements.

The policies provide cover for yield losses as a direct consequence of hail damage and can also include cover for various quality-related downgrades. Table 25.1 highlights how most policies will respond to both partial and total yield losses at different times of the season.

In the event of a hail loss, a specialist agricultural adjuster will be appointed to quantify any yield loss 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 will then be indemnified based on the grower's specific coverage structure.

Today's insurance policies calculate losses in a similar way, but growers have the flexibility to customise their coverage. They can choose their expected yields, bale prices, deductible amounts, extra options, and payment terms. These choices will affect the premium rates and the overall premium they will pay. Additionally, where the farm is located plays a big role in determining the cost. Farms in regions that experience higher frequency and severity of hail, will attract higher premium rates than those in places with less frequent or severe hail.

When comparing products, you should seek specialist advice from your preferred crop insurance specialist.

Other risk tools

Parametric insurance

A parametric insurance policy responds based on the outcome of an index or parameter. Parametrics are utilised to cover the financial impact of many natural perils including: rainfall – too much or too little; temperature – too high or too low; wind speed; cyclone, earthquake, 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 traditional insurance is either too expensive or unavailable. 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 designated recording station regardless of whether a loss is actually incurred on-farm. This creates what is known as basis risk – which is the risk that the trigger is met at the 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 parametric insurance policies are slowly being adopted to cover weather related risks, they require careful consideration to ensure all the cover variables are accurately structured to ensure the cover will reflect an on farm loss.

People management

Acknowledgements: **Sonja O'Meara**, **Rachel Holloway**, **Paul Sloman** and **Wayne Schwalbach**

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. There are currently 11 minimum employment standards that an employer must abide by.

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 the appropriate category of award wages. Most cotton farm employees will be employed under the Private Clerks Award (for office employees) or the Pastoral Award. 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).

Legal requirements

Annualised salary – A number of years ago 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.

Best practice...

- Ensure you are aware of the correct Award classification and wage required for each employee.
- Remember that the award wage increases annually.
- 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.

RD&E in focus

The CRDC-funded action research project *SHIFT: Delivering best practice for management of future skills* was funded from 2021-2024 and supported cotton growing enterprises to identify and implement strategies, tools and resources to better attract, develop and retain their workforce. These resources cover a wide range of non-technical skills for people management, including leadership, advising new entrants, and the importance of clear communication. Find a full list of topics, content and resources at the end of this chapter.

- If an accidental 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 within a week 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.

For the Pastoral Award an employer can roster an employee for an average of 38 hours per week over a period of 4 weeks (not exceeding 152 hours). Therefore if rostered correctly an employer can roster an employee over a 4 week period without incurring overtime until the employee works past the 152 hours, Sunday to Saturday.

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.**
- **From 1 January 2025 intentional wages underpayments have been criminalised in all States.**

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, they will be exposed to risks of underpayment, attract penalties 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: fwc.gov.au

Fair Work Ombudsman: fwo.gov.au

***my*BMP – Human Resources and Work Health and Safety module:** mybmp.com.au

Work Health & 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.

WHS Legislation

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.
- Safe use of plant, structures and substances.
- Facilities for the welfare of workers are adequate (e.g. toilets, fresh drinking water, first aid).
- Inductions for all new staff and in the correct use of new machinery.
- 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.
- 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.

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.

The definition of a **'worker'** includes any person who carries out work for a PCBU, such 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.

Psychosocial hazards

A psychosocial hazard or work stressor is any occupational hazard related to the way work is designed, organised and managed, as well as the economic and social contexts of work.

A psychosocial hazard doesn't need to arise from a physical substance, object or hazardous energy, and it is the responsibility of the PCBU to eliminate psychosocial risks. If that is not reasonably practicable, they must minimise them reasonably.

