Australian Cotton Production Manual

The latest in cotton RD&E brought to you by

CRDC and CottonInfo

Australian Government
Cotton Research and Development Corporation

CottonInfo

Best Practice

Contents…

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Foreword

By **Annabel Twine** (CottonInfo) &
Ruth Redfern (CRDC/CottonInfo)

Welcome to the 2018 *Australian Cotton Production Manual*. This Manual is a key reference tool for best management practices in cotton, and is brought to you by the organisations responsible for cotton industry research, development and extension (RD&E): the Cotton Research and Development Corporation (CRDC) and CottonInfo.

CRDC invests in RD&E projects for the Australian cotton industry. A partnership between the Australian cotton industry and the Australian Government, CRDC exists to enhance the industry's performance. In 2018–19, CRDC will invest $24.3 million into approximately 300 RD&E projects with over 100 research partners on behalf of growers and the Government.

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

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

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

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

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

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

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

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

Remember, the CottonInfo team of regional extension officers, technical leads and *my*BMP experts are standing by to assist you with all your cotton information needs. You can find our contact details on the inside back cover of this Manual.

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

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

Australian Government
Cotton Research and Development Corporation

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The Australian cotton industry

By **Ruth Redfern** (CRDC/CottonInfo)

Acknowledgement Dr Michael Bange (CSIRO)

Cotton is the most used textile fibre in the world, renowned for its versatility, breathability and strength. It has been grown throughout the world for thousands of years, with more than 100 countries currently growing cotton. It was first brought to Australia with the First Fleet in 1788, however Australia's modern cotton industry began in the 1960s, largely in the Namoi Valley of NSW.

From these small beginnings, Australia's cotton industry is now a valuable agricultural export commodity. Cotton is currently the major agricultural crop grown in many rural and remote regions of Queensland (QLD) and New South Wales (NSW).

Australian cotton aims to be the highest yielding, finest, cleanest and greenest cotton in the world. On a global scale, Australia is not a large cotton producer – only around three per cent of the global crop is grown within Australia, by some 900 cotton growers on 1250 farms in QLD and NSW, with commercial trials in Victoria (VIC).

However, Australia is one of the largest exporters of cotton, with nearly 100 per cent of the national crop exported, generating an average of $1.9 billion in export revenue annually. The majority of Australian cotton goes into high quality yarns for use in the woven and knitted apparel sector in the Asia Pacific, with China accounting for 68 per cent of our export market. Australian cotton is often purchased for a premium, as it meets many of the spinners' quality and consistency requirements.

The industry generates significant wealth and provides an economic foundation to many regional and remote rural economies, employing up to 10,000 people across 152 communities.

A culture of innovation within the industry, supported by and embracing a well-organised research, development and extension (RD&E) framework, has been a major contributor to the industry's success. Improved practices driven by RD&E over the past 16 years have reduced insecticide use by more than 90 per cent and improved water-use efficiency by 40 per cent, while improvements in fertiliser and energy use are driving an ongoing reduction in nitrous oxide emissions.

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

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

In recent years, new cotton varieties, new farming technologies, and favourable weather and market conditions have facilitated an expansion in southern NSW cotton-growing regions, reaching as far south as the Victorian border. The industry has also historically invested in developing cotton production practices for northern Australia, in preparation for any future commercial developments.

Growing cotton through best management practices

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

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

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

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

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

Connecting growers with research

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

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

CottonInfo is designed to help growers to improve their productivity and profitability via best practice (working hand in hand with *my*BMP), and helping the industry as a whole become more responsive to emerging, or emergency, issues. The CottonInfo team of regional extension officers,

technical leads and *my*BMP experts can provide you with the latest information, driven by research, on a range of cotton topics – from soil health and plant nutrition to biosecurity and water use efficiency.

For more, visit the CottonInfo website: www.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, sustainable and valued by the community. It has roles in policy and grower representation, best management practices (through the delivery of the *my*BMP program), promotion and education, and biosecurity.

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

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

For more, visit the Cotton Australia website: www.cottonaustralia.com.au

CRDC: science underpinning the cotton industry's success

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

CRDC's investment in RD&E is funded through an industry levy, with matching Commonwealth contributions. Almost $350 million has been invested in over 2,500 cotton RD&E projects by growers and the Government over the past 28 years – delivering real impact for growers. Impact assessments in core areas of CRDC investment – optimising water use efficiency and crop nutrition RD&E – show that CRDC has delivered return on investments to growers of $8.29 to $1 and $5.40 to $1 in these areas respectively. In addition, the impact assessment of one specific CRDC-supported project – QDAF's Central Queensland early planting research – found that the research delivered a return on investment to growers of $17.10 to $1.

The 2018-19 year marks one of transition for CRDC, with the CRDC Strategic Plan 2018-23 coming into effect in July. CRDC's aim through this five-year Strategic Plan is to contribute to creating $2.0 billion in additional gross value of cotton production for the benefit of Australian cotton growers and the wider community. The plan has five key areas of focus: increasing productivity and profitability on Australian cotton farms; improving cotton farming sustainability and value chain competitiveness; building the adaptive capacity of the Australian cotton industry; strengthening partnerships and adoption; and driving RD&E impact.

To help achieve this, growers and the Government will co-invest $24.3 million into cotton RD&E during 2018-19, across some 300 projects and in collaboration with over 100 research partners.

For more, visit the CRDC website: www.crdc.com.au

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

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

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

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

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

For more, visit the CSD website: www.csd.net.au

The Australian cotton industry: working together

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

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

The cotton plant

By **Sandra Williams & Michael Bange** (CSIRO)

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

Cotton fibre forms on developing seeds inside a protective capsule called a boll. When seed is mature the boll ruptures and opens, allowing the fibre to dry and unfurl. A cotton plant's primary purpose is to produce seeds – in uncultivated cotton, the fibre is just a by-product which the plant produces to aid in seed dispersal.

When cotton is picked, both the seed and the attached fibre are harvested, compressed into modules and transported to a gin where the seeds and contaminants (leaf and twigs) are separated from the fibre. The fibre is then compressed into 227 kg bales, classed according to fibre quality, and exported around the world to textile mills. A by-product of the ginning process is cotton seed, which is also a valuable commodity.

Cotton plant physiology

The success of a cotton crop relies on climate and management. In developing a good management strategy it is important to understand how cotton develops and grows in order to ensure that the crops needs are met to maximise yields.

Perennial growth habits

In its native habitat as a perennial shrub, cotton can survive year after year. Therefore in situations where the cotton crop has inadequate resources (moisture, solar radiation, nutrients or carbohydrates) 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 (eg. cloudy weather), excessively hot weather, or limitations on root systems (eg. soil compaction and water stress), particularly during flowering, can lower yields.

But being a perennial, the cotton plant has an indeterminate growth habit. This means that the plant develops fruit over an extended period of time, so in many cases the plant can often compensate after a stress event (ie. pest attack, physiological shedding), by continuing to grow and produce new fruit.

Cotton development

As a cotton plant develops it follows a specific pattern. The rate at which it develops is largely determined by temperature. For the majority of the season and in most cotton growing regions early crop development is reliably predicted from seasonal temperature records by calculating Day Degrees (DD). DD describes the accumulation of heat units related to the daily maximum and minimum temperature that a crop experiences each day. Cool temperatures (<15°C average daily temperature) and excessively hot temperatures (>36°C) can delay crop development.

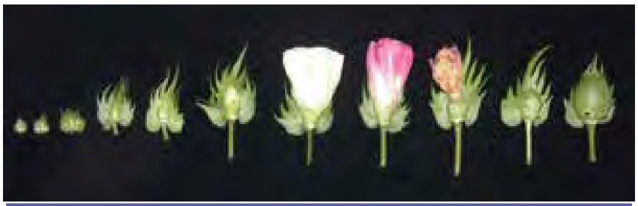
DD is described by the following equation:

DD = (Maximum Temp. –12 + Minimum Temp. –12) ÷ 2

When minimum temperatures are less than 12°C, DD are calculated as:

DD = (Maximum Temp. –12) ÷ 2

This accumulation of DD has been calibrated with specific targets for a range of cotton development events (Table 1). The term 'cold shock' refers to when minimum temperature <11°C, and cotton development is delayed. The DD requirement for first square and first flower increases by 5.2 every time a cold shock occurs.



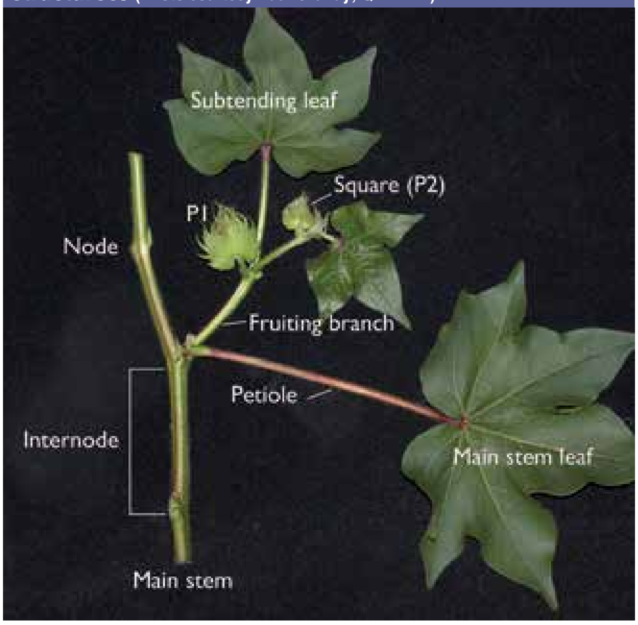
The cotton plant develops from a tiny flower bud or 'square' which continues to grow until it flowers. The flower desiccates after about 3 to 4 days, exposing a small green boll. This boll will continue to grow until it matures.
(Photo courtesy Paul Grundy, QLD DAF)

During cotton plant growth and development, two types of branches, vegetative (monopodial) and fruiting (sympodial) will arise. Having only one meristem (growing point), vegetative branches grow straight and look much like the main stem. Vegetative branches can also produce fruiting branches. The first fruiting branch will generally arise from nodes 6 or 7. With the potential to grow multiple meristems, this branch will grow in a zig-zag pattern and produce multiple fruiting positions. Figure 1 shows a fruiting branch that has formed above a main stem leaf. This branch has produced two fruiting structures along with their subtending leaves. The pattern of development and growth of the plant as a whole is described in Figure 2, where the development of new fruit occurs at the top of the plant on new fruiting branches as well as along older fruiting branches.

Cotton growth

Maintaining vigourous vegetative growth before flowering is important as it is these leaves, branches and roots that will support/supply the

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



future boll load. As a cotton plant develops, new leaves grow and expand, producing carbohydrates to allow new growth of leaves and the developing roots. Once reproductive structures begin to develop, vegetative and root growth will normally slow down as the plant begins to supply resources to the developing fruit. When there are excess resources to the needs of the developing fruit, the rate of vegetative and reproductive growth continues. Good crop management aims to keep the reproductive and vegetative growth in balance for as long as the season allows, timing cut-out to maximise the number of mature fruit (bolls) at harvest. The longer the period of fruit production before cut-out generally translates into higher yields. At cut-out the supply of carbohydrates, water and nutrients equals the amount needed by the developing bolls and new growth ceases.

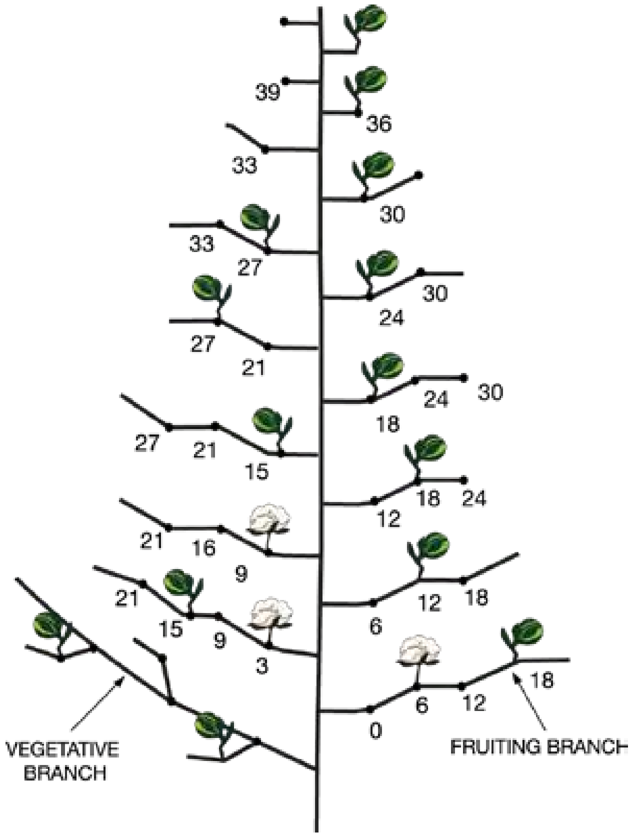
During crop growth certain growth parameters (eg. node production and fruit retention) should be measured and recorded to help with management decisions for maximum yield.

TABLE 1: Cotton growth stages with target DD.

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

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

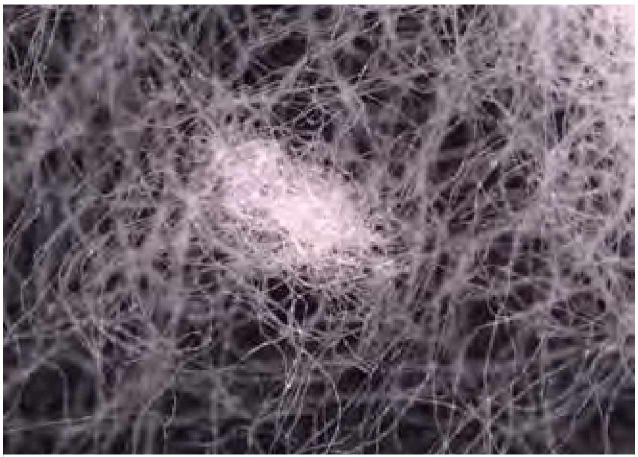
FIGURE 2: Rate of development of fruiting sites on a cotton plant, adapted from Oosterhuis 1990. Numbers represent days from appearance of first square to the production of a new fruiting site.



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 Managing crop growth Chapter for further information.

Approaching cut-out, bolls grow and they become larger sinks for carbohydrates, water and nutrients, leaving less available for new growth. NAWF (Nodes above white flower) is the number of nodes from the uppermost first position white flower to the terminal. This number will naturally decrease as the season progresses as growth slows from the terminal, and 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 = 4 or 5). More information on measuring NAWF and cut-out can be found in Preparing for harvest Chapter.

Just as flowering progresses in a pattern up the plant, so does the maturation and opening of bolls. Therefore measuring the number of nodes from the uppermost first position cracked boll (NACB – nodes above cracked boll) to the terminal is an effective way to determine crop maturity. Crops are considered mature and ready for defoliation decisions if they have reached 4 or 5 NACB. More information on measuring NACB can be found in 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). Obtained by means of a Wild Makroskop M420 microscope equipped with a Leica DFC290 digital camera.
(Photo courtesy of 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 2.

For more information the following resources and tools are available at www.cottoninfo.com.au and www.mybmp.com.au

- **FIBREpak**

TABLE 2: Cotton fibre development.

Fibre development	Notes
Initiation	This occurs just before flowering and at flowering. It is the initiation of fibre cells on the seed coat which can take up to 3 days. After the initial burst of fibre initiation a second set of fibre cells are initiated. These develop into the fuzz left behind on the seed after ginning.
Elongation	This is the rapid expansion and growth of the fibre cell's primary wall (partially controlled by internal water/turgor pressure). During this time the plant is sensitive to stress (water, nutrition and cool temperatures). Final fibre length is determined both by the length of this period and rate of fibre elongation.
Secondary wall thickening or fibre thickening	Is the formation of the secondary wall where cellulose (a product of photosynthesis) is laid down in layers inside the fibre cell's primary wall. The amount of cellulose deposited is affected by factors that affect photosynthesis. Due to fluctuations in photosynthesis on a daily basis, fibre growth rings are formed. They consist of 2 cellulose layers, a thicker layer that is formed during the day and a more porous layer that is laid down at night.
Maturation	This is where the fibre cells dry out and the fibre becomes a twisted ribbon-like structure. Mature fibre is easily detached from the fuzzy seed.

New growers' checklist

By **Cotton Australia**

New growers should have a thorough understanding of their responsibilities before making the decision to grow cotton. There is no single recipe for producing a profitable and sustainable cotton crop, but you will find that to be successful you must approach cotton production with long term planning and commitment. The good thing is that once you have made the choice to grow cotton, you will not be on your own.

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

Some questions for first time cotton growers

- **How committed are you to cotton?**
  To be successful you must apply good planning, thoroughness, timeliness and careful management to all your business and cotton production practices.
- **Who will harvest your crop?**
  Cotton picking machinery is expensive. Most new growers employ picking contractors to harvest the crop, but in good seasons, contractors can be in short supply.
- **Have you planned for cotton?**
  Among the critical factors in growing cotton are: fitting cotton into your crop rotation program, sound weed management, good soil management, integrated pest management strategies and effective stubble management after harvest. Review relevant chapters in this manual to help plan and inform your decisions.
- **How much of your time does cotton require?**
  Cotton is a relatively complex crop to grow, requiring specific agronomic knowledge and some farming techniques that you may not have used before. A cotton crop will require timely and constant attention from planting to picking through to post crop management.
- **How do you feel about using chemicals?**
  In the past decade, the Australian cotton industry has reduced its reliance on insecticides by more than 90 per cent, but some chemical usage may be required. You must be prepared to apply the industry's Best Management Practices for pesticide use.
- **Do you have sufficient water for cotton?**
  In the planning process, decisions about cropping and what area to sow can be made seasonally. Develop a water budget, based on expected water availability and likely crop requirements. Irrigators should also consider whether their system is adequate for timely and efficient irrigations, and can also meet peak water demand. If you are considering raingrown cotton, it is important to ensure that your soil's Plant Available Water Capacity (PAWC) and starting profile is sufficient and climate risks are considered.
- **How do you feel about complying with GM cotton regulations?**
  Growing a genetically modified cotton means that you must sign a contract with the owner of the technology. All commercial GM cotton technologies in Australia require compliance with resistance management plans that form part of the licence conditions. You should be aware of all the requirements of the resistance management plans and crop management plans for the respective products. Refer to the IPM and resistance chapter.
- **Have you talked to your neighbours?**
  It is your responsibility to ensure chemical drift is minimised on your farm and does not occur outside your property boundaries. Cotton is highly susceptible to phenoxy herbicides such as 2,4-D. The core best management practice for safe and responsible pesticide use is to develop a pesticide application management plan (PAMP) and establishing good communication can help ensure risks around pesticide application are managed. Letting your neighbours, local resellers, spray contractors and aerial operators know that you have cotton can help minimise risk, particularly in new or isolated areas. The web based application, CottonMap, enables cotton growers to map their fields so that people in the neighbouring areas can see that there is cotton in the vicinity (www.cottonmap.com.au). Don't forget apiarists as neighbours. BeeConnected can help identify nearby hives locations and facilitate communication between spray applicators and beekeepers (www.beeconnected.org.au). For more on minimising spray drift and maximising efficient spray application, refer to Chapter 18. For more information on developing a PAMP and taking an area-wide management approach, see Chapter 11.
- **How will you finance your crop and manage risks?**
  Cotton has high growing costs. Financing the crop is a major consideration, and it is recommended that you speak to a financial advisor. Hail presents a significant risk to summer crop production including cotton. It is important to discuss insurance coverage with an experienced specialist. Refer to Chapter 25.
- **Who will buy your cotton?**
  Cotton has unique marketing parameters based around fibre quality. Discuss premium and discount sheets as well as price with an experienced cotton merchant/marketer. For a list of Australian merchants, please see www.austcottonshippers.com.au
- **Is your current machinery adequate to grow cotton?**
  Can you adapt your existing machinery? Or will you need to engage the services of contractors? Minimise machinery acquisitions until you are sure about your long term commitment to cotton growing.
- **Have you contacted a consultant?**
  Seek the services of a cotton consultant early for management advice and crop planning, particularly if you have limited cotton agronomy experience. Speak to experienced local cotton farmers for advice on the selection of a reputable consultant, your local Cotton Grower Association is a good place to start or for more information, contact Crop Consultants Australia at www.cropconsultants.com.au
- **Have you contacted a spraying contractor?**
  Unless you plan to do all of your own spraying you should discuss your requirements with an aerial and/or ground rig operator before the season commences. Ensure you use a reputable and accredited spray contractor with adequate insurance coverage.
- **Have you contacted a farm inputs supplier?**
  You will need to source suppliers for farm inputs such as seed, fertiliser, herbicides, insecticides, growth regulators, defoliants and a licence to grow GM cotton Technology User Agreement (TUA).
- **How will you stay up to date?**
  The industry has a large number of resources to support cotton growers and it is important to stay informed on emerging issues and best practice.

Refer to the organisations on pages 4 to 6: The Australian Cotton Industry Chapter.

Planning

Photo courtesy Ruth Redfern

Climate for cotton growing

By **Jon Welsh** (CottonInfo/AgEcon)

Climate for cotton growing

Ideal conditions for cotton entail sunny warm days with maximum temperatures spanning 27°C–32°C with overnight minimums of 16–20°C. Daytime temperatures in excess of 32°C place additional stresses upon the plant which has to transpire more water to keep cool. Night time temperatures above 22°C will begin to impede respiration processes whilst temperatures below 11°C (cold shock) or above 36°C (hot shock) will result in a shock to the plant that temporarily arrests development (Constable and Shaw 1988). Extended periods of low solar radiation (eg. cloudy weather), too much or too little rain/water and excessively hot weather, particularly during flowering can impact on yields.

Planning

Being able to assess the climate risk for a coming season can help with decision making, particularly with regards to managing inputs. In terms of formulating a climatic risk assessment in the lead up to planting cotton there is a host of information available to growers on the current status of El-Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM).

El Niño-Southern oscillation index

ENSO refers to the sea surface temperature anomaly in the tropical Pacific Ocean. A strongly positive Niño 3.4 index is associated with El Niño (historically dry) events and a strongly negative index is associated with La Niña (historically wet) events. The Southern Oscillation Index 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 historically conditions are more favourable for rain.

Indian Ocean Dipole

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

Southern Annular Mode (SAM)

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

Best practice…

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

TABLE 1: Tips for planting.

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

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The Madden Julian Oscillation (MJO)

The MJO is a tropical disturbance that propagates eastward around the global tropics with a cycle on 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 quite 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.

Using General Circulation Models (GCMs) for planning

With the vast majority of information presented to users in the form of dynamic computer generated colour charts or models, it is useful to identify accuracy and inputs of these models. Three categories of model predictions exist:

- Weather outlooks. A zero-8 day prediction normally run on 12 hourly intervals.
- Multi-week (or sub-seasonal) predictions. This category is currently the focus area 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 once or twice weekly.
- Seasonal outlooks display rainfall and temperature guidance for the following 3 months. These models are refreshed by research agencies usually once a month. Accuracy levels are highest in winter and spring seasons. Statistical and ensemble predictions also compliment model outputs.

Moisture Manager surveys all model outputs and hindcast performance at critical periods throughout the year. Some tips for using seasonal GCM's for planning ahead for your next crop are shown in Table 1.

Figure 1 shows the skill of these individual models and their derived inputs. The accuracy of seasonal forecasts is gradually improving over time with technology and may add value to planning and budgeting decisions in farming businesses.

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

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

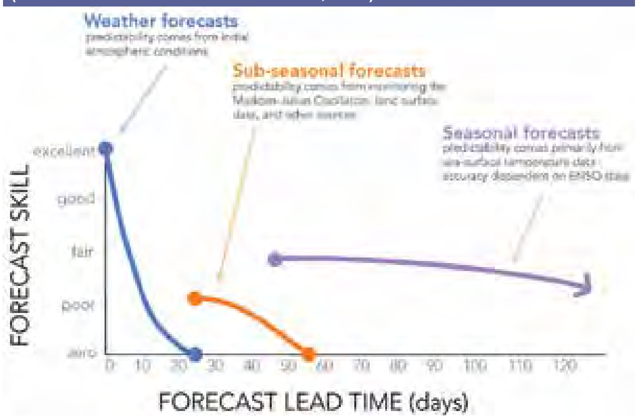


TABLE 2: Southern Annual Mode – Correlation strength with rainfall in cotton growing areas.

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

Correlations shown are calculated at the 95 per cent confidence interval. SAM correlations are Positive with rainfall. I.e. A positive SAM anomaly has a positive affect on rainfall.
Source: CottonInfo, BOM, CSIRO 2014.

TABLE 3: Tips for in crop.

Recommendation	Rationale
Survey seasonal temperature outlooks	These are useful for determining likely evaporation rates and crop water demand. The first port of call for moisture risk analysis. Temperature forecasts will identify changes from the mean, which require preparation on the farm to schedule irrigations.
Check BOM extreme heat model regularly	4 day heat waves can be a game changer to any crop. The BOM heat model will pick up heat cells out to 10 days.
What is the MJO* doing?	The MJO is a broad trough of low pressure, when active, can trigger a rain event. See 'Moisture Manager' for regular updates.
Survey 3 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 around 10 days out.
Survey short term rain models	When multi-week models predict a rain event, short term models such as the BOM WATL site and other GFS** sites need to align. Surveying 3 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.

2–3 weather models on an 8-16 day lead, heat wave forecasts and the status of the Madden-Julian Oscillation. Studies have shown that ENSO has little effect on rainfall in cotton areas post-December. The Indian Ocean Dipole matures in November each year and has little/no influence thereafter.

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 a valuable source in determining likely outcomes when planning a winter or summer crop. Three sources of statistical analysis can aid in decision making:

- **CliMate:** download the i-phone app or go to www.climateapp.net.au. Choose a weather station closest to you and run analysis *How Often?, How's the Season? or How Likely?* A range of probabilities show likelihood of rainfall and temperature at a given location (see below figure for the CliMate homepage).
- **Analogue Years:** Dr David Stephens, formerly with Dept of Agriculture Western Australia determines an "analogue" or "like" year for the current calendar year. This allows the reader to research the rainfall on the location to understand when and how much rain fell through various seasons. Keep an eye on the Moisture Manager for reference to analogue years; and
- **SOI Phase prediction:** On the first of every month the SOI phase prediction is released with a probability of rainfall being above or below median for the next three months. This output is based on historical rainfall based on previous behaviour of SOI phases.

In-season climate risk management – growing season

Planting

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

First flower/boll fill/harvest

Into the growing season, the climate drivers of our climate systems are beginning to change to a more dynamic system influenced by local sea surface temperatures, upper air disturbances and tropical convective moisture. With the exception of Central Queensland, the effects of El Niño Southern Oscillation will be reduced at the onset of summer and the usefulness of longer term seasonal (3 monthly) rainfall models for planning will become limited.

When scheduling irrigation and fertiliser applications there are some information tools and general principles available to aid crop management. Table 3 shows some suggested practices.

Useful information:

'Moisture Manager' is an information-rich, user-friendly and up-to-date weather and climate service essential for farming businesses looking for an edge in climate risk management. Moisture Manager is delivered by CottonInfo: the Australian cotton industry's joint extension program, supported by Cotton Australia, Cotton Seed Distributors, the Cotton Research and Development Corporation.

This project is supported by funding from the Australian Government.

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

Visit www.cottoninfo.com.au/climate

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

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

Australian Government

Raingrown (dryland) cotton

By **Michael Bange** (CSIRO)

Risk and potential

This chapter presents information to assist in establishing differences in yield potential, reliability and risks for raingrown/dryland cotton between row configurations and regions. Extensive field research has been utilised including the use of the OZCOT crop simulation model coupled with historical climate records.

Improvements in variety performance and technology traits have simplified the process of growing raingrown cotton, making cotton a more reliable and consistent performer within the rotational mix.

Raingrown cotton growers need not take uncalculated risks. History can often serve as our best guide to the potential risks and benefits of different cropping strategies. The use of crop simulation models are a powerful, and often the only, way to address such issues without suffering the consequent pain and real life experience when misfortune strikes. 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 raingrown cotton production in different regions.

The OZCOT crop simulation model uses historical weather data, basic soil parameters, and defined management options to give estimates of potential crop yields. The model has been comprehensively tested across both commercial raingrown (including skip rows) and irrigated crops throughout the industry.

Best practice…

- **Soils with a greater plant available soil water holding capacity reduce risks associated with raingrown production. As with all raingrown crop production, full profiles also significantly reduce year to year variation in yields.**
- **The optimal sowing window in most regions is 15th Oct to 15th Nov.**
- **Skip row configurations reduce the potential '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 it can lead to differences in potential yield and associated risk.**
- **Be aware of average rainfall and variability between October and April in your region.**
- **Be aware of the ability of crops to access moisture in skip rows. Some soil types will limit root growth.**

The intention behind skip row configurations is to slowly provide available soil water to the planted rows to allow continued growth during dry periods. In practice, the benefits lie primarily in:

- 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.

Rainfall

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

Predicting raingrown cotton yield potential

The information presented in this chapter uses the OZCOT crop simulation model developed by CSIRO. Some assumptions used in this study were: Cracking clay soils storing 200 mm or 250 mm of available soil moisture in 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 7 plants per metre of row; nitrogen non-limiting; climate data 1957–2010.

The model simulates potential yield. It does not account for the affects of insect pests, diseases, weeds, management failures, and soil nutrient limitations other than N. The model also does not simulate the effects of climate and management on fibre quality, which is another important consideration when growing raingrown cotton.

Sowing opportunities

The risk of failing to obtain a sowing opportunity was assessed for three, 30 day periods starting the 15th of September. A sowing opportunity was defined in terms of adequate soil moisture and temperature and there was no account for Bollgard sowing 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 3 consecutive days.

The Darling Downs, Moree and Gunnedah were found to have a slightly lower risk of failing to sow for the 90 day period starting 15th September for raingrown cotton production than for most other areas especially for the period 15th October to 15th December (Table 2). Experience in these regions is commensurate with these findings. Refer to the Climate for cotton growing chapter for more information on assessing the climate risk for the coming season.

Raingrown regional yield potential and row configuration

A number of field studies have been conducted to compare the relative yield of skip row configurations compared with solid 1 m plant

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

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

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. It should also be noted that there are also significant fibre quality advantages attained from skip row configurations. Figure 1 shows data from experiments to highlight this point.

In recent years the expansion of raingrown cotton into new areas and the need for greater flexibility in farm equipment setup has meant that a greater range of row configurations have been considered. Two configurations that are now being used are alternate row (1 in 1 out, 80 inch [2 m]) and super single (1 in 2 out). The analyses presented here do not explicitly use the OZCOT crop simulation model to predict yield potential for these two row configurations as the model has never been validated for these situations. However, the responses presented in Figure 2 can be used to convert the

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

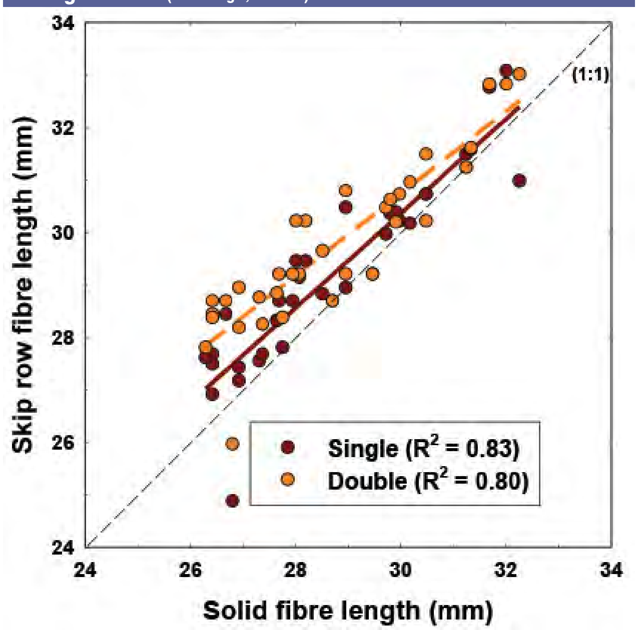
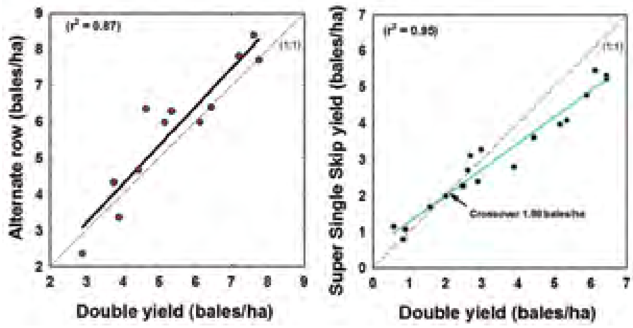


TABLE 2: Probability of failing to sow based on the sowing opportunity for different periods starting 15th September.

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

double skip yields to the equivalent alternate row and super single yields. It can be seen from these graphs that in general, yields for the alternate row configurations are similar or slightly better across all double skip yield potentials. For super single, yields are greater for this configuration when double skip yield potential is less than 1.98 bales/ha.

FIGURE 2: The relationship of lint yield of alternate row and super single skip row configurations to double skip row configurations. Also shown is the 1:1 line (dotted). Where values are on the 1:1 line they are equal.



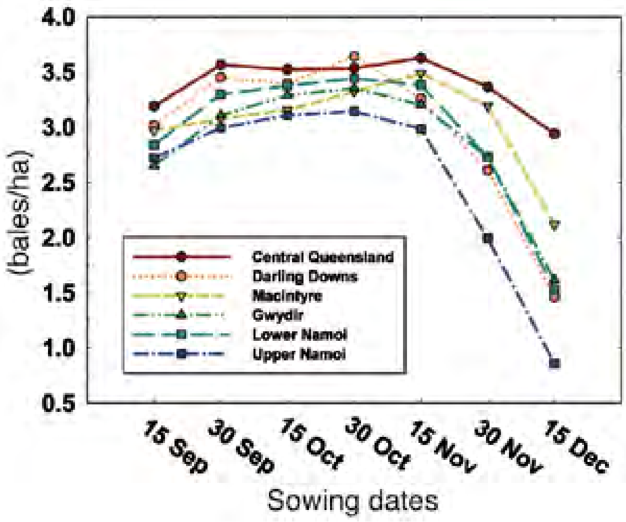
In Tables 3 to 5 the average potential yield from three different row configurations (solid, single and double) is presented on a regional basis along with the associated 'Probability of exceedence' values. Probability of exceedence is used to indicate yield variability that exists with different seasonal climatic conditions experienced in each region. For example an 80 per cent probability of exceedence means that there is an 80 per cent 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 (ie. higher 80 per cent and lower 20 per cent probability of exceedence) of attaining better yields with double skip in soil with a lower plant available water holding content (200 mm vs 250 mm).

Time of sowing

The length of sowing windows in raingrown crops is often longer than for irrigated crops as the length of growing season is less for raingrown 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, the optimum sowing time for most regions based on mean

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



yields was from 15th October to the 15th November. In all regions mean yields of crops grown in single skip configuration were less when crops were sown early before the 30th September (Figure 3). The latest sowing date where there was no substantial penalty to average yield was the 15th November for all regions with the exception of the Darling Downs, where yield reduced after the 30th October. Later sowings within this window can give the crop more time to capture rainfall when the crop needs it most. Sowing times outside this window not only reduce mean yield but also increase potential yield variability. Consideration must also be given to the timing of crop maturity, which may be influenced by sowing, as rainfall at harvest can affect lint quality considerably.

Conclusions

It is important to note that these analyses act only as a general guide to the potential yield and risks of raingrown production for different regions. The outcomes and interpretation may change depending on a number of farm specific factors, for example: soil water holding capacity, starting soil moisture and costs. Most benefit comes from simulating growers' specific conditions using their own soil type and costs. Further comments on management and financial considerations of raingrown cotton and different row configurations in raingrown cotton production are included in this manual.

Biotechnology has helped to reduce some of the risks associated with growing cotton, however raingrown cotton still presents a relatively large risk. Crop simulation models such as OZCOT, combined with climate risk tools (Chapter 3) provide useful tools to help evaluate the risk.

Other raingrown cotton considerations

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

- If you haven't grown cotton previously or recently, review the New growers' checklist Chapter 2.
- Raingrown production systems require varieties that yield well in water limited situations – refer to Chapter 7.
- Cotton can be a useful rotation option in many raingrown cropping systems. Refer to Chapter 6 for rotation and previous crop history considerations.
- Seasonal climate forecasts may offer opportunities to adjust crop management in light of probable weather trends. Responses can include modification to row configurations or fertiliser rates. Crop models can also be linked to climate data to assess potential risks with different forecasts. Refer to Climate for cotton growing Chapter 3 for more information.

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

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

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

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

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

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

- An integrated approach to insect, weed and disease management is important in ensuring cotton remains profitable. While biotechnology provides many benefits to the industry, it is important that the stewardship responsibilities, such as requirements for pupae busting are understood, see Chapter 11 for insecticide and Bt stewardship, and Chapter 12 for herbicide stewardship.
- 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 raingrown cotton. Refer to Chapter 23.
- The gross margin presented as an example in Chapter 24 is for irrigated cotton. For an example of a raingrown cotton gross margin refer to NSW DPI Summer Gross Margins: www.dpi.nsw.gov.au/agriculture/farm-business/budgets/summer-crops.

Reference:

Bange M.P., Carberry P.S., Marshall J., and Milroy S.P. (2005) Row configuration as a tool for managing rain–fed cotton systems: Review and simulation analysis. Australian Journal of Experimental Agriculture 45(1): 65–77.

A summary of climate indicators can be found in the fortnightly CottonInfo newsletter or receive the updates automatically by registering on www.cottoninfo.com.au

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

Row spacing in raingrown cotton: www.youtube.com/cottoninfoaust

More information: www.drylandcotton.com.au

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Irrigated or semi-irrigated cotton

Contributing authors:
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Water is a production tool just like any other management input and planning is a critical part of this management. Regardless of how growers manage their water or how much water is available, the goal is to optimise production per megalitre of water – water use efficiency (WUE) or water productivity. Improving it involves a whole farm water management plan.

Water budget

The first step is to have a water budget. A water budget needs to be prepared at the beginning of each season to estimate how much cotton can be grown with the available water. A water budget is part of risk management ie. it helps to reduce the risk of not having enough water to finish a crop.

To prepare a water budget you need to know: 1) seasonal crop water requirements; 2) the climate and its variability; and, 3) the available water supply.

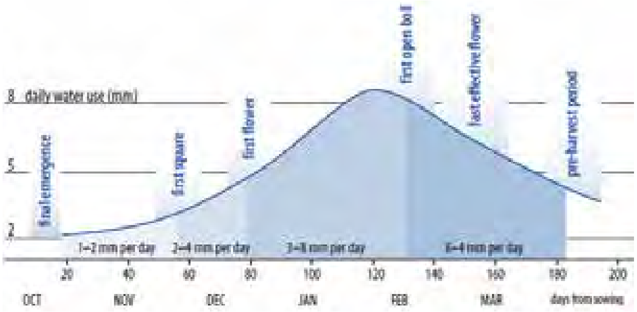
Seasonal Crop Water Requirements: Understanding crop water requirements (ie. crop evapotranspiration (ETc)) is crucial for planning your mix of crops, the area to be planted and how irrigation is managed. Table 1 shows the water requirements for a variety of crops.

Best practice...

- **A water budget for the farm should be prepared and used as part of planning crop management.**

A crop's requirement for water changes throughout the growing season, following the pattern of evapotranspiration (crop water use) as shown in Figure 1. The rate of evapotranspiration is determined primarily by meteorological factors and the availability of soil water.

FIGURE 1: Nominal seasonal Daily Water Use (mm/day) for cotton production. (Source: WATERpak Figure 2.1.3)



Tools such as CropWaterUse – a web based application is available to help growers calculate the theoretical daily and seasonal water use of a crop for a range of crops, including cotton – https://waterschedpro.net.au The IrriSAT technology also provides a method for determining crop water use, where remote sensing is used to determine site specific crop coefficients, providing a locally derived evapotranspiration (ETc) or daily crop water use (www.irrisat-cloud.appspot.com/).

Once you understand how much water your crop is going to use, it can be adjusted for the expected seasonal conditions, hence you need an understanding of **climate variability** for your region. This requires knowledge of your region's median rainfall, the probability of above or below median effective rainfall and when rainfall occurs (how will timing affect irrigation, dam supplies or extraction limits). Investigating climate, past rainfall records and current climatic patterns may help predict what sort of season you could expect eg. wetter or drier than a median year, and plan accordingly. Refer to the Climate for cotton growing chapter for more information.

Finally you must know your **available water supply,** ie. irrigation water (regulated and unregulated rivers allocation), on-farm capture, total storage capacity and ability to trade water. Don't discount the importance of understanding how much soil moisture you have available for your crop. A full profile at the start of the season can reduce your total irrigation water requirements.

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

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

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

The maximum area of crop that can be irrigated is determined by crop water requirements, the irrigation system capacity and efficiency and the availability of water.

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

For example:

A cotton crop in Southern Queensland might require about 900 mm (9 ML/ha) of water. Historical figures indicated that the median rainfall during the season for this location is 350 mm (3.5 ML/ha). So for a median year the irrigation requirement is 5.5 ML/ha.

At planting, the grower has 300 ML in storage and 700 ML of available allocation. The grower estimates that another 500 ML will be harvested during the season.

Irrigation water available: 1500 ML

Irrigation requirement: 5.5 ML/ha

Whole Farm Efficiency: 64 per cent, ie. 36 per cent of irrigation water lost through deep drainage, in-field leaching and evaporation and seepage from on farm storages and channels.

Area = 1500 ÷ 5.5 × 0.64 = 175 ha

A number of studies have been undertaken to consider the area to dedicate to irrigated cotton production and have found that at least 5-6 ML/ha of water supply is required. Refer to WATERpak Ch 3.3 and Table 3.3.1 WATERpak, pg 265 for more information.

Growers in situations of limited water supply should consider what area to plant and how much of this should be irrigated. The answers to these questions will be influenced by many factors specific to the location, farm and grower, and are discussed below.

Useful resources:

CropWaterUse tool accessible online via https://waterschedpro.net.au

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

WATERpak Chapter 1.2 Water use efficiency, benchmarking and water budgeting, pp 18-21. www.cottoninfo.com.au/publications/waterpak

Limited water/semi-irrigated

Under normal water availability scenarios, most farms will practice full irrigation. In other words, irrigation water is applied to completely meet crop water demand or evapotranspiration (ETc) that is not supplied by rainfall or stored soil water.

When water supply is limited, growers have a number of management options available:
1. Fully irrigate a reduced area of irrigation.
2. Deficit irrigate a larger crop area.
3. Include different crops that require less irrigation.,
4. Change plant row configuration.

As previously mentioned, full irrigation occurs when irrigation water is applied to completely meet crop water demand or evapotranspiration (ETc) that is not supplied by rainfall or stored soil water, with the typical aim of maximising yield. In contrast, 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, and irrigation applications should be timed to the most yield sensitive growth periods. Different crops have different season ETc requirements and thus crop choice, maturity length and planting time can be used to adjust to limited water.

If, when calculating irrigated area for cotton, the irrigation water supply is pushed below 5-6 ML/ha, then partially irrigated skip row may be an option in some regions (WATERpak pg 266). Adjusting to lower water availability by removing selected rows after establishment is detrimental to overall performance of the field as water used by the plants in the skip row has been wasted on unproductive growth and remaining plants may have suffered more moisture stress than would have otherwise been the case.