For more information on common types of psychosocial hazards visit safeworkaustralia.gov.au/safety-topic/managing-health-and-safety/mental-health/psychosocial-hazards

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 not just 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 – the absolute worst scenario. 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 worker's 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: safeworkaustralia.gov.au
AgSkilled NSW – WHS safety training agskilled.org.au
Qld WHS Law: worksafe.qld.gov.au
NSW WHS Law: safework.nsw.gov.au
SmartAg Qld: qff.org.au/projects/smartag
SafeWork NSW has a small business safety rebate program in place. For further information and eligibility: www.safework.nsw.gov.au/advice-andresources/rebate-programs/small-business-rebates
Farm safe: farmsafe.org.au
***my*BMP – Human Resources and Work Health and Safety module:** mybmp.com.au

"If we consider attraction and retention as the way we know we have a 'winning' employer of choice status, ensuring we have the skills, structures and are taking actions focused on effectively addressing each of the pillars of SHIFT is how we master our game"

Nicole McDonald, SHIFT researcher. .

Watch Nicole's presentation on SHIFT at the 2024 Australian Cotton Conference:
youtu.be/JvtpKT_bC1c

TABLE 26 SHIFT Resources by Nicole McDonald, Jo Eady, Chantal Corish and Amy Cosby
(with thanks and recognition to Australian cotton growers who were part of the co-design process).

SHIFT
Our Enterprise. Our People.

Skills Area	Guide Title
Leadership Behind the Farm Gate	• Leading people is not the same as growing crops • Top up your leadership traits • What's your leadership style
New Entrants	• Set yourself and others up for success in the workplace • Help your team to shake the shame • How to receive feedback
Clear communication	• How to give effective instructions • How to give effective feedback • How to plan for purposeful conversations
Team Effectiveness	• Support your team to grow technical and non-technical skills • The art of supporting team members to be accountable • Effective delegation builds capable teams • How to motivate your team to move mountains
Enterprise	• How to build your enterprise value proposition • How to create an internal enterprise communication plan • How to set up for a smooth entry to your enterprise
Guides for Entering New Roles	• The Australian Cotton Enterprise Non-Technical Guide for New Entrants • The Australian Cotton Enterprise Non-Technical Guide for Team Leaders
Podcast Episodes	• SHIFT Episode 1: Leadership Behind the Farm Gate • SHIFT Episode 2: Supporting New Entrants

You can access links to all Guides via the CottonInfo website here: cottoninfo.com.au/blog/shift-resources

Glossary

Adjuvant Any substance added to a spray mixture to enhance its performance or overcome an inhibiting factor, including wetting agents, 'stickers', thickeners and buffering agents. Always check the label for compatibility with the pesticide(s), formulation and application method being used.

Allelopathy Biological phenomenon where one plant inhibits the growth of another.

Alluvium Sediment that has been deposited by flowing water, such as a flood plain.

AMF Arbuscular mycorrhizal fungi (formerly known as VAM) form a partnership with most crop plants, including cotton. AMF colonise the roots of the plant and act as an extension of the root system, transferring nutrients, particularly nitrogen, phosphorus and zinc from the soil to the plant. In return the plant provides sugars generated through photosynthesis.

Area Wide Management (AWM) Growers working together in a region to manage pest populations as well as weed control, biosecurity and disease discussions.

At-planting insecticide Insecticide applied with the seed during planting as a granule or as a spray into the seed furrow.

Beneficials Usually used to describe natural enemies (predators, parasitoids or pathogens of crop pests), but also includes other organisms with a benefical impact on the cropping system, such as pollinators, or soil fauna that increase stubble breakdown or improve soil health.

Biological insecticides Insecticides based on living entomopathogenic (infecting insects) organisms, usually bacteria, fungi or viruses, or containing entomopathogenic products from such organisms e.g. Gemstar, Vivus and Dipel.

Bollgard® 3 is a third-generation insect control trait technology that provides three different modes of action to target Helicoverpa species – the main pest affecting cotton grown in Australia. Bollgard 3 contains three proteins, Cry1Ac, Cry2AB and Vip3A, each 'killing' larvae in a different way.

Broad spectrum insecticide Insecticides that kill a wide range of insects, including both pest and beneficial species. Their use, particularly early season, reduces numbers of beneficials (predators and parasitoids) leading further pest outbeaks.

Bt Protein produced by *Bacillus thuringiensis* bacteria that is toxic to particular insect species.

Buffer zone Self-imposed unsprayed area when the wind is blowing towards a sensitive area to minimise risk of spray drift damage / residues beyond the buffer.

Cold shock Delays in cotton growth and development when the daily minimum temperatures fall below 11°C, 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 Term 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 e.g. Round-up Ready).

Cotton bunchy top disease (CBT) A virus spread by the cotton aphid (*Aphis gossypii*).

Cotyledons Paired first leaves that emerge from the soil when the seed germinates.

Crop compensation Cotton's capacity to 'catch-up' after damage without affecting yield or maturity.

Crop maturity Usually occurs when 60–65% of bolls are mature and open. Cotton bolls are mature when their fibre is well developed, seeds are firm and seed coats are turning brown.

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) and production of new fruit ceases.

Damage threshold Level of damage from which the crop will not recover completely, leading to economic loss of yield or delay in maturity. Usually considered in conjunction with pest thresholds to account for both pest numbers and plant growth. For instance a plant with 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 crop's root zone. It can help flush salts from the soil, but excess deep drainage wastes water and nutrients.

Defoliation Removal of leaves from the cotton plant in preparation for harvest by artificially enhancing the natural process of senescence and abscission with the use of specific chemicals.

Denitrification Biological process encouraged by high soil temperatures that occurs when there is waterlogging, such as during and after flood irrigation and/or heavy rainfall. Plant available N (nitrate) is converted to nitrogen gases which are lost from the system.

Desiccant Harvest aid chemical that damages the leaf membrane causing loss of leaf moisture, producing a desiccated leaf.

Doffer Picker component that unwinds and removes cotton from the spindle so that it can be transported to the chamber in an air stream.

Double knock Sequential application of two weed control options with different modes of action in a short time-frame.

Double skip Row configuration used in dryland/semi-irrigated situations to conserve soil moisture.

Earliness A term that describes an earlier crop maturity that maybe desirable to achieve improved yield, quality, and logistical outcomes.

Efficacy Effectiveness of a product against pests.

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

First true leaf First seedling leaf after the cotyledons. It has the appearance and arrangement of a normal cotton leaf.

Flaring (of pests) Pest population increase following a pesticide application intended to control another species. Usually occurs in species with very fast life cycles (mites, aphids, mealybugs or whitefly), and following the use of broader spectrum insecticides that impact natural enemy populations.

Flush High volume irrigation carried out in minimal time.

Fly cotton Fibres (single or in small bunches) that fly out into the atmosphere during processing. 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). They have several nodes in a zig-zag growth habit, each with a square and subtending leaf.

Fruit load The number of fruit (squares or bolls) on a cotton plant.

Gross Production Water Use Index (GPWUI) Gross amount of lint produced per unit volume of total water input (b/ML), including irrigation, rainfall and total soil moisture used (where the rainfall component can comprise either total rainfall or effective rainfall).

Guess rows A narrow or wider row created where two ground engaged implements meet in their respective paths, as a consequence a narrow or wider row in relation the rest of the implement may arise. This may be problematic with subsequent operations such as cultivation.

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 from the moth genus *Helicoverpa*. In Australia there are two species, *Helicoverpa armigera* (cotton bollworm) and *Helicoverpa punctigera* (native budworm). Larvae of both species are major pests of cotton, capable of dramatically reducing yield.

Herbicide Resistance Management Strategy (HRMS) Tool for weed management in irrigated and dryland farming systems incorporating herbicide tolerant (HT) cotton, to delay glyphosate resistance.

Honeydew Sticky sugar-rich waste excreted by sap-feeding insects. It can interfere with photosynthesis, affect fibre quality and cause problems with fibre processing.

Hulls Outer coverings of cotton seeds, and the by-products of the dehulling necessary for cottonseed oil extraction. After removing the lint, the hulls are separated from the kernel by screening.

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

Hypocotyl Part of a plant embryo or seedling between the cotyledons and the radicle (the first root that emerges).

Indeterminate Plant species that are capable of continuing to grow after a period of stress.

Irrigation deficit Readily available water capacity.

In-furrow insecticide See at-planting insecticide.

Insecticide resistance An insect develops a mechanism for dealing with an insecticide, such as production of enzymes which break the insecticide down quickly before it kills the pest, and the insecticide no longer kills individuals that are resistant. Can lead to control failures when using that product or mode of action group on resistant populations.