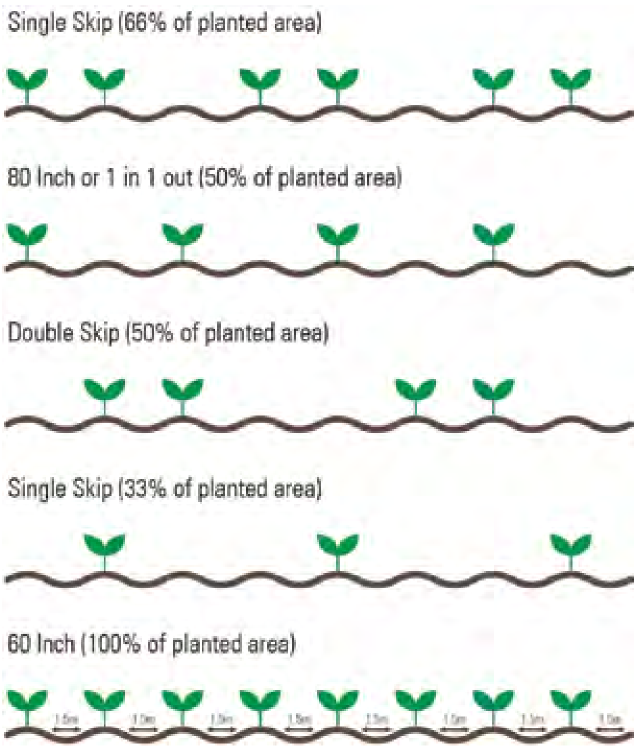
Best practice...

- **A water budget for the farm can help plan for limited water scenarios.**

Row configurations and semi-irrigated cotton

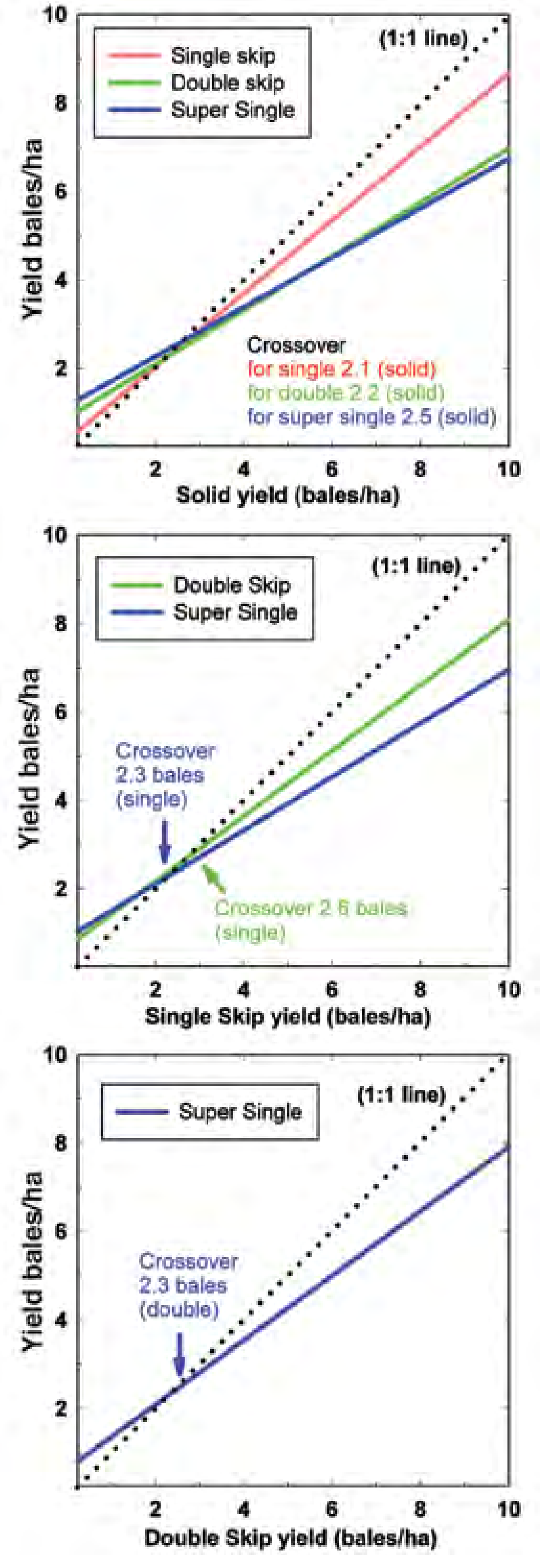
There are a range of different configurations being used by growers across the cotton industry in semi-irrigated situations. These include single skip, 1.5 m and 2 m (60 and 80 inch), double skip, super single and some non-uniform configurations (refer to Figure 2).

FIGURE 2: Row configuration guide.
(Source: CSD Getting the most out of skip row irrigated cotton)



Semi-irrigated single skip (3 irrigations) left and solid plant (fully irrigated) on the right. (Photo courtesy CSIRO)

FIGURE 3: Comparison of average yields of various combinations of row configurations. Responses are generated from controlled comparisons undertaken over many seasons. Crossover 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, when comparing double skip to single skip, the average yield potential at which single skip outperforms double skip is 2.6 bales/ha.
(Compiled by M. Bange CSIRO 2012)



The reasons for using skip-row include:

- Reduced risk of crop failure.
- Buy time to get rainfall or irrigations.
- Spread the irrigation interval.
- Make better use of in-crop rainfall.
- Reduce variable costs.

The positive and negative features of each configuration including the relative water use efficiencies depend on the individual situation. What works best in one farming system may not in another due to differences in soil type, environment, cropping history, available equipment, water availability and other factors.

The yield/cost/fibre quality mix of each configuration

Growers contemplating:

- Whether they would benefit from using skip row configurations.
- Which skip row configuration they would use … should consider the following points:

Extensive research has shown that while skip row cotton does limit yield potential (Figure 3), the combination of reduced fibre length discounts and variable cost savings in growing skip row cotton often lead to a better risk/return proposition.

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

While **one-in-one-out (1.5 m or 2 m)** cotton has not been included in these comparisons, grower experience and some trial work has shown its yield potential to similar or slightly higher than double skip but possibly more prone to fibre quality discounts because it does not have the advantage of mild early stress. Detailed research is currently being undertaken to investigate this issue. A more uniform growth habit in one-in-one-out cotton can reduce lodging; allow better spray penetration and defoliation processes when compared to double skip.

Double Skip provides more insurance against lower yields when compared to single skip especially when conditions are less favourable. Having a plant row 50 cm one side and a 1.5 m skip row to the other, this configuration provides the benefits of 'partial root zone drying' which toughens the plant up. Plants can be prone to lodging, especially vegetative branch fruit which takes advantage of the extra light available in the skip area. It is best suited to drier profiles and hotter environments.

Some growers have tried **Super Single** (one-in-two-out) in semi-irrigated situations. The widely spaced plant rows 3 metres apart means the yield potential and potential upside in a good season is severely limited. However, may be an option with a full soil moisture profile at planting and minimal irrigation water resources where there is a high chance of severe water limitations during flowering and boll fill. This configuration allows growers to minimise growing costs as well as limit the likelihood of fibre quality discounts.

Non-uniform configurations have been tried in some circumstances but can lead to variability in maturity, and subsequent difficulties in management.

Skip row configurations function by increasing the volume of soil that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plants have to explore, providing a bigger reservoir of available moisture and allowing the plants to hold on for longer during dry periods.

Skip row cotton provides an 'in between' option for increasing the area of cotton which can be grown, allowing some upside in production if conditions improve and far less downside in potential fibre quality discounts if the season deteriorates.

In some cases, inherent growing characteristics such as soil type and location may mean there is minimal advantage in adopting skip row practices.

Planting row configuration effects on cotton gross margin

The vigourous tap root of the cotton plant allows for wider exploration of the soil profile for moisture and nutrients, particularly when compared with fibrous root type crops. This characteristic has led to the use of wide row configurations that increase the total amount of soil moisture available to the plants. The wide row spacings provide greater surety in yield and maintenance of base grade fibre quality. Therefore the row configuration chosen in combination with the seasonal conditions experienced will have an influence on the likelihood of quality discounts being incurred on delivery of the cotton. Refer also to Raingrown (dryland) cotton chapter for additional information.

Savings in variable costs of inputs such as planting seed, insecticides, defoliants and the picking operation are likely with wider row configurations. In wide row configurations, efficiencies in picking can be made through not trafficking every pass, with some contractors altering machinery or charging on a green hectare basis. The biotechnology licence fee can either be based on green hectare or end point royalty scheme, where fee is related to yield.

Taking this into account, a lower yielding wider row configuration crop can at times give a better gross margin than a higher yielding crop on a closer configuration. In many ways growing skip row cotton really emphasises that gross margin is not just a function of the yield produced, but very much a combination of yield and costs associated with the row configuration chosen.

Useful resources:

CSD fact sheet – Getting the most out of skip row cotton: www.csd.net.au

WATERpak chapter – 'Row configuration' (pg 266) www.cottoninfo.com.au/publications/waterpak

CottonInfo video – Strategies to manage limited water: www.youtube.com/cottoninfoaust

Conducting a whole farm water balance can help determine how much water is available for crop production and where losses are occurring. (Photo courtesy Mel Jenson)

Whole farm water balance – the key to better water management

By **Jim Purcell** (Aquatech Consulting)

Key points:

- Measure to manage.
- Not only does water need to be managed in the crop root zone, but also at the whole farm level.
- Water losses can best be identified and then reduced by completing a whole farm water balance.
- Measuring equipment and easy to use software packages are now commercially available to complete seasonal and even daily whole farm water balances.
- Water balance and improved water use efficiency can be done in stages starting with the very easy.

Important considerations:

- Key measurement is needed to complete any water balance.
- Make a start, don't stress about super accuracy. Do the easy things first and work through at your own pace.
- Do not chase accuracy for accuracy's sake. A good estimate is better than nothing and is a good start.

A successful and profitable irrigation enterprise is one that manages precious water at both the crop root zone level (soil moisture monitoring and irrigation scheduling) and at the whole farm level (how much water do I have? what are my losses? and therefore how much do I have left for crop production?).

Irrigation scheduling and soil moisture monitoring has good adoption in the cotton industry but the whole farm water management area is lagging. The tools for whole farm water balance have progressed greatly in the past 10 years. The use of these commercial tools and water management consulting services has steadily grown as irrigators strive to improve their profitability with less water.

Below is a step by step process to better manage water at the whole farm level. In summary:

Step 1

- Measure and record the basics.
- Complete a simple seasonal whole farm water balance.

Best practice…

- **Information is recorded each season to help make better whole farm irrigation decisions including water volumes, water quality, PAWC, water use indices.**
- **Using standard indices and available tools to determine and benchmark water use efficiency performance for the farm over time will help identify opportunities for improving water use efficiency.**

- Review the results.
- Fix the easy stuff.
- Repeat until happy.

Step 2

- Stop at Step 1 if you are happy with your WUE.
- Having already set your farm up on WaterTrack, suggest you routinely complete a whole farm water balance.
- Suggest benchmarking against your neighbours (everybody will learn and improve).

Step 1 – Seasonal whole farm water balance

Measurement

Measurement is essential for any good management and water management is no different. To achieve good measurement start with the following:

- Ensure all water meters are installed correctly and measuring accurately. Check them with another meter.
- Survey all storages to establish accurate depth to volume to surface area characteristics. Ensure all tail water and buffer storages are included. Storage surveys can now be done with water in the storages! (Contact Aquatech Consulting).
- Fit storage meters in all storages. Gauge Boards are a start but don't really do enough. It is very difficult to measure the volume of a stormwater harvesting event with gauge boards unless the gauge boards are read just before and just after each event and recorded. Aquatech™ Storage Meters have been developed over the past 10 years. They read and log water level, storage volume and water surface area at any required interval (normally 30 minutes but can be changed). These meters have been approved for use by NSW Water. This not only allows water volume to be accurately monitored in real time but also provides flow rates into or out of the storage. A storage meter also records the water surface area which allows the calculation of water volume loss from seepage and evaporation. Telemetry now means your data is conveniently available by internet (read your storage volume, depth and surface area while on a holiday overseas!).
- Take strategic measurements of soil seepage characteristics and storage and channel evaporation characteristics. This allows calculation of the seepage and evaporation losses in each storage, channel and drain. Irrimate™ Seepage and Evaporation Meters can be hired from Aquatech Consulting. These meters measure both seepage and evaporation characteristics. It is not necessary to measure every storage or every channel and drain to get meaningful results. Start with estimates based on soil type and then calculate the actual losses from the Storage Meters.

Record keeping

The next step is basic record keeping. The aim is to provide enough information to be able to complete a seasonal water balance. Enough basic information is required to calculate accurately how much water the crop actually needed during the particular season and how much water was made available to grow that crop.

In simple terms, the total measured available water, less the calculated actual crop water requirements for the season, equals the water lost to production. It should always be remembered that it is impossible to produce an irrigated crop without some losses. The real question is "How much lost water can be saved and used to increase production and profit?" To establish this, it is necessary to be able to split up the total water lost to production into components:

- Storages losses (wet-up, seepage and evaporation).
- Channel system losses.
- Drainage system losses.
- In-field losses.
- Operational losses (stuff-ups resulting in water lost out of the system).

The records needed for a seasonal whole farm water balance include:

- Meter readings from all inflows – (river, scheme channel and/or bores).
- Storage volumes at the start of the season.
- Storage volumes at the end of the season.
- Floodplain Harvested water volumes (Aquatech Storage Meters™).
- Rainfall runoff captured from your fields and farm (Aquatech Storage Meters™).
- Rainfall on fields.
- Field number or name and area.
- Crop yield.
- Reference Evapotranspiration for each day during season (automatically provided in WaterTrack™).
- Field soil type (menus provided).
- Field soil moisture deficits (mm) at the start of the season and end of season (estimated or from soil probes if available).
- Crop emergence date and end date (when crop stops transpiring eg. cotton defoliation).
- Dates of each field irrigation.

While these records or similar are currently noted in some form or another by most irrigators, Aquatech Consulting provides record sheets and/or spreadsheets for easy record keeping.

Seasonal water balance

Your farm is then set up in WaterTrack Divider™ (www.watertrack.com.au) and the whole farm water balance is completed for the last season.

The Seepage and Evaporation characteristics for channels, drains and storages can be calculated from nearby Storage Meters or estimated initially from soil types (menus provided).

Calculation of actual crop water requirements is based on daily Reference Evapotranspiration (ETo) values for your particular farm and season and crop factors. ETo can be sourced from a weather station on the farm or normally from the Bureau of Meteorology SILO database. If WaterTrack™ is used for the whole farm water balance, the program automatically obtains and updates daily ETo from the Bureau of Meteorology. All that is required is the farm latitude and longitude from Google Earth.

Review the results

All irrigation farms will lose water; it is inevitable. The question is "Where are the losses and are they OK?" WaterTrack Divider™ (www.watertrack.com.au) will complete a simple seasonal water balance and provide Water Use Efficiency Indices required for *my*BMP and Water Management Plans.

Step 2 – Improve measurement and routinely complete whole farm water balance

WaterTrack Divider™ is a low cost and easy way to continue completing Whole Farm Water Balance. While the first couple of times we may rely on estimates of seepage and evaporation, for instance, these characteristics can be calculated from the data from the Aquatech Storage Meters™. The farm is already setup in WaterTrack so each year after year 1 is easy. Whole Farm Water Balance is ideal for benchmarking WUE performance with your neighbours.

This is a great step forward in Water Management and will significantly increase profit.

It is not possible to achieve good WUE results without completing a whole farm water balance!

Where to go

Consultants like Aquatech Consulting, Narrabri NSW, and others can run your whole farm water balance as a service and advise whether the losses are typical, good or bad and can then advise on the type of works and cost to reduce losses. WaterTrack Divider™ even provides a basic economic calculator. This can determine if the proposed capital works are economic for the water savings and how long the payback period is from the extra production.

Aquatech Consulting currently supports other consultants to provide the equipment, software and support to their clients. Most growers prefer this work done by their consultant as a service but others can be trained to do it themselves if required.

Useful resources:

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

CottonInfo factsheet: Irrigation benchmarking www.cottoninfo.com.au/water-management

Best practice…

- **Evaluate full potential performance of existing system (eg. furrow) when considering change to alternative system (eg. to overhead, drip etc).**
- **When assessing the viability of an alternative investment consider yield and prices risk, the extent of water savings and risk of water availability, likely impact of changing energy costs, and availability of labour. Identify site specific constraints of existing infrastructure and design accordingly.**
- **Successful operation requires ability to change mindset from furrow irrigation techniques. Full potential of systems such as overhead and drip are achieved via ability for greater control (which requires more refined scheduling).**
- **When evaluating irrigation systems, Gross Production Water Use Index (GPWUI) is the best water use index for comparing bales per ML between farms, regions and seasons. This relates total production (bales) to the total amount of water used, from all sources including irrigation water, rainfall (total or effective) and soil moisture.**

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

Aquatech Consulting, Jim Purcell E: jim@aquatechconsulting.com.au www.aquatechconsulting.com.au www.watertrack.com.au

Irrigation systems

The four most commonly used cotton Irrigation systems are the two surface irrigation systems; siphon (furrow) and bankless channel, and the two pressurised systems; overhead irrigation (centre pivots and lateral moves) and sub-surface drip.

Siphon/furrow irrigation

Siphon/furrow irrigation is the primary system used by the Australian cotton industry, but labour resourcing in recent years is encouraging some growers to look to alternatives.

Typically, 60 to 70 per cent of the water applied to the field is used by the crop, the remainder is recycled as runoff or lost to deep drainage. As a result of extensive efforts the industry has achieved significant improvements in the performance of furrow irrigation.

Work conducted by Gillies (2012) and Montgomery & Wigginton (2007) measured application efficiencies as high as 90 per cent for individual irrigation events. Relatively small management changes and an understanding of soil infiltration properties can help optimise siphon irrigation and significantly increase water use efficiency.

Automated irrigation with small pipe through bank or smart-siphons

The challenge of labour resourcing and timely irrigation management are driving efforts in automated siphon irrigation. Automation has the potential to deliver more precisely targeted irrigation to crop demand, avoiding stress caused by waterlogging or delayed irrigation. There are two automated small pipe through bank options in use in the industry:

- The double head ditch option; as at "Waverley", Wee Waa.
- Siphon gang option using the Smart Siphon; as at "Keytah", Moree.

Setup costs for automation of existing siphon fields are outlined in Table 3 and will be influenced by the approach chosen, field dimensions and the row configuration 30 inch vs 40 inch (0.75 m vs 1 m).

Useful resources:

CottonInfo videos:

Moving to an autonomous irrigation system: www.youtube.com/cottoninfoaust

Automated small pipe irrigation system: www.youtube.com/cottoninfoaust

CottonInfo fact sheets, case studies, and booklets:

Key factors to consider in improving furrow irrigation: www.cottoninfo.com.au/water-management

Evaluating furrow irrigation performance – results from 2006-07 season: www.cottoninfo.com.au/water-management

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

Water management (from an irrigator's perspective): www.cottoninfo.com.au/water-management

2016 and 2018 irrigation research tour booklets: www.cottoninfo.com.au/water-management

Smarter Irrigation for Profit fact sheets:

Autonomous furrow irrigation with small pipe through bank: www.cottoninfo.com.au/water-management

The value of water level monitoring: www.cottoninfo.com.au/water-management

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

More Profit per Drop materials:

Pipes through the bank case study: www.moreprofitperdrop.com.au

Pipes through the bank video featuring Craig Saunders & Justin Schultz: www.moreprofitperdrop.com.au

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

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

Bankless channel irrigation

Bankless channel surface irrigation systems are designed to address the labour resourcing challenge faced by industry. The field is split into bays and watered at a high flow rate. All furrows in a bay are irrigated at once without the need for siphons.

There are several design options, but the two most common approaches are:

- The conventional form; a series of terraced bays with a vertical separation of between 0.1 to 0.2 m. Bays typically have either a zero or very shallow positive (uphill) field slope of around +0.01 per cent (1:10000). Bays must have no cross-slope and can be configured with beds or flat planted. All bays are connected by a bankless channel.
- The second design, known as GL bays, uses the same approach to deliver water to a bay in that water spills from the bankless channel into the adjacent bay. However, in contrast, approximately 20 metres from the bankless channel, the bay slope changes from a positive field slope to a conventional negative field slope, where the water advances down the field in a similar way to a siphon field. Like siphons, the wheel tracks come through first. The tail-water then backs up and waters up dry rows until it meets the other water coming down.

Note: The GL Bays design was developed by Glenn Lyons, GL Irrigation Pty Ltd, St George.

Pros

- Reduced labour, it can be managed by one person.
- Improved machinery efficiency – no need for rotobucks or driving through ditches during spraying and picking.
- Ability to better manage crop water use in response to hot, dry weather and pending rainfall events.
- Limited maintenance – tail drains are graded every 2–3 years but no need to do head ditches.

Cons

- Not suitable for paddocks with varying soil types.
- Need suitable slopes and can require significant removal of top soil in some locations.
- Installation costs can involve significant earth work.
- More suitable to properties in the developmental phase as opposed to converting pre-levelled siphon fields to bankless systems.

Useful resources:

WATERpak Chapter 5.4 Bankless Channel Irrigation Systems pg388 www.cottoninfo.com.au/publications/waterpak

More Profit per Drop Bankless Channels – Bullamon Plains case study and video: www.moreprofitperdrop.com.au

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

Overhead irrigation – centre pivots & lateral moves (CPLM)

The Australian government's water reforms and on-farm irrigation infrastructure funding programs have stimulated investment in a range of improved irrigation technologies, including Centre Pivot and Lateral Move (CPLM) irrigation systems. This is driven by cotton growers striving to manage labour resourcing and potentially save water.

Overhead systems do not require furrow or bed development, which will reduce land preparation requirements and can increase their suitability to other crop options.

The 2011–12 review of CPLM irrigation systems in the Australian cotton industry gives an updated overview of performance and management and provides an important comparison to the Foley and Raine (2001) review.

Four main observations arose from the 2011–12 review:

- Around half the CPLM systems were unable to meet a crop's peak water requirement as the Managed System Capacity was below 90 per cent of peak crop water demand.
- Most irrigators are now installing CPLMs on country that has been levelled or had drainage works.
- Despite acknowledging that performance of CPLM systems should be checked at commissioning and regular intervals afterwards, only a small proportion of participants indicated that they did so.
- While most participants are concerned about running costs of CPLM systems, about half were operating their systems above optimal pressure, potentially incurring higher running costs than necessary.

The review found the adoption of overhead irrigation systems is based on their potential to save water and labour, to maximise rainfall capture and minimise waterlogging, and the flexibility they offer for growing a range of crops in diverse situations.

Water savings depend on the performance of the existing irrigation system. A well performing surface system can be as efficient as overhead irrigation system. Optimisation of an existing furrow system could significantly reduce potential gains expected from investment in an alternative system.

Savings of 30 per cent have been found where CPLM machines have replaced surface irrigation, however these savings can be offset by higher energy and capital costs and must be balanced with water reliability.

Overhead Irrigation is very different to surface irrigation and requires a completely different mindset. Management in terms of crop agronomy and irrigation time and volume largely influence the potential returns per ML of water applied. You must manage the whole irrigation system, not just the machine.

Before replacing a surface irrigation system with an overhead irrigation system, you should assess the performance of the existing system, to be sure the change is warranted.

The following recommendations should be considered before investing in overhead systems:

- Conduct a 'with or without' financial assessment.
- 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.
- System capacity needs to be high enough to satisfy peak crop demand.
- Expect to invest significant time in planning and set up. It will take several years to maximise the performance of an overhead system.

- The performance of systems should be checked 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. In areas with low reliability the return on investment from an overhead system would need to be spread over years when irrigation water may not be available.
- Obtain a 'site specific' system design tailored to match the environment (eg. soil characteristics, topography). A well-designed overhead 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.
  – Have minimal energy and labour inputs.

A 'with' and 'without' scenario analysis with support from a suitably qualified agri-business financial advisor is a robust method to assess the economic and financial performance of investment in CPLMs. This approach involves the following steps:

- Prepare a whole farm profit analysis for the current farming system ('without' scenario) and one with the CPLM investment ('with' scenario).
- Undertake a financial analysis over the life of the investment for the 'with' and 'without' scenarios.
- Complete an economic analysis to calculate and compare the Internal Rate of Return and the Net Present Values for the 'with' and 'without' scenarios.
- Perform a marginal analysis to calculate the marginal return and payback period for the CPLM investment.

Table 2 provides a comparison between irrigation systems. This information is useful in planning and design.

Useful resources:

Smith P., Foley J., Priest S., Bray S., Montgomery J., Wigginton D., Schultz J. and Van Niekerk R. (2014) "A Review of Centre Pivot and Lateral Move irrigation installations in the Australian cotton industry", NSW Department of Primary Industries: www.cottoninfo.com.au/water-management

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

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

More Profit per Drop YouTube video series – DAFF QLD Growers Guide to Centre Pivots and Lateral Moves: www.moreprofitperdrop.com.au

OVERsched – an on-line CPLM management tool for visualising soil moisture deficits and irrigation scheduling options. NCEA Knowledge Management System for Irrigation (KMSI): www.kmsi.usq.edu.au

Sub-surface drip irrigation (SDI)

The second of the pressurised irrigation systems, sub-surface drip irrigation (SDI) involves the application of water below the soil surface through emitters with a discharge equivalent to crop water requirements – to meet the crop evapotranspiration demand. It is a low pressure, low volume irrigation system that uses buried drip tubes. SDI tape is laid permanently and has been documented to last for 10–15 years.

Recent developments in SDI technologies and materials have increased system affordability and reliability with systems now capable of achieving irrigation efficiencies as high as 90–100 per cent.

To ensure that SDI irrigated cotton systems provide anticipated improvements in labour, yield and water use efficiency, care should be taken to ensure that the system has the appropriate pumping and filter capacity to meet crop requirements. A system setup with limited capacity will struggle to achieve the desired Gross Production Water Use Index (GPWUI) targets.

It is also important that there is reliability in water supply from year to year to justify the significant capital investment. 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 potential benefits of SDI are:

- Water savings, control of runoff and deep drainage, increased rainfall capture, and reduced soil surface evaporation.
- Reduced incidence of disease and weeds.
- Enhanced fertiliser efficiency.
- Reduced labour demands.
- Field operations possible even when the irrigation is turned on.

Useful resources:

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

More Profit per Drop (www.moreprofitperdrop.com.au) website has a range of articles discussing SDI.

WATERpak Chapter 5.6 Drip Irrigation: Design, installation and management pg 426. www.cottoninfo.com.au/publications/waterpak

TABLE 2: Comparative Irrigation System Costs. (Adapted from source: IAL; Author: Peter Smith, Sapphire Irrigation Consulting)

Irrigation system	Capital costs/ha ($/ha)	Irrigation efficiency (% approx.)	Expected life (years)	Labour requirement	Electricity costs per kWh ($)		Diesel costs per litre ($)	
					10c	30c	120c	150c
Siphon	4500–6000	50–80	25+	High	8.82	13.23	14.18	17.72
Lateral Move*	3000–7000	80	15+	Low	26.46	39.68	42.54	53.17
Centre Pivot**	3500–7000	80	15+	Low	52.91	79.37	85.08	106.35
Drip	7000–9000	85	15+	Low	44.09	66.14	70.90	88.62

*Lateral move with gravity fed channel ~1.5 times length of LM run
**Centre Pivot with pump, motor and main ~1.5 times CP length
This table is to be used as a guide only.
'Capital Cost per ha' is the common range of costs encountered for the particular system – not including unusual extremes.
'Irrigation efficiency' is an estimate of typical, practical overall system efficiency that a good farmer could attain over a period of years with good maintenance and management. It is not the peak possible efficiency.
'Expected life' is the typical, realistic life from a normally maintained system.
'Labour requirement' is an estimate of the labour required to properly operate and maintain a system
Assumed pump efficiency = 70%. Derating factors: Electric 14% Diesel 20%. Assumed fuel consumption = 220 g/kWh = 0.26 litre/kWh.

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Irrigation systems comparison trial – 2018 update

By **Louise Gall** (Gwydir Valley Irrigators Association)

The grower-led Keytah System Comparison project at Moree, NSW, provides a commercial assessment of the yield and water use efficiency of the four most common irrigation systems; siphon, bankless channel, lateral move and sub-surface drip, as measured using the standard Gross Production Water Use Index (GPWUI).

A breakdown of capital (set-up) and annual operating costs for each of the trial system are presented in Table 3.

The primary message from the research is that the optimised implementation of each of the systems will produce good yield and GPWUI's, as such optimising existing systems may be the most appropriate change to make to improve irrigation performance on your farm. The most significant differences between systems were influenced by seasonal conditions. The decision on which system is right for you will be driven by soil, climate and the availability of the resources of water and labour. The Keytah System Comparison project is a partnership between the Gwydir Valley Irrigators Association (GVIA) and Sundown Pastoral Company, it has been possible through funding from the CRDC and the Federal Government Smarter Irrigation for Profit program.

TABLE 3: GVIA Systems Comparison; capital (set-up) and annual operating costs for each trial system

Irrigation type	Capital set up ($/ha)	Annual operating costs ($/ha/annum)	Comment
Siphon (furrow)	$1500/ha	$150 -$175/Ha/annum	• Siphon irrigation was the most consistent yielding system regardless of season conditions. • GPWUI were comparable to other systems. • Siphons have low operating energy, maintenance and capital setup cost.
Small pipe through bank (automated smart siphons)	$800 – $1100/ha	Will be available September 2018	• Setup costs for automation of existing siphon fields will be influenced by the approach chosen, field dimensions and the row configuration 30 inch vs 40 inch (0.75 m vs 1 m). • Automation will address labour resourcing and potentially improve optimisation of siphon irrigation.
Bankless	$1500 – $2500/ha (depending on the amount of soil being moved)	$20/ha/annum	• Low operating costs are attributed to no capital equipment depreciation, and minimal labour and energy cost. • The Keytah system comparison trial found that the bankless channel system produced yield and GPWUI comparable to the other three systems under review.
Lateral move	$6000/ha	$240/ha/annum	• The lateral move has produced the highest average yield of 12.3 bales/ha and the highest average GPWUI in the first four years of the trial. • Operating energy, maintenance and capital setup costs are more than for surface irrigation systems.
Drip	$9000/ha	$250/ha/annum	• System setup will impact on yield potential. • Drip systems have high operating energy, maintenance and capital setup costs compared to other systems.

Field selection, preparation, rotation & cover crops

By **Steve Buster** (NSW DPI)

Acknowledgements: Susan Maas (CRDC), Michael Braunack (CSIRO), John Bennett (USQ), David Lawrence (DAF QLD), Paul Grundy (DAF QLD)

Cotton soils

There are a number of considerations, when determining for the first time if soil is suitable for cotton. The Plant Available Water Capacity (PAWC) needs to be sufficiently large to ensure the moisture needs of the crop can be met. For example, large values of Plant Available Water Capacity (PAWC), which are found in some clay-rich alluvial soil types and deep black earths, allow a longer interval between furrow irrigations and under raingrown conditions, if the profile starts out full, delay the onset of moisture stress in crops.

Crops are more likely to produce high yields when their roots are able to grow freely. To allow adequate water entry, and to encourage root exploration by quickly re-establishing aeration after irrigation and rainfall, cotton soil needs to have good porosity for infiltration and internal drainage.

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

Surveying soil variability

Money spent on a soil survey before development usually is repaid several times over because of the potential management problems that it highlights. Soil survey information provides a benchmark that can be used to check progress with soil quality management as the cotton farming project proceeds.

Best practice…

- **Crop growth will be easier to manage in a field with a uniform soil type.**
- **Conduct soil sampling to determine your soil's physical and chemical properties.**
- **Prevent or minimise erosion in susceptible areas and establish a monitoring plan to track progress.**
- **Rotation crop planning should take into account issues such as weeds, previous herbicide use, insects, disease, water use, soil health trends, and soil structural issues.**

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

When planning a new cotton development, each management unit should have soil condition and slope as uniform as possible. To achieve this aim, the soil should be mapped before any irrigation design work is carried out. In fields already developed for irrigation, variability problems may be so severe that the field must be redeveloped. Again, soil surveys should be made before redesigning.

Increasingly, precision agriculture is improving the ability of farmers to monitor and manage within field variability. A detailed understanding of the physical and chemical structure of the soil at known areas of a field can provide additional perspective to spatially collected data. Refer to the Precision ag Chapter.

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

Land forming

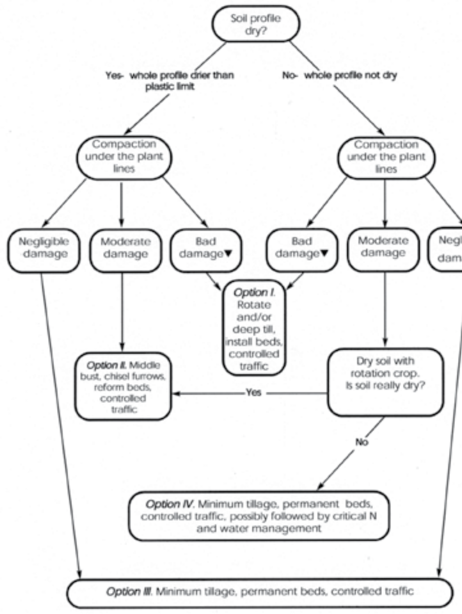
An appropriate slope and field length, in combination with furrows and hills/beds, will ensure good surface drainage and reduce waterlogging. Land forming using laser grading usually is needed to provide the required slope across all parts of a field, particularly under irrigation.

Land forming of cotton fields can create soil problems, particularly the exposure and spreading of unstable subsoil. This subsoil may have inadequate organic matter, be sodic, depleted of mycorrhiza, have a high pH and perhaps be saline. Depending upon the depth of cuts required, some farmer/operators have found it preferable to stockpile the original topsoil, landform the subsoil, and then replace the topsoil. Care needs to be taken to not exacerbate any further compaction problems by trafficking wet subsoil in this situation as the ability to remediate deep soil will be limited. If subsoil is exposed to the surface under laser levelling conditions both physical/chemical constraints need to be managed to limit any yield reduction. Refer to the Nutrition chapter for information on how to manage soil nutrient constraints.

Soil compaction

Soil compaction can significantly reduce cotton yields by restricting root growth, which in turn reduces water and nutrient uptake. Figure 1 provides an example of compaction symptoms. Some compaction is an inevitable consequence of machinery use throughout the season, and can remain from previous seasons. Where the soil is wetter than the plastic limit, the point at which 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 the major rooting depth to minimise compaction if not using

FIGURE 2: Tillage and rotation options after a dry harvest.



▼ Bad damage = serious compaction in the bed subsoil, sub-surface and/or surface (SOILpak score less than 0.5)
Moderate damage = moderate compaction in the bed subsoil, sub-surface and/or surface (SOILpak score between 0.5 and 1.5)
* Negligible = absence of compaction problems (SOILpak score greater than 1.5)
If economically necessary to grow cotton immediately, apply critical N and water management

controlled traffic farming (CTF). If using CTF then some compaction is good as it allows traffic by machinery when the rest of the field is 'above' the safe moisture level.

Ideally, trafficking wet fields should be avoided, using the crop to dry soil down to well below plastic limit prior to harvest, however compaction cannot always be avoided. The JD7760, is a heavy machine (upwards of 36 tonnes) with a much greater potential to cause soil compaction compared to the previous basket picker systems (a little over 20 tonnes). A recent CRDC funded study to assess the impacts of the round bale picker on the farming system found that for the six Vertosol soils studied, there were significant occurrences of soil compaction beneath all wheels. All sites had some change in subsoil porosity down to 0.8 m, with significant compaction observed to this depth on more than 50% of soils.

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

Soils may take years to recover from structural damage. Remediation of compacted soil often takes a combination of strategies using a series of biological cracking from rotation crops and/or deep tillage to improve the yields and profits of future crops. The greatest effect of remediation of compacted clays soils is where there is a number of wetting and drying cycles from various rotation crops. Matching rotation crops and rooting structures with compaction levels needs to be considered and not just assumed to occur because it is a rotation crop. The best option is to minimise compaction events as much as possible and move into a CTF system. Figure 2 provides guidelines on management options for compaction following a dry harvest.

Useful resources:

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

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

Rotation and previous crop history

In higher rainfall systems, cotton is often considered a 'pillar' crop, that underpins the profitability of irrigated and raingrown farming systems. As such, it is vital to consider the previous crop history and crop choices for their impacts on cotton through irrigation water use, soil water accumulation in raingrown systems, weeds, insects, diseases, and soil structure and soil health. Indeed, rotation crops can be used as a tool within the farming system to maximise the advantages and minimise the disadvantages at a field and whole of farm basis. Recent research and on-farm monitoring has shown that large productive crops and systems with short fallows are best to maintain soil organic matter levels and support more biological activity. This is a challenge in raingrown systems where long fallows are used to build soil moisture, especially following cotton or other crops such as chickpea that provide little ground cover. The use of short-term cover crops may then help capture rainfall by maximising infiltration and minimising evaporation, and maintain Arbuscular Mycorrhiza (AM – formerly known as VAM) levels for efficient phosphorus uptake in cotton.

Long-term field experiments have also looked at management impacts on key beneficial microbial communities in cotton farming systems. Legumes in rotation provide high quality organic matter and have a significant positive effect on N mineralization 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 activities.

Crop rotations and fallow can be an important part of an integrated weed management system, providing the opportunity to use different groups of herbicides, as well as incorporate other measures such as strategic cultivation and crop competition. Refer to the Integrated Weed Management chapter for more information.

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

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

The Cotton Rotation Crop Comparison Chart (Disease management Chapter 13), provides a comprehensive matrix as to the different rotation crops available and their positive and negative impacts.

Useful resources:

Refer to the Cotton Rotation Crop Comparison Chart Chapter 13.

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

***my*BMP – www.mybmp.com.au**

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Selecting the seed

By **Robert Eveleigh** (CSD)

There are a range of varieties that can be selected and grown. Varieties are generally chosen based on yield, quality and disease resistance characteristics. But other traits such as determinacy, leaf shape and season length may also be important. Five varieties containing the Bollgard 3 technology will be available for planting in 2018 (see below).There are also three varieties containing the Roundup Ready Flex trait without BG3 and one straight conventional cotton variety. The full range of cotton varieties available are outlined on the CSD web page: www.csd.net.au.

Yield

In irrigated production systems yield is the primary selection characteristic. Some varieties are widely adapted and can perform in a range of environments. The new Sicot 714B3F is derived from the Sicot 71 family. This variety has demonstrated exceptional yield performance in a wide range of environments and is also the best choice for growers in regions with shorter seasons such as the upper Namoi and southern NSW and Victoria.

Sicot 746B3F and Sicot 748B3F are full season varieties that perform well in full season environments. They have similar yield, quality and disease tolerance. Sicot 748B3F however, is more vigourous than Sicot 746B3. Sicot 748B3F should be selected for fields that generally produce shorter cotton – such as fields with a history of soil constraints or if full water cannot be guaranteed.

Raingrown production systems require varieties that yield well in water limited situations. The best raingrown varieties are generally very indeterminant and have robust fibre characteristics. Sicot 748B3F is generally the best variety for central and western raingrown environments while Sicot 714B3F is more suited to short season raingrown environments or late planting.

The relative performance of cotton varieties can be compared online at www.csd.net.au using the variety comparison tool and the latest variety guide should be consulted to assist in selection.

The final yield of any variety is the product of its yield potential limited by the environment. It is worth your time to select the best performing variety for your farm. In fact different fields on your farm may require different varieties to achieve the highest yields. Varieties can be selected on past performance but most new varieties will have to be selected on the previous seasons trial data. Historically cotton growers change varieties rapidly to grow the higher yielding replacements. Cotton varieties bred in Australia have demonstrated a 1.8% increase in average yield per year, so newly released varieties are probably the best choice for your farm.

Best practice…

- **In addition to yield potential, consider quality traits, disease ranking and leaf shape when selecting variety.**
- **If planning to access biotechnology traits, contact a Technology Service Provider (TSP) to find out more about requirements and stewardship.**

Quality

Australian cotton quality is regarded as some of the best in the world. Breeding has improved fibre characteristics. Fibre length and strength has been increased significantly in recent years. Micronaire values vary from year to year and are influenced by the environment but breeding has helped keep micronaire values in the premium range for most growers. Lack of contamination also makes Australian cotton attractive to spinners. Some varieties such as Sicot 754B3F have exceptional fibre characteristics and may achieve additional premiums. Pima cotton has the best fibre quality and commands a higher price for lint, however no varieties are currently commercially available.

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

TABLE 1: Varieties containing BG3 summary.

	Sicot 746B3F	Sicot 748B3F	Sicot 754B3F	Sicot 714B3F	Sicot 707B3F
Climate suitability	Central/Hot	Central/Hot	Central/Hot	Cool/Central	Cool
Production	Irrigated	Irrigated, Raingrown	Irrigated	Irrigated, Raingrown	Irrigated
Maturity	Full	Full	Full	Medium/Full	Medium/Full
Growth habit	Compact	Tall	Tall	Compact	Compact
Boll size	Med/Large	Med/Large	Med/Large	Med/Large	Med/Large
Relative gin turnout	45	44	43	42	42
Relative Length	1.21	1.23	1.24	1.20	1.19
Strength	31	31	30	30	30
Micronaire	4.5	4.5	4.5	4.4	4.6
Bacterial blight	Immune	Immune	Immune	Immune	Immune
V-Rank	101(10)	101(10)	91(10)	113(10)	112(9)
F-Rank	139(5)	135(5)	155(5)	130(7)	117(1)
Seed size (ave seed/kg)	11730	11795	11850	10045	9675

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the hotter regions selecting varieties with lower relative micronaire may assist in minimising discounts and achieving premiums. In raingrown situations selecting varieties with the best fibre length will reduce the chance of length discounts. Variety selection can also impact on grades. Okra leafed varieties sometimes achieve slightly lower grades than normal leaf varieties due to the leaves 'catching' on the cotton plant at defoliation time and contaminating the lint. Careful defoliation and ginning will limit any grade loss.

Disease

Breeding has provided the main method of managing our major diseases such as Bacterial Blight, Verticillium and Fusarium wilt. The industry has developed a ranking system (F rank for Fusarium and V rank for Verticillium) to allow growers to compare the disease resistance of varieties.

A standard ranking scheme has been developed which indicates the resistance performance of commercially available cotton varieties as a percentage of industry nominated benchmark varieties (with the number of trial comparisons used to determine the number reported in brackets).

The best commercial varieties available currently have an F rank of about 155 and a V rank of around 112. Breeding aims to improve the disease resistance over time and new varieties generally have improved F rank. Breeding varieties with higher V ranks is slow and difficult. CSIRO breeders are working hard to develop better verticillium tolerance. By selecting varieties with the highest disease resistance in fields with significant disease pressure, yields will be maximised. In the case of Fusarium and Verticillium, selecting the most resistant varieties can help to reduce the inoculum in the soil, thereby reducing its impact on subsequent crops.

The latest disease rankings are available in the CSD Variety Guide and online at www.csd.net.au

Refer to the Integrated Disease Management chapter for more information.

Okra leaf shape

The 'okra' leaf shape has been used in some Australian varieties since the early 1980s. It is a useful trait that has demonstrated some resistance to heliothis, mites and more recently whitefly. Varieties with 'okra' leaves have also been shown to be more water use efficient. But the trait requires careful breeding to achieve equivalent yields to the best normal leafed varieties. There are currently no commercial varieties with okra leaf shape but breeding with the trait is continuing and CSD is currently seed increasing a new okra leaf variety that may become commercially available within the next few years. For more information about cotton varieties go to www.csd.net.au or contact CSD.

Biotechnology

Today there are two broad classes of cotton biotechnology traits which are approved and available in Australian cotton varieties providing either insect protection, herbicide tolerance or in varieties which are 'stacked' with a combination of both traits.

Bollgard 3 technology has now replaced Bollgard II. Bollgard 3 controls a range of lepidopteran pests including the Helicoverpa spp. and produces 3 insecticidal proteins Cry1Ac and Cry2Ab, and Vip3A. One of the key benefits of Bollgard 3 is the significant reduction in insecticide use which has allowed for an increased adoption of Integrated Pest Management (IPM) principles as well as providing growers with a consistent platform to manage insect control costs. Bollgard 3 reduces, but does not eliminate the continued threat insect resistance poses to the Australian cotton industry. Continued vigilance and adherence to the approved resistance management plan is essential.

Roundup Ready Flex technology confers full season tolerance to glyphosate herbicides. The ability to use registered glyphosate herbicide in-crop to control a wide range of weeds, allows growers to design weed control programs that can target individual fields and specific weed problems. The technology has reduced the reliance on pre-emergent herbicides and has allowed growers to more effectively use minimum tillage techniques and reduce manual weed chipping costs. Development of the 2nd generation of stacked herbicide traits is underway and expected to be available by 2021.

When selecting a variety, the presence of a trait is indicated in the name of the variety.

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

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

Accessing biotechnology traits

The access to the various traits is governed by the major technology companies who develop and commercialise the technology via an annual license called a TUA. The TUA forms the basis of the relationship between the grower and the technology company. The primary purpose of the TUA is to clearly define the terms and conditions associated with use of the technology in a particular cotton season. It covers a broad array of matters and includes the prices, payment and risk management options for the technology. It also includes stewardship requirements particular to a technology. There is a requirement to undertake training from the trait provider prior to accessing the technology.

In practicality, the actual licensing process is managed by Technology Service Providers (TSPs) on behalf of the technology companies. TSPs are primarily well known local and national retailers of crop protection products and cotton planting seed. Growers should direct initial enquiries about accessing biotechnology to their local TSP's.

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

A list of current TSPs can be located at: www.monsanto.com.au/products/cotton/

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Nutrition

By **John Smith** (NSW DPI & CottonInfo)

Acknowledgement: Ben Macdonald (CSIRO) and Graeme Schwenke (NSW DPI), Jon Baird (NSW DPI), Brendan Griffiths (UNE), Chris Dowling (Back Paddock), Jon Welsh (CottonInfo/AgEcon), Oliver Knox (UNE)

Ensuring the crop has adequate nutrition is critical to maximising yield, but with fertiliser application making up one of the highest variable cost line items in the irrigated cotton gross margin, nutrient efficiency is a key management consideration.

Long-term farm management and fertiliser strategies should build and maintain adequate soil nutrient levels for continued high levels of production.

Maintaining a balance between crop removal and soil supply sustains lint yield and quality of cotton and other crops within the farming system, as well as preventing the development of nutrient deficiencies and the risk of adverse off-site consequences of over-application.

Cotton crop nutrition should not occur in isolation, but should be planned with consideration of other management practices such as:

- Position in the 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 or starting soil moisture levels in raingrown production).
- Soil physical condition.

Nutrient removal

High yielding cotton in the Australian production system typically leads to the removal of large amounts of nitrogen (N), phosphorus (P) and potassium (K) from the soil in the harvested seed-cotton (Table 1).

Nutrient supply

The supply of nutrients for a cotton crop is dependent on residual nutrient reserves in the soil from a previous crop, in-crop mineralisation of nutrients from soil organic matter, and nutrients added as fertiliser. Routine soil analysis, as part of crop management, can provide an indication of the fertility level in your soil at that point in time. A decision support tool to better account for soil mineralised N is currently being developed through funding from CRDC.

Once soil nutrient levels have been measured and seasonal nutrient tactics developed, then fertiliser requirements can be more accurately calculated. Seasonal nutrient tactics take into consideration historical and expected yield, cropping history, cropping system and nutrient losses, crop use efficiencies, plant nutrient recovery and uptake, soil condition and characteristics – decision support programs such as NutriLOGIC can assist.

There is considerable variability in the supply of nutrients from the soil both across a farm and within a field. The use of yield maps, land-forming cut and fill maps or soil surveying equipment, such as Electromagnetic Surveys (EM Surveys, commonly used by Precision Ag advisors), can be used to guide fertiliser inputs spatially within fields. An important aspect for nutrient supply is that for most nutrients more than 50 per cent is taken up during the flowering period (see Table 2). This has two major implications; firstly, 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; secondly, late application of most nutrients has little impact on plant development and yield.

Best practice...

- **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.**
- **Monitor nutrient levels in soils during the cropping rotation to ensure nutrition strategies are not leading to a decline in soil fertility or excessive nutrient loading.**
- **Making the most of nutritional inputs relies on good irrigation, disease and weed management.**

Nitrogen

Cotton sources most of its N as nitrate-N from the mineralisation of soil organic matter and residual soil mineral N. Mineralisation is a biological process within the soil that results in the release of nutrients in a form that are available for crop uptake. Typically around 2/3 of the crop's N needs comes from soil N while the remaining comes from N fertiliser. Uptake of the soil N is much more efficient than the uptake of fertiliser N. A farming system that incorporates legumes and cover crops increases soil carbon, soil mineral N and lint yield.

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

Irrigation management can also influence the amount of nitrogen, both soil and fertiliser, that is lost from the system.

The cotton plant uses N throughout the entire growing season, with the greatest requirement during the flowering stage (Figure 2). Insufficient nitrogen supply during this period will reduce yield. However, excess

250 N on left and zero N on right. (Photo taken by John Smith NSW DPI)

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

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

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

nitrogen can also have significant detrimental impacts on cotton. 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 problems associated from over-fertilising with N. All these impacts have considerable economic costs associated with them and result in reduced profitability through lower yields, quality down-grades, increased production costs, higher fertiliser costs and reduced N efficiencies.

Matching N supply to crop N requirements requires close monitoring and management because N availability is affected by a range of physical, chemical and biological processes that occur in the soil. These processes are influenced by climatic conditions such as temperature and rainfall intensity. Irrigation deficits and incidence of waterlogging also affect the amount of nitrogen taken up by the plant, retained in the soil or lost to the environment (Figure 1). Therefore, the key to maximising the return from N inputs is in applying the right fertiliser, at the right rate, at the right time, in the right place.

Right fertiliser

There are different chemical or physical forms of fertiliser that can be used to supply N to cotton, eg. manures and composts, granular fertilisers, anhydrous ammonia (gas), and liquid fertilisers. Anhydrous ammonia (82 per cent N) and urea (46 per cent 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

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

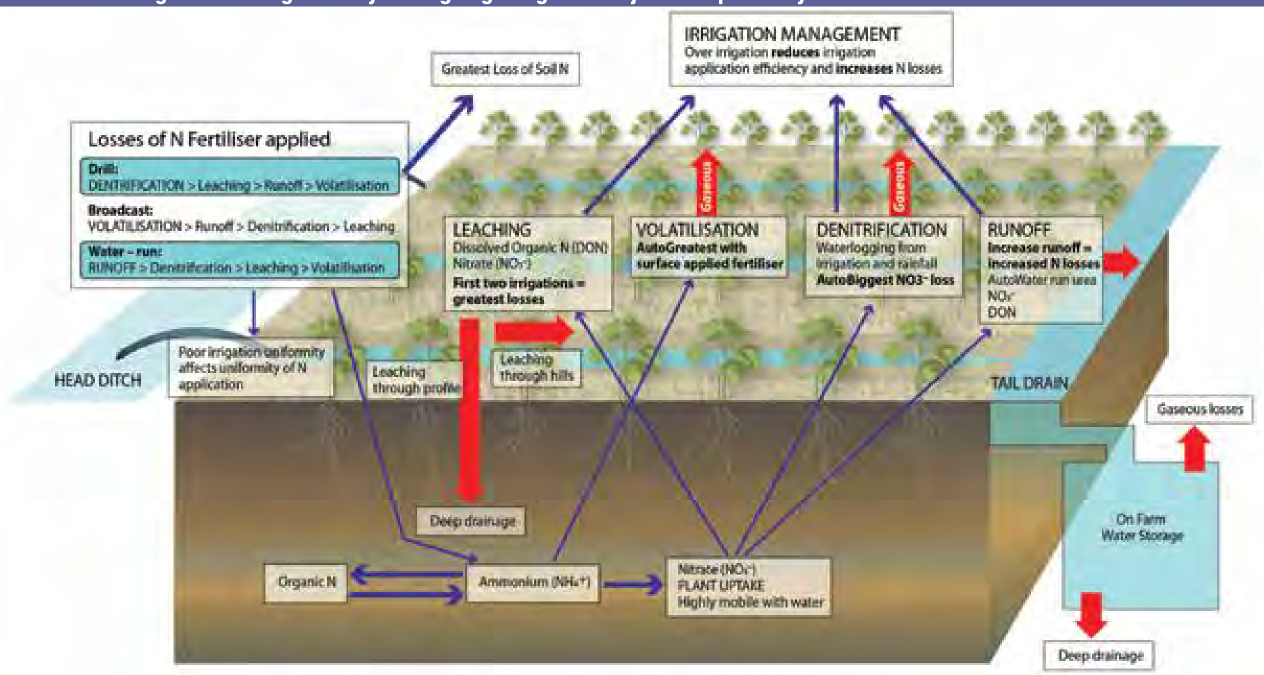
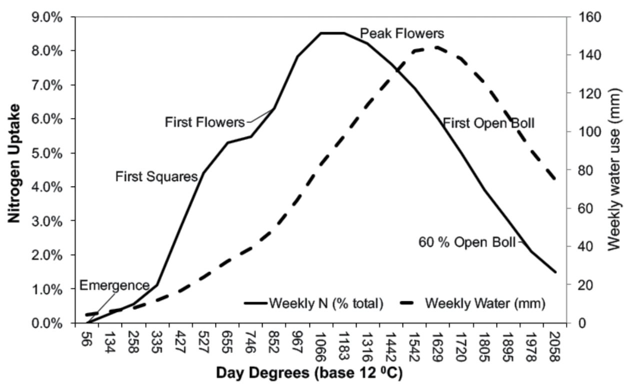


FIGURE 2: The pattern of plant N uptake and water use for an irrigated cotton crop. (Source: Chris Dowling, Back Paddock)



incorporated, anhydrous ammonia (gas) needs to be applied at a depth of at least 15cm by trained staff using specialized equipment. Studies have shown that the effectiveness of water-run anhydrous ammonia can be poor due to uneven distribution and substantial losses due to ammonia volatilisation. Urea has the advantage of being able to be applied using a range of different application methods and times. However, it does need to be timed with a rain event or incorporated quickly after application to reduce the risk of significant ammonia volatilisation losses.

Right rate

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

- Determine soil nutrient status using pre-season soil sampling (ideally to a depth of 60–90cm 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 soil and fertiliser N, soil condition and characteristics – decision support programs such as NutriLOGIC can assist.
- Develop a fertiliser use plan that is best suited to your farming system and environment.

The fertiliser rate will depend on the type of fertiliser being used, when it is being applied and how much of each nutrient is required. The composition of the fertiliser (percentage of each nutrient in the fertiliser) will dictate just how much of the product needs to be applied to meet the crop requirement. If all the fertiliser is being applied up front, 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.

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

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

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

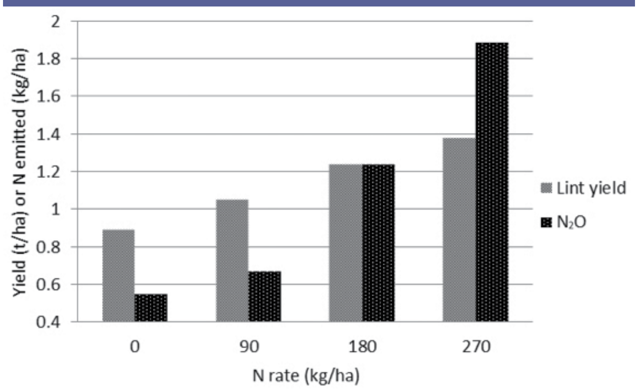
production (representing denitrification N losses) increased exponentially as the rate of applied N increased beyond crop uptake capacity in a wheat/cotton rotation field experiment conducted on the Darling Downs. Figure 3 shows the relationship between lint yield and nitrous oxide emissions in response to variable rates of nitrogen application. 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. When applying N prior to planting remember:

- Apply in winter when soils are cool to reduce the period of risk of substantial losses through denitrification and leaching due to heavy rainfall events.
- Allow sufficient time after application into moist soil and before planting (3 weeks) to prevent seedling damage (especially with anhydrous ammonia fertiliser).
- Apply N at the correct depth and position to prevent unnecessary losses and seedling damage.
- Composts and manures need to be spread and incorporated prior to planting. N from recycled organic material may not be available to the crop established in the year of application.
- Split application allows for rate adjustments as the season progresses which may improve the return on the fertiliser inputs thereby improving efficiency. However, timing of split application is critical and rain (wet soil) may impact on the ability to apply fertiliser in-crop in a timely

FIGURE 3: Cumulative nitrous oxide (N_2O) emissions and lint yield in response to N application on cotton at Kingsthorpe (Qld) on a heavy black clay in 2010–11. (Source: Scheer, et al 2013)



manner, increasing the risk of crops being nutrient deficient during high demand periods (eg. flowering for N).

- Applying N too late can favour diseases such as Verticillium wilt and boll rots (see disease chapter), may delay maturity, and affect defoliation.
- Anhydrous ammonia (gas) fertiliser cannot be applied too close to planting as seedling damage may occur from ammonia burn, (this can also be a problem with urea especially where placement is close to the seed row).

Right place

Most fertilisers (other than foliar) are applied to the soil, pre-plant, at depth (preferably 300 mm) and off the plant line. Applying fertilisers too close to the plant line may cause seedling damage due to the salt or toxicity effects. Anhydrous ammonia should be applied deeper than 15 cm to reduce losses to the atmosphere through ammonia volatilisation. Soil condition will affect these losses with escape from dry soils occurring due to air spaces within the soils, whilst losses from wet soils occur back through the application furrow. Other fertilisers eg. P, K, Zn etc. can be broadcast and then incorporated later to maximise contact between the roots and fertiliser, although recent research into P and K application indicates the preference for application at depth or even before the previous crop within the rotation due to the lack of mobility of these nutrients within the soil.

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

Right fertiliser, at the right rate, at the right time, in the right place is important for the supply of all nutrients. It is of particular importance for N fertiliser application because of the potential for loss of N from the system and must be considered within your system when preparing an N management plan (Figure 1). These include:

- **Denitrification –** This is the most important loss of nitrate-N in irrigated cotton systems and can easily lead to losses greater than 50 per cent of the N especially where excessive rates are used to achieve yield targets, or where poor layout dictates long irrigations which results in extended water-logging. It is a biological process that occurs under low oxygen conditions, such as during water-logging, where nitrate N is converted into nitrogen gases and lost to the atmosphere. One of these gases is nitrous oxide, a greenhouse warming gas that is accumulating in the atmosphere and is contributing to ozone depletion.
- **Leaching and runoff –** Nitrates can be washed through the soil profile and out of the root zone or removed in runoff water. If you are recirculating or water-running N then use it quickly on another field. Add the N in the head ditch near to the crop to avoid losses.
- **Ammonia volatilisation –** Particularly important when solid urea is applied to the soil surface and not incorporated properly or in a timely manner. Risk of loss via this pathway is greater where: plant residues retained on the soil surface prevent the granules from contacting the soil; and, where soils contain low clay contents; soils are wet and drying; conditions are windy. Free lime (Calcium carbonate) present in the soil can accelerate ammonia volatilisation where ammonia sulfate fertiliser is used.
- **Removal of seed cotton –** Most of the crop N removed from the system is found in the cotton seed and can be significant, particularly in high yielding crops.
- **Burning stubble –** The heat from fire destroys organic matter in the surface soil, and much of the N, P and S contained in the soil organic matter and crop residue will be lost to the atmosphere during burning. Burning stubble is not common in modern cotton farming systems.

Nitrogen Fertiliser Use Efficiency (NFUE)

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

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

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

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

Phosphorus

The aim of phosphorus (P) application to crops should be to replace that removed in crop products thereby at least maintaining the same level 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 plants cells, is used in plant genetic processes and regulation of plant metabolism.

Plant P deficiency causes reduced seedling vigour, poor plant establishment and root development, delayed fruiting and maturity. Plants will appear stunted with red/purplish colour. Phosphorus is highly immobile in the soil meaning that it basically stays where it is put in the soil. This makes the application challenging in cotton crops because of the coarse root structure of the cotton plant.

Cotton roots do not congregate in areas of high P concentration like fibrous root systems of cereals plants, adding to the challenge of where best to apply P to get it into the plant. However, only about 20–30 per cent 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 of P in the soil, of which fertiliser application in previous years has contributed.

Placement of fertiliser P is something that needs careful consideration because cotton roots 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. P must be available throughout the soil profile where plant roots will be active. By treating a large area this maximises the fertiliser that may be exposed to interception in the soil by the plant roots.

Low rates of P can be applied with the seed (up to 9 kg P/ha or 40 kg/ha MAP, 1 m row spacing) where there is good seedbed moisture. There is some risk with this due to the production of ammonia and salinity during the breakdown of MAP (DAP should not be applied with the seed) that may affect germination and seedling establishment. Side-dressing of P fertiliser between sowing and squaring may not be as effective as applying P before planting.

Soil P is available to crop via several pools and interactions. It is important to understand the pools and interactions to understand how the soil test methods relate to them. There are three soil test measurements of P that are important to understand for P budgeting:

- The 'labile' or 'sorbed P'(fast release) is the pool delivering P into the soil solution, as the plants draw solution P from the soil. This pool is most strongly correlated to the 'Colwell' measurement test.
- There are also slower release pools of P in the soil. It is these that generally hold the compounds formed in cotton growing soils from prior fertiliser application, eg. calcium phosphate. It is this pool that delivers P into the fast release pool, and is the pool that is most likely to be depleted over time. This pool is measured using the 'BSES' soil P test, in the surface 0–10 cm, and the sub-surface depth of 10–30 cm.
- The Phosphorus Buffering Index (PBI) provides an indication of the likelihood of applied fertiliser P being tied up. The higher the number the more likely the fertiliser P will be tied up: <140 low; 140 280 moderate; >280 high. The majority of cotton soils are in the low to moderate PBI which increases P placement and timing options.

Measuring both the labile and slow release pools of P is important in tracking soil P fertility. The Colwell P test may remain relatively constant over time indicating a sufficient level of P input. However, the slow release pool maybe 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 shows up as a decline in the labile pool (decreasing Colwell P test) it will be more difficult and expensive to restore background levels of P in the soil.

Use soil testing in conjunction with plant tissue testing (critical level around 0.33%) as well as nil and high fertiliser P application strips in fields to determine if P is limiting and whether responses to applied P are being achieved.

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

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

Potassium

Potassium (K) is a mobile nutrient within the plant and has a role in energy transfer, osmotic regulation (maintaining turgor), protein synthesis and nitrogen metabolism. Adequate K nutrition has been linked to reducing the incidence or severity of plant diseases and improving yield and fibre quality.

There are several forms of K found in the soil that are available to the plant. These include K in the soil solution freely available, exchangeable K held on clay particles and organic matter and non-exchangeable K held in and on clay particles and not readily available to plants. While most soils have large amounts of K only a small proportion (less than 2 per cent) is available to plants.

Potassium is absorbed as the $K+$ ion from the soil solution. Its uptake is affected by competition with the other cations in the soil solution, including $NH4+$, $Na+$, $Mg++$ and $Ca++$. Other soil factors that affect K uptake include cation exchange capacity (CEC) and soil structure. As CEC rises, the soil solution K concentration typically falls due to selective adsorption of K onto exchange sites on the clay surface, with the rate of K supply to the plant reduced. Sodic or poorly structured soils allow K in the soil solution to diffuse less efficiently towards the depleted zones around cotton roots, also reducing the ability of the soil to meet crop K demand.

Premature senescence is a potassium-related disorder that can occur in cotton regardless of the supply of K from the soil. Other nutrients, including phosphorus, have been found to be deficient in affected plants, although not to the same extent as K. The disorder is chiefly caused by the imbalance between a plants nutrient demand due to a high boll load, and the plants inability to meet this demand. 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 plants capability to meet crop demand especially during the period of peak demand between flowering and boll fill. Deficiencies at this time will have detrimental effects on lint yield and fibre quality. There is also evidence of an association with Alternaria infection, although both can occur independently.

When deficiencies are experienced later in the season, as the developing boll load is a strong and competitive sink for available K, the youngest mature leaf (YML) at the top of the canopy is often the first to show symptoms.

Treatment of K related early senescence is rarely effective after the appearance of symptoms. Increasing soil K supply, and foliar application of K to the crop canopy in the weeks preceding the critical growth period and a triggering weather event have been the most effective strategy to reduce the incidence and effect of senescence.

Other essential nutrients

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

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

Although plentiful in the soil, 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 deficiencies in alkaline soils. Deficiencies are generally short lived when related to waterlogging events and should be managed via foliar application for most cotton soils.

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

For more information the following resources and tools are available at www.cottoninfo.com.au and www.mybmp.com.au

NUTRIpak, FIBREpak, SOILpak

Vetch Fact sheet

Nutrients removed in harvested seed-cotton

Nutrilogic

Australian Soil Fertility Manual (2006) Graham Price (Ed). Fertiliser Industry Federation of Australia.

Monitor your soil

It is important to monitor your soil because farming practices impact on the soil chemical and physical properties. While there are no hard and fast rules about when to do this, a good start would be to conduct comprehensive cropping soil tests in increments of 30cm down to depths of 60–90cm once within the farming rotation. This would be best done before a cotton crop given that it has the highest nutrient requirement. In a continuous cotton cropping rotation this would be best done once every three – four years.

Due to inherent soil variability within fields it is important that soil samples are representative of differences within the fields. Fertiliser manufacturers and suppliers have sampling protocols based on field size or soil type variability within fields. In irrigated cotton fields differences in soil N levels have been identified between head ditch and tail drain ends of the field and should be considered separately for the determination of crop N budgets.

The soil samples need to be sent for analysis as soon as possible after sampling. If samples are likely to sit for even a small number of days they are best stored in a fridge to minimise the soil biological activity that is occurring in the sample. The biological activity is a potential source of greater variability in the soil samples.

Monitoring can then be used to identify new or changes in existing issues 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 soil related problems can result in poor seedling emergence, poor plant growth, loss of bolls and poor boll set, reduced yields, erosion, increased land management costs and other management issues.

Soil organic matter

Importance of soil organic matter

Soil organic matter plays an important role in 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.

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 (%) x Fallow period rainfall (mm)

In-season mineralisation
Net N mineralisation =

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

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

Organic matter losses

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

Managing soil organic matter

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

Inputs of organic materials include:

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

Losses can be reduced by changing management practices:

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

It may be difficult to achieve this balance in every cotton production system, due to soil type, environmental conditions and agronomic constraints.

Some of these practices have conflicting impacts. For example, retaining crop stubble on the surface reduces buildup 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, research has shown that a strategic, targeted tillage operation to incorporate stubble and control pupae, can help increase soil carbon. Cultivation can promote loss of soil water and expose the soil to erosion.

Most of a crop's nutrient requirements are met from the recycling of soil organic matter and the nutrients released during the decomposition of this material. Inorganic fertilisers are required when the soil is unable to meet a crop's nutrient demand and are critical in optimising production. Manures and composts can be an important source of organic matter for soils as well as a valuable supply of nutrients. However there is a time lag between the applications of these materials and when nutrients become available to the crop because the nutrients are released slowly to the soil through biological processes.

In irrigated cotton systems, research has shown that the decline in soil organic carbon levels can be reduced or stabilised with changes to conventional cropping systems. By eliminating deep tillage operations, soil structure can be maintained and by incorporating stubble, good soil health is promoted. Other management practices, including reducing fallow periods and optimising water and nutrient applications, can also play important roles.

Sodic soils

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

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

TABLE 3: Sodicity classification for Australian soils.

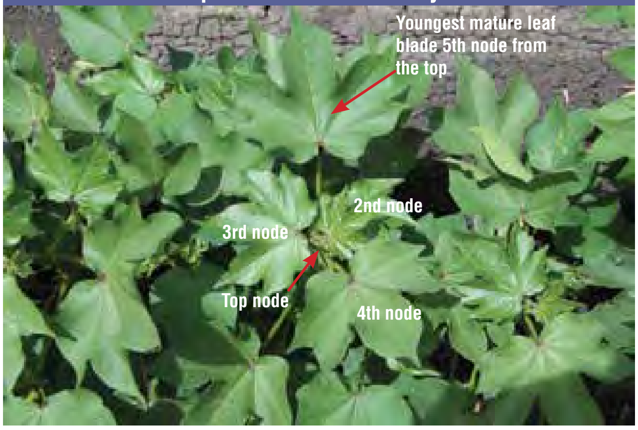
Classification	Definition
Non sodic	ESP <6
Low sodic	ESP 6 – 10
Moderately sodic	ESP 10 – 15
Highly sodic	ESP >15

As soil sodicity increases there are several detrimental effects on the soil's physical properties that influence plant growth and yield potential. Soil dispersion increases in sodic soils resulting in reductions in the infiltration rate of the soil, the hydraulic conductivity of the soil, and the plant available water capacity of the soil. So, in sodic soils, water is not able to get into the soil as fast, cannot travel within the profile as well and there is less ability to store water for plant growth. These soils become increasingly hard-setting and have greater susceptibility to waterlogging. There is only a narrow band of ideal conditions for plant growth between the soil being too wet and then becoming too dry with a physical barrier of hard soil for root penetration.

Sodic soil can be ameliorated by applying calcium to displace the sodium from the clay surfaces. The best form of calcium to use is determined by the pH of the soil. If the soil is alkaline, gypsum will give the best results while if the soil is acid, lime should be used. In this case, lime also has the added benefit of raising the pH of the soil. Sodicity at depth (>30cm) is difficult and expensive to manage because of limited penetration of surface applied and incorporated ameliorants.

The addition of organic matter to soil helps to reduce the effects of soil sodicity. Organic matter helps hold the soil aggregates together, stabilises soil chemistry, reduces dispersion and improves soil structure. It is difficult to get sufficient organic matter deeper into the soil.

FIGURE 4: Identification of youngest mature leaf blade used for leaf and petiole nutrition analysis.



Management of paddocks with sodicity at depth (>60cm) should be done by adjusting inputs to better match the reduced yield expectations in combination with careful planning of rotation crops.

Saline soil

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

Salinity is measured by testing the soil solutions electrical conductivity (EC).

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

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

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

Compaction

Soil compaction is characterized by a reduction in airspace and increase in soil density and strength restricting root growth, reducing the availability of nutrients and water to the cotton plant. It can also increase denitrification, further reducing the availability of nitrogen. Some compaction is an inevitable consequence of using heavy machinery on soils, but by implementing good management practices, minimum tillage systems and guidance systems, the impact can be minimised or localized (eg. tramlines).

Restoration of compacted areas can be difficult and expensive when it occurs at depth. Machinery operations on wetter than ideal soils can quickly exacerbate a problem.

For more information the following resources and tools are available at: www.cottoninfo.com.au and www.mybmp.com.au

WATERpak

NUTRIpak

SOILpak

Chapter 8 sponsored by – Growth Agriculture INNOVATE AG

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, may be rectified by applying the appropriate fertiliser with little or no impact on the crop.

Vegetative growth rate

Tracking the vegetative growth rate (VGR) can also provide an indication of how the crop is developing and can be used, along with petiole and leaf testing, to identify if reduced growth is related to nutrition or some other disease, pest or environmental conditions.

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

Leaf analysis can be used to monitor all nutrients including micronutrients. Sampling leaf tissue twice (at flowering and cut-out) produces the most useful information. Follow sampling directions carefully, 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 (eg. during waterlogging or cloudy weather).
- Sample at least 50 petioles or 50 leaf blades from the youngest mature leaf, normally 4th or 5th unfolded leaf from the top of the plant (refer to Figure 4).
- Leaf blades must be immediately removed from the petiole
- Collect samples with clean, dry hands or clean gloves, as sweat and sunscreen can contaminate.
- Samples should be loosely packed in a paper bag and stored in a cool place (refrigerator) immediately and transported to laboratory as soon as possible.

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

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

For more information the following resources and tools are available at: www.cottoninfo.com.au and www.mybmp.com.au

NutriPAK

SoilPAK

NutriLOGIC

Cotton Symptoms Guide

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-par 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 (OM) are key components in being able to do this.
- **There are several pools of phosphorus in the soil.** It is important to understand these and the soil test methods that relate to them. The 'labile' or fast release pool of P is the pool delivering P into the soil solution that the plants draw from. This pool is most strongly correlated to the 'Colwell' P soil test. There are also slower release pools of P in the soil and you measure this pool using the 'BSES' soil P test. It is critical to at least replace what the plants are removing each year. As P is relatively immobile in the soil, and cotton seems to have difficulty locating bands of P, it is important when you apply P fertilisers to treat the largest volume of soil possible, to ensure maximum root interception, and to some depth if practical.
- **Promoting your soil biology with cover crops and rotations can help to buffer any N in your system and reduce losses.** There is more soil biology under rotations and cover crop systems than fallows and this increased biomass can sequester N, preventing losses and allowing it to be recycled into the crop over a season. Remember the soil is providing about two thirds of your crop N, so you need enough soil biology there to do this effectively.
- **A cover crop's roots allow for better water infiltration, provide more continuity of carbon to feed your soil biology and protect your top-soil from the ravages of heavy rain and wind.**
- **15 bale 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 penalties from water logging can be 12kg lint per hectare per hour ($21/ha/hr).
- **Storing N in your soil and irrigation water is going to lead to losses.** Try to match the N in the soil to meet the crop's demands and if you are recirculating or water-running N then use it quickly and add the N near to the crop. Once N is in the soil or water it is converted to nitrate and from there it can be lost. When denitrification occurs small amounts of nitrous oxide, a greenhouse warming gas, is emitted into the atmosphere, as well as large amounts of nitrogen gas. There are always likely to be some losses, but management can help reduce them. When finishing the crop, foliar N application may be an alternative to water-run urea to avoid large losses of N in hot conditions.
- **Grab your copy of NUTRIpak and SOILpak and learn more about soil processes that affect your crop and how to manage them.** As (the late) Dr Ian Rochester would have said: "Stop treating your soil like dirt." Consider your soil, your rotation, the use of cover crops, review and improve your nutrient management.

Energy use efficiency

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

Energy inputs are becoming increasingly scrutinised by policy makers and can also be a considerable cost to primary producers generally, and this is particularly true for cotton. Fuel, oil and electricity costs totalled $275/ha in 2017, behind employee wages ($485/ha) and nutrition ($515/ha) as the highest cost line item in an irrigated cotton gross margin (Boyce, 2017).

Irrigated cotton growers can reduce energy costs in one of three ways: reduce demand through saving water; improving energy efficiency of machines/pumps and finally; and, substituting traditional grid or liquid fuels with renewable energy sources. Improving energy efficiency also makes significant reductions in Greenhouse Gas (GHG) emissions. Reducing GHGs are important in maintaining the 'clean and green' image of the Australian cotton industry, and this helps our product access export markets for sustainable cotton.

To understand the range, costs and contributions of energy use to cotton production, a number of steps can be taken to ensure best management practice.

Monitor to manage

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

- For all pumps, measure diesel and electricity use: $/ML/m head. This is an easy first step to benchmark any given pump against industry findings (refer to Best practice box for benchmarks).
- Review your electricity bills and meter readings to ensure readings are correct and tariffs are appropriate for your farm situation. It's a good idea for demand tariff customers to tendering usage via an electricity broker.
- Adding a variable speed drive or improving Power Factor Correction (PFC) (located on your electricity invoice) can also achieve energy savings and high investment returns.
- When purchasing liquid fuels consideration is given to buying strategy and period of demand (to manage seasonal fluctuations), storage life of fuel and fuel quality.
- Using heat wave prediction service to prepare the farm for high energy demands eg. maintaining inventory, servicing diesel motors, adequate fuel supplies on hand.

Best practice…

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

Water management to reduce energy costs

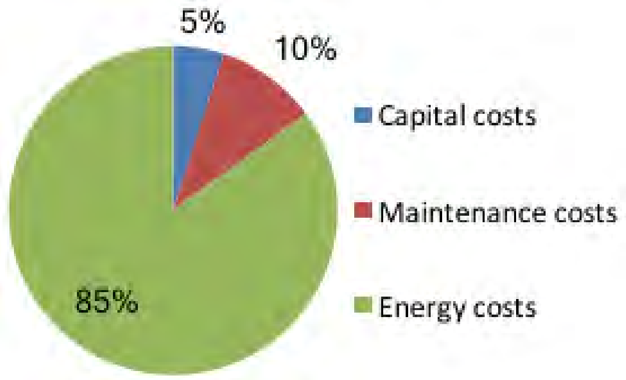
Reducing or optimising the amount of water pumped around the farm can substantially lower demand and energy costs. CottonInfo has a suite of resources with the latest research and knowledge on water use and management range from collection through to field distribution (eg. WaterPak). Again, measuring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

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

Auditing a pump site

History shows that pump stations in the cotton industry are generally over looked when it's time to upgrade farm machinery or equipment. Cotton

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



growers tend to spend more time in the farm ute or tractor, which receives an upgrade every three to five years, while the pump station continues to operate alone on the river bank or out in the field with very little attention. For the past 10 years, plus, there have been many man hours and dollars spent in research to identify where energy is consumed on-farm and how to improve our energy efficiency. From this research, it has been determined that irrigated cotton farms consume approximately 45% of their on-farm energy through pump stations, for bore irrigators this can be as high as 75%. Next time you're planning a new site for a pump station or walking past an existing pump station, consider how much could be saved when applying the lessons learnt to date.

Pump station are a long term significant investment, not only have they become expensive to operate, but get it wrong and you put your crop at risk. Areas to consider when investing into a pump station include the capital costs, maintenance costs and energy costs. Figure 1 illustrates the weighting for each category with the majority of costs accrued in energy through the project life.

Investing in capital and maintenance cost are ways to improve energy efficiency. Pulling out a Perkins engine from the old harvester and connecting to a pump found at last week's clearing sale might have a cheap capital outlay and pump the required irrigation water. But as a result, there is now a significant increase to maintenance and fuel costs. Such systems can potentially save up to 50% in energy costs and considerable man hours 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 stations 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/management plan and any recommendations for future upgrades to improve energy efficiency. In some cases, it is also possible to increase water flow rate.

Data collected and information required to conduct an energy audit are as follows:

- Establish the tasks required of the pump station.
- Annual operating hours.
- Area under irrigation.
- Production.
- Pump and motor make and model.

Measurements include:

- Suction and discharge pressures.
- Pump shaft and motor shaft speeds.
- Water flow rates.
- Static elevations.
- Fuel or electricity consumption.
- Pipe distribution network.

As a management plan, knowing what speed to operate the pump for best efficiency and maximum water flow rate gives options to meet the tasks required, whether it be flood harvest, irrigation or numerous others. A number of observations from previously conducted pump audits has resulted in a number of findings.

A high number of engines and electric motors have been over sized for the task required of the pump. This can lead to low loads 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 ideally should be below 2m/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 and not only reduce performance, increase energy costs but it can also cause significant damage to the pump itself and require regular impeller replacements if left unchecked.

It has been measured, ingesting cotton trash can reduce pump performance by 20%. Ingesting cotton trash also causes severe vibrations in the pump with potential further damage to equipment. Refer to Figure 2.

Air entrainment – 2% by volume reduces pump performance by 20%. Many growers have witnessed the whirl pools or vortices near the pump inlet. This is one way for air entrainment to occur, it has been witnessed that a corrosion hole approximately the size of a five-cent piece in the suction pipe has caused significant reduction in pump performance.

Poor sump designs, predominately too small or not enough depth of water, decreases pump performance. Water velocities in a sump should be kept below 0.3m/s. Keeping in mind that one cubic meter of water weighs one ton, this requires significant energy to change the water direction with high velocities when entering the suction pipe.

Pump station setup is critical. Many pump stations are noted of having excessive pipe network, or the pump station itself located in a poor position.

The older style mechanical engines while reliable do consume more fuel than the more modern electronically controlled diesel engines.

FIGURE 2: Cotton trash can reduce pump performance by up to 30 per cent. (Photo courtesy Phil Szabo)

These have been some of the more significant issue for the industry. 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 phase of cotton production are the processes where all of the heavy tillage tractor operations occur. These are energy intensive practices that require optimising 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 in the following areas.

Checking ripping depth and groundspeed: research has shown by reducing engine speed and gearing up, fuel consumption can be reduced by 7 litres per hour (168hp tractor). Fuel consumption can be further reduced by 10% with a small (25mm) increase in ripping depth. Deep ripping does not always provide an economic solution in some soil types (GRDC fact sheet, 2017).

Experts have observed that farmers in Australia tend to overballast their tractors. Setting up a correctly ballasted tractor can optimise fuel consumption, reduce wear and service costs and reduce compaction damage to soil. How to ensure your tractor is correctly ballasted and wheel slip is reduced for maximum traction and fuel efficiency can be found at AgInnovators.

Incorporating renewable energy into irrigation

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

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

- Satisfactory commercial payback occurs on solar only irrigation projects where water extraction rates are high and an earthen 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 (eg. capturing overland flow) of surface water has proven challenging with analysis showing standalone PV investments are on the low-end of commercially acceptable returns at the time of writing.
- Hybrid systems allow a pricing hedge of different energy sources and can reduce the reliance on fossil fuels and grid power. Figure 3 shows a hybrid diesel/solar bore in operation in the Macquarie Valley pumping 5ML/day. At dawn and dusk, DC current from PV is mixed with AC current from the generator to ensure consistent voltage supply to the irrigation pump.
- A new pumping system can offer considerable labour savings through remote monitoring and precise measurement of water resources, pump performance and pumping inputs.
- Installation returns of PV hybrid systems have shown acceptable project payback where an earthen storage can be utilised or year-round or out-of-season generation can be utilised. This may occur through pumping into storage in cooler months, operating grain drying equipment or (potentially) charging electric vehicles/machinery and replacing fossil fuels.
- A recent determination by Independent Pricing and Regulatory Tribunal (IPART) (taking effect on July 1, 2017) has seen feed-in-tariff rates increased. Those with grid connected irrigation pumps can now receive at least 10-12.5c per kWh supplied back to the energy retailer. With the cost of PV continuing to fall, domestic and industrial users have a rare opportunity to achieve commercially acceptable returns and payback periods in the current environment of rising energy prices and PV subsidies.

All references and detailed resources found at:

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

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

www.qff.org.au/projects/energy-savers/information-resources/

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

www.grdc.com.au/uploads/documents/GRDC_DeepRipping_6pp_.pdf

www.aginnovators.org.au/initiatives/energy/information-papers/tractor-ballasting

Precision ag

By **Claire Welsh** (CSIRO/University of Sydney)

Acknowledgements: Andrew Smart (Precision Cropping Technologies), Brook Sauer (McGregor Gourlay Ag Services), Nicole Dimos, Joanne Peche and Amanda Woods (SPAA), Brett Whelan (SIA USyd), David Lamb (PARG UNE), Richard Heath (AFI), Leanne Wiseman (Griffith University).

Leveraging Technology to benefit your farming enterprise.

Precision agriculture (PA), also known as site-specific-crop-management (SSCM) or mosaic farming, refers to the integration of information, computing and sensing technologies (ICT) to production-based agricultural systems.

PA is not a single technology, but a varying scope of integrated or connected sensors, monitors, records, imagery, environmental data and increasingly, analytics; individual components being selected to form a system that meets unique needs and operation size.

The application of PA is a systems management approach that utilises enabling technologies to compile quantitative, site-specific information to facilitate analysis of the production system, as well as enable an increased automation of resulting agronomic and management practices.

Commercial PA applications leverage differing combinations of specific enabling technologies such as: global navigation satellite systems (GNSS, of which GPS is one), geographic information systems (GIS), widespread 3G/4G internet access, smartphone operating systems, variable rate technology (VRT), proximal and/or remote sensor networks (yield monitors, canopy temperature sensors), cloud computing capacities, robotics/automated systems including unmanned aerial vehicles (UAVs) and autonomous tractors, and machine communication controls.

Research in action

- **The Accelerating Precision Ag to Decision Ag research project has investigated best practice for data use in agricultural production systems.**
- **The project has found the overall benefit of digital agriculture is the optimization of farming strategies/practices and resultant increased profit returns to growers.**
- **All project reports can be found here www.crdc.com.au/precision-to-decision**

Best practice…

- **There is no one-size-fits-all person or product that can provide all your PA solutions!**
- **Begin round-table discussions with your agronomist, machinery provider and/or technical consultant (together) around developing short and longer term goals for PA implementation (and anticipated production and profit gains).**
- **Create a PA implementation plan – harness these unique skill-sets to enable sound agronomic/management decisions in the field, whilst ensuring that what you want to achieve is possible with your current farm and IT equipment.**

PA methods and associated software, hardware and infrastructure have been evolving for more than 25 years and with regards to cotton crop production, has been traditionally divided into 2 main areas:

1. **Spatial Control.** This includes implement guidance utilising the Global Navigation Satellite System (GNSS, ie GPS), as well as remote monitoring and control. Driver interfaced spatial control products have been widely adopted; implementation is reasonably straightforward and benefits are easily quantifiable.
2. **Site Specific Crop Management.** Is data-intensive farming involving the collection and analysis of increasingly high resolution spatial agronomic and production data. This is decision-based and to-date, predominately aggregated and analysed at the farm or enterprise level. SSCM applied to field and irrigated row crop production requires a change of focus from managing field-level (averaged) conditions, to observing and addressing within-field variations in yield-limiting features.

Consistent with wider societal changes (think individual households through to medicine and the military), improvements in data science, enabling technologies and infrastructures, are driving an ongoing progression of connectivity and incorporation of digital technologies at all stages of agricultural (cotton) research, development and production.

The rapid evolution of Digital Agriculture (Digital Ag, Decision Agriculture) refers to a much wider, increasingly adaptable integration and aggregation of sensing, data analysis and delivery components, to enable decision-focused analysis of broad-scale data sets and the provision of evidence-driven solutions to modern farming system challenges. Digital Agriculture tools and services vary in scope and are specific to the outcome, for example:

- "Smart" information systems (eg. Cloud based software tools and hybrid hardware/software packages) that enable autonomous device-to-device communication and the uptake and analysis of data streams from multiple sources at varying scales (field, enterprise, locality and national).
- Machine learning and artificial intelligence (AI) that leverages aggregated data sets (big data) to reveal patterns, trends, and associations and provide customised predictions, decisions and/or recommendations,
- Information systems capable of innovative modes of delivering data and knowledge to growers and advisors, including in real time and in-situ.

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Why should I look to utilise these technologies in my cotton production business?

Changing climatic conditions, intensive capital (land) requirements, market volatility, the availability and expense of skilled labour and increasing energy costs are contributing to an increased production risk and complex decision making environments for Australian cotton producers. Additionally, improved end-user access to supply chain information is increasing requirements for sustainability, compliance, traceability and product differentiation.

The integrated and tailored application of PA technologies and associated smart digital services, enables producers to meet these productivity and sustainability challenges. Use of these technologies increases the availability of objective agronomic, production and environmental information necessary to optimise production decisions and maximise the production potential to be gained from coexisting mechanical, chemical and biotechnology developments. The net result is improved production efficiencies and profitability, and a reduction in input costs and unintended impacts on the environment.

Where to begin?