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 uses knowledge of pest biology, behaviour and ecology to implement a range of tactics throughout the year, in an integrated way that suppresses and reduces insect pest populations. Conserving natural enemies is a key component of IPM.

Irrigation system efficiencies Comparison of water output to a water input at different points of the irrigation system of the farm as a whole, expressed as a percentage.

Irrigation Water Use Index (IWUI) Gross amount of lint produced per unit volume of irrigation water input (b/ML). Includes irrigation water used only and does NOT count rainfall or used soil moisture.

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 Residual herbicide used to control weeds during the growth of the cotton crop.

Last effective flower (LEF) Uppermost/youngest flower on the plant that will fully mature to a harvestable boll. LEF timing 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 Plants with large and heavy boll loads falling into each other towards the end of the season.

Main stem leaves Leaves that grow directly off the main stem.

Main stem node A point on the main stem from which a new leaf grows.These nodes may also produce fruiting or vegetative branches.

Mepiquat chloride Cotton growth regulator.

Micronaire Measurement of specific surface area based on the pressure difference 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 Number of main stem Nodes Above the first position Cracked Boll. An indication of plant maturity that can be used in making decisions about the final irrigation or defoliation

Natural enemies Organisms that kill or reduce the number and viability of crop pests. Predators, pathogens and parasitoids.

Natural mortality Expected death rate of insects in the field mainly due to climatic and other environmental factors including natural enemies.

NAWF Number of main stem Nodes Above the first position White Flower that is closest to the plant terminal.

Neps Entanglement of cotton 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.

Okra leaf type Cotton varieties with deeply lobed leaves 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 predicts cotton growth, yield and maturity given basic weather, agronomic and varietal data.

Parasitoid Insect that lays its eggs on or in another arthropod. The larvae develops within the host, killing it on emergence

Pathogen A 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.

Peak flowering Crop development period 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 to growing terminals (known as tipping out), leaves, roots, or fruit (including squares or bolls).

Pest resurgence Pest population increase following a pesticide application intended to reduce it. 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 Stalk that attaches the leaf to the stem.

Pima cotton Cotton species *Gossypium barbadense* with an extra long staple. It is limited to regions with long growing seasons and is not grown commercially in Australia. Normal (upland) cotton is of the species *Gossypium hirsutum*.

Pipe through the bank (PTB) A permanent structure installed through the head ditch to deliver water to the field. These may be small, such as a 75-90mm pipe, larger such as a larger diameter gated pipe or a concrete structure with doors.

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 (when 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, Mepiquat chloride and Pix).

Plant mapping Method used to record the fruiting dynamics of a cotton plant. Useful for understanding where the plant has held or is holding the most fruit and consider factors that may affect fruit load such as pest damage, water stress, heat.

Plant stand Number of established cotton plants per metre of row.

Plastic limit Water content level where soil starts to exhibit plastic behaviour.

Post-emergent knockdown herbicide 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 Production of bolls exceeds the supply of carbohydrates too early in the crop's development and production of new fruiting nodes stops, resulting in a less than ideal boll load.

Pre-plant knockdown herbicide A herbicide used to rapidly control weeds prior to planting.

Pupae Life stage where insects with markedly different juvenile stages morph into an adult. In *Helicoverpa* sp, pre-pupal caterpillars more to the soil and burrow below the surface, forming a brown capsule similar to a butterfly chrysalis.

Pupae busting Tillage to reduce the survival of the overwintering pupal stage of *Helicoverpa*. An important tool in reducing the proportion of the *Helicoverpa* population carrying insecticide resistance from one season to the next.

Radicle The embryonic root of the plant, usually the first part of the embryo to emerge from the seed when germinating.

Rank (growth) Very tall cotton crop (long internode lengths) with excessive vegetative plant structures. 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 Regrowth from left over root stock from a previous season (also known as 'stub' cotton). Control of unwanted cotton is an essential part of good integrated pest and disease management

Refuge A crop planted to generate significant numbers of susceptible moths that have not been exposed to the Bt proteins in Bt cotton. These moths will disperse into the local population where they may mate with any resistant moths emerging from Bt crops, delaying the development of resistance.