There is a wide and rapidly expanding variety of PA software, machinery, software/machinery hybrid technology, sensors, services, data storage and analysis options available. It can be difficult to determine the most suitable (if any) technologies for application across the farm enterprise. Compounding the selection issue can be: the scarcity of a clearly articulated value proposition for these services/technologies; a lack of on-farm technological infrastructure (either machinery or connectivity) able to interact digitally with the various software services; underlying data ownership and privacy concerns; and, lack of universal (brand neutral or colour-blind) operating platform on which to integrate all facets.

FIGURE 1: Measurable agronomic, climatic and landscape factors influencing yield.

Implementation can be self-managed at enterprise level, outsourced to service providers (local, national or global scale) for project management or a hybrid of both for differing production/enterprise segments. Successful on-farm application and interaction with the various PA technologies and services is a staged process, with strong agronomic foundations, involving:

1. **Observation and capture** of production, climate, soil, topographic and as-applied data sets.
2. **Decision based data assessment**. This process can be manual or automated, derived from research-based and/or machine learning logic and consolidated at an enterprise scale or aggregated into a larger data set.
3. **Implementation** of a timely, site specific strategic response.

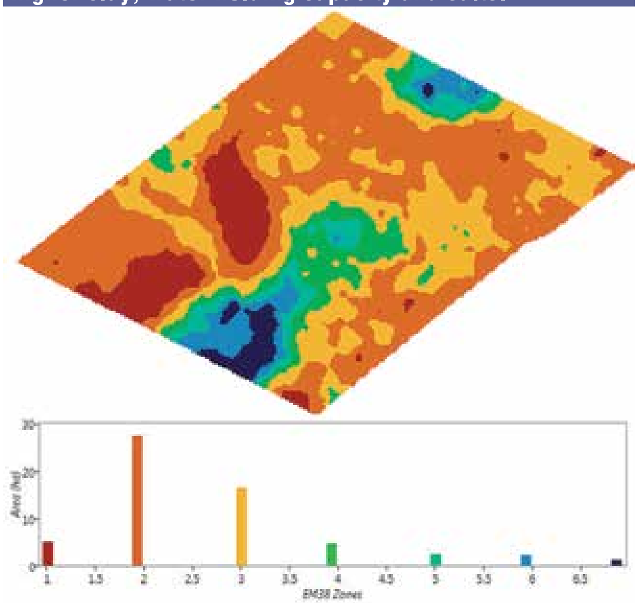
Understanding the spatial variability in crop production and yield levers

Within-field production variability in Australian cotton farming systems cannot usually be attributed to any one single factor. Every square meter of the paddock is unique, with a combination of varied production history and inputs, soil types, topography and weed, disease and insect burdens. Complex, location-unique relationships generally exist between several factors impacting on lint yield and quality, across a particular field for a particular time scale. In order to maximise profitability, it is important to consider all potential drivers of production variability (Figure 1), and to comprehensively understand what site-specific combinations are present.

Quantifying spatial variability utilising commercial systems

An increasing multitude of “spatial tools” (sensors + carrier equipment), exist to measure variability in cotton production systems. Commercial examples, which are often packaged with supporting software/equipment, include: Yield monitors, seed tube sensors and planter weigh pins, EM, EC and pH soil sensors, canopy temperature sensors, capacitance probes, multispectral/thermal sensors on satellites, planes or Unmanned Aerial Vehicles (UAV), as well as light and pheromone based insect sensors.

FIGURE 2: EM38V survey captured with full moisture profile where red = low conductivity and blue = high conductivity. Low EM zones represent lower clay, water holding capacity and salts. High EM zones represent higher clay, water holding capacity and salts.

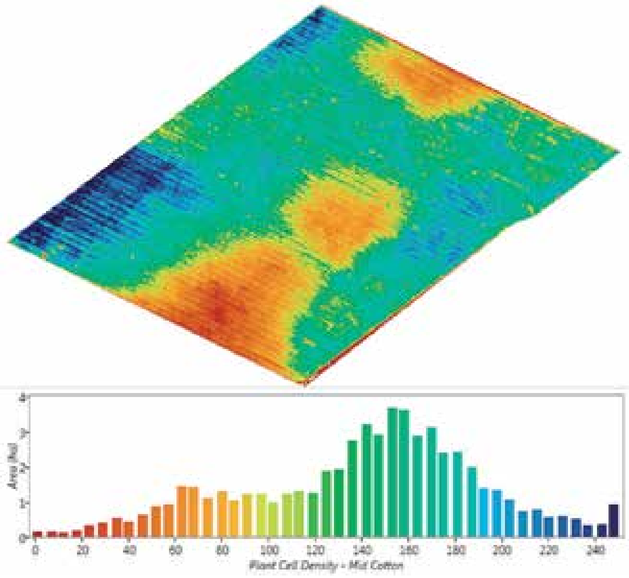


Ground-truthing data sets from sensors in-field is an important consideration; optimised decision making using such data, requires significant understandings of the underpinning plant physiological responses and agronomic/soil/topographical/climate characteristics, at a local scale.

Several data sets from a variety of commercial providers have been utilised widely and have proven to be consistently reliable for quantifying variability:

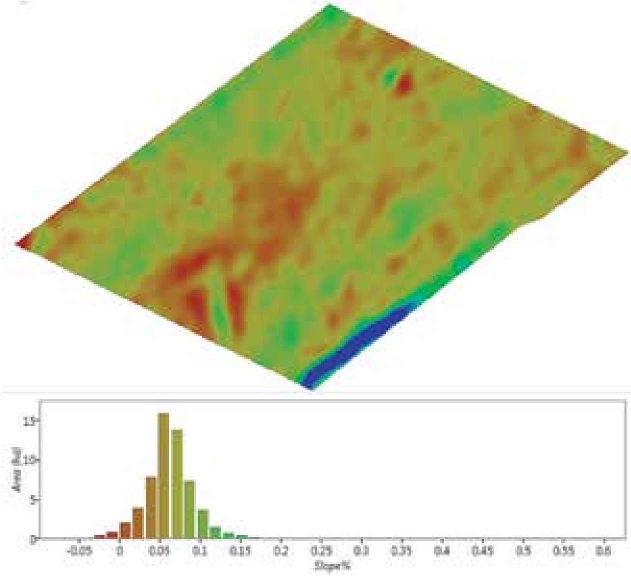
- **EM surveys.** Electromagnetic induction (EM) surveys, as Figure 2, measure apparent soil electrical conductivity (ECa) by inducing an electrical current into the soil. Soil ECa is highly correlated to a combination of soil properties including water content, clay content, and salt content. In non-saline soils ECa variations are most often a function of soil texture and moisture content. EM surveys when combined with soil sampling to ground-truth, enable the formation of: Soil type maps, crop-specific yield-potential management zones related to PAWC (notably for raingrown systems) and the identification of subsoil constraints and deep drainage or leakage areas.
- **Remotely sensed multispectral or hyperspectral imagery.** Airborne (plane, UAV) and satellite multispectral imaging systems, as Figure 3, measure the sunlight reflected off crops. Chlorophyll-containing crops have strong reflectance in the green wavelength range and low reflectance in the red and blue wavelengths. Plant Cell Density (PCD) and Normalised Difference Vegetation Index (NDVI) are indices which use the red and near infra-red (NIR) light bands and, in combination with strategic in-crop inspections, have been used extensively in cotton farming systems for plant stand biomass evaluation and crop growth stage assessment.

FIGURE 3: Airborne imagery captured on 15th December 2002 where the relative PCD values on the X axis indicate the amount of biomass: Red = low biomass and blue = high biomass. NB: At this time in the season this map is mainly used for in-crop growth management.



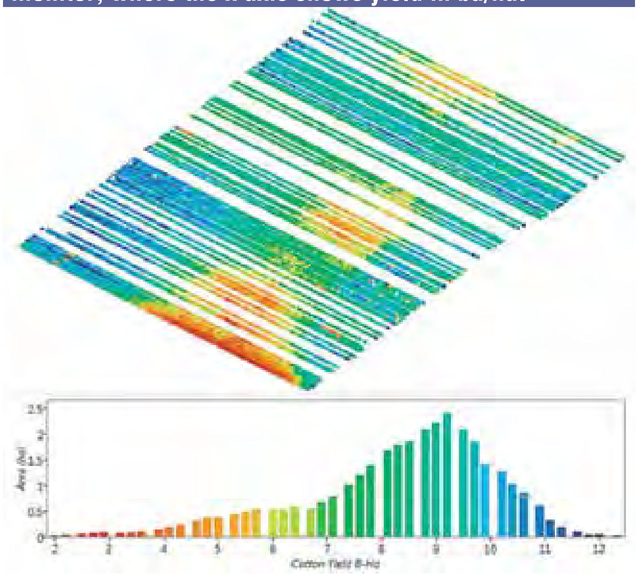
- **Elevation** (including topographical derivatives such as slope, aspect and wetness maps). The relationship between topography, soil water infiltration, and subsequent yield is quite complex because often where terrain changes so does soil type. Topography (as illustrated in Figure 4), is a primary determinant of the movement of water and subsequent infiltration, and its measurement and management can yield strong benefits. Fortunately, elevation maps can be created as a by-product by most Real Time Kinematic (RTK) tractor guidance systems. Elevation data coupled with EM surveys provide valuable information about the likelihood of waterlogging within irrigated fields. High EM and low elevation areas of the field will often be subject to prolonged waterlogging which has severe detrimental effects on cotton production.

FIGURE 4: Slope% map created from an RTK tractor steering system where the X axis shows soil level above or below a "plane of best fit (0)" as a percentage (ie.15ha of this field is 0.05 per cent above the plane).



- **Yield.** Recording an actual lint quantity response (as illustrated in Figure 5), is critical as a starting point for developing information about inherent field variability (and the integrated effect of environmental factors that influence yield). The influx of John Deere's self-propelled round bale pickers with monitors and "Harvest ID" service packs, has also enabled the capacity to (with the collaboration of ginning companies) match ginning data to specific round module Radio-Frequency Identifications (RFID) to create lint yield quality maps.

FIGURE 5: Cotton yield from an actual cotton yield monitor, where the x axis shows yield in ba/ha.



Connectivity is key

Connectivity is a critical enabling attribute in facilitating both automation and the collection and storage of in-field data. There are many forms of connectivity both within the farm and from your farm to external parties. The best connectivity option for your farm needs to be evaluated to meet data needs now and in the future, such as the size of your data, and how often you need to send data.

Data considerations

Spatial data quantifying variability in both crop production and associated yield levers can be collected on a varying scale from whole field to management zone and grid based sampling techniques. The scale utilised will be largely dependent on the cost/benefit associated with an increased resolution of investigation.

Spatially referenced production, agronomic and environmental data that has been sourced from calibrated sensors (ie. is of good quality), stored and curated (ie. correct metadata attached etc.) is a valuable asset with regards to both ongoing enterprise development and capital valuation. Such data sets being included in asset registers with property sale listings.

The real value of agronomic and production data can only be realised and exploited once it has been processed (curated, combined with other data and analysed) and translated into a meaningful, optimised and actionable production decision. During this process of deriving a value proposition, the original data set that was created on-farm (raw data) is transformed so that it is no longer recognisable from its original form, requiring a significant investment in both knowledge and technology on the part of the service provider.

As opposed to a focus on questions around "data ownership", significance should be given to the sharing rights associated with such data; who is able to access/utilise the transformed data and for what purpose. Negotiation of balanced commercial agreements allow growers to capture a portion of the benefits of transformation and analysis of farm (raw) data and enable service providers to realise a return on the digital product development investment.

Creating and effecting differentiated management solutions.

Spatial variability in crop production or yield limiting factors, provide the initial indication that a variable response may be warranted via grid-based treatment formats or the division of a field into broader sub-units (eg. "management zones"). The use of analysis of spatial information for management decisions will reflect:

- The machinery and associated technology/services on hand or under acquisition.
- The defined end goal to be achieved – strategic or tactical, over a short time frame (in crop) or longer (multiple seasons).

The adoption of a more intensive crop management strategy will have costs associated; the generalised (manual) adoption pathway outlined (Table 1) has been structured to ensure maximum benefit is gained from the least additional cost.

TABLE 1: Generalised pathway for implementing site specific crop management practices.

Steps to implementation	Applicable PA concepts, solutions and products
1. **Optimise uniform-rate agronomic practices,** improve farming efficiencies through adoption/ refinement of spatial control technologies and establish digital data capacities.	• Conduct a GPS survey of field boundaries. • Document machinery configurations, monitors, and guidance capabilities. *(Point to consider – is there scope for improving efficiencies/reducing overlap via upgrading GPS/guidance accuracy?)* • Identify and address whole-field/large scale topographic and soil pH, sodicity, macro/micro nutrient issues. • Establish capacity to collect, store, analyse and retrieve digital agronomic and production data: acquisition of GIS software/hardware/storage capacity. • EM survey and soil sampling. (Please see "Where to go for help")
2. **Determine magnitude and extent of crop production variability.** Measure where, and by how much crop production varies within fields, across the farm unit and over multiple seasons.	• Strategically: collect, process and store yield data over multiple (3+) years. Creation of production based management zones and stability maps. • Tactically: in-crop remote sensing utilising multispectral imagery to measure variances in crop reflectance across a field. Strategic in-crop inspections will assist determination of plant stand biomass and crop growth stage status. *(Point to consider – process can be self-managed, partially managed in collaboration with a technical service provider, or completely outsourced. Please see "Where to go for help")*
3. **Quantify agronomic, climatic and topographical yield levers.** Measure where, and by how much yield limiting factors vary within fields and across the farm unit.	• Not all factors can or should be investigated; begin investigations with the most evident yield limitations. • Crop scouting, soil and tissue testing tools. • Remote sensing imagery (multispectral). • Soil and/or canopy sensors. • EM survey and soil sampling. • As-applied data (ie planting data).
4. **Integrate and analyse data layers.** Determine the major causes of variability in multi-year yield output, or for in-season crop growth.	• Analyse yield data against agronomic, climatic and topographical data sets. *(Point to consider – varying scales of investigation and analysis from whole field, production zone to grid sampling).* • Analytics and decision support tools (ie CottAssist) *(Point to consider – process can be self-managed, partially managed in collaboration with a technical service provider, or completely outsourced. Please see "Where to go for help")*
5. **Differential action.** Optimise the use of inputs to amplify production and maximise profit.	• Creation of zone or grid based prescriptions (Rx) for the use of seed, water, fertiliser, insecticide, fungicide, herbicide and growth regulators. • Variable rate controllers and associated machinery hardware. *(Point to consider – this may involve adapting standard agronomic practices to test options)*
6. **Continued refinement.** Maintaining resource base and operation information.	• Output quality control and strategic marketing. • Monitoring yield quality parameters, farm or regional benchmarking, business diagnostics. • Yield moisture monitors and Harvest ID RFID packages. • Wireless data transfer capabilites (inbuilt or external such as CanBus drives). • Upscale mapping and specialised storage capacities.

Best practice…

- **The accelerating Precision to Decision Agriculture (P2D) project is supported by funding from the Australian Government's Department of Agriculture and Water Resources as part of its Rural R&D for Profit program.**

Australian Government

- **A P2D Online Grower Toolbox and Materials has been developed to provide online resources and materials to help growers manage their data found here www.acipa.edu.au/p2d-online-grower-toolbox-home.html**
- **As with entering into any contractual relationship, it is critical that you read and understand the fine print of your data contract and ask questions rather than just click on the "I agree" or sign the contract. Read the fact sheet "What to look for in your Ag data contracts" found on the website above.**

New Digital Agriculture technologies will continue to emerge, being designed to make production decisions easier, quicker and more profitable. Ongoing collaboration with trusted professional advisors to ensure a solid agronomic foundation and ground-truthing of digital agriculture concepts/services to your specific enterprise, ensures that the technologies being selected and utilised will have actionable results that are quantifiable and of ongoing benefit.

Practical examples to consider

When first implementing Variable Rate (VR) inputs, start with those that are less time critical, such as applying ameliorants out of growing season. By no means a definitive list, below are a few examples that can be actioned given the availability of appropriate machinery and software infrastructure:

- **Variable rate planting (population):** Matching the seeding rate to soil type and/or topography.
- **Variable rate planting (hybrid):** Changing crop hybrid varieties within a field to match soil conditions and/or topography.
- **Variable rate fertiliser (starter):** Redistributing planting/starter fertiliser to allocate rates to specific production zones, created or ground-truthed from intensive soil nutrient sampling.
- **Variable rate fertiliser (pre-sowing):** Redistributing fertiliser to allocate rates to specific production zones, based on previous crop yield and ground-truthed from intensive soil nutrient sampling.
- **Variable rate fertiliser (topdress, in-crop):** Using remotely sensed multispectral imagery to identify zones of differing reflectance. Ground-truthing via in-crop inspections and tissue testing being critical to determining links between reflectance zones and crop biomass/crop nutrient status.
- **Variable rate herbicide (in-crop):** Using early season multispectral imagery to identify high density populations of weeds, which after ground-truthing can be patched out by applying variable rates of knockdown herbicides (RR crops).
- **Variable rate irrigation (in-crop, pivot/lateral):** Utilising soil EM and topography derivatives (aspect, slope) to create production potential management zones.
- **Variable rate herbicide (resistance mapping for no-till, raingrown):** Utilising multispectral imagery after a solid field application of knock-down herbicide, to determine areas for application of double knock or alternative control methods.
- **Variable rate growth regulator (in-crop):** Utilising in-crop multispectral imagery and subsequent ground-truthing to determine biomass/crop growth based management zones.
- **Variable rate soil ameliorant (gypsum, lime):** Utilising EM surveys and/or grid soil sampling to create management zones.

Where to go for help

- Universities (ACPAg USyd, UNE) and CSIRO (Land and Water).
- Ag Retailers (CGS, Elders, Landmark, MGAS, PHR, AgNVet).
- Industry groups (SPAA).
- Specialist PA consultants and software suppliers (PCT, PrecisionAgiculture.com, BackPaddock, SST Software, AgWorld).
- Independent crop consultants (Crop Consultants Association).
- Machinery and specialist telemetry equipment retailers.

Integrated Pest Management & resistance management

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What is Integrated Pest Management (IPM)?

IPM and resistance management are integrally linked. IPM principles help to prevent the over-reliance on chemical control of pests and ensure beneficials can provide some non-chemical regulation of pest populations. Stewardship helps to ensure that the industry has access to technologies such as biotechnology traits and 'softer' insecticides from which to build an IPM system.

Successful pest management aims to keep pest populations to levels that do not cause economic damage and to maintain profitability year after year.

IPM is the use of all available tactics and resources to reduce the frequency with which pest outbreaks occur on your farm and your reliance on insecticides for their management. Using knowledge of pest biology, behaviour and ecology, IPM helps managers to identify opportunities to stack the odds against the pest, such as giving their natural enemies an advantage, and reducing a pest's ability to survive between crops. IPM is both pre-emptive and responsive. Upfront tactics work to reduce the incidence of insect pests on your farm. Active tactics enable you to manage pest populations in-crop at levels that protect its quality and yield including the responsible use of insecticides. IPM is a whole year, whole farm approach to managing pests which firstly requires you to devise a plan, taking stock of the resources available to you.

The outcome of an effective IPM system is long term stable management of pests and beneficials, reducing the risk of resistance, so that economic losses of crop yield and quality and threats to human health and the environment can be minimised.

Why is Resistance Management important for IPM?

Resistance is an outcome of exposing pest populations to a strong selection pressure, such as an insecticide. Genes for resistance usually naturally occur at very low frequencies in insect populations. They remain rare until they are selected for, by exposure to a toxin, either from an applied pesticide or from a biotechnology trait, such as the Bt toxins within Bt cotton. Once a selection pressure is applied, resistance genes can increase in frequency because the insects that carry them are more likely to survive and produce offspring. If selection continues, the proportion of resistant insects relative to susceptible insects may continue to increase until reduced effectiveness of the toxin is observed in the field.

The key challenge to long term effective management is conserving and utilising beneficial insects for pest control and preventing over-reliance on chemical control of pests that will lead to insecticide resistance and render insecticidal control options ineffective. Insecticide resistance can destroy an industry and the collapse in 1975 of the cotton industry in the Ord River Irrigation Area in Western Australia is testament to this. History has shown repeatedly that reliance on a single tactic curative approach (sample, chemical spray) will result in resistance problems, and the cotton industry in eastern Australia has been seriously challenged by insecticide resistance in its 50 year history. This experience has instilled a strong recognition by the Australian cotton industry that resistance management is a key component of pest management. The industry has taken a proactive approach to protecting the efficacy and longevity of biotechnology traits and insecticides used to control pests in the Australian cotton industry through implementation of tactics to reduce resistance development.

Insecticide Stewardship

The cotton industry has implemented an Insecticide Resistance Management Strategy (IRMS) to manage the risk of insecticide resistance of major pests in cotton including aphids, mites and *Helicoverpa* spp. and is applicable to both Bt and non Bt cotton. The IRMS is updated annually and can be found in the Cotton Pest Management Guide.

The evolution of the IRMS is driven by the Transgenic and Insect Management Strategies (TIMS) Committee. TIMS is an industry committee facilitated by Cotton Australia. The results from industry funded insecticide and miticide resistance monitoring programs, carried out each season, are used to inform the committee of any field scale changes in resistance levels. TIMS consults extensively with cotton growers and consultants in all cotton regions as part of finalising the IRMS each season.

The IRMS is designed to both delay resistance development and to manage existing resistance. Some core principles used in the IRMS include:

- Rotation with different modes of action.
- Limiting the time period during which an insecticide can be used. This restricts the number of generations of a pest that can be exposed to selection in each season.
- Limiting the number of applications, thereby restricting the number of selection events.
- Pupae busting is an important non-chemical tool for preventing resistance carryover from one season to the next. The guidelines for performing pupae busting in sprayed conventional cotton are based on the likelihood that larvae will enter diapause before a certain date.

The IRMS is split into two regions: Northern and Central/Southern. This delineation reflects the different growing seasons from central Queensland through to southern NSW. Since *Helicoverpa* spp. and mirids are capable of travelling long distances, the delineation is also designed to reduce the chance that pests moving between regions would be reselected repeatedly by the same insecticide group.

Useful resources: Refer to the IRMS section in the Cotton Pest Management Guide. Available from www.cottoninfo.com.au

Stewardship of Bt cotton

Bt cotton contains genes derived from the common soil bacterium *Bacillus thuringiensis* (Bt). These bacteria produce a large array of crystalline proteins, two of which are produced in Bt cotton, Cry1Ac and

Cry2Ab. Cry1Ac is specific to Lepidoptera (moths, including our major pests, *Helicoverpa* spp.) and Cry2Ab to Diptera (flies) and Lepidoptera, giving inbuilt protection against the larvae of *Helicoverpa* spp. In 2016 third generation Bt technology was approved for commercial release in the Australian market. Bollgard 3 builds on the Bollgard II platform with the addition of a third gene, Vip3a. This 3 gene product provides a more robust resistance management strategy, with the objective to improve the longevity of Bt technology for the industry.

The introduction of insecticidal transgenic varieties into the Australian cotton market has allowed the industry to reduce its pesticide use by more than 90 per cent and provides a strong platform for IPM. However, resistance is a great threat to the continued availability and efficacy of Bt cotton in Australia. The Resistance Management Plans (RMP) for Bt cotton were established by regulatory authorities in association with industry to mitigate the risks of resistance developing to any of the proteins contained in Bt cotton. This is not only important for protecting the longevity of Bt cotton, but also future biotechnology products that may build on these or similar traits.

To evaluate the effectiveness of RMPs the CRDC funds a program that monitors field populations of moths for resistance to Cry1Ac, Cry2Ab and Vip3A. Monsanto Australia operates a separate but complimentary monitoring program. The data provides an early warning to the industry of the onset of resistance to Bt, and is used to make decisions about the need to modify the RMP from one season to the next. CSIRO screens against the new protein in Bollgard 3 (Vip3A) has found that in *H. armigera* the frequency of genes conferring resistance is around 1 in 20 moths. Not only is this higher than expected, it is much greater than the starting frequencies for Cry2Ab. Vip3A resistance genes have also been detected in *H. punctigera* at a frequency that is higher than expected and higher than the starting frequencies for Cry2Ab. This highlights that effective resistance management will continue to be critical to ensure the efficacy of this technology is maintained, both now and into the future.

Bollgard 3 RMP

RMPs are based around 5 key elements that impose limitations and requirements for management on farms that grow Bt cotton. These are mandatory growing of refuges; control of volunteer and ratoon plants; a defined planting window; restrictions on the use of foliar Bt; and pupae destruction. The interaction of all these elements should effectively slow the evolution of resistance.

Planting windows

There are usually 3-4 generations of *Helicoverpa* spp. in a cotton growing season, depending on temperatures for that year, so the risk strategies around the RMP have been developed based on these numbers. The purpose of planting windows is to confine crop development and maturity to limit the number of generations of *Helicoverpa* spp. exposed to Bt cotton each season.

The introduction of Bollgard 3 has allowed for more flexibility in planting windows. In central and southern regions, the planting window is Aug 1–Dec 31 as climate is the primary driver for planting time.

In warmer regions there is not always a climatic limit on how long crops can be grown. The RMP for Bollgard 3 crops in these regions sets specific planting dates (refer to each individual RMP for full details). The RMP in Central Queensland includes requirements for all Bollgard 3 and associated trap crops to be destroyed by a set date (refer to the details in *The Pest Management Guide*).

Insects live in the landscape not on farms. Working with neighbours can improve IPM success. (Photo courtesy of Guy Roth)

Mandatory refuges

The aim of a refuge crop is to generate significant numbers of susceptible moths that have not been exposed to the Bt proteins in Bt cotton. This strategy works because in Australia resistance to the Bt proteins has so far been found to be recessive, so if a resistant moth (rr) from the Bt crop mates with a susceptible moth (SS) from the refuge, the offspring they produce (rS) are also killed by the Bt toxins.

The current (2018–19) RMP options for irrigated or raingrown Bollgard 3 refuges are:

- 100 per cent sprayed conventional cotton.
- 5 per cent unsprayed conventional cotton.
- 2.5 per cent pigeon pea (relative to the area of Bollgard 3 cotton grown).

No matter which refuge is grown, it is critical that they are managed to be most attractive to Helicoverpa moths when Bt cotton is also most attractive. Ideally, refuges should be as or more attractive to Helicoverpa than the corresponding Bt crop to attract females to lay eggs in the refuge. The RMP requires that growers ensure their refuge crops receive adequate nutrition, irrigation (for irrigated refuges), and weed and pest management (excluding Helicoverpa sprays). An important characteristic of mandatory refuges is their synchronicity with the corresponding Bt crop. Management should aim to ensure that the refuge is flowering (both pigeon pea and cotton refuges) at the same time as the Bt cotton.

Role of non-mandatory refuges

Helicoverpa are polyphagous which means that they feed on a wide range of host crops and vegetation, including cotton. Bt cotton dominates the total area of cotton grown in Australia but at a landscape scale it often forms part of a mosaic of other crops and vegetation. Non-cotton crops and natural vegetation are known to be important for Bt resistance management by providing alternative sources of Bt susceptible moths apart from those produced by the mandatory refuges. But we cannot confidently rely on these unstructured refuges to produce moths because their effectiveness and distribution is highly variable between seasons and regions.

Control of volunteer and ratoon plants

The presence of volunteers within a refuge diminishes the value of a refuge, as some of the moths emerging from that refuge have had some exposure to the Bt proteins. Larvae that carry a gene for resistance, heterozygous (rS) individuals, may emerge and develop on the refuge (conventional cotton or pigeon peas) crop before moving onto a Bt volunteer within the refuge. In this way, the rS larvae could be exposed to the Bt proteins as larger individuals that may better tolerate it and survive to produce offspring. This could lead to an increase in the frequency of resistant individuals in the population.

The same risk to resistance from Bt volunteers also occurs in fallow fields and non-cropping areas. The good farm hygiene practice of removing all volunteers in and around cropping areas is not only important in removing disease and pest carryover hosts but also in reducing the resistance risk to Bt technologies.

Restrictions on use of foliar Bt sprays

Sprayed cotton refuges are grown for commercial cotton yields, requiring active control of Helicoverpa with foliar insecticides. To ensure that no selection for Bt resistance can take place in this type of refuge, the use of foliar Bt insecticide is prohibited. Sprayed cotton refuges are much larger than unsprayed refuge types because of the lower rates of Helicoverpa survival.

In unsprayed cotton and pigeon pea refuges, 'unsprayed' is in reference to insecticides which control Helicoverpa species. In these refuges, all foliar applied insecticides with activity against Helicoverpa species are excluded. These refuges are able to produce high numbers of Helicoverpa moths from much smaller areas.

Pupae destruction

South of Central Queensland, Helicoverpa larvae enter a diapause phase in the soil as temperatures begin to cool and daylength decreases in early autumn. This dormancy strategy allows the pest to survive the winter months in temperate regions when host plants are scarce and temperatures are generally too low to allow successful development. Cultivation of the soil between seasons, during the dormancy phase, is an effective way of preventing any moths that developed resistance in the previous year from contributing to the population in the following year.

In Central Queensland, due to the warmer temperatures and smaller changes in daylength, Helicoverpa pupae produced late in the season are less likely to go in to diapuase, making pupae busting less effective. Late season trap crops are used as an alternative. Trap crops of pigeon peas are timed to be at their most attractive after the cotton has cut-out. Moths emerging from the Bt fields late in the season should be attracted to the pigeon peas to lay their eggs. Once the cotton has been harvested, the trap crops and any insects in them are destroyed through cutting and cultivation which also kills any pupae. The introduction of Bollgard 3 has allowed some flexibility in the pupae destruction requirements, based around individual crop defoliation dates and the likelihood of pupae entering diapause. Refer to the Bollgard 3 RMP for full details.

Changes to pupae busting have the potential to enable cotton to be grown with less soil disturbance. This may have benefits such as improving soil structure and soil moisture storage, particularly for raingrown growers. However, the reduction in tillage can also present new weed or ratoon management issues or contribute to greater nutrient stratification of the soil profile over time.

The full details of the RMP are published annually in the Cotton Pest Management Guide along with the latest annual results from the resistance monitoring program.

For more information refer to the RMP chapter in the Cotton Pest Management Guide.

IPM planning all year round

When it comes to pests, "forewarned is forearmed". Assess the attributes of your farm and develop an IPM plan as part of your decision to grow cotton. Your plan will become a good reference point during the growing season if tough decisions need to be made. Challenge yourself to set goals in your plan that will be relevant for many seasons and help you work towards your overall goals for the farm business. Working with others, such as those who provide you with advice, can be an excellent way of ensuring everyone is working to the same priorities for the farm business. Some examples of IPM goals that your business may aspire to are:

- Start each cotton season with low/no pest populations on the farm.
- Avoid unnecessary insecticide sprays especially early in the season.
- Follow the cotton industry's Insecticide Resistance Management Strategy (IRMS) when an insecticide is required.
- Make non-crop areas of the farm more productive for beneficials.
- Avoid pest outbreaks that are generated within the farm.
- Minimise impact on bees and beneficials.
- Participate in Area Wide Management.

Recognise your resources

Insects and mites move around the landscape for basic reasons – to find food, to find a mate, to find a favourable place for their juveniles to thrive, because they are blown by wind or because they're seeking shelter from harsh weather. Your IPM resources are the attributes of your farm that act to make these basic needs difficult for pests to satisfy, or conversely easier for them to satisfy away from the crop you are aiming to protect.

Veg is valuable

Perennial native vegetation connects beneficials to crops – both in space and time. The role beneficials can play in pest suppression in crops is dictated by their ability to persist within a landscape and to move between habitats across the landscape.

Manage for groundcover and diversity

Vegetation which is diverse provides a suite of resources for beneficials as different organisms have different habitat preferences and food requirements. Native vegetation with many layers, from trees and shrubs through to grasses and small herbs encourages a diversity of beneficials.

The understory layer of grasses and herbs is most easily changed through management and season. The presence of livestock can result in simplification of the species if grazing periods are too long or there are too few watering points. In time, allowing stock to graze selectively can not only result in loss of the best species, but bare areas will also occur. Drought can result in similar degradations or exacerbate the impacts of grazing management 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*), 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 their predators. When weeds take over beneath trees and shrubs, these areas can become net exporters of pests rather than net exporters of beneficials.

When planning revegetation, prioritise the incorporation of trees and shrubs that flower prolifically. Eucalypts and melaleucas attract feeding insects that are not pests of cotton, which in turn attract a broad range of predator insects that will move into cotton. If seeding of ground species is possible, look to establish a mix of tussocky and sprawling grass together

Industry training in sampling techniques is available. (Photo courtesy of Paul Grundy, QLD DAF)

with a mix of winter and summer active legumes. Leaving logs, dead trees and litter where they fall will enhance the habitat for a range of beneficials.

Prioritise connectivity

Many beneficials have limited dispersal ability and can only move up to 1km from native vegetation. Consider linking patches of native vegetation such as riparian corridors or fenceline tree plantings to assist beneficials to move between patches of native vegetation and crops.

Enhance habitat with water

More insect species will inhabit vegetation located near a water source. Semi-permanent or permanent water increases and stabilises vegetation condition, especially during drought. Selecting sites for revegetation that incorporate water sources, will increase the role of vegetation in your farm's natural suppression of pests.

Channels that are nude of vegetation maximise the reticulation capacity of the system in major events. However, establishing vegetation on some channel areas, significantly improves the capacity of the system to breakdown pesticide residues on farm. Where water flows more slowly, residues are filtered out 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 breakdown 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.

Useful resources:

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

Managing Riparian Lands in the Cotton Industry. Available from www.cottoninfo.com.au

A yellow nightstalker eating a mirid. (Photo courtesy of Mary Whitehouse, CSIRO)

Your neighbours (AWM)

Insects live in landscapes, not on farms. Area Wide Management (AWM) acknowledges that insects are mobile, and that the management regimes used on one farm can have implications for the surrounding locality. By sharing strategies and coordinating tactics, neighbouring cotton growers have in the past increased their success in implementing IPM.

Tactics that are more effective when coordinated with neighbours are weed management, planting windows, selecting insecticides in line with the IRMS and post season cultivation of diapausing Helicoverpa pupae (Bt Resistance Management Plan). In many areas farmers also need to work together towards longer term projects such as to connect areas of remnant vegetation across the landscape. A critical aspect of AWM is to bring together farmers based upon geography, even if they do not grow cotton.

A key element of most groups that have worked well has been regular meetings before and during the season to share information, discuss strategies and their knowledge of pest presence.

Useful resources:

IPM Guidelines for Cotton Production Systems in Australia and Cotton Pest Management Guide. Available from www.cottoninfo.com.au

Rotation crops

Rotation crops are hosts for a range of pests, some in common with the pests of cotton. Crop selection is based on markets and seasonal outlook, but consequences for pest management should be factored into decision making, particularly the use of insecticides. The same principles of IPM apply in all crops. The lower your farm's total use of insecticides, the greater the local persistence of insect predators.

Where rotation crops are grown at the same time as cotton, try to align insecticide selections with the Cotton IRMS. Some rotation crops can increase pest abundance, that can then migrate into nearby cotton crops. Risk can be managed in terms of timing and location.

For more information: Refer to the Field selection, preparation, rotation & cover crops Chapter 6.

Refer to the Cotton Rotation Tool. Available from www.cottoninfo.com.au/cotton-rotation-tool

Weed management

Weed management is perhaps the most undervalued tactic in IPM. Many cotton pests rely on volunteer cotton plants and weed hosts prior to migrating into cotton fields. Pests that gain the greatest advantage from weeds are those that are unable to hibernate when conditions are unfavourable. Cotton aphids, mirids and silverleaf whitefly are pests that have to constantly find host plants to survive.

Mild, wet winters create the highest risk of pest carryover from one cotton season to the next mainly because of the abundance of host plants in these conditions.

For pest suppression leading into each cotton season, weeds need to be managed in fallow fields, along field borders and irrigation channels and in perennial vegetation and pastures.

Zero tolerance for regrowth and volunteer cotton

Regrowth of cotton after harvest (ratoon cotton) provides habitat for nearly all cotton pests – *Helicoverpa* spp., spider mites, green mirids, mealy bug and aphids. Control of volunteers around field edges, along roadways and in irrigation channels is as important as control within cropping fields. In areas with low accessibility this will require hand chipping.

Prioritise 'zero tolerance' throughout winter right up until cotton planting. Regrowth cotton is also the major risk for carry-over of Cotton Bunchy Top (CBT) disease. Cotton aphids feeding on infected plants through winter can spread CBT to adjacent cotton crops in the spring. However without a source of infected plant material, aphids will not continue to be infected and lose the ability to transmit the disease as they move around.

Coolibah trees *(Eucalyptus microtheca)* are a primary source of nectar and pollen for honey bees. These trees grow on the black soil plains along many of the river courses in the cotton growing areas. When heavy budding occurs, beekeepers often move large numbers of hives into cotton growing areas for honey production. Budding and flowering only occurs in response to good spring rains meaning the timing is likely to coincide with the time when insecticides are used in cotton. In northem NSW the buds appear in November and the trees begin to flower mid-late December finishing about the end of January. Budding and flowering times vary by a few weeks in southern and central Qld areas.

The Technology User Agreement for Bt cotton requires the control of cotton regrowth.

Useful resources:

Refer to the Managing cotton stubbles/residues chapter.

Volunteer and ratoon cotton section of Cotton Pest Management Guide. www.cottoninfo.com.au/publications/cotton-pest-management-guide

WEEDpak. www.cottoninfo.com.au/publications/weedpak

Upfront (before planting) tactics

Varietal tolerances

Select a variety that suits the growing region in terms of season length. Early vigour is an important characteristic. A number of pests, such as thrips and symphlya can only cause economic damage to cotton when vigour is lacking and early growth is slow. Choosing variety characters and growing conditions that favour vigourous establishment can reduce the need to use insecticidal seed treatments and protect the crop from pests to which no effective insecticidal options are available.

Another plant characteristic that lowers the ability for pests to thrive on cotton is leaf shape. The okra leaf shape reduces the rate at which silverleaf whitefly, cotton aphid and two-spotted mite populations are able to increase in cotton.

Bt traits are ideally suited to IPM as the level of control of Helicoverpa spp. provided by the plant reduces the need to spray for these pests, which in turn lowers the need to spray for other pests. Without the primary disruption from larval sprays, insect predators are able to establish and build over successive generations, keeping their prey populations in check. Planning for Bt cotton should consider how the requirements of the RMP will be met, including location and amount of refuge as well as planning and budgeting for refuge management (nutrition, irrigation, weed control).

Field selection

When selecting fields for planting cotton, consider the proximity to sensitive areas – such as watercourses, pastures and buildings – relative to the prevailing wind direction. Bt cotton may be most appropriate for fields adjacent to sensitive areas. Conventional cotton may be best placed embedded amongst Bt cotton and rotation crops, where pest loads are diluted across all the crop area. When spraying is required for larvae control, the surrounding crops will also act as sources for rapid re-entry of beneficials.

As part of field selection, stubble loads and soil pest activity should be monitored in the lead up to planting. The presence/absence of soil pests can have a strong bearing on crop establishment, particularly if there's high probability that soil moisture conditions and average daily temperatures will be variable. There are no insecticidal control options for nematodes – field selection is an important component of managing the rare but serious risks associated with this pest.

Seed bed preparation

Vigourous, healthy, early growth enables crops to recover from what can at the time, appear to be significant early season damage from soil-dwelling pests such as wireworm, mealy bug and symphyla. When plant vigour is strong and growth is rapid, cotton can fully recover without reduction in yield or delay in maturity.

For more Information: Refer to the Crop establishment Chapter 15.

Planting time

Ideal soil temperatures for cotton establishment are 16°C–28°C. Temperatures below this result in slow emergence and reduced vigour, increasing potential for damage from soil pests (refer to the Crop establishment chapter). Refer to the RMP for planting time requirements for Bt cotton and refuges. Good planting conditions (temperature and seed bed) can help seedlings to recover quickly from early pest pressure, reducing the requirement for insecticidal control.

Very late planted cotton is more susceptible to pests such as whitefly

A 'zero tolerance' approach to cotton volunteers between crops is an important IPM strategy which can be difficult and expensive to control. In areas susceptible to whitefly, coordinated planting windows can provide a period free from host crops to reduce population build-up, as well as preventing late crops from being inundated by mass movements of adults coming from senescing, defoliated or harvested crops.

Create a diversion

Trap cropping aims to concentrate the pest in a small area of host crop that is more highly preferred and attractive than the crop you are aiming to protect. It is an IPM tactic that can be utilised on a farm level or area wide basis, either way it requires strategic planning and management to be effective.

Lucerne can be used as an effective trap crop for green mirids and aphids, as these insects prefer lucerne over cotton. Planted in strips within fields or along field edges, or in a field adjacent to a cotton field, lucerne can effectively serve as a trap for mirids and aphids as well as enhancing the build-up of beneficial insects. For strip configurations, strips at least 8 metres wide are required for every 300 rows of cotton. The configuration should be chosen to fit in with machinery and equate to about 2.0–2.5 per cent of the field area. Alternatively, lucerne can be grown on the borders of a field, using an area equivalent to 5 per cent of the field, or can be planted in a field adjacent to cotton.

In Central Queensland cotton growers use summer trap crops of pigeon pea as part of the RMP for Bt cotton. A summer trap crop aims to draw Helicoverpa spp. away from the Bt crop and concentrate them in a small area where they are controlled. In the RMP, the trap crop is destroyed with slashing and cultivation.

Useful resources:

Agronomic management of lucerne in cotton systems, refer to cotton's WEEDpak publication, Section I4. www.cottoninfo.com.au/publications/weedpak

Communicate responsibilities and expectations

While IPM aims to reduce the farm's reliance on insecticides, they inevitably still play a role. Risks associated with their use need to be actively managed. The core best management practice for safe and responsible pesticide use is to develop a pesticide application management plan (PAMP). Developing a PAMP helps identify the risks associated with pesticide applications specific to your farm situation and the practices that are to be put in place to minimise the risks. Implementing a PAMP makes everyone involved in a pesticide application aware of their responsibilities.

A PAMP has two essential functions:

- Establishes good communication with all involved in the application of pesticides. This communication is required both pre-season and during the season. It should exist between the grower, the applicator, the consultant, farm employees and neighbours.
- Establishes the application techniques and procedures that are to be used on your farm.

Good record keeping is essential for demonstrating the implementation of your PAMP. Records enable farm management to check the effectiveness of pesticide applications, to comply with regulatory requirements and to demonstrate due diligence.

For more information.

Refer to the Pesticide Management module in *my*BMP. www.mybmp.com.au

In crop tactics

Monitoring

Monitoring data provides the basis on which tactical decisions about pest management can be made in-crop. There are several important purposes of crop monitoring:

- Determining whether the crop is growing optimally.
- Detecting the presence of insects – pests and predators – through the field.
- Finding evidence of crop damage or set-back (from pests, diseases or other disorders).

Making well informed and rational pest management decisions will provide the best opportunity to protect yield and minimise the need to spray and incur further pest control costs.

Check frequently

Both Bt and non Bt crops should be checked at least twice weekly, with different emphasis depending on the time of the season. Once squaring commences, emphasis is across plant growth, fruit retention, insect presence and signs of damage. After cut-out the emphasis is on insect presence and signs of damage. Refer to the Insects chapter of the Cotton Pest Management Guide for pest-specific advice about frequency of monitoring in relation to crop stage.

It is generally not possible to make a decision about whether insect control is needed based on just one check. Good decision making is generally based on rates of pest population development and the time remaining in the season during which the crop is susceptible to damage.

Finding evidence of insect damage

Damage monitoring includes: leaf loss; growing point damage; loss of squares/flowers; and, boll damage. The type of damage encountered will provide clues as to which insects are responsible – which can help to target monitoring for pest presence. The type of damage inflicted by each of cotton's main insect pests is described in the Insects chapter of the Cotton Pest Management Guide.