Resistance management plan (RMP) Proactive plan to mitigate the risks of resistance developing to any of the insecticidal proteins contained in Bt cotton. Compliance with the RMP is required under the terms of the Bt cotton Technology User Agreement.

Retention Proportion of fruiting sites on a plant that are present versus those that have been lost.

Secondary pests Pests that do not usually become a problem unless their natural enemies are impacted by insecticides. See also 'Flaring'.

Seed treatment Insecticide and/or 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 foliage feeders such as thrips or aphids.

Selection pressure The cumulative risk of using the same pesticide mode of action on a pest population. Each spray event will control susceptible individuals, leaving behind those that are resistant. More selection events means a greater 'pressure' or chance of selecting a resistant population.

Shedding Abortion and loss of squares and bolls from the cotton plant. Can be due to the plant balancing the supply and demand for the products of photosynthesis, and is strongly influenced by factors that negatively affect photosynthesis (such as cloudy weather), or in response to pest damage to the fruit. Young squares are more likely to be shed than more developed squares, flowers and bolls.

Short fibre Fibres shorter than 12.7 mm (0.5 inch).

Side-dressing Normally refers to adding in-crop fertiliser.

Single skip Row configuration used in dryland/semi-irrigated situations to conserve soil moisture.

Sodicity Measure of exchangeable sodium in relation to other exchangeable cations. A sodic soil contains sufficient exchangeable sodium to interfere with plant growth.

Soil water deficit Difference between a full soil moisture profile and the current soil moisture level.

Spring tickle Shallow cultivation to promote early germination of weeds prior to sowing that can then be controlled with a non-selective knockdown herbicide.

Square Cotton flower bud.

Squaring nodes Node at which a fruiting branch is produced.

Standing stubble Stalks from a crop that has been harvested or sprayed out and left to stand in the field.

Subtending leaves Leaves connected directly to a fruiting branch.

Terminal The growing tip of a cotton stem, particularly the main stem.

Tex 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 Loss of the terminal growing point, causing the plant to develop multiple stems.

Trap crop Crop planted to concentrate a pest population into a smaller less valuable area by providing a host that is more highly preferred and attractive than the crop you are aiming to protect.

True leaves Any leaf produced after the cotyledons.

Upland cotton *Gossypium hirsutum* is the species grown commercially in Australia.

Vegetative branches Similar in form to the main stem. 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 Growth of roots, stems and leaves as distinct from the reproductive growth of flowers and bolls.

Vegetative Growth Rate (VGR) A measurement of plant height and the number of nodes present, used to help with decisions regarding early use of season growth regulators.

Volunteer cotton Plants that have germinated, emerged and established unintentionally either in field or external to the field (roadsides, fencelines etc). 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 Seed is planted into dry soil and the first irrigation applied post planting. Has advantages in hot climates, because it cools the soil. In cool regions, decreases in soil temperature may be disadvantageous.

Water use efficiency (WUE) The generic term that describes the optimisation of production per megalitre of water.

Wetters 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

AAAA – Aerial Agricultural Association of Australia.
ACGA – Australian Cotton Ginners Association.
ACRI – Australian Cotton Research Institute, Narrabri.
ACSA – Australian Cotton Shippers Association.
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.
DAP – Di-ammonium phosphate.
EC – Electrical Conductivity.
ENSO – El Niño Southern Oscillation.
EM Survey – Electromagnetic Survey.
EPA – Environmental Protection Authority (NSW).
ESP – Exchangeable Sodium Percentage.
GFS –Global Forecast System
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 DPRD – New South Wales Department of Primary Industries and Regional Development.
OGTR – Office of the Gene Technology Regulator.
PAMP – Pesticide Application Management Plan.
PAWC – Plant available water capacity.
Qld DPI – Qld Department of Primary Industries.
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).
UniSQ – University of Southern Queensland.
ULV – Ultra Low Volume.
VGR – Vegetative Growth Rate.
WUE – Water Use Efficiency.

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MEET OUR TEAM

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CottonInfo HELPING YOU GROW

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