Detecting the presence of insects – pests and predators

There are a number of sampling techniques that have been thoroughly evaluated by industry research and are associated with the thresholds for insecticide intervention. Visual and Beat Sheet sampling are the most commonly used techniques – each has different strengths – meaning it is optimal to use a combination of both techniques. For example, conducting detailed visual sampling is the only accurate method for all stages of *Helicoverpa spp.*

Useful resources:

Collecting and recording data about insect pests is described in the Insects chapter of the Cotton Pest Management Guide. www.cottoninfo.com.au/publications/cotton-pest-management-guide

Build bigger populations of beneficial insects

Predatory insects, parasitic insects and spiders consume pests. Collectively they are known as 'beneficials'. When abundant, beneficials can considerably reduce pest numbers, reducing the reliance on insecticides to keep pests below damage thresholds. The abundance of beneficial insects in a cotton crop is affected by food resources, mating partners, proximity to other sources of habitat, climatic conditions and insecticide sprays. For an IPM system to work effectively, both the attraction and conservation of beneficial insects is critical.

In cotton, lag phases in the build-up of beneificial populations can reduce the ability for pest managers to utilise their services. Lags occur when the rate at which the pest population increases is initially faster than the rate at which the beneficial population increases. During the lag period, the crop may suffer economic damage from the pest. Lags are minimised where nearby habitat – rotation crops and perennial vegetation – creates higher starting populations of beneficials, where prophylactic application of insecticide can be avoided and where any insecticides that are needed are highly selective.

For pests such as mealy bug, where there are no effective insecticidal options, beneficials play a particularly critical role. The abundance of some beneficial species can be increased through mass releases. Beneficials can be purchased for release in the crop.

Useful resources:

The Association of Beneficial Arthropod Producers Inc (ABC Inc) – www.goodbugs.org.au

Download: Pests and Beneficials in Australian Cotton Landscapes – www.cottoninfo.com.au

Browse: Spotlight, "Buying in Bugs," Spring 2012 Edition – www.crdc.com.au

Pest thresholds

Economic thresholds based on research are available for most major pests in cotton. These thresholds should be used in conjunction with information on forecast, crop stage, other pests present, plant damage, pest ecology and beneficial abundance to make decisions about the need to spray. While some thresholds only monitor one lifecycle stage it can be useful to also be aware of all life stages.

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

Choose insecticides wisely

Where insecticide control is warranted, insecticide choice is a key decision for IPM managers. When choosing an insecticide, in addition to the efficacy against the target pest, it is very important to consider its selectivity. Some insecticides have very little impact on beneficial insects while others are highly disruptive. Specific information about the relative selectivity of all insecticides available for use in cotton is tabulated in the "Impact of insecticides and miticides on predators, parasitoids and bees in cotton" Table in the Cotton Pest Management Guide.

Knowing the selectivity of the insecticide helps to assess the risk that following its use, populations of other pests may 'flare' (increase rapidly). For example, increases in populations of non-target pests such as aphid, mite, whitefly and mealybug may follow insecticide applications if the beneficial populations keeping them in check are disrupted.

Efficacy is how well the insecticide controls the insect in the field. Efficacy depends partly on how toxic the insecticide is, but also on other factors such as how long the insecticide lasts (residual), if it only works on one or some lifecycle stages, and how the active ingredient gets to the pest. Understanding how an insecticide works can ensure that efficacy is maximised. Good coverage is required for contact materials that cover the plant's surface and require insects or mites to directly contact the active ingredient for control. Translaminar products only travel a short distance into the leaves, so while coverage is still important it is less critical to control spider mites, which normally feed on leaf undersides. Systemic insecticides are carried in the plant and so coverage is less critical, however most can only move upward, and may take time to move up to the new growth. Some insecticides have a fumigant action ie. the material is volatile and produces a gas which may be lethal or repellent to the pest. Environment factors such as cloud, humidity and sunlight/radiation can also affect efficacy depending on the product.

Pupae destruction is an important part of the RMP. (Photo courtesy Trudy Staines, CSIRO))

Pests such as aphids and mites often infest the edges of a field, or mealybug can create 'hot-spots', not the entire field area. Discuss with your consultant whether it is possible to manage this type of infestation by only spraying the field borders. This may enable beneficial populations to keep pace with the remainder of the pest population in the field.

Be kind to bees

Bees collect nectar from cotton's extrafloral nectaries (under leaves) as well as from the flowers so they may forage throughout much of the season. Insecticide use makes cotton crops a high risk environment for bees. Bees are particularly susceptible to insecticides such as fipronil, abamectin, indoxacarb and pyrethroids. Insecticides that are toxic to bees are identified as such on the label. The productivity of hives can be damaged if direct contact with foraging bees occurs during the application, if foraging bees carry residual insecticide back to the hive after the application and when insecticide drifts over hives or over neighbouring vegetation that is being foraged by bees.

The annual Cotton Pest Management Guide provides additional information about insecticide risks to bees as well as tables showing the relative toxicities of cotton insecticides to bees and residual toxicity risks for bees.

With good communication and good will, it is possible for apiarists and cotton growers to work together to minimise risks to bees, as both the honey industry and cotton industry are important to regional development.

The risk to bees can be reduced by:

- Notifying the apiarist when beehives are in the vicinity of crops to be sprayed to allow removal of the hives before spraying. It is important to consider that bees can travel up to 7km in search of pollen and nectar. Beekeepers require as much notice possible, at least 48 hours, to move an apiary.

- 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. DO NOT spray over plants in flower while bees are foraging."**
- Paying particular attention to windspeed and direction, air temperature and time of day before applying pesticides.
- Using buffer zones as a mechanism to reduce the impact of spray drift or overspray in vegetation used by bees.
- Avoiding drift and contamination of surface waters where bees may drink.

BeeConnected is a nationwide, user-driven smart-phone 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 bee connected service go to www.beeconnected.org.au/

Follow the IRMS when selecting pest control options

IPM principles including selective insecticide use is consistent with the IRMS, as this helps conserve beneficial insects. Insecticides appear in the IRMS in order of their selectivity – the most selective at the top of the chart available for use early season and the least selective at the bottom available for use at the end of the season. Spraying for one pest can simultaneously select resistance in another pest that is present, even though that pest may only be present at sub-threshold levels and not be specifically targeted. As such the IRMS includes all insecticide actives commercially available for use in cotton, and as such should be consulted for every insecticide/miticide decisions.

Useful resources:

View the Cotton IRMS in the annual Cotton Pest Management Guide.
www.cottoninfo.com.au/publications/cotton-pest-management-guide

Resistance monitoring

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

Useful resources:

Aphids, mites and mirids: Kate Langfield 02 4640 6389.

Silverleaf Whitefly: Dr Jamie Hopkinson, QLD DAF, 07 4688 1152.

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

Defoliation for late season pest management

The timing of defoliation can be an important IPM tool. Late pest infestation problems can sometimes be avoided by a successful defoliation. The Silverleaf Whitefly Threshold Matrix illustrates that control of whitefly to protect crop yield and quality is required between peak flowering and 60 per cent open bolls. As the crop approaches the point where it can be defoliated, the reliance on insecticide intervention declines.

Pupae destruction – an IPM in-crop tactic

Pupae destruction is an important IPM tactic. As mentioned earlier in this chapter, pupae under cotton at the end of the season have a higher probability of carrying insecticide and Bt resistance. Their destruction has proven to assist in the management of resistance. Pupae busting is required following harvest of Bt cotton in some situations (refer to the RMP) and is recommended in the industry's IRMS for all cotton.

Useful resources:

Refer to the Cotton Pest Management Guide.
www.cottoninfo.com.au/publications/cotton-pest-management-guide

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Integrated Weed Management

By **Eric Koetz** (NSW DPI)

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

Integrated weed management (IWM) is the term used to describe the strategy to not only manage existing herbicide resistance and prolong the use of life of each herbicide, but also reduce the rate of species shift, manage the cost of future weed control by depleting the number of weed seeds in the soil, and of course help to improve crop productivity through effective weed management.

Herbicide resistance

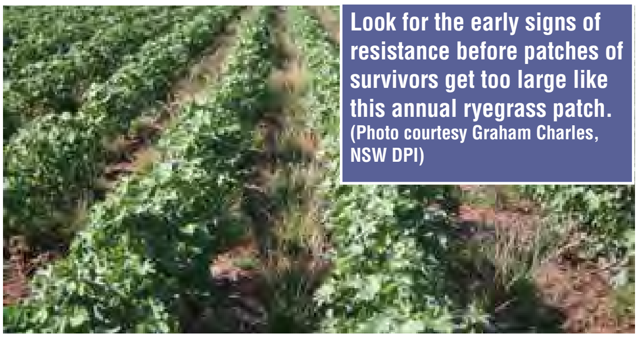
Herbicide resistance is normally present at very low frequencies in weed populations before the herbicide is first applied. Using the herbicide creates the selection pressure that increases the resistant individuals' likelihood of survival compared to 'normal' or susceptible individuals. The underlying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

Best practice...

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

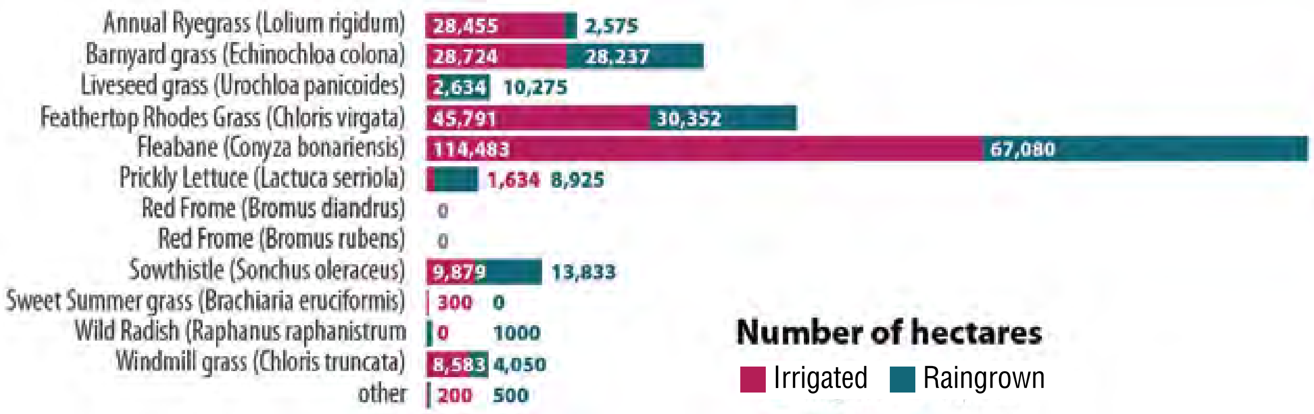
Herbicide resistance has been confirmed in 46 grass and broadleaf species in Australia, across 11 distinctly different herbicide chemical groups (www.croplife.org.au). Cases of multiple resistance have also been commonly reported. Glyphosate resistant weeds continue to appear in Australian cotton farming systems. The latest 2016–17 CCA survey reports over 100,000 ha of glyphosate resistant hectares. As of January 2018, 17 weeds of cropping systems have developed resistance to Glyphosate. In the cotton growing areas, populations of 6 common grass weeds – annual ryegrass, barnyard grass, liverseed grass, sweet summer grass, windmill grass and feathertop Rhodes grass and two broadleaf species – sowthistle and flaxleaf fleabane have resistance to glyphosate (Figure 1).

Populations of winter grass, northern barley grass, willow leaved lettuce, prickly lettuce, tridax daisy and wild radish are present throughout the cotton industry and have also developed resistance to glyphosate elsewhere in Australia. In response to this issue the Australian cotton industry has developed a Herbicide Resistance Management Strategy (HRMS). The key message from the HRMS is to use 2 non-glyphosate weed control tactics in fallow + 2 non-glyphosate tactics in-crop and ensure that there are 0 survivors (2+2 and nil survivors). Refer to the Cotton Pest Management Guide for more information.



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

FIGURE 1: Area of glyphosate resistant weeds. (Source: CCA 2016–17 qualitative survey)



Planning weed management

It is important to strategically plan how the different tactics will be utilised to give the best overall results for the existing weed spectrum.

A short term approach to weed management may reduce costs for the immediate crop or fallow, but is unlikely to be cost effective over a five or ten year cropping plan. Over this duration, problems with species shift and the development of herbicide resistant weed populations are likely to occur where weed control has not been part of an integrated plan.

There are five principles in developing a successful long term approach to weed management:

- Know the weed spectrum and monitor for changes.
- Use a diversity of cultural, in-crop and fallow management tactics to actively reduce the seed bank, as well as preventing emerged weeds from surviving through to seed set.
- Rotate herbicide modes of action.
- Monitor and follow up to ensure weeds that survive a herbicide are controlled by another tactic before they are able to set seed.
- Come Clean Go Clean to prevent movement of weeds seeds onto, off, or around the farm.

Planning and deployment of tactics should consider the full range of farming systems inputs that can impact on weeds as shown diagrammatically in Figure 2.

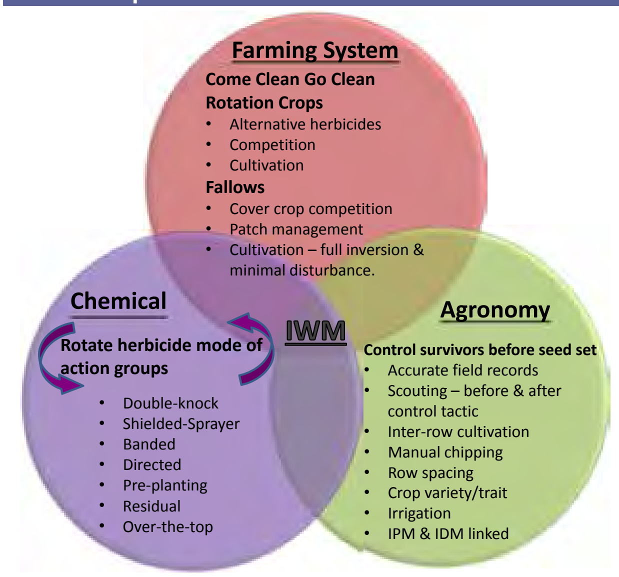
The HRMS should be used as a tool for planning weed management in irrigated and raingrown cotton farming systems to help delay and manage glyphosate resistance. Refer to the Cotton Pest Management Guide for more information. For a more detailed assessment of the resistance risks for individual paddocks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

In-crop implementation of tactics

Correct weed identification

Ensure that weeds are correctly identified before deciding upon a response. Similar species may respond differently to control measures.

FIGURE 2: An integrated weed management system should consider the full range of farming systems inputs that can impact on weeds.



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

If you suspect herbicide resistance:
Dr John Broster (seed test), Charles Sturt University
Herbicide resistance testing service, PO Box 588, Wagga Wagga, NSW 2650
Ph: (02) 6933 4001, Email:jbroster@csu.edu.au

Or

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

For example, the strong seed dormancy mechanisms of cowvine (Ipomoea lonchophylla) make it less responsive to a tactic like the spring tickle than bellvine (Ipomoea plebeia) which has very little seed dormancy. Herbicide susceptibility can also differ between similar species.

For technical information on weed ID refer to the Weed Identification and Information Guide available from CottonInfo
www.cottoninfo.com.au/publication- type/id-guides

Scouting

Scouting fields before weed control is implemented enables the weed control option to be matched to the species present. Soon after a control is implemented, scouting should be repeated to assess efficacy.

Timely scouting allows questions that affect the next weed control decision to be answered:

- Were the weeds damaged but have recovered?
- Has control been better in some parts of the field than others?
- Has there been good control but a subsequent germination?

To be effective in preventing resistance, weeds that survive a herbicide must be controlled by another tactic before they are able to set seed. Prompt scouting is required as some weeds are capable of setting seed while very small and many weeds respond to varying day-length, so a winter weed emerging in late winter or spring may rapidly enter the reproductive phase of growth in response to lengthening daylight hours.

For more information on the growth and development of common weeds refer to Weed Growth & Development Guide in WEEDpak
www.cottoninfo.com.au/publications/weedpak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• Mepiquat 38
• Thidiazuron 500 SC
• Thi-Ultra SC
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Herbicides
• Glyphosate 450
• Glyphosate 540 K
• Halox 520
• Paraquat 250
• Pendimethalin 330
• S-Metol 960
• Staroxy 200 EC
• Triclopyr 600
Insecticides
• Abamectin
• AceTam 225
• Alpha-Cyp 100 Duo.
• Amitraz 200 EC/ULV
• Bifenthrin 100 EC
• Chlorpyrifos 500
• Difen 500
• Indox 150
• Pyrip 100
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Identify and closely monitor areas where machinery such as pickers and headers breakdown. Weed seeds are often inadvertently released when panels are removed from machines for repairs. There have been many instances where weeds such as parthenium have been spread this way. Whenever possible, it is best practice to ensure that all machinery maintenance occurs in a centralized area, such as around the farm sheds, so that any new weed incursions will be readily observed and managed.

Weed scouting in non-crop areas of the farm is a valuable source of information for planning future weed management strategies.

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

Good record keeping

Good record keeping will help to develop strategies and are invaluable for mitigating problems if they occur. Good records are important as all Modes of Action (MOA) have a select number of applications before resistance will occur (Table 1). Consider the records from past years in this year's decisions, particularly in relation to rotating herbicide modes of action and safe plant back periods for residual herbicides.

Useful resource:

GRDC IWM Manual web link. https://grdc.com.au/resources-and-publications/iwmhub/section-3-herbicide-resistance#howweed

Timely implementation of tactics

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

Timing to protect yield potential

In addition to targeting weeds in a timely manner, after planting, it is important to manage weeds to prevent yield loss, as young cotton is not a strong competitor with weeds. The critical times when weed competition can cause yield loss are provided in Table 2 for a range of weed densities and weed types. Irrespective of the type of weeds, early season control is critical to prevent yield loss. The higher the weed population, the longer into the season weed control is required. Preventing yield loss as well as preventing weed seed set ensures there is an economic return from weed control both today and in the future.

TABLE 1: Years of Herbicide application before resistance evolves. (adapted from Preston, 2006)

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

Rotate herbicide groups

All herbicides are classified into groups based on their mode of action in killing weeds. Rotate herbicide groups whenever possible to avoid using the same group on consecutive generations of weeds (Table 1). 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 the majority of the mode of action groups. Refer to the Cotton Pest Management Guide.

Closely follow herbicide label recommendations

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

Stop seed set, and actively manage the seedbank

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

TABLE 2: Guide to the critical period for weed control to prevent 2 per cent yield loss.

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

Consider other aspects of crop agronomy

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

Cultural control

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

Rotation crops

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

Herbicide tolerant cotton traits

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

Crop competition

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

Irrigation

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

Post-harvest management

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

Patch management

Intensive management of small patches of herbicide resistant weeds can allow options to be used that would be considered too expensive or intensive to be done over a whole paddock or the whole farm. Research has found that patch management could be particularly efficacious for weeds such as awnless barnyard grass that are predominately self-pollinating species, that have a relatively short seed bank life and are not transported by wind. Use GPS to mark coordinates and remove existing weeds before they flower.

Tactics could include chipping, spot spraying or spot cultivation. Monitor for subsequent germinations until the seed bank has been exhausted.

www.cottoninfo.com.au/barnyard-grass-understanding-and-management-bygum

Herbicides

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

Mode of action (MOA) – refers to how the herbicide acts against the weed to kill it. Repetitive use of the same mode of action group over time is closely associated with the selection of herbicide resistance within weed populations. Refer to the product label for mode of action.

Rotation of herbicide mode of action groups is a key principle for integrated weed management as well as herbicide resistance management. Ensure any weeds that survive a herbicide application are controlled with another tactic (different mode of action, cultivation, chipping).

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

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

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

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

Non-selective herbicides – such as glyphosate or paraquat control a broad spectrum of both broadleaf and grass weeds. Despite being '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 – refers to application of more than one herbicide in a single operation, which can reduce application costs. It is important that full label rate of each component is used. Refer to the label or manufacturer to determine suitable mix partners, as some products are antagonistic, reducing weed control, damaging the crop when mixed together or through physical incompatibility (forms sludge).

Shielded spraying – the practice in which shields are used to protect the crop-rows while weeds in the inter-row area are sprayed with a non-selective herbicide.

Band spraying – the practice in which a given area (band) of selective herbicide is applied to weeds in either the crop-row or inter-row area.

Double knock tactic

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

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

Non-residual herbicides

Non-residual, foliar applied herbicides can be used to control emerged weeds while they are young and actively growing. Some herbicides from Group G mode of action may also provide short term residual control of subsequent germinations, depending upon the herbicide, weed and application rate combination.

Where cotton with Roundup Ready® technology is to be planted this is an excellent opportunity to rotate herbicide mode of action by using the Group L, G or N products prior to planting. These alternate mode of action products can also be used to control herbicide tolerant cotton volunteers. Depending on the weed spectrum, more selective products from other modes of action may also be used.

Spot spraying

Spot sprayers may be used as a cheaper alternative to manual chipping for controlling low densities of weeds in-crop. Ideally, weeds should be sprayed with a relatively high rate of a herbicide from a different herbicide group to the herbicides previously used to ensure that all weeds are controlled. This intensive tactic can be particularly useful for new weed infestations where weed numbers are low, or where weeds are outside of the field and difficult to get to such as roadside culverts.

New weed detection technologies provide an opportunity to use spot spraying across large areas of fallow. This can provide opportunities to reduce herbicide costs, while still ensuring robust label rates are applied to problem weeds. Growers using optical sprayer technology should check individual product labels for direction of use and application rates. Limited brands are approved for use via this application method. For growers using WeedSeeker(R) technology, APVMA permit PER11163 provides additional use patterns for some non-residual and short or longer term residual herbicides.

Residual herbicides

Residual herbicides remain active in the soil for an extended period of time (weeks or months) and can act on successive weed germinations.

This can be particularly effective in managing the earliest flushes of in-crop weeds, when the crop is too small to compete. Residual herbicides must be absorbed through either the roots or shoots, or through both.

The use of residuals in the farming system requires good planning as they must be applied in anticipation of a weed problem. Knowledge is required of the potential weed species, expected density and understanding of the seedbank dynamics.

Most residual herbicides need to be incorporated into the soil for optimum activity. Adequate incorporation of some residual herbicides is achieved through rainfall or irrigation, but others require incorporation through cultivation which may conflict with other farming practices such as minimum tillage and stubble retention. Soil surfaces that are cloddy or covered in stubble may need some pre-treatment such as light cultivation to prevent 'shading' during application.

While advantageous to weed management, the persistence of residual herbicides needs to be considered within the farming system in terms of rotation cropping sequence. Persistence is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics.

It can be quite complex. For example, moisture can be a big factor, however it is not the volume of rain, but the length of time the soil is moist, that is the critical factor. A couple of storms, where the soil dries out quickly, won't contribute as much to the breakdown of residuals, compared with soil staying moist for a few days. Refer to product label for more information. Product labels provide information on plant back limitations. If growers are concerned in the lead up to planting, look for the presence of susceptible weeds in the treated paddock or pot up soil from the treated and an untreated area, sow the susceptible crop and compare emergence. Where there is a concern, consider planting an alternative crop that is tolerant of the herbicide, or if cotton is to be used, plant the paddock last and pre-irrigate if it is to be irrigated.

Persistence in the environment can also be a concern for industry, and it is important to ensure that best practice is followed in terms of capture and management of runoff water.

Useful resource:

www.grdc.com.au/SoilBehaviourPreEmergentHerbicides

Chapter 12 sponsored by – eChem crop protection

Windmill grass set seed in cotton. (Photo courtesy T. Cook NSW DPI)

Tillage and cultivation

Inter-row cultivation

Inter-row cultivation can be used mid-summer to prevent successive generations of weeds from being targeted by repeated applications of post-emergent herbicides with the same mode of action.

Cultivating when the soil is drying out is the most successful strategy for killing weeds and will reduce the soil damage caused by tractor compaction and soil smearing from tillage implements. But letting the soil dry down too much will result in poor implement penetration, bringing up clods, require more horsepower and be hard on equipment.

'Spring tickle' (flush and cultivate)

The spring tickle uses shallow cultivation in combination with a nonselective, knockdown herbicide. The aim of the spring tickle is to promote early and uniform germination of weeds prior to sowing, which is then controlled with a herbicide mode of action not used in the crop, to ease weed pressure in the crop. Some weed species are more responsive to the spring tickle than others. Highly responsive weeds include bellvine and annual grasses – liverseed grass and the barnyard grasses. Weeds that are less responsive include; cowvine, thornapple, noogoora burr and bathurst burr.

The shallow cultivation (1–3 cm) can be performed using implements such as lillistons or go-devils. Best results are achieved when the cultivation follows a rainfall event of at least 20 mm. Adequate soil moisture is needed to ensure that weed germination immediately follows the cultivation.

Where moisture is marginal, staggered germination may result in greater weed competition during crop establishment.

Manual chipping

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

TABLE 3: Effect of tillage type on emergence of fleabane.

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

Bury seed of surface-germinating species

Use strategic cultivation to bury weed seeds and prevent their germination. Some weed species, such as common sowthistle (milk thistle), feathertop Rhodes grass and flaxleaf fleabane, are only able to germinate from on or near the soil surface (top 20 mm). Tillage operations such as pupae busting, where full disturbance of the soil is required, can be timed to assist in situations where these species have set seed. Burying the seed more than 20 mm below the surface will prevent its germination. This tactic is most successful when used infrequently as seed longevity of common sowthistle and flaxleaf fleabane will be extended from ~12 months to ~30 months by seed burial, meaning that a cultivation pass burying seed which is on the surface could at the same time expose older but still viable seed buried in a previous operation (see Table 3).

Control survivors before they set seed

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

It is critical to the longer term success of the IWM strategy that survivors not be allowed to set seed, 0 survivors.

Come Clean Go Clean

To minimise the entry of new weeds into fields, clean down boots, vehicles, and equipment between fields and between properties. New Risk Management requirements have been implemented in NSW under the Biosecurity Act 2015. Pickers and headers require special attention. Eradicate any new weeds that appear while they are still in small patches. Monitor patches frequently for new emergences.

Irrigation water can be a source of weed infestation with weed seeds being carried in the water. While it is not practical to filter seeds from the water, growers should be on the lookout for weeds that gain entry to fields via irrigation. Give special consideration to water pumped during floods, as this has the greatest potential to carry new seeds. If possible, flood water should be first pumped into a storage to allow weed seeds to settle out before being applied to fields. Control weeds that establish on irrigation storages, supply channels and head ditches.

For more information refer to the Weed section of the Cotton Pest Management Guide. www.cottoninfo.com.au/publications/cotton-pest-management-guide www.dpi.nsw.gov.au/about-us/legislation/list/biosecurity-act-2015

Integrated Disease Management

By **Sharna Holman** (QLD DAF and CottonInfo)

Acknowledgements: Susan Maas (CRDC), Stephen Allen (CSD), Karen Kirkby, Peter Lonergan (NSW DPI), Linda Smith, Linda Scheikowski, Cherie Gambley, Murray Sharman (QLD DAF), Ngaire Roughley (CSD) and Duy Le (NSW DPI)

Developing an Integrated Disease Management (IDM) strategy for your farm

A plant disease occurs when there is an interaction between a plant host, a pathogen and the environment. Therefore effective integrated disease management involves a range of control strategies which must be integrated with management of the whole farm.

Disease control strategies should be implemented regardless of whether or not a disease problem is evident, as the absence of symptoms does not necessarily indicate an absence of disease.

IDM at planting

Preparing optimal seed bed conditions

- 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.
- Fields should have good drainage and not allow water to back-up and inundate plants.

Sowing date/temperature

Sowing in cool and/or wet conditions favours disease. While cotton can be planted once the soil reaches 14°C or above at 10 cm depth, at 8am, from a disease perspective it is best to plant when temperatures are 16°C and rising. Refer to the Crop establishment chapter.

Plant resistant varieties

There are a number of varieties that have good resistance to Verticillium wilt or Fusarium wilt, with levels of resistance indicated by higher V rank and F rank respectively. It is important to know the disease status of each field to inform this planning. In addition to resistance, consider the seedling vigour of a variety particularly when watering up or planting early. Refer to CSD variety notes for more information.

When the Black root rot pathogen is present, use the more indeterminate varieties that have the capacity to catch up later in the season. Avoid growing susceptible varieties in fields that contain infected residues.

For back to back fields, disease risks can be higher, increasing the importance of planting resistant varieties and using other IDM strategies.

Replanting

Replanting decisions should be made on the basis of stand losses, not on the size of the seedlings. Refer to the Crop establishment chapter.

IDM in crop

Fungicides

All cotton seed sold in Australia for planting is treated with a standard fungicide treatment for broad spectrum disease control. Other examples of fungicides include seed treatments for seedling disease control and foliar sprays for the control of Alternartia leaf spot on cotton in specific regions.

Irrigation scheduling

Applying water prior to planting provides better conditions for seedling emergence than watering after planting. Watch for signs of water stress early in the season if the root system has been weakened by disease and irrigate accordingly. Avoid waterlogging at all times, but especially late in the season when temperatures have cooled. Irrigations late in the season that extend plant maturity can result in a higher incidence of Verticillium wilt. Tail water should also be managed to minimise the risk of disease spread.

Best practice...

- **If an exotic pest or disease is suspected, contact your State Agriculture Department or the Exotic Plant Pest Hotline 1800 084 881.**
- **Practice good integrated disease management at planting, crop and post harvest.**
- **Where possible, select disease resistant varieties.**
- **Monitor the crop for disease symptoms, with the information used to identify where the disease occurs on the farm and monitor the disease over time.**
- **Manage volunteer and ratoon cotton plants through the year, in crop and non-cropping areas.**
- **Follow good farm hygiene practices (Come Clean Go Clean) to minimise spread of pests, weeds and diseases onto and off your farm.**

Monitor for plants with unusual symptoms. (Photo courtesy Jamie Iker)


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Agronomic management

High planting rates can compensate for seedling mortality, but a dense canopy favours development of bacterial blight, Alternaria leaf spot and boll rots. Avoid rank growth and a dense canopy with optimisied nutrition and irrigations and with the use of growth regulators where required.

If Black root rot is present, either manage for earliness to get the crop in on time (in short season areas) or manage for delayed harvest to allow catch up (in longer season areas).

Balanced crop nutrition

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

Conduct your own in-field disease survey

It is important to be aware of what diseases are present, where they are present on-farm and whether or not the incidence is increasing. Monitoring and recording disease incidence and severity allows a comparison over time (see below for in season monitoring). Train farm staff to look for and report unusual symptoms. Contact your state department cotton pathologist for assistance in identifying suspected disease and confirm pathogen strain.

QLD DAF pathologist, Linda Smith – 0457 547 617.

NSW DPI pathologist, Duy Le – 0439 941 542.

Exotic Plant Pest Hotline 1800 084 881.

Refer to the Cotton Symptoms Guide or the Cotton Pest Management Guide for instructions on how to send a sample.

In season disease monitoring

Early season

- An early season disease survey is conducted within 4 weeks from planting.
- Compare number of plants established per metre with number of seeds planted per metre. Refer to Crop establishment chapter for replanting considerations.
- Walk the field and look for plants that show signs of poor vigour or unusual symptoms.
- Examine roots by digging up the seedling – never pull the seedling from the ground.

During and late season

- Late season disease surveys are conducted after the final irrigation but before defoliation.
- Walk field and look for plants that are dead, show signs of poor vigour or have unusual symptoms.
- Cut stems of plants showing symptoms of disease and examine for discolouration.

IDM post harvest

Control alternative hosts and volunteers

Having a host-free period prevents build up of pathogen inoculum and carryover of disease from one season to the next. The pathogens that cause Verticillium wilt, Fusarium wilt, Black root rot, Tobacco streak virus and Alternaria leaf spot can also infect common weeds found in cotton growing areas. Refer to WEEDpak F5 Table 1 for weeds known to be hosts of cotton pathogens.

It is particularly important to have a host-free period as some diseases, such as Cotton Bunchy Top, can only survive on living plants. Controlling alternative hosts, especially cotton volunteers and ratoons will help reduce the risk of quality downgrades and yield loss from Cotton bunchy top.

For more information on checking your farm for volunteer plants visit www.youtube.com/cottoninfoaust.

Crop residue management

The pathogens that cause Verticillium wilt, Fusarium wilt, Black root rot, boll rots, seedling disease and Alternaria leaf spot can all survive in association with cotton and some rotation crop residues. Crop residues should therefore be managed carefully to minimise carryover of pathogens into subsequent crops.

If Fusarium wilt is known to be present in a field, residues should be slashed and retained on the surface for at least one month prior to mulching, in order to disinfect the stalks through UV light exposure.

In all other circumstances (including the presence of Verticillium wilt and other diseases), crop residues should be incorporated as soon as possible after harvest to afford a host-free disease period.

Crop rotations are utilised to assist in disease management

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

Cotton is believed to be dependent on mycorrhiza, specialised fungi, 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 top-soil (especially more than 40 cm) may result in a lack of mycorrhiza, leading to poor establishment and growth of seedlings as well as symptoms of nutrient deficiency. Symptoms are transient and crops may recover later in the season. A cereal or green-manure crop may restore sufficient mycorrhizal fungi for cotton.

The Cotton Rotation Finder can assist with developing a rotation strategy www.cottoninfo.com.au/cotton-rotation-tool.

IDM all year round

Control of insect vectors

Diseases caused by a virus or phytoplasma are often prevented by controlling the vector that carries the pathogen. Cotton bunchy top (CBT) can be transmitted by aphids feeding on infected plants then migrating to healthy plants. Transmission of Tobacco streak virus (TSV) to plants relies on the virus from infected pollen entering plant cells through the feeding injury caused by thrips. Control of insect vectors should consider IPM principles and resistance risks (See IPM chapter).

Viruses can only survive in living plants. Control of cotton ratoons and volunteers throughout winter will reduce pathogen levels and also lower vector insect populations, drastically reducing disease risk.

TABLE 1: Potential disease implication of rotation crops with cotton (in relation to the following cotton crop) (from Cotton Rotation Crop Comparison Chart).

	Allelopathy	Seedling disease	Phytophthora boll rot	Alternaria leaf spot	Black root rot	Fusarium wilt	Verticilium wilt	Sclerotinia	Nematodes
Spread	N/A	Soil-borne and waterborne spores, infected crop residues, infected stubble.	Waterborne spores (including rain splash onto bolls), infected crop residues.	Airborne and waterborne spores, infected crop residues, infected stubble. Seed borne dispersal has been reported overseas but is thought to be insignificant.	Soil-borne and waterborne spores, infected crop residues.	Soil-borne or waterborne spores, infected crop residues, seed borne dispersal.	Soil-borne or waterborne spores, infected crop residues.	Waterborne spores (including rain splash onto bolls), infected crop residues.	Soil-borne or waterborne spores.
Survival	N/A	Fungi can survive indefinitely as saprophytes on plant residues in the soil.	Infected crop residues.	Infected crop residues, volunteer cotton plants and alternative crop/ weed hosts (can be living or dead/dying plant tissue).	Volunteer cotton plants and alternative living crop/weed hosts.	Can survive in organic matter in the soil/ rhizosphere of some other crops/weeds. It may not cause disease in these other plants but can survive at a reduced population level.	Can survive in soil or infected crop residues in the absence of a host.	Infected crop residues.	Can survive at least two years in the absence of a host in dry soil through anhydrobiosis.
Canola	Increases risk of allelopathy	Decreases risk	Non-host	Decreases risk	Non-host; repeated use of non-hosts to decrease. Can be biofumigant crop.	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as a host in international literature.	Increases risk	Non-host
Chickpeas	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Survives in crop residues. Incorporate infected residues early.	Non-host	Decreases risk	Increases risk	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as a host in international literature.	Increases risk	Increases risk
Cotton (ie. back to back)	Decreases risk	Survives in crop residue; incorporate infected residues early to minimise risk. Good bed preparation is important.	Early incorporation may reduce carry over.	Early incorporation may reduce carry over.	Increases risk	Increases risk, especially if growing low F rank varieties.	Risk is related to inoculum level and environmental conditions. Fields with a long history of cotton are at higher risk.	Increases risk	No resistant varieties available, increases risk.
Faba beans	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Reported host of *Pythium* sp	Non-host	Decreases risk	Increases risk	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as a host in international literature.	Increases risk	Decreases risk when resistant varieties are grown
Long fallow	No	Decreases risk if crop residues incorporated.	Decreases risk in weed free fallows	Decreases risk if previous crop residues incorporated.	Decreases risk in weed free fallows.	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	Decreases risk	Reported host of *Pythium sp* and *Rhizoctonia solani*	Non-host	Decreases risk	Non-host; repeated use may decrease	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported internationally as a potential asymptomatic host.	Decreases risk	Non-host

TABLE 1: Potential disease implication of rotation crops with cotton (in relation to the following cotton crop) (from Cotton Rotation Crop Comparison Chart).

	Allelopathy	Seedling disease	Phytophthora boll rot	Alternaria leaf spot	Black root rot	Fusarium wilt	Verticilium wilt	Sclerotinia	Nematodes
Mung beans	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Reported host of *Rhizoctonia solani*	Non-host	Decreases risk	Increases risk	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as a host in international literature.	Increases risk	Increases risk
Pigeon pea	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Reported host of *Pythium sp.*	Non-host	Decreases risk	Increases risk	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Non-host	Increases risk	Increases risk
Safflower	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Decreases risk	May increase – listed as a host in QLD and WA	Decreases risk	Non host; repeated use of non-hosts to decrease risk.	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as a host in international literature.	Increases risk	Non-host
Sorghum	Increases risk of allelopathy	Reported host of *Rhizoctonia solani.*	Non-host	Decreases risk	Non-host; repeated use may decrease risk.	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Decreases risk	Decreases risk	Non-host
Soybean	Incorporate infected residues early.	Survives in crop residues. Incorporate infected residues early.	Non-host	Decreases risk	Increases risk	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as a host in international literature.	Increases risk	Decreases risk when resistant varieties grown
Sunflower	Increases risk of allelopathy	Reported host of *Pythium sp* and *Rhizoctonia solani.*	Non-host	Non-host	Non-host; requires repeated use of non-hosts in the rotation to reduce incidence.	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as a host in international literature. Choose resistant varieties.	Increases risk	Increases risk
Vetch	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Reported host of *Pythium sp.*	Non-host	Decreases risk	Biofumigant when incorporated	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Asymptomatic host that may increase risk.	Increases risk	Increases risk
Wheat/barley/ triticale/oats	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Decreases risk	Non-host	Decreases risk	Non host; repeated use of non hosts to decrease risk.	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Reported as an asymptomatic host in international literature, may maintain or increase risk over time.	Decreases risk	Non-host

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

Come Clean Go Clean

Minimise the risk of moving pathogens on or off your farm, from field to field or farm to farm by considering vehicle and machinery movements within the farm and having a strategy for ensuring clean movement of vehicles and machinery onto and around the farm. Minimise spillage and loss when transporting modules, hulls, cotton seed or gin trash.

Ensure all staff, contractors and visitors are aware of the requirements and your commitment to 'Come Clean Go Clean' before entering the farm.

Useful resources:

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

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

Best practice…

- **All farm personnel, consultants, contractors and visitors are made aware of farm biosecurity requirements.**
- **Ensure all farm inputs brought into the farm are pest-free.**
- **Ensure a wash-down facility is available.**
- **All machinery, vehicles and equipment are inspected for any soil and plant debris, cleaned in the washdown facility before moving on and off your property.**
- **A sign-posted designated parking area is provided for visiting vehicles and contractor equipment that is away from production areas with a record of visitors kept.**
- **Use farm vehicles to transport visitors around the farm.**

Come Clean. Go Clean.

Practicing good farm hygiene will help prevent the entry and spread of diseases, weeds and pests onto your farm. The introduction of these pests can have a significant impact on your farm and business so it is important to make sure you take the time to incorporate farm hygiene practices and Come Clean Go Clean into your business.

Step 1: Wash-down

Park on a clean wash down pad where contaminants can be trapped. Apply compressed air or high pressure water to all surfaces to remove all trash and mud, being sure to get into crevices where residual mud or trash might be trapped. Don't forget to clean out the inside of the cab and vehicle foot pedals and other surfaces that have come into contact with dirty footwear. (Photo courtesy C. Anderson, NSW DPI)

Step 2: Cleanse

Apply an agricultural detergent liberally to all surfaces to assist with soil removal from machinery and vehicles especially mats, tools and footwear. Leave the detergent to work for 10 minutes and then rinse unless directed otherwise by label. (Photo courtesy Susan Maas, CRDC)

Step 3: Decontaminate

Consider adding an agricultural decontaminant to your farm biosecurity plan to ensure that wash down procedures are thorough. Follow label instructions on usage. Please refer to your reseller for their preferred decontaminant. (Photo courtesy Susan Maas, CRDC)

Step 4: Rinse

Rinse off your wash down product. Clean all the mud off the pad with high pressure water so it is clean for the next person and that mud and debris isn't picked up by wet tyres. Where equipment has not been cleaned down on farm, thoroughly inspect to ensure cleanliness.

Make Come Clean Go Clean a priority

Come Clean Go Clean takes commitment especially during busy periods such as harvesting. The risks are real, so ensure that all equipment and people stop and clean down.

Inform people

Well designed signage informs visitors that Come Clean Go Clean is important and they share responsibility for protecting the farm from risk.

Signs should be placed at all external entrances, directing visitors to have clean vehicles and to contact the farm office before entering.

Come Clean Go Clean requirements should be communicated with contractors and consultants well in advance.

Wash-down facilities

On farm facilities allow farm employees, contractors and visitors to clean their vehicle and equipment in an easy to manage area where waste water can be contained. Facilities should be readily accessible, have sealed or packed gravel surface, access to high pressure water, wash down product and power, and be away from production areas and not drain into waterways or cropping areas.

For more information go to www.mybmp.com.au or contact CottonInfo Tech lead Sharna Holman – Disease & Biosecurity (0477 394 116).

Sustainable cotton landscapes

By **Jane Trindall** (CRDC) **& Stacey Vogel** (CottonInfo)

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

Diversity in vegetation (native and other crops) can act as a refuge for cotton pests that haven't been exposed to Bt toxins/insecticides used in cotton providing additional source of susceptible individuals, slowing 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 offsetting agricultural emissions helping cotton farms achieve carbon neutrality. Healthy soils can sequester carbon and improve nutrient cycling.

Three key principles are listed below to assist you better understand and manage the natural assets on your farm for both environmental and production benefits.

Healthy landscapes

Improving the health of individual stands of natural vegetation and linking them together on your farm and in the district will improve the numbers and diversity of plants and animals on your farm, including beneficial insects, bats and birds, which provide natural pest control.

Manage for groundcover & diversity

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

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 for ecosystem service provisions of pollination, natural pest control, water quality and carbon sequestration and storage.**
- **Control environmental weeds and volunteer crop plants that act as hosts for pest species.**
- **Monitor water quality and apply irrigation water efficiently.**

Cotton farmers are custodians for an average of eight kilometres of riparian land of which 91 per cent is actively managed (2014 Cotton Industry Survey). (Photo courtesy of Cotton Australia and Greg Kauter)

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*), milk/sowthistle (*Sonchus oleraceus*), in winter and bladder ketmia (*Hibiscus trionum*) and thornapples (*Datura* spp.) in summer, are better hosts for pests than beneficials, and some weed species also host viruses such as the Noogoora burr complex (*Xanthium spp*), a known host for the pathogen (*Verticillium dahliae*).

When planning revegetation, prioritise the incorporation of trees and shrubs that flower prolifically. Eucalypts and melaleucas attract feeding insects that are not pests of cotton, which in turn attract a broad range of predator insects that will move into cotton. If seeding of ground species is possible, look to establish a mix of tussocky and sprawling grass together with a mix of winter and summer active legumes. Leaving logs, dead trees and litter where they fall will enhance the habitat and reduce erosion.

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 nearby the crop. Native vegetation corridors or 'bridges' between remnants facilitate the dispersal of beneficial insects through the landscape and provide local habitat when crops aren't present.

Where there is little remnant vegetation in an area, focus revegetation efforts on the creation of corridors that link areas together. Fenceline plantings, wind breaks and roadside verges can provide effective habitat for beneficials and facilitate movement into and between crops. Plant species diversity and perenniality 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 pest 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.
- Leave logs, rocks, dead trees and litter in natural areas where ever you can.

- Protect big old trees with hollows.
- Work with your neighbours to control weeds and pests in the natural areas in the district.
- If you would like to vegetate areas on your farm, think about linking corridors between natural areas and use local species to increase survival rates, improve natural pest control and increase the numbers of plants and animals on your farm.

Healthy rivers

Across the country, cotton farms are located along the rivers in the northern Murray Darling basin and the reef catchments of the Fitzroy. On many cotton farms rivers, wetlands and billabongs are lined with majestic River Red Gums and iconic Coolibahs that define rural Australia. Many studies have shown that these areas are in good condition (as in '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 some storm 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 in the past enabled cotton growers to retain regulatory access to pesticides.

Channels that are nude 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 breakdown pesticide residues on farm. Where water flows more slowly, residues are filtered out 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 breakdown in different ways. Strategically combining vegetation on some channels flowing into non-vegetated storage areas means the system will be efficient at both microbial and UV degradation of pesticides.

What to do along waterways:

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

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

Healthy soils

Whether in your field or in the natural areas of your farm, healthy soil can make farming a whole lot easier. Maintaining healthy soils reduces the risk of ongoing investment of time and money to restore costly soil issues like salinity, sodicity and erosion. Simple practices to maintain soil biology, structure, organic matter and carbon will protect your farm for the long haul.

What to do:

- Manage irrigations to minimise deep drainage and salinity risks (see Irrigation management chapter and healthy water section below).
- Manage traffic.
- Maintain groundcover.
- Graze sustainably.
- Match landuse and land capability.
- Benchmark per cent groundcover based on soil type/capability.

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

Healthy water

Decreasing quality of the water used for irrigation (from streams and groundwater) and rising groundwater levels are real threats to the irrigation industry as well as the environmental functions of these two ecosystems.

Consider the impact of water quality on irrigation equipment as well as soils. (Photo courtesy of Melanie Jenson)

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 condition can be established. Any trends or changes in water quality and level can be acted upon and considered in the farm management plan to both maximise crop yield and to ensure the long term viability of the farm water resources.

Water quality monitoring

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

pH

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

pH thresholds for irrigation water.	
pH 5.5 – 8.8	Irrigation water suitable for most plants
pH <4	Irrigation water can contribute to soil acidity
pH >9	Irrigation water may contribute to alkalinity
pH >8.5 or <6	Irrigation water may affect spray mixes ie. precipitation of salts and/or corrosion and fouling

Electrical conductivity of water (ECw)

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

Sodium adsorption ratio

SAR 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 (ie salinity of the soil) as well as the soil type (see the Cotton Soil and Water Quality Fact sheet).

Water quality tool

A Water Quality Tool is available on the CottASSIST website (www.cottassist.com.au) to assist landholders assess suitability of water for irrigation.

The tool can also help growers make water shandying decisions to dilute the impacts of poorer quality bore water.

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

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

Monitor groundwater levels

Groundwater levels can change over time, where an aquifer may either 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.

The other side of the farm. (Photo courtesy of Ruth Redfern)

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 (for example, nitrogen), which may be a loss to the farming system and contribute to poorer off-site water quality.
- Leaching of salts which can cause salinization of underlying groundwater systems.
- Raising of water levels in shallow groundwater systems.

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

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

Useful resources:

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

- **The Australian Cotton Water Story**
- **WATERpak**
- **CottASSIST Water Quality Tool**
- **DIY Groundwater Monitoring Fact Sheet**
- **Cotton Soil and Water Quality Fact sheet**
- **Ecosystem Services Fact Sheet**
- **Salinity Management Handbook (www.publications.qld.gov.au/dataset/salinity-management-handbook)**

Your local NRM groups or LLS may be able to provide additional advice and resources:

- **Fitzroy Basin Association www.fba.org.au**
- **Queensland Murray Darling Committee www.qmdc.org.au**
- **Condamine Alliance www.condaminealliance.com.au**
- **North West Local Land Services www.northwest.lls.nsw.gov.au/**
- **Central West Local Land Services www.centralwest.lls.nsw.gov.au/**
- **Western Local Land Services www.western.lls.nsw.gov.au/**
- **Riverina Local Land Services www.riverina.lls.nsw.gov.au/**

In season

Photo courtesy Ruth Redfern

Crop establishment

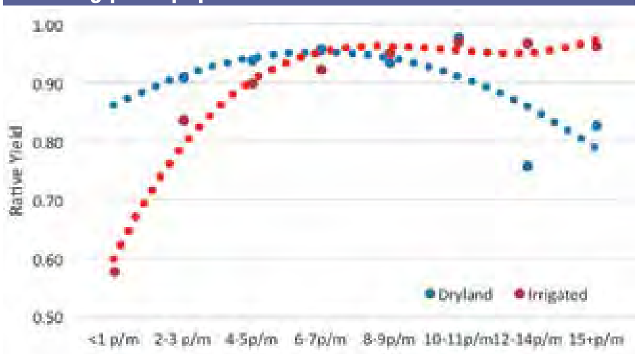
By **James Quinn** (CSD)

Establishing a cotton crop is a critical operation, it sets the standard for the entire season, influences crop growth, development and management. If unsuccessful it is difficult to manage and costly to rectify.

Target plant population

To optimise yield you should aim for an evenly spaced established plant population from 8–12 plants per metre in fully irrigated conditions and between 5–8 plants per metre in raingrown planting conditions. Additionally, you need to avoid large gaps. Figure 1 shows the results of CSD plant population trials.

FIGURE 1: Summary of CSD irrigated (32 trials) and raingrown (9 trials) showing the relative yield of differing plant populations.



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 raingrown or marginal conditions.
- Where you normally grow a larger plant size that can compensate well into gaps in the plant stand (eg. in wetter, warmer climates and good soil types).

Best practice…

- **Planting outside the ideal conditions and the planting window for your district may require special management.**
- **Some varieties have lower seed density and require careful management in terms of seed bed, soil temperature, and planter set up and operation.**
- **Replant decisions should be based on good field information about the current population, its health and the cause of the stand loss. A low and gappy plant stand can be very costly and difficult to manage. Replanting Bollgard II needs to occur within the planting window.**

Aim for the higher end of the range when:

- Early crop maturing is essential (eg. southern and eastern regions).
- Where you normally grow a smaller plant size that cannot compensate well into spaces (eg. tight soils).

Planting rate

The key considerations when determining how much seed you need is your desired plant stand target, and then calculating the effect of factors listed below which will negatively impact on the establishment of your crop. From these assumptions a seeding rate can be determined and kilograms planted per hectare can be calculated.

The seed size and germination data for the variety grown will have a large impact on the final planting rate. On average there are about 11,000 seeds/kg however there are differences between varieties, which can impact significantly on the final kilograms per hectare planting rate. The seeds per kilo information for cotton planting seed can be obtained by following up the AUSlot information on the CSD website.

Germination data: All CSD cotton planting seed has a minimum germination of 80% at the point of sale. Germination data for both Warm and Cool Test Data for individual lots are available on the CSD website or contacting CSD's Extension and Development agronomists.

Seedling survival is rarely 100% so you can never bank on seeds/ha and plant/ha being the same. Annual seedling mortality surveys are conducted by State Agricultural Departments and show the differences in seedling survival by growing region:

- **Bed condition:** Ideally a well consolidated, friable and uniform seed bed. Uneven or excessively cloddy beds can result in uneven seed depth and seed/ moisture contact, resulting in a staggered germination and gaps. Stubble can act as a physical barrier to seedling planting or emergence and hinder the uptake of moisture by the seed.
- **Soil insects:** Particularly wireworm, can attack young seedlings. Seed treatment insecticides will control them but because the insect needs to feed on the plant before it dies, some plant loss can still occur. Additional insecticide applied to the planting slot maybe required where high numbers of wireworms are present.
- **Soil temperature:** Ideal soil temperatures for cotton establishment are 16°C–28°C. Temperatures below this result in poor or slow emergence and increased chance of soil disease incidence and severity.
- **Seedling diseases:** Such as rhizoctonia, pythium and fusarium can kill young plants during and after emergence. This will be more prevalent at low temperatures, where there is high levels of crop residues and in fields with a history of disease. Additionally Black root rot can hamper cotton root growth and expansion and result in sluggish above ground growth.

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

- **Compaction:** Smearing of planting slot or layers of compaction below the plant line can hinder root growth and in conjunction with soil moisture drying down, cause a small seedling to get stranded.

Many of these factors are unavoidable and the best and easiest way to manage them is to increase the seeding rate.

Irrigated plant population trials carried out over numerous seasons has shown there are more disadvantages in having a plant population that is too low than there are to having one too high.

Planter setup

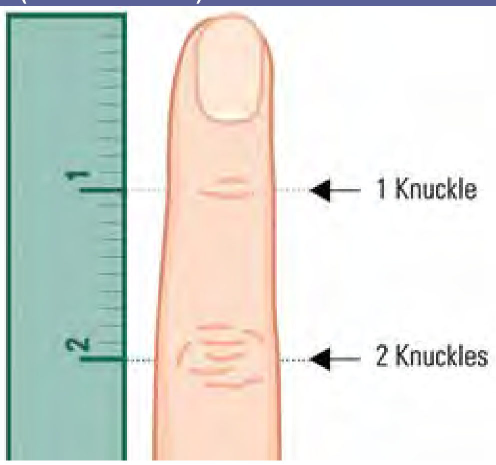
Ensure planter is well serviced and operational well before planting time because breakdowns in the field can rob you of time and allow surface soil moisture to further dry away:

- Ensure the planter is level.
- Check that discs and press wheels are uniform and engage the soil in the correct manner.
- Check that monitors are calibrated and working correctly.
- Chains and cogs need to be properly adjusted and lubricated.
- Spray lines and filters should be cleaned to stop blockages when planting herbicides or in-furrow sprays are to be used.
- During the operation, regularly check seed depth and the condition of the soil around the seed. This is especially important when planting on rain moisture where you may get some 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 minor repairs.
- Planter seeding rates should be calibrated as well as granular insecticide rates if used.

Planting depth

The depth you want your seed depends on the establishment method and soil and seed bed conditions you are intending to establish your crop in. Many people like to use the 'knuckle' as a quick and easy measurement tool in the field. Please refer to example shown in Figure 2.

FIGURE 2: Checking the planting depth using your knuckles (1 inch = 2.5 cm).



Important considerations

Establishment Method	Ideal depth
Planting into moisture (rain or pre-irrigated)	2½ and 4½ cm 1 to 1½ knuckles

- If the beds are too wet at planting, you end up with a shiny, smeared slot which is very difficult for the young roots to penetrate. The result is often young seedlings dying from moisture stress, even if there is plenty of moisture down below.
- Check the consistency of the soil above the seed. If the pressure from the press wheels on the planter are set too high, you can get a compacted zone above the seed and the young seedling will have a tough time getting out.
- Some dry soil above the seed slot is useful to prevent losing moisture from around the seed, however if there is too much, a rainfall event after planting will turn this dry soil into wet soil, and increase the depth for which the young seedling needs to push through.

Establishment method	Ideal depth
Planting dry and watering up	2½ cm 1 knuckle

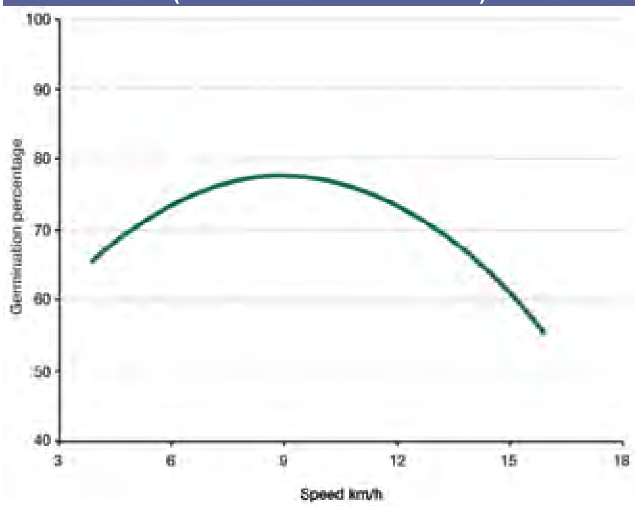
- This method has advantages in hot climates, because it cools the soil and crop establishment is rapid. However, consider pre-irrigating when:
  1. There is a large seed bank of difficult to control weeds.
  2. The soil is very dry and temperatures are high.
- Any shallower than 2½ cm and the plant doesn't have the chance to scrape off the seed coat at germination and seedling growth of that plant will be quite slow until that coat is thrown off.
- 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 when the water hits it and dropping the seed down to great depths, resulting in a poor or variable strike. This is especially important for crops coming out of sugarcane or corn.
- Sowing can be followed by an over-the-top application of Roundup Ready® herbicide, targeting newly emerged weeds.

Planting speed

Planter speed has the potential to affect both seed placement and seed spacing.

If the planter units are operated under field conditions that cause them

FIGURE 3: Effect of planting speed on cotton establishment (results of 12 trials 2013–14).



to bounce, depth placement and even spacing problems can result. The data shows that there is an ideal plant speed around 8–10 km/hr. Outside this range the data shows that the average population decreases.

Planter speed should be based on knowledge of equipment and soil and seed bed conditions. When selecting your operating speed there is a trade off between getting over the county and your accuracy in establishment. Figure 3 shows the effect planting speed has on establishment during the 2013–14 cotton season.

Planting time

The ideal planting time will vary between seasons and districts.

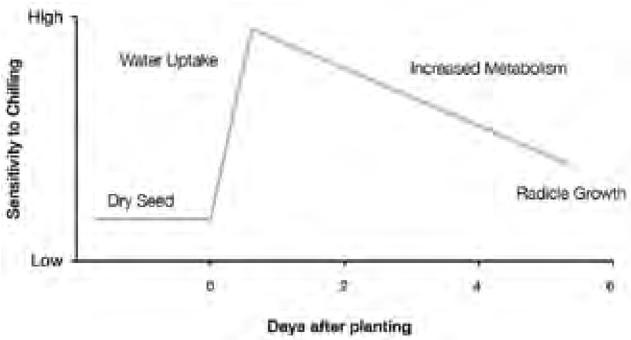
The Bollgard 3 RMP allows for a broad range in planting dates from August 1st to December 31st. For many districts there will be an optimum planting time where yield, fibre quality and maturity are maximised. In many districts planting outside the optimum window, could result in yield, fibre quality and maturity penalties.

Planting should not occur 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 rate of development and germination of a cotton seedling. Below 12°C the growth of a cotton plant is severely retarded and enzymatic activity within the cotton plant does not function properly until temperatures are above 15°C. There is a strong relationship between time to establishment and soil temperature, with the higher the temperature the faster the rate of development and germination.

FIGURE 4: Cotton sensitivity to cold temperatures during the germination period.



Cotton is a temperature-sensitive crop and the way the crop deals with the extremes of temperature is by shutting down or slowing physiological processes in the plant.

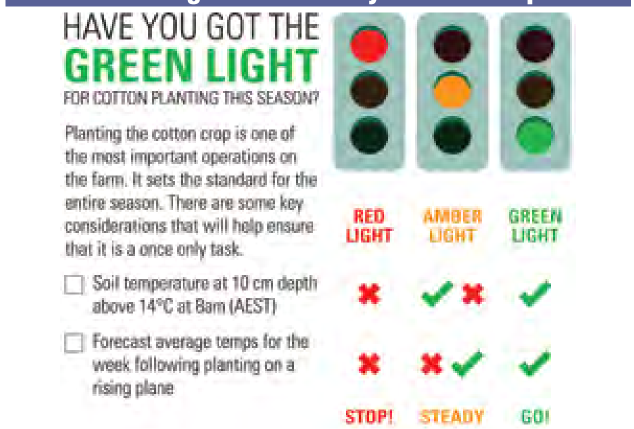
Temperature experienced post-planting will also have an impact on the time taken for the plant to emerge. The slower the plant grows, the greater the chance of seedling death occurring through disease and insect damage. Figure 4 shows that the most sensitive time for chilling injury is at the time the seed takes in moisture, and reduces as the germinating seedling progresses through to establishment.

This is why it is so important to monitor soil and air temperatures to find the appropriate window to plant the crop. It has been an Australian cotton industry guideline for many years that cotton planting should not begin before soil temperatures reach 14°C or above at 10 cm depth, at 8.00am Australian Eastern Standard Time (AEST). Planting at temperatures below this will diminish root and shoot growth, reduce water and nutrient uptake and make plants much more susceptible to attack from seedling diseases and insects. 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. The following guidelines should be considered when determining if conditions are suitable for planting cotton.

Soil Temperature and Forecast are now on CSD Web Site, the results of the 43 soil temperature probes are displayed at www.csd.net.au/soil_temperatures. Hourly temperature results are displayed as well as a forecast of the air temperature for the following week.

Avoid planting into fields with established weeds – they will draw moisture out of the profile so it's not available to the young seedlings. (Photo courtesy Susan Maas, CRDC)

Before entering the field ask yourself the question



1. If you cannot give a green tick next to at least one of these statements, then planting conditions are definitely unsuitable – **STOP!**
2. If you can give a green tick to only one of these statements – **BE CAUTIOUS. Adjustments may need to be made.**
3. If you can give both statements a green tick – **Let's GO!**

Temperature effects on speed of germination

There is a strong relationship between time to establishment and soil temperature, with the higher the temperature the faster the rate of development and germination.

A faster rate of development is desired, as the cotton plant emerges faster and starts to generate its own energy from sunlight. Root growth is rapid, minimising the influence of pest and disease pathogens and allows for the developing root to be firmly footed in soil moisture. Table 1 shows the influence that temperature has on both the survival and rate of emergence of cotton seedlings.

TABLE 1: Effect of temperature on cotton seedling survival and growth rate. (Constable and Shaw 1988)

Min soil temp at 10 cm	Seeds emerging and survival	Days to complete emergence
10	56%	29
14	73%	17
18	90%	5

History shows the incidence of replant has been much higher in situations where soil temperatures have been lower than ideal.

Agronomically, the end date for planting is more important in short season areas where early crop maturity is essential. This is evident by the comparison of ideal planting times for northern, central and southern regions. Figure 5 shows the calculated yield potential for many cotton growing regions within Australia.

The adoption of Bollgard 3 cotton has helped eliminate some of the desire for very early planting because:

- These crops tend to retain more early fruit and hence a quicker time between planting and picking.
- The season-long Helicoverpa control offered by this product diminishes the risk of high late-season insect numbers and control costs associated with conventional cotton.

Particularly when planting on rain moisture, beware of uneven moisture throughout the bed which will cause variable crop development.
(Photo courtesy CSD)

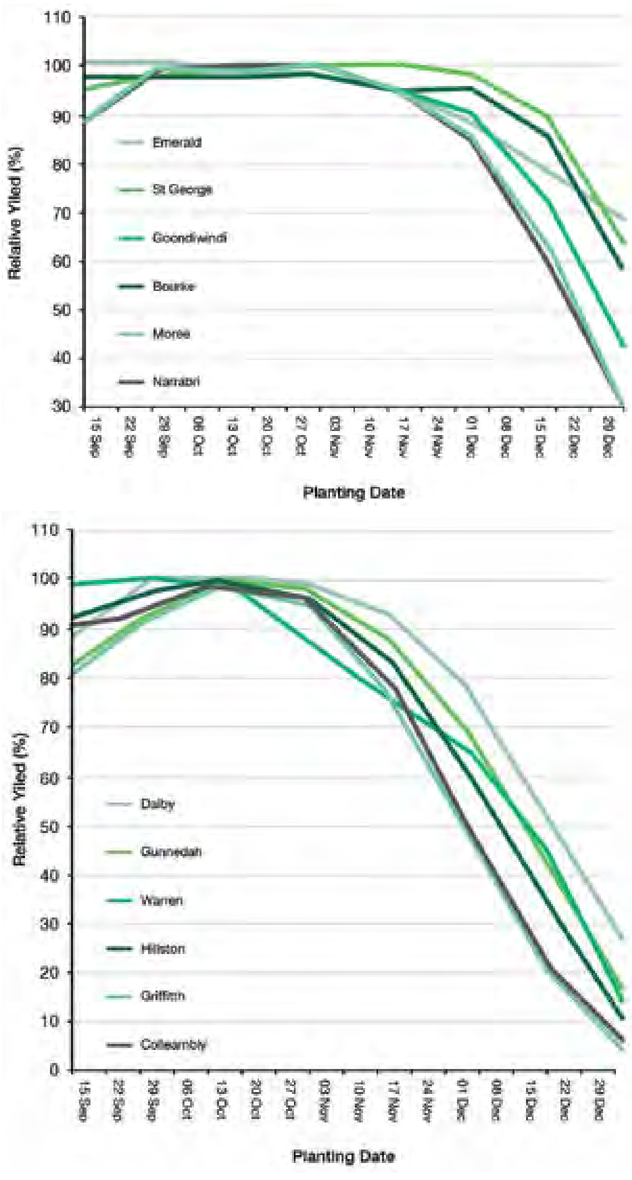
Where season length allows, planting slightly later has a lot of advantages:

- It will increase the likelihood of warm temperatures at planting, resulting in increased seedling survival and vigour.
- A crop established under warm conditions has the potential to produce bigger plants, hence greater leaf and stem area to sustain boll development later in the season.
- Later planting will delay the peak flowering period past the hot conditions often associated with late December/early January period. This can reduce the likelihood of premature cut-out and high micronaire.

Planting 'slightly later' will mean different things in each region, depending on season length:

- In cooler areas in the south and east it may mean planting in mid October.
- In central regions it may mean mid to late October.
- In northern and western regions it may mean mid October to early November.

FIGURE 5: Yield potential by sowing date for Australian cotton growing regions.
(Data generated by CSIRO using the OZCOTT model)



Other factors that need to be considered in determining planting date:

- Late maturing crops may be more susceptible to pests such as silverleaf whitefly and aphids.
- Availability of harvest machinery, if a crop is much later than others in the district.

In all cases people growing Bollgard 3 cotton need to plant within the planting window for their district. This information is available in the annual Resistance Management Plans.

Establishment method

Planting dry and watering up

This method has advantages in that control over soil moisture, and due to the shallower planting depth associated, the establishment is rapid.

When planting dry, it is very important to be aware of the consistency of the seed bed. A poorly consolidated (or cloddy) seed bed can collapse when water is applied. This can facilitate the movement of the seed down to a greater depth, which may result in poor or variable establishment.

A disadvantage of this method is that water can cool the soil temperature, especially early in the planting window and, in southern locations it can adversely affect germination rate and the incidence and severity of seedling diseases.

Pre-irrigation

Consider pre-irrigating when:

- There is a large weed seed bank of difficult to control weeds and the soil is very dry and the soil temperature is high.
- Planting any shallower than 2.5 cm, does not allow the plant the chance to scrape off the seed coat at germination and the growth of that plant will be slow until the seed coat is thrown off.

Care should be taken when deciding on the time to plant post pre-irrigation. If the beds are too wet, planting discs will create a shiny, smeared planter slot which is very difficult for young roots to penetrate. The result is often young seedlings dying from moisture stress even if there is plenty of moisture below.

Additionally, traversing the field with planting units when the soil is still wet will lead to wheel track compaction which can hamper root exploration and inhibit yield potential.

Planting on rain moisture

Although this is what raingrown growers do every year, many irrigators also aim to establish their crop on rain moisture to save water on pre-irrigation or watering up.

There are a number of factors that will improve the likelihood of success with planting into rain moisture and some cautionary points for those attempting it on irrigated country.

Stubble: The presence of standing stubble will increase the chance of seedling survival in moisture planting situations dramatically because it increases the amount of infiltration and hence moisture available to the seedling, it reduces surface evaporation and it protects the young seedling from the elements. But be aware that too much stubble can have a negative impact at planting time with stubble causing hair pinning in the slot and blockages of the planting discs. Ideally plant the cotton between the rows of standing stubble or push it aside with trash whippers

Bare fallows in irrigation country: This is a risky practice and often results in replants 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 into the seed zone.

- In cloddy seedbeds the fine materials may be wet but the larger clods may be dry and may draw moisture away, drying the seed bed.
- Check across a field to see whether the rainfall has been uniform.
- When planting, check soil moisture levels in the seed zone regularly. Planting depth may need to be adjusted throughout the planting operation due to movements in seed zone moisture content.
- 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 as an early first irrigation may be required.

Do I need to replant?

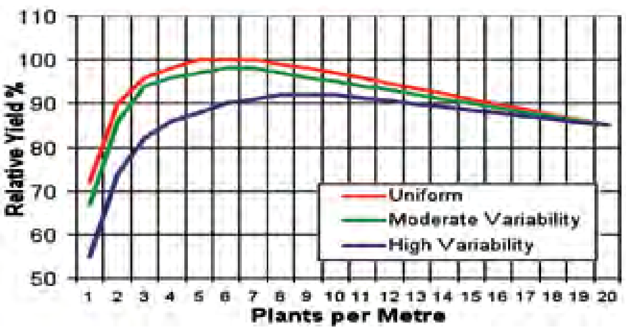
The decision as to whether to replant or not is sometimes a straightforward decision, and other times not. The obvious question is "will I achieve a better result with the plants I've got or should I start again?"

The decision needs to be made carefully, based on good field information on the current population, its health, the cause of the stand loss, the implications of replanting and the implications of managing a low plant stand. Some factors to consider:

Measure your plant stand

Figure 6 demonstrates the relative potential yield of plant stands that are variable or non-uniform compared with a uniform stand. A plant stand with high variability is one having 2 or more gaps greater than 50 cm in length every 5 metres of row. The data also shows that 5–10 plants/m of row has the best yield potential; variable stands will reduce yield for all plant populations.

FIGURE 6: Relative yield potential at a range of Plant Stand Uniformities. (Source: G Constable, 1997)



Causes of the plant stand loss

Establishing the cause of the stand loss is important so you can determine whether further plants will die and also if you choose to replant, whether the crop will succumb to the same problem again. Often stand loss is due to a combination of factors:

- **Insect damage:** If insects such as wireworm are the cause of plant loss assess whether they are still present and continuing to kill plants. If you replant, use an in-furrow insecticide or a robust seed treatment at a higher planting rate.
- **Diseases:** If seedling diseases is the cause of the stand loss consider whether plants are still dying and likely to reduce the plant stand further. Generally higher soil temperatures will reduce their incidence and severity when replanting.

- **Soil characteristics:** In sodic or hard setting soils, seedlings may be slow in emerging or get stuck under a crust. Sometimes the mechanical breaking of this crust to allow the young seedlings through may be more effective than replanting.
- **Herbicide damage:** If when planting, herbicides are washed into the root zone injuring or killing young seedlings, consider whether this will reduce the population further and whether it will impact on replanted plants.
- **Fertiliser burn:** If ammonia burn has killed young seedlings, the replant should be off-set from the original problem so it does not reoccur.
- **Hail or sandblasting damage:** Try and determine whether the surviving seedlings will regrow.

The implications of replant

Replanting date: Relative yields decline by late October in warmer growing regions and earlier in cooler regions (Figure 5). This reduction in yield potential should be factored into replant decisions, as a low population or gappy stand may have a greater yield potential than one which could be replanted.

Soil moisture status: In seasons where irrigation water is such a limiting factor, the soil moisture status is a critical factor in determining whether or not a replant is justified.

- Is flushing or rainfall going to get dry seeds up?
- What implication does this have to the water budget for the rest of the planted acreage?

Dry seeds: Seeds can survive in soil for a long time. Consider if a stand will be improved if rainfall or irrigation geminates these dry seeds.

Variety selection: If the replant means you are planting late in the window, choose a variety which has performed well in late planted scenarios in your area. These are typically the more determinant variety with inherently longer, stronger and mature fibre as cooler conditions at the end of the season can negatively impact on fibre quality. Check variety guides for suitable varieties.

Remember, any replanting of Bollgard II varieties needs to be completed within the planting windows for Bollgard II. There are wider planting windows for Bollgard 3 and no restrictions on planting date for non-Bollgard varieties.

The implications of not replanting

Sometimes sticking with the plant stand you have is a better option than replanting. There are some considerations of managing a low plant population:

Lower yield potential: If possible, prioritise resources to fields with a better plant populations and higher yield potentials. This is particularly relevant in limited water situations.

Weed populations: Low plant populations with gaps may encourage weed problems later in the season due to lack of competition. A plan for their management should be devised early.

Useful resources:

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

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

The CSD Cruiser Fund Soil Temperature Network www.csd.net.au/soil_temperatures

Effect of planter speed www.csd.net.au/planter_speed_effect

Cotton planter setup checklist www.csd.net.au/assets/greenlight/planter_setup_check_list-235cd6fb9e5bad50520a87c6e5749fc3.pdf

Irrigation management

Contributing authors **Ali Chaffey** (NSW DPI),
Janelle Montgomery (CottonInfo) & **James Quinn** (CSD)

Irrigation is one management tool that can be used to regulate vegetative and reproductive growth to maximise yields and fibre quality. Appropriate irrigation scheduling improves water use efficiency, reduces water logging, controls crop canopy development and improves the effectiveness of rainfall.

Water use by cotton plants

Plants lose water through their leaves to keep cool and to move nutrients around the plant. They absorb water from the soil to replace water they have lost. Water is also important for photosynthesis, cell expansion, growth, nutrient supply and turgor pressure (prevents plant from wilting and controls stomatal opening).

Irrigation efficiency – plant response to water

Too little – Water stress

Cotton has an indeterminate growth habit (that is, it is a perennial that keeps growing), and therefore under favourable conditions the number of leaves, new nodes, fruiting branches and squares can increase rapidly, unlimited by a phenological time frame and nutrition, and continue to be produced while conditions remain favourable. During the pre-flowering stages of growth, production of carbohydrates (through photosynthesis) is in excess of demands, and as a result vigourous vegetative growth occurs. As plant growth continues, the demands for carbohydrates by the component plant parts such as bolls increase, and production becomes limited by environmental conditions as the season progresses. Boll growth exerts large demands for carbohydrates and it is through the balance between boll demand and leaf production that vegetative growth becomes restricted.

Best practice…

- **Monitoring the plant, the soil and the expected weather conditions will help in scheduling irrigations to meet crop demands and avoid plant stress.**

Water stress can restrict both vegetative and boll growth. It has been shown that 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. Stress during peak flowering is likely to result in double the yield loss compared to stress during squaring and late boll maturation (Table 1).

Useful resources:
WATERpak Chapter 3.1 Cotton growth responses to water stress pg 239 – 247.
WATERpak Chapter 3.2 Managing irrigated cotton agronomy pg 248-263.

Too much – Water logging

The major and immediate effect of waterlogging is a reduction in the transfer of oxygen between the roots and the soil atmosphere. Plant roots may become so oxygen deficient that they cannot respire. As a consequence, root growth and absorption of nutrients is decreased leading to less overall plant growth. A reduction in node numbers leads to a reduction in the number of fruiting sites and consequently a reduction in the number of bolls produced. Research has shown a reduction of 48 kg/ha (0.2 b/ha) of lint for each day of waterlogging.

TABLE 1: Yield loss (%) per day of water stress (extraction of > 60 per cent plant available water).

	Past conventional*	Bollgard**
Squaring	0.8	1.1
Peak flowering	1.6	1.7
Late flowering	1.4	2.7
Boll maturation	0.3	0.69***

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

Furrow irrigation remains the dominant irrigation method used by the Australian cotton industry. When optimised under appropriate conditions furrow irrigation can produce high water use efficiency. (Photo courtesy Alan Redfern)

Cotton is most susceptible to waterlogging during the early stages of flowering as this is when the plant is setting the fruit load that will dictate final yield. As the plant gets older there will still be effects but they won't be as severe because the fruit is basically established on the plant.

Plants exposed to rainfall-induced waterlogging may also suffer from the reduced sunlight availability associated with overcast conditions. Under these conditions the plant cannot fix enough carbon to maintain normal functions and may shed fruit as occurs under any other form of stress.

In addition to the immediate physiological impacts of waterlogging on the crop, there are also significant impacts on nutrient availability and uptake. Waterlogging increases the rate of denitrification and plant uptake of Nitrogen (N), Iron (Fe), Zinc (Zn) (reduced) and Manganese (Mn) (increased), are directly affected by a decline in soil oxygen. Irrigation strategies designed to avoid potential waterlogging events not only contribute towards improved yield and water use efficiencies but can also benefit crop nutrient efficiencies. Waterlogging also tends to decrease the plants ability to regulate sodium uptake and, although cotton is reasonably tolerant of salinity, exposure to increased concentrations may impinge on yield potential.

Optimised irrigation system designs allow delivery to the head-ditch, run-times and tailwater collection/return such that exposure to waterlogging and deep drainage are minimised.

Useful resources:

CottonInfo video: Waterlogging in cotton – www.youtube.com/cottoninfoaus

WATERpak Chapter 3.4 Impact of waterlogging on cotton www.cottoninfo.com.au/publications/waterpak

Monitor to manage – irrigation efficiency

Monitoring the conditions, the plant, and soil moisture will help in scheduling irrigations to meet crop demands and avoid plant stress.

A successful philosophy to follow from the start is 'measure to manage'. The use of both water meters and soil moisture probes enables the fine tuning of management strategies that can lead to improved efficiencies.

It's also important to monitor crop growth. Monitoring of squaring nodes, fruit retention and nodes above white flower (NAWF) will help keep track of how a crop is progressing compared to potential development when under stress. Knowing what stage the crop is at will help in predicting crop water use, peak water demand occurs during peak flowering.

Raingrown growers can use HowWet? (www.apsim.info/How/HowWet/how%20wet.htm), a Windows based program which uses farm rainfall records to estimate how much plant available water has been stored in the soil and the amount of organic nitrogen that has been converted to an available form during a fallow (non-crop period). HowWet? 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-irrigation or watering up

The decision for the cotton grower to pre-irrigate or water up the crop is, like so many others, a decision that has to be made specifically to suit a particular farm. In certain situations it may also be necessary to combine the two options by pre-irrigating to plant into moisture and then giving the crop a "quick flush". Every farm is different and a range of questions need to be considered before making a decision eg. is it likely to rain before/ during/after planting?, what are the implications associated with the different tactics in relation to seedling disease and weed control, am I set up for dry or moisture planting? The likely advantages and disadvantages of pre-irrigation and watering up are summarised in Table 2. Refer also to the Crop establishment Chapter.

Scheduling in-crop irrigations

Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximise crop productivity. Good scheduling should provide plants with water that is within a desired range and should limit over or under irrigation so that balanced growth is achieved. For some current varieties, (eg. Bollgard 3) insufficient available water prior to and during flowering will reduce plant size and lead to early cut-out while too much water can lead to rank growth or waterlogging.

Useful resources:

CropWaterSched irrigation scheduling tool www.waterschedpro.net.au

TABLE 2: Advantages and disadvantages of different options for the first irrigation.
(Adapted from WATERpak Table 3.3.2. pg 256. S Henggeler)

Pre-irrigation	Watering-up	Pre-irrigation and late flush
Likely advantages		
• No time pressure to apply the water • 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 – 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 per cent even • Faster planting operation and less machinery needed	• Helps in fixing up plant stand problems • Can give the crop the necessary "Boost" to get going after 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	• Reduction in soil temperature after planting in cool conditions, cool and wet soils can result in higher disease pressure • Herbicide damage more likely • Sides of beds might erode when flushing for a long time • Can germinate weeds at the same time as the crop • Water logging if rain occurs after flushing	• Likely to use more water

First Irrigation

The first irrigation plays an important role in setting up for plant growth and fruit retention, fibre quality and boll weight. Its timing is perhaps the most difficult irrigation scheduling decision as it is a balancing act between not stressing the plant from waterlogging while ensuring stored water in the soil profile is fully explored by the developing root system.

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 impact of water stress on plant development. It is difficult to recover the growth needed for supporting fruit growth if water stress has slowed growth. The timing of first irrigation will vary depending on seasonal conditions and in-crop rainfall and would need to be earlier on lighter soils with compaction which inhibits root penetration.

- Monitor your soil moisture, root extraction patterns, daily water use and plant vigour.
- As a rule of thumb, irrigate at 50 per cent available soil water within the root zone.
- Check weather forecasts as hot and dry cool or wet weather near the time of first irrigation can be detrimental to crop growth and water use efficiency.
- Ensure fresh roots are accessing moisture.

Useful resources:

CottonInfo video: First Irrigation webinar– www.youtube.com/cottoninfoaust

Subsequent irrigation scheduling

Once in-crop watering has started, stick to the target soil moisture deficit. As a rule, the best deficit to aim for is approximately 50 per cent of the plant available water-holding capacity (PAWC). This is conservative for heavy clays and at times it may be possible to dry them to a 60 per cent 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 percentage of PAWC needs to be reduced because the stress occurs more rapidly and the crop can't adjust its growth and metabolism quickly enough.

For all irrigated cotton crops, water stress should be avoided during peak flowering and early boll fill stages. If irrigation water is limited, it should be saved for the flowering period. Stress during peak flowering will result in greatest yield loss.

Stretching irrigations beyond the target deficit can lead to significant yield losses, so it's generally better to skip the last irrigation rather than stretching irrigations during flowering.

Soil moisture monitoring will help irrigation scheduling decisions, along with checking weather forecasts. For example, when the weather forecast is for low evaporative demand (ETo<5 mm/day) irrigation can be delayed past the normal target deficit and if rainfall occurs during this period then there is opportunity to capture this rainfall in the crop and save water.

Careful monitoring of soil moisture extraction graphs, daily crop water use and crop development and growth will assist with getting the schedule right.

Keep a check on squaring nodes, first position retention and NAWF.

Final irrigation(s)

Ideally the last irrigation will provide sufficient water to optimise final yield and fibre quality, adequate soil moisture to facilitate efficient take-up and function of applied defoliant, and a soil profile that is sufficiently dry enough to enable harvest without causing soil compaction.

Assessing the water requirements and knowing the amount of soil moisture remaining will allow calculation of the best strategy with the remaining water, options to consider include stretching the second last irrigation, bring the last irrigation forward (smaller deficit) so that less water is applied in the last irrigation or skipping the last irrigation.

End of season water requirements can be determined by:

- Estimating the number of days until defoliation; and
- redicting the amount of water likely to be used over this period.

The number of days to defoliation

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 also to Preparing for harvest chapter for more information on NACB). The last effective flower method is useful as a forward planning technique for budgeting water requirements in advance. The NACB is useful for monitoring final irrigation requirements as the crop matures. An example of each method is provided in WATERpak, Chapter 3.2 Managing Irrigated Cotton Agronomy.

The date of the last effective flower can be used to match the time when a manager may choose to cut-out the crop to ensure crops can realistically mature in suitable growing conditions, as well as determining the approximate number of days until defoliation to plan irrigations after cut-out. Cut-out occurs when the plant's demand for assimilate (products of photosynthesis) finally exceeds supply so that production of new squares and flowers virtually ceases, normally when the plant reaches 4-5 NAWF. The Last Effective Flower works on the principle that it takes 430 Day Degrees for a square to become a flower, and 750 day degrees for a flower to become an open, mature boll.

NACB can also be used to estimate the number of days until defoliation using:
Days to defoliation = (total NACB -4) x 3

This is based on the principle that it takes about 42 day degrees for each new boll to open on each fruiting branch. If warm, sunny conditions prevail this could be around 3 days per node, however, mild and overcast conditions will slow opening.

Estimate the predicted water requirements and compare to remaining soil moisture.

At the time of first open boll, crop water use may be 5-7 mm/day, but this can decline to only 3-4 mm/day during the last 2 to 4 weeks prior to defoliation. If roots are extracting to a good depth (at least 1 m) at cut-out, plants can easily extract 70 per cent of the available water prior to last boll maturity. In cracking clay soils, plants can extract 125 to 150 mm soil moisture, which is equivalent to 25 to 30 days water use (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 1 irrigation or 2 irrigations between the cut-out irrigation and the final irrigation depending on soil type, the deficit you prefer, rooting depth and plant water use.

Whilst yield and quality losses can still occur after cut-out the reduction in yield is lower compared to stress during flowering (see Table 1). Therefore, if water is becoming limiting, you can stretch irrigations after cut-out with little impact on yield – refer to Scheduling with limited water later in this chapter.

Timing final irrigation

Crops that experience stress before 65 to 70 per cent of bolls are opened or before reaching 4 NACB (Nodes above cracked boll) can suffer yield and quality reductions. If bolls do not reach maturity before harvest, there will be high levels of immature fibres.

Measuring Nodes Above (last) Cracked Boll (NACB) is most commonly used to accurately time final irrigation and defoliation.

There will be crops with lower plant stands, poor development or damaged crops where measuring NABC will not work so well and you will have to do more cutting of bolls, even on vegetative branches to find the most mature boll to accurately time final irrigation.

The prime objection of the last irrigation is to ensure that boll maturity is completed without water stress. Once a boll is 10–14 days old, the abscission layer responsible for boll-shed cannot form. Consequently late water stress (beyond cut-out) does not significantly reduce boll numbers and therefore yield. However, fibre quality can be more seriously affected by late water stress. Crops that come under stress prior to defoliation (60 to 70 per cent open – 4 nodes above cracked boll) can suffer some fibre quality reduction, especially micronaire. The degree of reduction obviously increases the earlier the stress occurs.

- Where retention of first position bolls is high monitor Nodes Above (last) Cracked Boll (NACB) to accurately time final irrigation and defoliation.
- Determine the water requirements of your crop from cut-out to defoliation by estimating the number of days until defoliation and predicting the amount of water likely to be used over this period.
- If water is becoming limiting you can stretch irrigations after cut-out because the water use drops off significantly. Stretching irrigations prior to cut-out results in significant yield losses, so where water is limited the impact will be less at the end of the season.

Useful resources:

CottonInfo Webinar Late Season Irrigation Management. www.youtube.com/cottoninfoaust

WATERpak, Chapter 3.2 Managing Irrigated Cotton Agronomy. www.cottoninfo.com.au/publications/waterpak

CSD Facts on Friday 9th January 2015. January- A Critical Time for Crop Development. www.csd.net.au/fofs/266-january---a-critical-time-for-cropdevelopment

CSD Facts on Friday 16th January 2015. Finishing the Crop with Limited Water. www.csd.net.au/fofs/267-finishing-the-crop-with-limited-water

Scheduling with limited water

When water is limited growers may need to change from their normal irrigation practice to optimise yield, quality and water use efficiency. As with fully irrigated production, the aim is to limit or minimise the amount of stress on the crop. 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.

In order to determine when to irrigate under limited water conditions it is important to monitor both 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 crop development to be predicted using daily temperature data (day degrees). Monitoring of squaring nodes, fruit retention and nodes above white flower will help keep track of how a crop is progressing compared to potential development when under stress. Knowing what stage the crop is at will help in predicting crop water use.

Monitoring NAWF will assist in deciding which crops 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 past. Stressed crops may reach cut-out earlier as leaf expansion and the development of new nodes slows in response to water stress. When irrigation water is limited stress has less of an impact if it occurs late or early in the season but stress during the flowering period can lead to significant yield loss as this is the period when the crop is most susceptible to stress.

Visual signs of crop stress 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 but rather an indicator that stress has or is occurring.

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 shortages delaying the first irrigation is preferable to lengthening the irrigation between flowering. Soil moisture monitoring is invaluable for timely irrigations and when water is limited predicting how much water will be needed to refill the profile. The short term forecast can help refine scheduling in predicting future crop water use.

Current recommendations for limited water situations

Aim to concentrate water applications during flowering (first flower to cut-out) and minimise stress during this period.

Monitor crop to determine how a crop is performing in comparison to the expected growth of a well-watered crop.

Continue to use a variety of tools to schedule irrigations including soil moisture and weather forecasts.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Useful resources:

WATERpak Chapter 3.1 Cotton growth responses to water stress.
WATERpak, Chapter 3.2 Managing Irrigated Cotton Agronomy.
www.cottoninfo.com.au/publications/waterpak

CottonInfo blog: Late season irrigation management www.cottoninfo.com.au/blog

CottonInfo blog: Water running short? How do we manage our irrigations? www.cottoninfo.com.au/blog

CSD Facts on Friday 9th January 2015. January – A Critical Time for Crop Development www.csd.net.au/fofs/266-january---a-critical-time-for-crop-development

CSD Facts on Friday 16th January 2015. Finishing the Crop with Limited Water www.csd.net.au/fofs/267-finishing-the-crop-with-limited-water

Video

CottonInfo Webinar: What does it take to yield well with limited water? www.youtube.com/cottoninfoaust

Limited water research www.youtube.com/cottoninfoaust

Strategies to manage limited water www.youtube.com/cottoninfoaust

Assessing the maturity of a crop www.youtube.com/cottoninfoaust

The authors would like to acknowledge that this chapter incorporates original contributions to WATERpak by Rose Brodrick, Nilantha Hulugalle, Mike Bange, Steve Yeates, Dirk Richards, Guy Roth, Dallas Gibb and Stefan Henggeler

Developments in irrigation scheduling technologies

Today, a deficit approach to scheduling is a commonly used technique on irrigated cotton farms. 70 per cent of cotton growers use soil moisture probes (the highest of all agricultural industries in Australia) to understand how much water their soil holds and how much is available for crops. More recently, R&D has led to advances in sensing and satellite imagery to assess crop stress and spatial variability.

IrriSAT: Weather-based irrigation scheduling

IrriSAT is a weather based irrigation scheduling and benchmarking technology that uses remote sensing to provide site specific crop water management information across large scales at relatively low cost.

The IrriSAT technology uses two sources of information:

1. A local weather station for reliable estimates of reference evapotranspiration (ETo).
2. Satellite imagery to determine crop coefficients (Kc) that are site specific for individual irrigation fields which are then combined with ETo to calculate crop water use (ETc).

The IrriSAT app is currently in development and available at www.irrisat-cloud.appspot.com/

IrriSAT assists with your irrigation scheduling decisions and can be used to examine variation in crop productivity within a field, across a farm or region.

Useful resources:

CottonInfo video: Using IrriSAT for irrigation scheduling – www.youtube.com/cottoninfoaust

CottonInfo webinar – IrriSAT use and applications for irrigation management in cotton www.youtube.com/cottoninfoaust

Canopy temperature sensors: Plant based scheduling

Crop canopy temperature sensors are a plant based irrigation scheduling technology, providing a measure of plant stress. Compared to a well-watered crop, a water stressed crop will have 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.
- Temperature sensors can be inexpensive and require little maintenance.
- Canopy temperature sensors are non-contact and non-invasive.

The use of crop canopy temperature sensors will provide confidence when making irrigation decisions, particularly during times of unusual weather conditions and will improve crop water stress management and improve water use efficiency.

Useful resources:

CottonInfo Webinar Cotton canopy temperature sensors: www.youtube.com/cottoninfoaust

Dynamic deficit scheduling

Dynamic deficits is an irrigation scheduling tool that involves having a flexible or 'dynamic' soil water deficit in furrow irrigation scheduling to more effectively match irrigations with potential crop stress and short-term forecasted climatic conditions.

This means dynamically changing the soil water deficits to improve growth by avoiding plant stress during periods of high evaporative demand, ETo > 5 mm/day (lower soil deficits) and improve water use efficiency by reducing the need for irrigation during periods of low evaporative demand, ETo < 5 mm/day, (larger soil deficits). Delaying irrigation in response to forecasted low ETo can also provide an opportunity to capture rainfall in the crop and save water.

A measure of plant stress is required to successfully implement a dynamic deficits approach, hence this tool works well with crop canopy temperature sensors.

Useful resources

2015 Cotton Irrigation Technology Tour Booklet www.cottoninfo.com.au/publications/cotton-irrigation-technology-tour-booklet

Crop Canopy Temperature Sensors scisoc.confex.com/scisoc/2014am/webprogram/Paper88636.html

Dynamic Deficits www.regional.org.au/au/asa/2012/soil-water-management/8066_brodrickr.htm

CropWaterSched irrigation scheduling tool www.waterschedpro.net.au

Crop Canopy Temperature Sensor, providing a measure of crop stress to assist with irrigation scheduling. (Photo courtesy Mel Jenson)

Managing crop growth

By **Sandra Williams, Michael Bange & Greg Constable** (CSIRO)

Acknowldegements: Dave Kelly, John Barber, Bernie Caffery, James Hill, Brad Cogan and Steve Warden (cotton consultants).

Vegetative growth

Maintaining vigourous vegetative growth before flowering is important as it is these leaves, fruiting branches and roots that will support its future boll load. After flowering this vegetative growth will normally slow down as the plant prioritises its resources to the boll (water, nutrients and carbohydrates). Only when there are excess resources to the needs of fruit growth, does vegetative and reproductive growth continue. Eventually, when all of the resources are allocated and there is no excess, further growth (both vegetative and reproductive) ceases and the crop will cut-out.

Competition for water, nutrients and carbohydrates between vegetative and reproductive growth is constantly occurring within each cotton plant. This is normally well regulated by the plant itself, but in some situations can become unbalanced. It is in these situations when the need for growth regulators like Mepiquat Chloride comes about. When fruit is lost, such as shedding during prolonged cloudy weather, very high temperatures, or due to insect attack, the resources that were being used by the fruit are now available for other growth. If growing conditions are good, the plant will respond by growing larger leaves and more stem. New fruiting sites will continue to be produced.

Similarly in conditions where there is abundant moisture, humidity, heat, ample nutrients, no soil constraints etc, there may be an excess of resources above the needs of the developing bolls. The crop will respond by growing more lush vegetative growth. Excessive vegetative growth can be a symptom of too much nitrogen, or too frequent irrigations. All cotton varieties have a similar response in vegetative growth.

Best practice…

- **Mepiquat Chloride manages excessive vegetative growth by shortening internodes and reducing leaf area to restore the balance between reproductive and vegetative growth.**
- **There are many factors that should be considered when making the decision to apply Mepiquat Chloride.**
- **Simple observations of height will not necessarily identify accurate Mepiquat Chloride response.**
- **Caution: Some defoliant products containing Ethephon, such as Prep, are labelled as a 'Growth Regulator'. Ethephon on a growing cotton crop has devastating consequences. Ethephon is used for preparing the crop for harvest and may cause significant fruit loss if used at inappropriate times.**

Control of growth, where excessive, can increase canopy light penetration and air circulation reducing physiological shedding, and increase fruit retention, possibly increasing yield. Mepiquat Chloride is also credited for a range of responses including inducing cut-out, achieving earliness, reducing attractiveness to late season pests and improving crop uniformity.

This chapter explains Mepiquat Chloride's mode of action and how to make the decision on whether an application is needed.

Mode of action

Mepiquat Chloride reduces the production of Gibberellic acid (GA) in a plant by partially inhibiting one of the enzymes involved in the formation of GA.

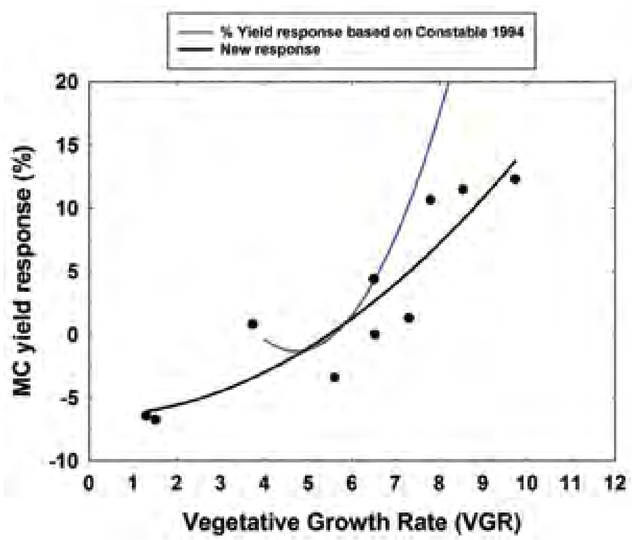
GA belongs to a group of plant hormones, Gibberellins, which are natural growth regulators in plants. They play an important role in stimulating plant cell wall loosening which allows stretching of the wall by internal pressure. This is known as cell expansion and is one mechanism allowing a plant to grow. In addition to GA, cell expansion is driven by a number of factors including water availability, humidity and temperature.

Impact on cotton growth

When cell expansion is inhibited following an application of Mepiquat Chloride, any new plant growth will normally have shortened internode length and smaller, thicker leaves. As cells are smaller and denser, and because the green coloured chlorophyll molecules are sitting closer together, the leaf colour is generally a dark green.

Even though Mepiquat Chloride is rapidly distributed throughout the entire plant, it only significantly limits the cell expansion in new growth. So generally it is only the top 3 or 4 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.

FIGURE 1: **VGR (at flowering) and the corresponding yield response % when MC is applied. The graph also compares the response curve from non-Bt cotton with the recent measure in Bt cotton crops.**



Yield

Recent research has been conducted to investigate the response between Vegetative Growth Rate (VGR) at early flowering and % yield response to

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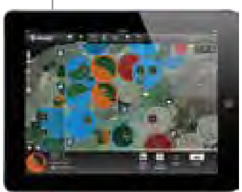

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Mepiquat Chloride in Bt cotton. Our results have shown a positive yield response to applying Mepiquat Chloride on cotton with a high VGR (>5), but a negative yield response in a crop with a low VGR (<5). As can be seen in Figure 1, these negative responses in Bt cotton have been more severe than previously measured on non-Bt cotton varieties in 1994.

Managing crop maturity with Mepiquat Chloride

Mepiquat Chloride can be used to assist in managing cut-out and thus crop maturity for a timely harvest. Restricting vegetative growth means that there are less assimilates (products of photosynthesis) produced by the plant from new leaves to enable new growth at optimal rates thereby causing the plant to approach cut-out more rapidly.

Getting the timing right of crop maturity is important for producing quality cotton by:

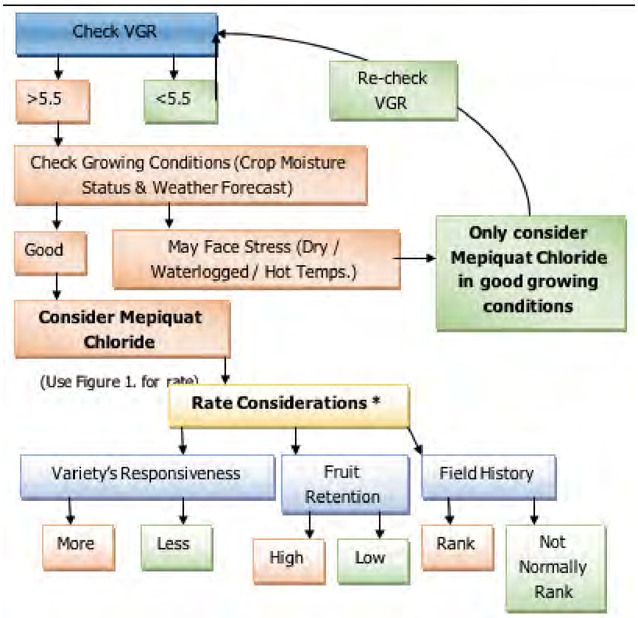
- Ensuring a timely harvest to avoid adverse weather conditions.
- Allowing an effective defoliation to reduce trash content.
- Reducing the amount of immature bolls that may increase the incidence of neps.

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 especially important for the shorter season and southern areas where on average, adverse weather conditions can occur earlier.

The time of cut-out is generally directly related to crop maturity. Cut-out can be monitored using a simple count of the number of Nodes Above the first position White Flower (NAWF) where 4 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 coinciding with 4 NAWF.

FLOW CHART 1: Early Flowering Decision Tree – This flow chart incorporates all of the factors and the decision processes that should be considered when making the decision to apply Mepiquat Chloride early in the season around flowering.



*Use Table 1 and Figure 2 for assisting with decisions regarding Mepiquat Chloride rates.

Crop uniformity

On occasions a crop can become patchy with excessive vegetative growth, for example when the crop has had a pest infestation that has not affected all plants, cases of uneven soil types, or head ditch and tail drain effects. In these situations Mepiquat Chloride applications can assist in making 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 significant opportunities to optimise the effectiveness of Mepiquat Chloride applications.

Making the decision at early flowering

Cotton's response to Mepiquat Chloride application/s depends on a range of factors, the most critical being whether there are other sources of stress already controlling growth, and the rate and timing of the application. Since GA plays an important role in cell expansion, preventing the plants production of GA can be detrimental to plant growth. Hence using a high rate of Mepiquat Chloride at an inappropriate time can result in yield reductions.

In making a decision as to whether Mepiquat Chloride can help, it is important to consider causes behind any excessive growth such as those described previously. In assisting these decisions at early flowering one should consider information on vegetative growth rate (VGR), field history, fruit retention, irrigation scheduling, current and future weather conditions, and cotton variety.

Measuring VGR – early flowering

Vegetative Growth Rate (VGR) is an effective technique to monitor vegetative growth. VGR is the rate of change of plant height relative to the rate of node development. The VGR measures the rate of internode increase and is better able to capture situations where crops are moving from optimal to poor conditions, or vice versa. This method is also able to identify the need for canopy management before crops are excessively vegetative. Simple observations of height will not necessarily identify accurate Mepiquat Chloride response.

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

Measurements should commence as the crop approaches first flower, which is normally late November for many regions and the plant has roughly 12 mainstem nodes. The monitoring should continue during the first half of the flowering period as rapid increases in growth rate can occur at anytime 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 taken into consideration (refer to Flow Chart 1).

Field history/soil type

Knowing how the cotton is likely to grow in each field is the key factor in making the decision to apply Mepiquat Chloride. Some fields, often due to lighter textured soil types allow better access to soil water and nutrition; and have a tendency for rank growth. In these situations you would expect to get a positive response from Mepiquat Chloride application/s, although it is still important to monitor these fields to determine the correct application rate and timing.

Mepiquat Chloride manages excessive vegetative growth by shortening internodes and reducing leaf area to restore the balance between reproductive and vegetative growth.

Fruit retention

After flowering the cotton plant will naturally become committed to giving more and more of its resources to the developing bolls. Therefore a high fruit load may already reduce the tendency for a crop to produce excess vegetative growth, hence a reduced need for Mepiquat Chloride. Caution should be applied to crops with early high fruit retention (like many Bt cotton crops) as research has shown any limitations to canopy size early in flowering will impact yield more than crops with lower fruit retention. Crops with larger boll loads will need larger canopies to support the growth of fruit.

Future stress events

It is always important to ensure that crops are not stressed for at least a week after the Mepiquat Chloride application as additional stresses can substantially limit vegetative growth and thus limit yield. Hot weather and/or water stress from being unable to irrigate the crop on time are examples.

Stress, especially moisture stress, will reduce vegetative growth and production of new fruiting sites allowing existing fruit on the plant to develop. This may lead to early termination of flowering and a probable yield reduction.

In cases of severe stress (water, prolonged period of cloudy weather, or a period of very high temperatures) fruit loss may occur. In these cases a symptom can be excessive vegetative growth once stress has been removed. Crops should be monitored closely following these events. Strategies to apply Mepiquat Chloride in anticipation of stress events that cause these affects are not recommended as the growth regulator could add to the stress or the event may not eventuate and therefore limit vegetative growth needed for continued fruit growth.

Variety

Research has shown that our Australian cotton varieties vary in their yield responsiveness to applications of Mepiquat Chloride (see Table 1). Varieties may differ in the response to Mepiquat Chloride because of determinacy (ability to regrow), rate of canopy development or fruit production, or because of differences in their architecture. Less responsive varieties may still require Mepiquat Chloride, so monitoring their VGR and taking into account all other factors remains important.

TABLE 1: Yield responsiveness to Mepiquat Chloride, between varieties under irrigated conditions.

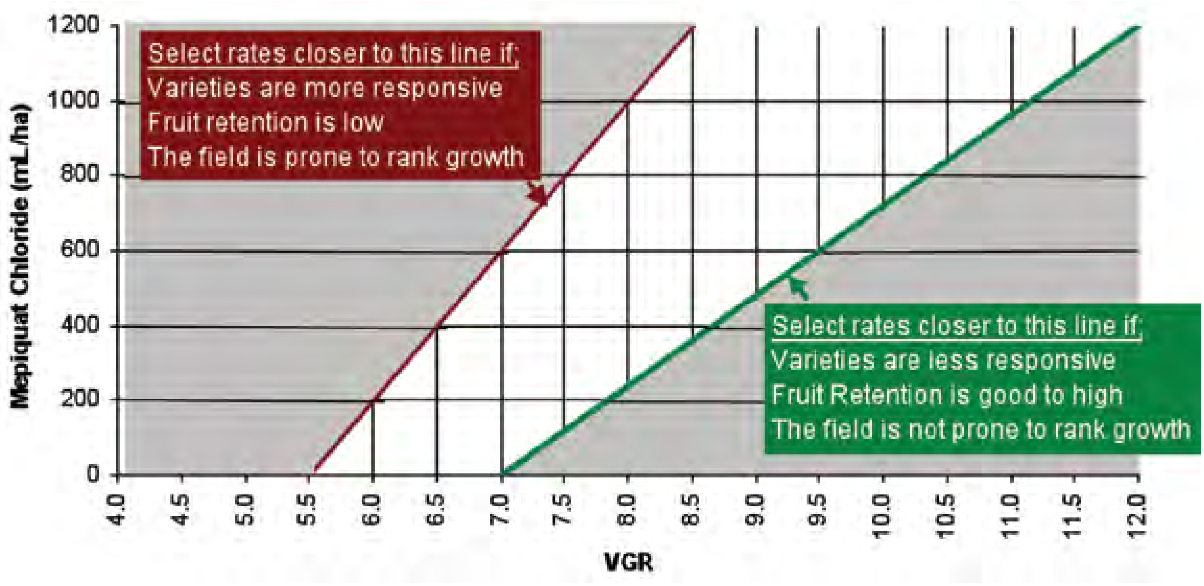
More likely to respond	Less likely to respond
eg. Sicot 754 B3F, Sicot 748 B3F, Sicot 730, Sicot 75 RRF, Sicot 71RRF	eg. Sicot 714 B3F, Sicot 746 B3F

Rate considerations at early flowering

Figure 2 has been designed to take all factors into consideration when deciding on the rate of Mepiquat Chloride to apply. The following examples will explain how to use the graph.

Example one: A crop has a VGR Measurement of 8, low fruit retention and the field is normally prone to rank growth. Information from the seed company has indicated that the variety is moderately responsive to Mepiquat Chloride, so using Figure 2 the application rate may be at a higher rate (For example 600–1000 mL/ha).

FIGURE 2: Mepiquat Chloride requirement graph incorporating VGR and other factors. Rates assume Mepiquat Chloride formulation of 38 g/litre. (Source: CSD)



Example two: A crop has a VGR of 6, good fruit retention, the field has no history of rank growth and information from the seed company has indicated that the variety is not greatly responsive to Mepiquat Chloride, therefore using Figure 2 applying Mepiquat Chloride may not be a benefit, although monitoring should continue.

Making the decision before cut-out

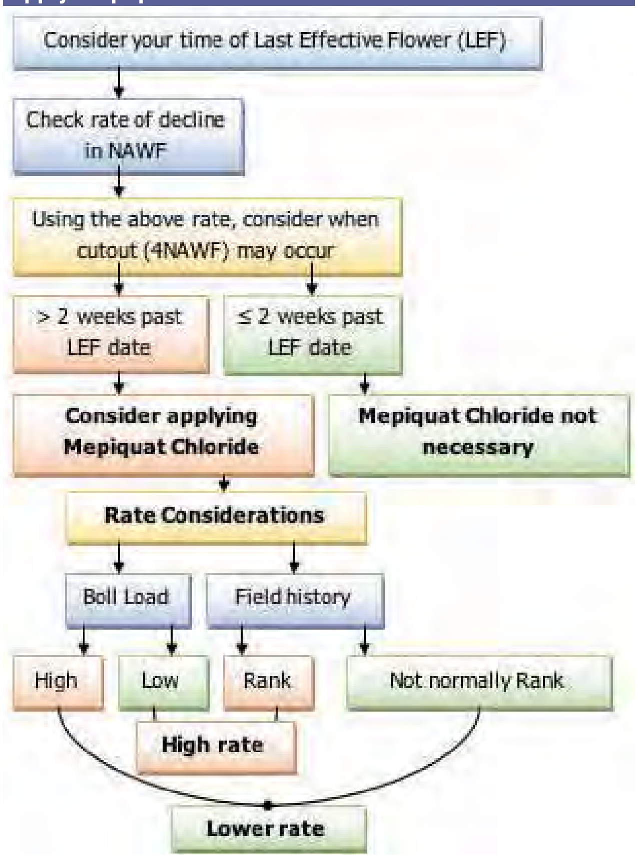
Given the right conditions, cotton will continue to grow late in the season. This late growth can increase the crop's attractiveness to late season pests and can also increase the number of immature (low quality) bolls at harvest. This is when Mepiquat Chloride maybe considered in order to slow down further vegetative growth. It is also important that if earlier or timely cut-out is to be achieved water and nutrient management should specifically 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 or not the crop is already approaching cut-out at an acceptable pace (refer to Flow Chart 2). These decisions are generally made in late January for most regions or about 3 weeks before the last effective flower (LEF) date.

Monitoring NAWF – late season

An effective technique used to assess how quickly cut-out is approaching, is monitoring the number of Nodes Above the 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 means that there has been less nodes produced since that particular flower was initiated as a new square.

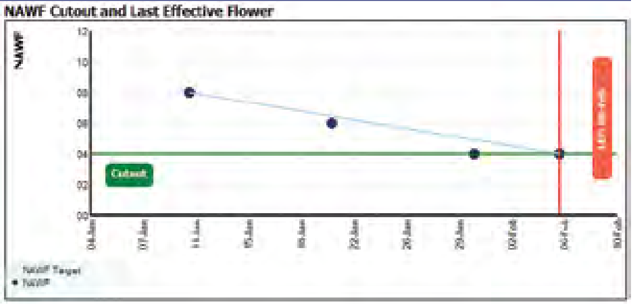
FLOW CHART 2: Cut-out Decision Tree – This cut-out chart is designed to help with late season decisions to apply Mepiquat Chloride.



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. Monitoring should occur post cut-out to ensure that any regrowth is identified and managed if necessary.

In an optimal situation, the NAWF should fall at the rate of one per 55–65 Day Degrees. Where there is a slow rate of NAWF decline and the forecast cut-out (4 NAWF) is beyond the LEF, then applying a cut-out rate of Mepiquat Chloride should be considered.The NAWF measurements in Figure 3 indicate a normal rate of decline as they reach the Last Effective Flower date at 4 NAWF. Therefore in this case, Mepiquat Chloride application would not have been necessary.

FIGURE 3: An example of using the number of Nodes Above White Flower to forecast the timing of cut-out.



Useful resources:

www.cottoninfo.com.au, www.mybmp.com.au and www.cottassist.com.au

FIBREpak

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Williams SA and Bange, MP (2015). Re-evaluating mepiquat chloride use in Bollgard II. *The Australian Cottongrower* 36, 16-21.

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

Efficient spray application

By **Susan Maas** (CRDC)

Acknowledgements: Graeme Tepper (Micro-met Research and Educational Services), Bill Gordon (Nufarm), Mary O'Brien (Mary O'Brien Rural Enterprises)

Movement of spray beyond the target area is undesirable as it represents wastage of product and exposure of non-target sensitive areas to potentially damaging materials. Achieving the best outcome from spray application requires the careful consideration of many factors. Application technique needs to be matched to the target, tank mix and weather conditions.

Spray drift

Spray drift can occur as droplets and particles or as vapours.

Droplet and particle drift

Droplet and particle drift is a common cause of off-target damage from pesticides. It is particularly obvious where herbicides drift onto susceptible crops. Water in the spray droplets evaporates resulting in finer droplets and particles of herbicide. Smaller droplets remain airborne longer and hence are susceptible to further evaporation and drift kilometres away from the intended target. Droplet and particle drift is the easiest form of drift to prevent. Under good spraying conditions, droplets are carried downwards by air turbulence and gravity to collect on the intended plant surfaces.

Vapour drift

Vapour drift is the movement of volatile components of herbicides in air currents during or after application. Volatility refers to the likelihood that the herbicide will turn into a gas. 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 avoided by choosing active ingredients with low volatility. The amine and salt forms of herbicides have a much lower volatility than the low volatile ester (LVE) forms. Even products with low volatility are still susceptible to droplet and particle drift. Avoid using any ester formulations of Group I (phenoxy) herbicides during summer.

Best practice…

- **Keep comprehensive records.**
- **Establish communication processes to manage safety and reduce risks.**
- **Careful consideration is given to selecting and applying pesticides.**
- **Use the correct application equipment and techniques.**
- **Ensure chemicals are transported, handled and stored appropriately.**
- **Ensure unwanted chemical and chemical containers are disposed of appropriately.**

Know what to do

Always read and follow the label when handling and applying chemicals. Label conditions may specify spray quality, and spray conditions including mandatory wind speed range, and no-spray zones/buffers. 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 work health and safety requirements related to storage and use of hazardous chemicals, which require risk assessments to be completed, in addition to maintaining a manifest and Safety Data Sheets for those chemicals deemed to be hazardous. Refer to the Cotton Pest Management Guide for more information on legal requirements in use of pesticides. The *my*BMP program can help growers to understand their legal obligations for application of pesticides.

Communicate with your neighbours

Pesticide Application Management Plan (PAMP)

Developing a PAMP helps identify the farm specific risks associated with pesticide applications and the practices that are to be put in place to minimise the risks. Implementing a PAMP makes everyone involved in a pesticide application aware of their responsibilities.

A PAMP has two essential functions:

- Establishes good communication with all involved in the application of pesticides. This communication is required both pre-season and during the season. It should exist between the grower, the applicator, the consultant, farm employees and neighbours, including apiarists. Farm maps that highlight sensitive areas can be useful. The web based application Cotton Map enables cotton growers to map their fields so that people in the neighbouring areas can see that there is cotton in the vicinity (www.cottonmap.com.au).
- Establishes the application techniques and procedures that are to be used on your farm.

Optimise spray equipment set up and operation

Nozzle selection

Spray nozzles produce a range of droplet sizes called the droplet size spectrum. Nozzle manufacturers now use internationally recognised classifications for droplet size spectrums referred to as the Spray Quality.

These are Ultra Fine, Very fine, Fine, Medium, Coarse, Very Coarse, Extremely and Ultra Coarse (according to the American Society of Agricultural & Biological Engineers (ASABE) or British Crop Production Council (BCPC) standards). As a guide, each time you move from one classification to the next coarser classification you approximately halve the driftable fraction (eg. from medium to coarse, or from coarse to very coarse). Hence it is always advisable to use the largest spray quality classification that will provide acceptable efficacy. Nozzle selection for the correct volume and spray quality requires careful consideration. Always follow label/permit directions in relation to spray drift including nominated droplet size category.

Be aware that the standards for classifying spray quality do change over time, so it is advisable to always consult the product label and obtain the latest nozzle charts before purchasing new nozzles.

***my*BMP resources: Backpocket Guide – Nozzle Selection for Booms and Bands**

Pressure at the nozzle

Never operate nozzles outside of the pressure range recommended by the manufacturer. Higher or lower than recommended pressures changes the droplet spectrum and the spray pattern, affecting both the risk of drift and the efficacy of the spray application.

Be aware that many air induction nozzles will require slightly more pressure than the minimum indicated on the manufacturers spray chart. Always assess the spray pattern and spray quality information (droplet size) at various pressures, to determine an appropriate minimum operating pressure.

Where automatic rate controllers are fitted to the machine, carefully consider the true range of speeds the machine is likely to operate, from the slowest field to the fastest field. Identify what the pressure at the nozzle will be at your lowest speed and your fastest speed and identify a nozzle that will produce the required spray quality across that range of speeds. Operating at recommended pressures can also minimise wear and tear on nozzles.

***my*BMP resources: Fact sheet Pre-Season Sprayer Checks, Back pocket guide to nozzle selection.**

Suitable water volumes and quality

Always follow label recommendations for water volumes for application. Typically in-crop applications to cotton will require application volumes of 100 L/sprayed hectare or more. Whereas, for fallow spraying in very low stubble situations with translocated herbicides (such as glyphosate and the phenoxys) equivalent efficacy has been shown for medium, coarse and even extremely coarse spray qualities at 50 L/ha and above. In higher stubble loads the application volume should be increased to at least 60 L/ha or more for fully translocated products. Equivalent efficacy in fallow spraying situations has also been shown at 70 L/ha and greater for products with minimal translocation, such as Spray.Seed®, again this application volume should be increased where higher stubble loads exist.

When using larger than a medium spray quality for some translocated products, increasing water rate does not necessarily increase efficacy, and in some situations may actually reduce performance in the field. Increasing water rates with fully translocated products can reduce efficacy when a low rate of product is used, when water quality may be marginal or where diluting the adjuvants included in the product reduces the products performance.

***my*BMP resources: Water Quality Fact sheet, Spray Mixing Order Fact sheet.**

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.

Vertical movement (boom bounce) of the spray boom should be minimised. Vertical movement can be limited by tuning the boom suspension and matching travel speed to release height. Alternatively consider fitting auto boom height. Auto boom height devices use ultrasonic sensors to detect the height of the boom above the target. These adjust the boom hydraulically to maintain the nozzles at a constant height above the target. Generally these systems will require a machine with good hydraulic capacity, but allow the machine to maintain boom height at travel speeds up to 28 km/h.

***my*BMP resources: Fact sheet on boom height control.**

Travel speed for ground rigs

Speeds above 15 km/h have been shown to increase the risk of drift for boom spraying; and speeds above 10 km/h increase the risk when using shielded sprayers. Higher speeds reduce deposition of spray droplets in the wheel track and behind stubble, and also increase the drift potential due to droplets being drawn into the machine's wake. When considering operating at higher travel speeds, greater attention must be paid to the potential risk of spray drift and ways of reducing that risk, such as nozzle selection.

***my*BMP resources: Fact sheet on managing wheel tracks.**

Maintenance and hygiene

Calibration – replace worn nozzles

The output of each nozzle should be checked pre-season and regularly during the season. Nozzles that vary more than 10 per cent from the manufacturer's specifications should be replaced. 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. Strictly follow the method of decontamination recommended on the label. No matter how much time is spent decontaminating the equipment there is always a risk of herbicide residues causing a problem (refer page 114).

Tank mix consideration

Always follow the manufacturers' recommendations for mixing. Where multiple product tank mixes and adjuvants are added to the one tank, incorrect mixing order can reduce the efficacy of those products.

***my*BMP resources: Mixing Fact sheet**

Using adjuvants to manipulate droplet size

More can be done to manipulate droplet size (spray quality) with nozzle selection, than with the addition of an adjuvant. Many adjuvants, especially non-ionic surfactants (wetter 1000 products) can increase spray drift potential by increasing the number of small droplets produced. Other adjuvants such as oils, Dead Sure and LI700 can actually reduce drift potential when used at recommenced 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 100–200µm), and not just an increase in the average droplet size (or volume median diameter (VMD)). When considering adjuvants, compatibility with the tank mix and spraying system should also be considered, since some adjuvants do not perform as well when combined.

Product choice

Where a range of products are available for a particular job, try to select products that have the lowest impact on the environment or sensitive areas. Refer to Table 3 in the Cotton Pest Management Guide to compare the relative toxicities of insecticides to non-target insect species such as beneficials and bees.

Additional considerations for aerial applications

Aircraft setup and operation

Higher airspeeds (above approximately 110–115 knots) can cause air shear, where droplets shatter into smaller sizes. Some faster, larger turbine aircraft have difficulty in producing a Coarse Spray Quality due to their fast airspeed. Reducing air speed (through slower aircraft) and/or reducing nozzle angle or deflection is an effective way to reduce air shear. The lowest air shear occurs when aircraft nozzles are directed straight back on the aircraft (0°) and operated at higher pressure. The boom length on an aircraft should not exceed 65 to 75 per cent of the wingspan, and sprays should only be released when the aircraft is level over the target (never while climbing). All aerial operators (using hydraulic nozzles or rotary atomizers) should be able to provide a written assurance to the grower that they are complying with the product labels spray quality requirements.

Weather conditions for spraying

Weather conditions are not only a primary determinant of efficacy, they determine whether the spraying operation should proceed, be delayed or aborted.

Review forecast conditions

Growers can also subscribe to websites that provide forecasts of conditions for spraying up to 10 days in advance. These sites evaluate a range of factors to produce tables indicating times that would be suitable for spraying. You can access the website at www.spraywisedecisions.com.au for more information.

Determine and record weather conditions

Weather conditions need to be checked regularly during spray applications (this means continual visual observations and actual measurement at least every 20–30 minutes) and recorded as per label requirements. Labels contain a legal requirement to measure weather parameters at the site of application. This can be done with handheld equipment (eg. Kestrel 3000, 3500, 4000 or equivalent) or portable weather stations. Alternatively on-board weather stations that provide live weather information while the sprayer is operating (such as the Watchdog systems) are available.

In addition to weather records, it is best practice (and a legal requirement on many labels) to record full product name, description of the crop or situation, it's location and the application equipment (including nozzle type and operating pressure), rate of application and quantity applied, and the name and contact details of the applicator and of the employer or owner. Refer to the Cotton Pest Management Guide for further details about legal responsibilities in applying pesticides.

***my*BMP resources: Weather monitoring fact sheet**

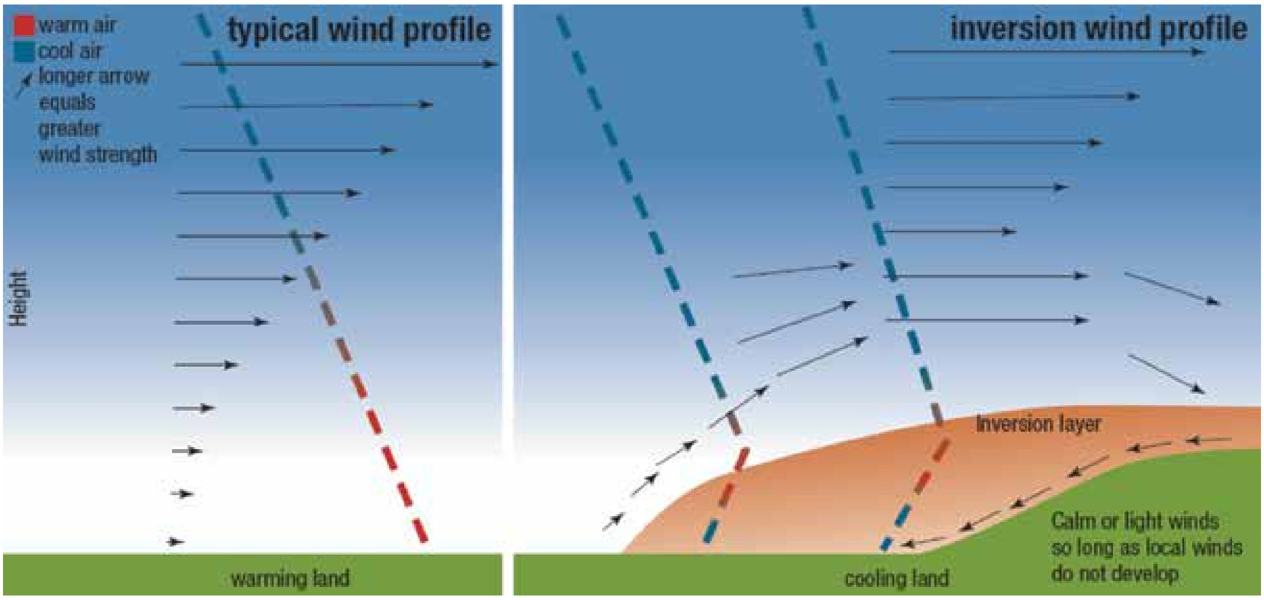
Temperature and humidity

Higher ambient air temperatures and lower relative humidity conditions increase evaporation rates. Since droplet size of water-based sprays decreases rapidly with higher evaporation rates, drift tends to increase.

Water-based sprays should not be applied under conditions of high temperature and low relative humidity (RH). Spraying is best conducted when the delta T (the difference between the wet bulb and dry bulb) is more than 2 and less than 10°C, however this is a guide only. When using coarse sprays at high water volume rates, evaporation may be less significant, which may allow some applications to continue into marginal delta T conditions (where soil moisture exists, and the targets are not in a stressed condition).

***my*BMP resources: Tips for reducing drift fact sheet**

FIGURE 1: Air movement under a surface temperature inversion differs from a typical wind profile (left). Surface winds de-couple from the surface, accelerate and flow over the inversion. Within the inversion, winds are typically light and often drain down slope, regardless of the overlying wind direction. Under an inversion the shape of the landscape also influences the direction in which airborne droplets will move (right). (Source Graeme Tepper)



Surface temperature inversion

DANGER – DO NOT spray when a surface temperature inversion exists.

"It has been found that in stable conditions, when vertical motion is suppressed, airborne pesticides don't disperse vertically but move horizontally at high concentrations near the ground. Whereas in unstable conditions when vertical motion is enhanced airborne pesticides tend to mix upward to weaker concentrations." – D. R. Miller, 2001 (refer to Figure 2)

During surface temperature inversions, distinct, isolated layers of air form close to the ground, and the potential for spraydrift is very high. Surface temperature inversions can result from a number of processes that cause the air closest to the ground to become cooler than the air above. As a rule of thumb, the greater the difference between daily maximum and minimum temperatures, the stronger the surface temperature inversion (refer to Figure 1).

Use visual indicators such as moisture, smoke and dust to determine if an inversion is present. Other clues include occurrence of mist, fog, dew or a frost or if the wind stops blowing, or it falls below 11 km/hr at any time during the evening or overnight – stop spraying as an inversion is likely.

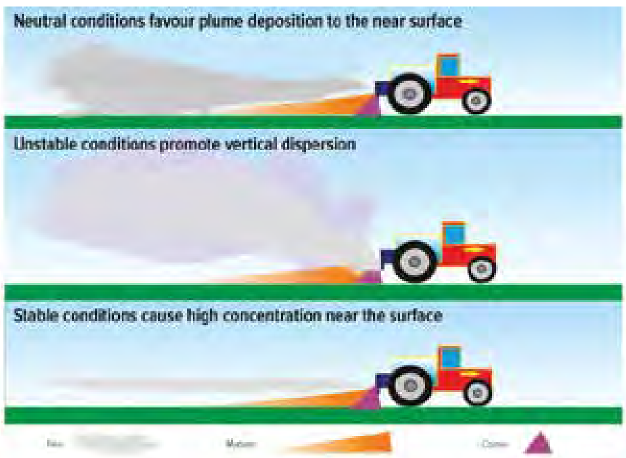
***my*BMP resources: GRDC Surface Temperature Inversions and Spraying fact sheet**

Wind

It is best to apply pesticides when the wind is blowing away from sensitive areas and crops. Wind speed must be steady between 3 km/hr and 15 km/hr during daylight hours, and above 11 km/h at night. Avoid calm, variable or gusty wind.

If the wind speed drops at night (to less than 11 km/h) – stop spraying immediately (see inversions). Be aware of local topographic and convective influences on wind speed and direction. Always read the label to see if a mandatory wind speed requirement exists, or if a No-spray zone is required for any of the products you plan to use.

FIGURE 2: Three common states of atmospheric stability and their relationship to spray application.
(Source: GRDC Weather Essentials for Pesticide Application booklet, 2017; author: Graeme Tepper)



Useful resources:

Understanding agrochemical labels www.youtube.com/cottoninfoaust

"Spray Drift Management Principles, Strategies and Supporting Information", www.publish.csiro.au/Books/download.cfm?ID=3452

SPRAYpak – Cotton Growers' Spray Application Handbook, 2nd Edition, available from www.cottoninfo.com.au/publications/spraypak

Spraywise – Broadacre Application Guide – Available through Croplands Distributors.

For more information about using vegetative barriers in spray drift management, see CottonInfo NRM/Pesticide Input Efficiency fact sheet – Using vegetative barriers to minimise spray drift on cotton farms www.cottoninfo.com.au/publications/nrmpesticide-input-efficiency-using-vegetative-barriers-minimise-spray-drift-cotton

For aerially-applied 2,4-D sprays, from wind tunnel research, see www.aerialag.com.au

Calculating banded sprays

By **Bill Gordon** (Nufarm) **& Graham Betts**

Banded sprays present an opportunity to place the recommended rate of the product onto an area smaller than the whole field (this way we use less chemical over the whole field, but still apply the equivalent rate/ha to the actual target area). There are often big differences between the consultant's recommendation, the applicator's instincts and what the machine can actually do with the nozzles available.

Often people want to know the actual application rate and how much chemical to put in the tank (based on green ha or sprayed ha), how far a tank will go (based on paddock ha) and what rate to put in the spray controller. Others want to know what nozzles they should use to achieve a recommendation they have received from their advisor.

To work out the true application rate we need to know the sprayed width, or average sprayed width for each nozzle, this allows us to calculate the litres per sprayed ha (L/sprayed ha sometimes called L/green ha). Label rates are always given as L/sprayed ha. Advisors should always give recommendations as L/sprayed ha. To apply the correct L/sprayed ha there are two main things to work out:

- **How much chemical to put in the tank,** which is based on L/sprayed ha.
- **What to put into a controller,** which is based on paddock ha per tank, (unless you want to play around with section widths).

Formula

(The following are a selection, there are many that work.)

Band width in metres: **eg 0.7 m band** ÷ 1 m row spacing = band width (m) ÷ row spacing (m).

Sprayed width per nozzle (m): = **band width (m) ÷ number nozzles per band** (eg 3 nozzles per 70 per cent band of a 1 m row = 0.7 m ÷ 3 = 0.23 m).

The application rate = **L/sprayed ha: L/sprayed ha = L/min/nozzle x 600 ÷ speed (km/h) ÷ sprayed width per nozzle (m).**

L/sprayed ha applies to each band (row), whether you spray 1 band (row), or many rows, whether it is a solid plant, single skip or double skip.

Number of sprayed ha per tank = **Tank size (L) ÷ L/sprayed ha.**

Amount of chemical to add per tank = **Sprayed ha per tank x chemical rate/ha.**

Paddock ha per tank (solid plant): = **Sprayed ha per tank ÷ band width (m)**.

Paddock ha per tank (Skip Row Configurations): eg Double Skip on 1 m row spacing (only planted 1 out of every 2 rows), this would be the same as only spraying 12 x 1 m rows with a 24 m boom.

Paddock ha per tank (skip) = Sprayed ha per tank ÷ the band width (m) x width of boom ÷ row width (m) ÷ number of planted rows under the boom.

Rate to put in the Controller: = Tank Size (L) ÷ Paddock ha per tank

***This works if you don't want to change the section widths in the controller.**

Selecting the correct nozzle size for a particular job

To work out what size nozzles you need to get a particular L/sprayed ha, you need to know what the required flow rate of each nozzle (L/min/nozzle) should be. If all nozzles are the same size this is relatively easy, as the flow rate will be the same for each nozzle.

For example the average sprayed width per nozzle if you had 5 nozzles per 1 m row at 100 per cent band would be 1 m ÷ 5 = 0.2 m.

If you had 4 nozzles per 1 m row and a 70 per cent band, then the average sprayed width would be 0.7 m ÷ 4 = 0.17 m.

To calculate the required flow rate of each nozzle, the formula you need to use is: **L/min/nozzle = L/sprayed ha ÷ 600 x speed (km/h) x average width of each nozzle (m).**

If you are using different combinations of nozzle sizes, you can still use the same formula, but it helps to work out the total flow rate for each band (or row), to do this, change the average width per nozzle to the band width or spray width per band (row) to get the total flow required per band (or row) and select nozzles with flow rates that add up to that total (all at the same pressure). Once you have calculated the required L/min/nozzle use a nozzle flow chart to identify appropriate nozzle sizes and pressures, and don't forget to check the spray quality produced to ensure it is consistent with the product label.

Useful resources:

- **The *my*BMP Pesticide application module, www.mybmp.com.au**
- **NuFarm Australia Ltd: 03 9282 1000, www.nufarm.com.au**
- **Cotton Pest Management Guide, www.cottoninfo.com.au**
- **GRDC fact sheets on:**
  - **Spray Mixing Requirements**
  - **Spray Water Quality**
  - **Pre-season check and Controller Settings**
- **Information on weather:**
  - **Weather essentials for pesticide application, Graeme Tepper, GRDC.**
  - **GRDC Fact Sheet on Weather Monitoring Equipment**
- **Information on weather forecasting tools:**
  - **www.spraywisedecisions.com.au**
  - **Agricast**
- **Information on pesticide application:**
  - **Spraywise Broadacre Application Handbook, Dr Jorg Kitt, Nufarm Australia**
- **Information on nozzle selection tools:**
  - **Teejet Nozzle Selection App**
  - **Hardi Nozzle App**

TABLE 1: Decontamination and cleaning agent guide.

Selected herbicide group	Chemistry	Examples of active ingredients	Herbicide examples	Cleaning product and rate per 100 L water
A	DIMs	Clethodim Sethoxydim Butroxydim Tralkoxydim	Select®, Sequence® Sertin® Factor® Achieve®	500 mL liquid detergent Dynamomatic or 1 L Absolute Boomer, or 120 g Nufarm Tank and Equipment Cleaner, all as per label instructions.
	FOPs	Clodinafop Haloxyfop Fluazifop Diclofop Quizalofop	Topik® Verdict™ Fusilade™ Diclofop® Targa®	
	DENS	Pinoxaden	Axial®	
B	Imidazolinones	Imazapic Imazapyr Imazamox Imazethapyr Various combinations of Imidazolinones actives	Flame® Arsenal® Raptor® Spinnaker®, Skipper® Onduty®, Intervix®, Lightning®, Sentry®	120 g of Nufarm Tank and Equipment Cleaner or very thorough water clean.
	Sulfonylureas	Chlorsulfuron Iodosulfuron-methyl Metsulfuron-methyl Sulfosulfuron Triasulfuron Mesosulfuron-methyl	Lusta®, Tackle® Hussar OD® Ally®, Associate® Monza® Logran®, Logran B-Power® Atlantis®	300 mL fresh chlorine bleach containing 4% chlorine, or 300 mL BC-45 Spray Equipment Cleaning Agent, or 1 L Absolute Boomer or CC49 as per label directions (check use by or expiry dates).
C	Triazines	Atrazine Simazine Prometryn	Atrazine Simazine Gesagard®	Water, with 120 g Nufarm Tank and Equipment Cleaner or 1 L Absolute Boomer® as per label instructions or tank mix partner/s requirements.
	Ureas	Diuron	Diuron®	
	Nitriles	Bromoxynil	Bromicide®	
D	Dinitroanilines	Trifluralin Pendimethalin	Treflan, Triflur Xcel® Stomp®, Rifle®	
F	Pyridinecarboxamides Pyridazinones	Diflufenican, Picolinafen Norflurazon	Brodal®, Nugrex® Sniper™, Paragon® Zoliar®	Nufarm Tank and Equipment Cleaner as per label instructions.
G	Diphenylethers Trialoinones Pyrimidindiones	Oxyfluorfen Carfentrazone-ethyl Saflufenacil	Goal™, Hammer®, Affinity® Sharpen®	100 g Alkaline detergent Omo, Spree, Surf, or or 1 L Absolute Boomer® as per label instructions.
H	Pyrazoles	Benzofenap Pyrasulfotole	Taipan®, Velocity®, Precept®	Nufarm Tank and Equipment Cleaner as per label instructions.
	Isoxazoles	Isoxaflutole	Balance®, Palmero®	500 g Alkaline detergent e.g. Omo, Spree, Surf, or 500 mL liquid detergent e.g. Dynamomatic, or 300 mL fresh Chlorine bleach containing 4% chlorine as per label instructions.
I	Benzoic acids	Dicamba	Kamba®	120 g Nufarm Tank and Equipment Cleaner
	Phenoxycarboxylic acids (Phenoxys)	MCPA (Dimethyl-amine) MCPA (Ethyl Hexyl Ester) MCPA (Iso-Octyl Ester) MCPA (Potassium Salt)	Nufarm MCPA 720, Agritone 750® Nugrex®, Paragon®, Bromicide® Broadside® Trooper 242®	2 L household ammonia, followed by 120 g Nufarm Tank and Equipment Cleaner as per label instructions.
		2,4-DB 2,4-D (Dimethylamine and Diethanolamine) 2,4-D (Ethylhexyl Ester)	Ozcrop 2,4-DB, Empress 2,4-DB® Amicide®, Surpass 475® Estercide Xtra 680®	2 L household ammonia, (to make a 1% solution in the tank) followed by 120 g Nufarm Tank and Equipment Cleaner as per label instructions.
	Pyridines	Clopyralid Fluroxypyr Triclopyr	Lontrel™, Archer® Starane™, Comet® Grazon™	120 g Nufarm Tank and Equipment Cleaner as per label instructions, or 500 g washing soda (crystalline sodium carbonate) + 4 L kerosine, or 2 L Ammonition.
J	Thiocarbamates	Tri-allate	Avadex Xtra®	Water, with 120 g Nufarm Tank and Equipment Cleaner or 1 L Absolute Boomer.
K	Chloroacetamides Isoxazoline	S-Metolachlor Pyroxasulfone	Dual Gold®, Bouncer® Sakura®	
L	Bipyridyls	Paraquat Diquat Paraquat + diquat	Gramoxone® Reglone® Spray.Seed	Thorough water clean, or as per tank mixing partner/s requirements.
M	Glycines	Glyphosate	Glyphosate Roundup products Weedmaster® Touchdown Wipe-out®	
N	Phosphinic acids	Glufosinate-Ammonium	Basta®, Liberty®	
Q	Triazoles	Amitrole	Amitrole, Illico, Para-Trooper®	Water, with 120 g Nufarm Tank and Equipment Cleaner or 1 L Absolute Boomer.
Z	Arylaminopropionic acids	Flamprop-m-methyl	Oat Master, Mavro, Farmoz Judgement	

Source: GRDC's Spray Application Manual GrowNotes™ - https://grdc.com.au/resources-and-publications/grownotes/technical-manuals
The cleaning products mentioned in this table are not the only products available for decontamination.

Managing for fibre quality

By **Michael Bange** (CSIRO)

Acknowledgements: Greg Constable, Sandra Williams, Stuart Gordon, Robert Long, Geoff Naylor & Rene van der Sluijs (CSIRO)

Importance of quality fibre

Producing a quality fibre is important. Not only because Australian cotton holds a reputation of being purchased for a premium, but because the consequences of producing poor fibre quality is substantial (See table 1).

In ensuring that fibre quality is maintained, 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 is a good start.

Crop management for improved fibre quality

Fortunately the majority of crop management factors which increase/optimise yield will also increase/optimise fibre quality. One exception may be instances of high yielding crops with undesirable high micronaire cotton.

Fibre length and micronaire are significantly affected by agronomic and climate effects, but fibre strength is more influenced by variety choice. Fibre growth and development is affected by most factors which influence plant growth. Since the fibre is primarily cellulose, any influence on plant photosynthesis and production of carbohydrate will have a similar influence on fibre growth. Cell expansion during growth is strongly driven by turgor (the pressure of fluid in the plant cell), so plant water relations will also affect fibre elongation in the period immediately following flowering. Thus in terms of primary (direct) responses, water status (irrigation) strongly influences fibre growth and ultimately final fibre length. Fibre elongation will also be affected by temperature and carbohydrate limitations.

Here fibre elongation refers specifically to the elongation of a fibre in length during its growth. In terms of fibre quality, fibre elongation also refers to the elongation in a fibre before it breaks in a strength test.

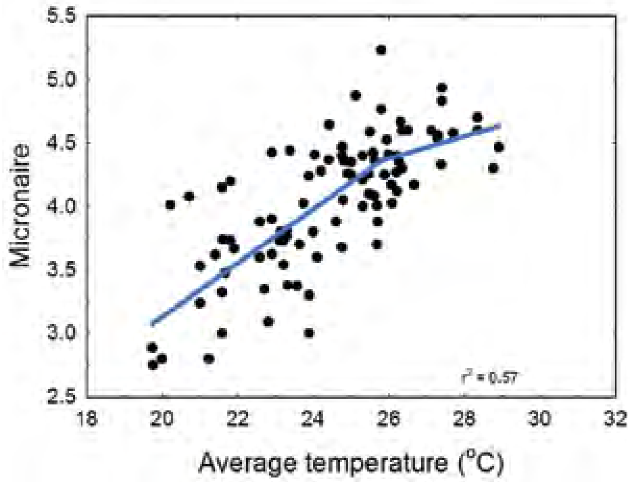
Fibre thickening is also affected by temperature and radiation effects on photosynthesis. Large reductions in fibre thickening can occur following long periods of low temperatures or cloudy weather, leading to low fibre micronaire.

Data from sowing time experiments in a range of locations over the past three decades have shown that sustained changes in temperature during fibre thickening can lead to explained differences in micronaire. Figure 1 shows the relationship of average temperature during the phase when the majority of bolls have their fibres thickening to influence micronaire.

Best practice…

- **The key management considerations for optimising fibre quality are variety selection and avoiding crop stress. So good water and fertiliser management is critical. Producing poor quality fibre can lead to significant price discounts.**

FIGURE 1: The response of micronaire to daily average temperature during fibre thickening taken from planting time studies. Varieties used in this study had an average micronaire of 4.05 generated at an average daily temperature of 24.4°C. (Adapted from Luo, Bange and Johnston (2014))



Potassium deficiency can have a significant impact on fibre length because of the role of potassium in maintenance of cell turgor by osmotic regulation. Other nutrient deficiencies can also reduce fibre length. But where nutrient deficiencies are not the major factor in a production system, nitrogen or potassium fertiliser treatments will not necessarily improve fibre length. Early crop defoliation or leaf removal can cause substantial reductions in fibre micronaire due to the cessation in carbohydrate supply for fibre thickening. Few agronomic or climatic conditions have been shown to consistently affect fibre bundle strength as strength is mainly determined by variety.

Severe weed competition in cotton can have strong effects on fibre properties as well as trash contamination.

Cotton's indeterminate growth habit also leads to many secondary (indirect) impacts of climate and management on fibre properties. Any management which delays crop maturity can lead to reduced micronaire due to exposure of a greater proportion of a crop to unfavorable conditions such as cooler or cloudy weather. Early stress with subsequent recovery, or higher nitrogen fertility 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. The issues to consider for each crop management phase are summarised in Table 2.

For more information the following resources and tools are available at www.cottoninfo.com.au and www.mybmp.com.au

- **FIBREpak Chapters 7 to 11**

TABLE 1: Consequences of poor fibre quality.

Fibre trait	Trait description	Ideal range	Consequences of poor fibre quality – cotton price	Consequences of poor fibre quality – spinning
Length	Fibre length varies with variety. Length and length distribution are also affected by stress during fibre development, and mechanical processes at and after harvest.	UHML in excess of 1.125 inch or 36/32nds. For premium fibre 1.250 or 40/32nds.	Premiums can be gained for long staple length. Significant price discounts below 33/32nds.	Fibre length determines the settings of spinning machines. Longer fibres can be spun at higher processing speeds and allow for lower twist levels and increased yarn strength.
Short fibre content	Short fibre content (SFC) is the proportion by weight of fibre shorter than 0.5 inch or 12.7 mm.	<8 per cent	No premiums or discounts apply.	The presence of short fibre in cotton causes increases in processing waste, fly generation and uneven and weaker yarns.
Uniformity	Length uniformity or uniformity index (UI), is the ratio between the mean length and the UHML expressed as a percentage.	>80 per cent	Small price discounts at values less than 78. No premiums apply.	Variations in length can lead to an increase in waste, deterioration in processing performance and yarn quality.
Micronaire	Micronaire is a combination of fibre linear density and fibre maturity. The test measures the resistance offered by a weighed plug of fibres in a chamber of fixed volume to a metered airflow.	Micronaire values between 3.8 and 4.5 are desirable. Maturity ratio >0.85 and linear density <220 mtex. Premium range is considered to be 3.8 to 4.2. (linear density <180 mtex)	Significant price discounts below 3.5 and above 5.0.	Linear density determines the number of fibres needed in a yarn cross-section, and hence the yarn count that can be spun. Cotton with a low micronaire may have immature fibre. High micronaire is considered coarse (high linear density) and provides fewer fibres in cross section.
Strength	The strength of cotton fibres is usually defined as the breaking force required for a bundle of fibres of a given weight and fineness.	>29 grams/tex, small premiums for values above 29 grams/tex. For premium fibre >34 grams/tex.	Discounts appear for values below 27 grams/tex.	The ability of cotton to withstand tensile force is fundamentally important in spinning. Yarn and fabric strength correlates with fibre strength.
Grade	Grade describes the colour and 'preparation' of cotton. Under this system colour has traditionally been related to physical cotton standards although it is now measured with a colourimeter.	>MID 31, small premiums for good grades.	Small premiums for good grades. Significant discounts for poor grades.	Aside from cases of severe staining the colour of cotton and the level of 'preparation' have no direct bearing on processing ability. Significant differences in colour can lead to dyeing problems.
Trash/dust (Leaf Grade)	Trash refers to plant parts incorporated during harvests, 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 the exudates of the silverleaf whitefly and the cotton aphid.	Low/none	High levels of contamination incur significant price discounts and can lead to rejection by the buyer.	Sugar contamination leads to the build-up of sticky residues on textile machinery, which affects yarn evenness and results in processing stoppages.
Seed – coat fragments	In dry crop conditions seed-coat fragments may contribute to the formation of a (seed-coat) nep.	Low/none	Moderate price discounts.	Seed coat fragments are difficult to remove as they are attached to the fibre and do not absorb dye and appear as brown 'flecks' on finished fabrics.
Neps	Neps are fibre entanglements that have a hard central knot. Harvesting and ginning affect the amount of nep.	<250 neps/gram. For premium fibre <200	Moderate price discounts.	Neps typically absorb less dye and reflect light differently and appear as 'flecks' on finished fabrics.
Contamination	Contamination of cotton by foreign materials such as woven plastic, plastic film, jute/hessian, leaves, feathers, paper leather, sand, dust, rust, metal, grease and oil, rubber and tar.	Low/none	A reputation for contamination has a negative impact on sales and future exports.	Contamination can lead to the downgrading of yarn, fabric or garments to second quality or even the total rejection of an entire batch.


WILL QUALITY AFFECT YOUR BOTTOM LINE?
...WE'LL TELL YOU

TABLE 2: Key in-field management considerations for optimising fibre quality.

Objectives	Pre planting	Sowing to first flower	First flower to open boll	Open boll to harvest	Harvest to gin
Realising the genetic potential for fibre length	Variety selection. Strategic planning for irrigation availability. Consider skip row for raingrown.	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.		Avoid delayed harvest and end of season rainfall
Maintaining fibre strength	Variety selection.		Maintain healthy crop.		
Producing fibre with mid range micronaire to avoid fibres that have too high linear density or are immature	Variety selection.	Monitor soil moisture and schedule irrigation to optimise plant vegetative size. Sow at appropriate date for the region to avoid early crops in hot areas or late crops in cool areas.	Management of plant vegetative size, structure and balance with boll setting pattern. Uniform boll set is achieved by having the appropriate plant type for the variety, region and climate. Optimise agronomic management such as water, fertliser and growth regulators. Adopt IPM to protect fruit, and leaves.	Timely harvest to avoid bad weather. Use appropriate nitrogen fertiliser rates to match crop requirements and assist cut-out. Schedule last irrigation to leave soil at refill point at defoliation. Use appropriate timing, product and rate for defoliation.	
Reducing the incidence of neps	Variety selection.		Optimise timing of cut-out to match season length to avoid significant amounts of immature open bolls at harvest.	Begin harvest aid application at 60% open bolls to avoid immature bolls at harvest.	Spindles and doffers maintained daily. Reduce spindle twist by not picking too wet.
Delivering clean white cotton with no stickiness	Weed management.	Weed management.		Fertiliser, irrigation and defoliant management as above. Refer to IPM guidelines for aphid and whitefly management. Consider defoliating earlier if crops shows signs of maturing rapidly.	Picker setup – avoid pin trash and bark. Follow guidelines for module placement, construction, tarping and transport. Keep good module records.
Preventing contamination	Farm hygiene to avoid contamination during harvest later. Weed management.	Weed management.			Farm hygiene. Picking height. Hydraulics on pickers and builders checked and maintained.

Harvest & post harvest

Photo courtesy Ruth Redfern

Preparing for harvest

By **Michael Bange** (CSIRO)

Acknowledgements: Sandra Williams, Greg Constable, Stuart Gordon, Rob Long, Geoff Naylor and Rene van der Sluijs (CSIRO)

The key to effective defoliation

Effective cut-out

Cut-out is when the crop ceases to produce new fruiting sites. Timing of cut-out must consider opportunity for further fruit production (yield) and potential losses in fibre quality and harvesting difficulties. The cut-out date should aim to optimise yield and quality allowing squares and bolls on the plant to mature and open, enabling harvest prior to cool/wet weather.

Management tips

During flowering, monitor cut-out at least weekly using the Nodes Above White Flower (NAWF) technique (Figure 1). NAWF = 4 to 5 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). So use a strategy to provide new growth such as irrigation or nutrition.

Consider how much time is left in the season. This can be done by estimating the date of the last effective flower (see Table 1). Crops approaching cut-out too slowly can indicate that there has been a loss of fruit and/or have plenty of access to water and nutrition.

If crops are continuing to grow and the time of last effective square and flower have passed, consider extending irrigation intervals and using a late season, high rate growth regulator application to restrict further vegetative growth, induce cut-out and avoid immature bolls at harvest.

Bolls produced after the optimum cut-out date may not contribute greatly to yield or quality. Along with monitoring NAWF it may also be useful to identify fruiting branches (with ribbons or tags that can be removed prior to harvest) that produced the last effective flower. 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.

Best practice…

- Any management which delays maturity can lead to reduced fibre micronaire, and should be avoided where possible.
- Timing of harvest should aim to strike a balance between further boll development; and the potential losses from adverse weather (rain, frost) and inclusion of immature fibre.
- In addition to timing of harvest aids, it is important to consider product, rate and application issues.

TABLE 1: Average dates for the last effective flower for various locations for different times when crops are expected to finish. These have been calculated using historical climate data since 1957.

Average target date of your last effective flower					
Town	Date when you want your crop to be finished (date of last harvestable boll)				
	1st Mar	15th Mar	1st Apr	15th Apr	1st May
Jerilderie	30th Dec	11th Jan	22nd Jan	30th Jan	5th Feb
Griffith	31st Dec	12th Jan	24th Jan	31st Jan	7th Feb
Hillston	5th Jan	17th Jan	29th Jan	5th Feb	12th Feb
Warren	6th Jan	18th Jan	29th Jan	6th Feb	13th Feb
Bourke	13th Jan	25th Jan	6th Feb	15th Feb	22nd Feb
Walgett	11th Jan	22nd Jan	4th Feb	13th Feb	20th Feb
Wee Waa	8th Jan	20th Jan	2nd Feb	10th Feb	18th Feb
Gunnedah	4th Jan	16th Jan	29th Jan	6th Feb	14th Feb
Spring Ridge	31st Dec	12th Jan	24th Jan	1st Feb	9th Feb
Moree	8th Jan	20th Jan	2nd Feb	11th Feb	20th Feb
Mungindi	11th Jan	23rd Jan	5th Feb	14th Feb	22nd Feb
St George	12th Jan	24th Jan	6th Feb	15th Feb	23rd Feb
Goondiwindi	8th Jan	20th Jan	2nd Feb	11th Feb	19th Feb
Dalby	2nd Jan	14th Jan	28th Jan	6th Feb	15th Feb
Theodore	9th Jan	21st Jan	5th Feb	15th Feb	25th Feb
Emerald	11th Jan	24th Jan	7th Feb	18th Feb	28th Feb

Note that as the date of last harvestable boll is delayed the time for last effective flower is not increasingly delayed. This is especially the case for cooler growing regions.

Late season growth regulator application

The application of high rates of growth regulator late in the season has become a common practice in many cotton growing regions. The aim is to assist cessation of production of late vegetative growth (and unnecessary late fruit). The application growth regulator is unlikely to have a negative effect on fibre quality and yield, and may help reduce neps in late crops that would have produced immature bolls. The practice can also reduce risk of providing late season food source for insect pests. Decisions on cut-out application of growth regulators are based on:

FIGURE 1: Monitoring nodes above white flower (NAWF) in conjunction with the timing of last effective square and flower is useful in determining whether crops are approaching the most appropriate time for cut-out (NAWF=4). This example shows that the crop is potentially 'cutting out' too early and limiting yield for the particular region. Red line is the last effective flower date.

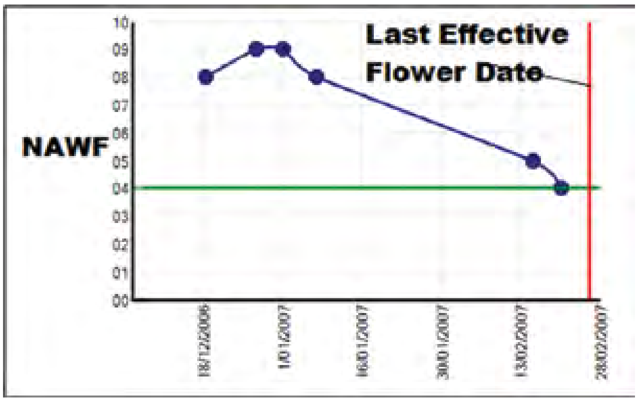


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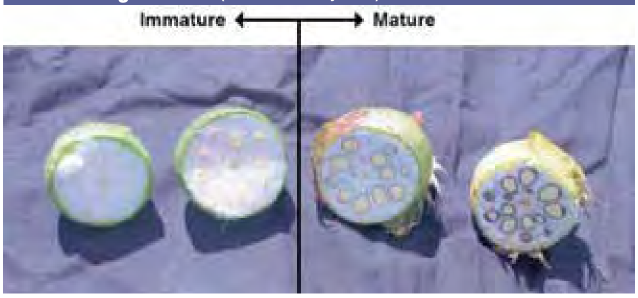
FIGURE 2: Bolls that are mature have seed coats that are turning brown. (Photo courtesy CSD)



- Attainment of target boll numbers.
- Resumption of unnecessary late vegetative growth or fruiting.
- Reaching last effective square or flower date for the region.
- Ensuring that the crop will not endure significant stress following application of the growth regulator as the combination may reduce yield substantially more than the effect of the stress alone.

Refer to Managing crop growth Chapter for more information.

Season length

Season length is another consideration that effects defoliation and harvest. Short growing seasons as experienced in southern and eastern growing regions should consider sowing as early as feasibly possible to avoid crops maturing and being harvested in cold and wet conditions. But sowing too early can increase risk of poor seed germination and crop establishment.

Ceasing crop growth for a timely harvest

Late flowering and especially regrowth will cause fibre quality problems directly which will be reflected in reduced micronaire and increased neps, and indirectly with poorer grades. Delayed harvests also expose clean lint to increased chances of weathering. Humid conditions or rainfall increases microbial damage thereby potentially reducing colour grades. Poor and untimely defoliation can have a significant impact on fibre maturity as well as the amount of leaf trash.

Management considerations from open boll to harvest include:

- Appropriate irrigation management for finishing the crop and avoiding regrowth.
- Managing aphid and whitefly infestations to avoid sticky cotton.
- Accurately determining crop maturity.
- Ensuring timeliness of harvest operations to avoid wet weather.
- Effective application of harvest aids.

A perfect system to attain the highest quality cotton would be to have a field with 70–80 per cent 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. Leaves would have matured naturally and allowed 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 (see sowing to first flower chapter of FIBREpak) or events which cause late regrowth (eg. excess soil moisture at harvest) can interfere with defoliation practices and picking. Delayed growth may also mean that fibre development may also occur in cooler weather (reducing fibre maturity, lowering micronaire and increasing neps).

Unnecessary and late season growth also supports late season insects which can damage yield and quality. In wet or humid weather leafy crops may also contribute to boll rot.

Timing of last irrigation is a balance between ensuring (1) there is enough moisture to allow the growth and maturity of harvestable bolls, and (2) fields are dry enough to assist defoliation, limit regrowth, and minimise picking delays and soil compaction. The moisture required for late crop growth is related to the time of defoliation. The broad aim is to plan to manage irrigations effectively to finish the crop and to limit regrowth by having soil moisture levels to refill points by the time of defoliation.

Determining end of season crop water requirements

Assessing the remaining water requirements will allow calculation of the best strategy for use of remaining irrigation to ensure that there is sufficient moisture to optimise yield and quality, and efficient take up and function of applied defoliant, while aiming to have a soil profile that is sufficiently dry at harvest to minimise compaction.

Factors to consider:

- Days to defoliation.
- Boll maturity.
- Crop water use.
- Plant available water – ability to extract water below normal refill point.
- Soil moisture objective at defoliation.

Refer to the Irrigation management chapter for more information on final irrigation/s.

Days to defoliation

There are a number of rules of thumb to help estimate days until defoliation and generate values for your own district. Aim to be at or close to (irrigation) refill point at time of defoliation:

- Defoliate when Nodes Above Cracked Boll (NACB) is equal to 4.
- Allow for it to take 42 degree days, around 3 days (up to 4 days in cooler regions) for each new boll to open on each fruiting branch.
- (Total NACB – 4) x 3 = days to defoliation.
- Aim to be at or close to refill point at time of defoliation.

Crop maturity is monitored to avoid early crop cessation

To determine crop maturity monitor plants that are representative of the crop.

Methods include:

- **Percentage of bolls open –** Crops can be safely defoliated after 60–65 per cent of the bolls are open. This method is simple and works well in crops with regular distribution of fruit.
- **NACB (Nodes above cracked boll) –** In most situations 4 NACB equates to the time when the crop has 60 per cent bolls open. This is a useful methodology on crops that are uniform in growth, and is less time consuming than percentage of open bolls.
- **Boll cutting –** The easiest and probably the most effective method to determine if bolls are mature or immature. It can be used effectively even when crops are not uniform (eg. tipped out plant, gappy stands). Bolls are mature when: they become difficult to cut with a knife; the seed is well developed (not gelatinous) and the seed coat has turned brown

TABLE 2: Dates of first frost for cotton production.
(Source: www.longpaddock.qld.gov.au/silo/)

Region	Years of climate data	Average date of first frost	Date of earliest frost recorded
Emerald	111	9 Jun	23 Apr
Dalby	111	26 May	17 Apr
St George	43	7 Jun	7 May
Goondiwindi	107	2 Jun	23 Apr
Moree	111	28 May	12 Apr
Narrabri	43	25 May	27 Apr
Gunnedah	62	22 May	11 Mar
Bourke	43	12 Jun	10 May
Warren	43	27 May	27 Apr
Griffith	59	14 May	14 Apr
Hillston	43	17 May	1 Apr

(refer to Figure 2); and when the fibre is pulled from the boll it is stringy (moist but not watery).

See also Timing of Application of Harvest Aids (over page).

Whitefly and aphid infestations are monitored and managed to avoid sticky cotton

A significant proportion of all cases of stickiness are attributable to honeydew exudates of the silverleaf whitefly (*Bemisia tabaci* B-biotype) (SLW) and the cotton aphid (*Aphis gossypii*). The sugar exudates from these insects lead to significant problems in the spinning mill.

Presence of honeydew on the surface of cotton late in the season can also contribute to reductions in grade as it provides a substrate for sooty moulds and other fungal growth. In humid conditions the growth of fungal spores along with honeydew may increase the grey colour of the lint.

SLW and aphids prefer to feed on the under surface of the leaf allowing the small transparent droplets of honeydew to fall to leaves and open bolls below. 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.

For more information see the Cotton Pest Management Guide.

Timeliness of harvest operation

Cotton that is severely damaged from weather is also undesirable in textile production because the lint surface has deteriorated and this is perceived to have dye uptake problems. It also can increase the roughness of the fibre which alters its frictional properties and thus how the fibre performs in the spinning mill.

As cotton weathers it loses reflectance, becoming grey due to moisture from both humidity and rain, exposure to ultraviolet radiation (UV) and from fungi and microbes that grow on the lint or wash off the leaves. Damage to the fibre will reduce micronaire as the fibre surface becomes rough retarding air movement in the micronaire chamber. Weathering will also reduce fibre strength making fibres susceptible to breakage during the ginning process, reducing length and increasing short fibre content leading to issues in yarn production.

When a boll opens under humid conditions microbes begin to feed on the sugars on the surface of the fibre and stain the lint. Under very humid conditions fungi can multiply on the lint causing 'hard' or 'grey locked' bolls which can reduce both quality and yield.

If bolls are opened prematurely by frost often it has a yellow colour that varies with intensity of the frost. Injury to moist boll walls as a result of frost damage releases gossypol which stains the cotton yellow.

A grower should examine their harvest capacity, regional weather patterns, and have monitored their crop development to avoid excessive weathering.

Specific considerations include:

- Time harvest to avoid excessive rainfall once bolls are open. Tools to assess rainfall frequency include: CliMate (www.australianclimate.net.au) and the Bureau of Meteorology (www.bom.gov.au/climate/averages).
- Plan to have the crop defoliated before first frost (see Table 2).

Effective application of harvest aid chemicals

Defoliation induces leaf abscission which is the formation of a break in the cellular structure joining the leaf to the stem allowing the leaf to fall off. Leaf removal is critical for reducing the amount of leaf trash in machine harvesters. These chemicals allow timely and efficient harvest of the lint to reduce quality losses from weathering and leaf stain from excess leaf trash. Boll opening is also accelerated by defoliation as removal of leaves exposes bolls to more direct sunlight, promoting increased temperatures for maturation, and drying and cracking of the boll walls.

Application of harvest aids are determined by: the timing, the type of chemical used, and the rates applied. The effectiveness of harvest aids is dependent on: uniformity of plant growth, weather conditions, spray coverage, and adsorption and translocation of the chemical by the plant. Optimum timing of harvest aids must strike a balance between further boll development and potential losses from adverse weather and the inclusion of immature fibre which can lower micronaire and increase neps (Figure 3). 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

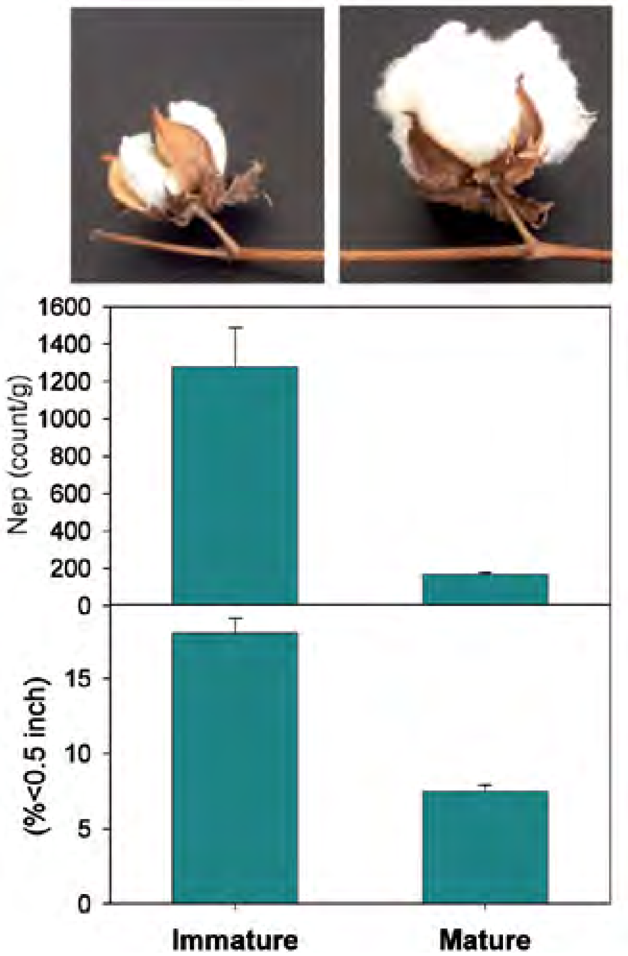
The categories of harvest-aid chemicals include herbicidal and hormonal defoliants, boll openers, and desiccants each with a different mode of action:

Defoliants (Thidiazuron, Diuron, Dimethipin) – All defoliants have a common mode of action to remove leaves. They increase the ethylene concentration in leaves by reducing the hormone auxin and/or enhancing ethylene production. Dimethipin alters the concentration of ethylene by reducing the amount of water in the leaf stimulating ethylene production. This change in ethylene concentration triggers separation in the abscission zone at the base of the petiole (leaf stalk). Chemical defoliant enters leaves through the stomates (minor route) or through the leaf cuticle (major route). Hormonal defoliants are applied to reduce auxin and/or enhance ethylene production, while herbicide defoliants injure or stress the plant into increasing ethylene production (similar to waterlogging or drought effects). If herbicide defoliants are applied at too high rates the plant material may die before releasing enough ethylene to cause defoliation resulting instead in leaf desiccation (leaf death).

Boll openers/conditioners (Ethephon, Cyclanillide, Aminomthanane Dihydrogen Textraoxosulfate) – These chemicals specifically enhance ethylene production by providing a chemical precursor for the production of ethylene, which leads to quicker separation of boll walls (carpels).

Desiccants and herbicides (Sodium Chlorate, Magnesium Chlorate, Glyphosate, Diquat, Paraquat, Carfentrazone-Ethyl) – Desiccants are contact chemicals that cause disruption of leaf membrane integrity, leading to rapid

FIGURE 3: 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)



loss of moisture, which produces a desiccated leaf. Desiccants should be avoided as they dry all plant parts (including stems) which can increase the trash content of harvested lint. Sometimes it is necessary to use desiccants if conditions do not enable the effective use of defoliants (eg. very cold weather). Desiccants are also a reliable method to reduce leaf regrowth. High rates of some defoliants can act as desiccants.

Timing the application of harvest aids

The type of defoliation product is unlikely to impact on fibre quality if timing is correct, but early defoliation can cause a significant reduction in all desirable fibre properties. Too early defoliation will increase the number of bolls (often from the top of the plant) harvested 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 defoliations earlier than 60 per cent of bolls open will reduce micronaire and increase neps. In crops that have non-uniform maturity it is advisable that there be no more than 29 per cent immature bolls (of total boll number) that are defined as immature bolls using the boll cutting technique to avoid increasing neps.

Key issues for use of defoliants

- Ensure defoliation practices occur before the onset of frost.
- Aim to have soil moisture at refill points at defoliation. Severely water-stressed crops will not allow defoliants to act effectively.
- If boll openers/conditioners are applied prior to boll maturation they may cause bolls to shed and reduce yield.
- The use of boll opener/conditioners should only be considered if the bolls that will be forced open are mature.
- Avoid application of defoliants when there is a risk of rainfall shortly after. Some defoliants are taken up slowly by the leaves and will wash off by rain, resulting in incomplete defoliation.
- To avoid regrowth issues it is prudent not to defoliate an area bigger than can confidently be harvested within 2 weeks.

Rate and chemical selection issues

- Varieties can sometimes differ in the needs for defoliation as they can differ in the quantity of wax on the leaf surface which affects harvest aid uptake, and plant hormone concentrations.
- Leaves most susceptible to defoliant are older leaves. Higher rates of defoliant will be needed for young healthy leaves. But there is a chance that young leaves may 'freeze' on the plant if defoliant is applied in too warm weather.
- Cool temperatures, low humidity and water stress prior to defoliant application can increase the waxiness and thickness of the leaf cuticle reducing the efficiency of chemical uptake. Wetting agents or spray adjuvants can assist with this problem.
- Because leaf drop requires production of enzymes, the speed with which a leaf falls off is highly dependant on temperature. There are different optimal temperatures for defoliant performance. Hormonal defoliants and boll conditioners have a higher optimal minimum temperature of around 18°C compared with herbicide defoliants that have optimal minimum temperatures ranging from 13 to 16°C. Higher rates are often needed to offset the effects of low temperatures.
- The defoliating effects of a chemical are usually complete 7 days after application.

Application issues

- Low humidity during application decreases uptake because chemicals dry rapidly on the leaf.
- For penetration of defoliants lower into the canopy consider using larger droplet size or directed sprays in the case of ground rig use. Use of spray adjuvants may decrease droplet sizes and this 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.

Refer to the Cotton Pest Management Guide and manufacturers details for specific chemical defoliation options and rates.

These guidelines have been extracted from FIBREpak – A Guide to Improving Australian Cotton Fibre Quality.

Useful resources:

- **FIBREpak (available from www.cottoninfo.com.au)**
- **Cotton Pest Management Guide (available from www.cottoninfo.com.au)**
- ***my*BMP (www.mybmp.com.au)**

All these Youtube videos can be viewed at: www.youtube.com/cottoninfoaust
Using harvest aids in cotton
Timing cotton defoliation
Assessing the maturity of a cotton crop
Making the decision to defoliate!
Timing your last irrigation
Cotton growth stages: cut-out

Harvesting & delivering uncontaminated cotton

By **René van der Sluijs** (CSIRO)

Traditionally, all cotton lint produced worldwide was harvested (picked or removed from opened bolls on the cotton plant) by hand, with mechanical harvesters developed and implemented in the early 1940s, It has been stated that mechanical harvesting has had the greatest impact on cotton since the invention of the cotton gin with some of the largest producers and exporters of cotton lint, including Australia harvesting 100% of their cotton mechanically. The adoption of mechanical cotton harvesters (either spindle or stripper) was mainly due to an increase in cotton acreage and yield which resulted in dramatic increases in production. Preharvest preparation and the actual harvesting plays an important role in determining fibre and seed quality, as the quality of ginned cotton is directly related to the quality of seed cotton prior to ginning. Irrespective of which mechanical harvesting method is used, the setup and adjustment of the machine, training and skill of the operators, and the effectiveness of defoliation and harvesting play a major role in the amount of trash and moisture present in the seed cotton.

Use of a properly maintained picker that is setup correctly

The two types of mechanical harvesting machines are the spindle picker and stripper. The spindle picker, which is used to harvest the bulk of the Australian crop is a selective type harvester that uses rotating tapered, barbed spindles (Figure 1) to pull seed cotton from opened bolls into the machine. Spindle harvesters are large and complex machines that are expensive to purchase, costly to maintain and require precise setup, adjustment and trained and skilful operators to obtain the maximum yield and value per hectare possible. Proper maintenance and correct setup of harvesters will help to ensure a clean and effective pick. Your best source of information about maintenance and setup is your harvester operator's manual.

The other type of harvesting machine is the cotton stripper, which is a non- selective type harvester that uses brushes and bats to strip seed cotton from bolls. These harvesters are predominately used to harvest seed cotton from raingrown (dryland) 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 lower grades.

Generally agronomic practices that produce high quality uniform crops contribute to harvesting efficiency. Soil should be relatively dry in order to support the weight of the harvesting machinery and avoid unnecessary soil compaction. Row ends should be free of weeds and grass and should have 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 mainly picked by means of the spindle harvester, this chapter will focus mainly on this system, however, many issues will apply to both spindle and stripper cotton harvesting systems.

Pre-season maintenance

A successful harvest requires a cotton harvester that is in good condition; even older harvesters can do an efficient job, if they are in good mechanical condition. Special care should be given to the spindles, moistener pads, doffers, bearings, spindle bushings, and the cam track.

Your best source of information regarding maintenance and setup is the operator's manual:

Best practice...

- **Regular maintenance and correct set up of Harvesters must be conducted for a clean and effective harvest.**
- **Check tarp quality of conventional modules and condition of plastic wrap of round modules.**
- **Check moisture levels of seed cotton and prior to and during harvesting and in modules.**
- **Come Clean Go Clean – Ensure farm hygiene practices are in place to avoid contamination, especially when constructing modules.**

FIGURE 1: Spindle pickers require regular maintenance to operate at high efficiency.

- Check and replace damaged tyres.
- Inflate tyres to the pressure specified before making any field adjustments.
- Ensure that row units are tilted as specified by machinery manufacturer.
- 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 have similar length and diameter.
- Ensure all spindles turn when the row unit is rotating.
- Doffers need to be ground and reset properly as required. Replace when damaged.
- Check moisture pads, bar heights and grid bars. Moisture pads should wipe each spindle clean to remove plant juices (sap) that may cause spindle twist.
- Check cam track, roller, drum head and bar pivot stud for excessive wear.
- Check pressure doors for wear, bends, gap and alignment.
- Clean basket pre cleaners and picker basket top.
- Check hydraulic lines, components and air hoses for leaks.
- Ensure drive belts are adjusted correctly and universal joints in the drive train are lubricated and in good condition.
- Check condition of steps and handrails on harvester.

Daily setup and checks

- Proper cleaning and servicing of the harvester before, during and after harvesting will result in better performance and lower the potential of fire.
- Check engine oil and coolant levels before starting engine of harvester for the first time in the morning.
- Picker heads should be greased when they are warm. To prevent excessive wear systems also require light greasing every two to four hours throughout the day. Spin heads to remove excess grease and wash down if excess still remains.
- 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 picking. Adjust doors to allow efficient removal of lint but avoid excessive green boll and stem bark removal.
- Doffers need to be checked daily and throughout operation. Too much clearance leads to improper doffing and spindle twist in the lint while lack of adequate clearance leads to rapid abrasion of doffer plates by the spindles leading to presence of doffer pad specks (often not detected until textile manufacture).
- Spindles and bushes should be regularly checked for wear, especially the ones near the ground. Worn parts should be replaced.
- Spindles should be kept clean as dirty spindles cause spindle twist (wrap) and incomplete doffing resulting in excessive accumulation causing the unit air system to choke, as well as inefficient picking.
- Use a recommended spindle cleaner in conjunction with the correct nozzle output determined by existing conditions (especially if there is green leaf present on the plants).
- Perform regular cleaning, either using a broom, your hands or compressed air, of the picking air suction doors, basket or bale chamber. Dispose of fly cotton where it cannot contaminate the module.
- Adjust water volume correctly according to the time of day and picking conditions. Higher rates are usually needed in the middle of the day when conditions are drier.
- To avoid harvesting green bolls, pressure doors should be set to light to medium and all grid bars should be in position.
- Seed cotton should be harvested at moisture levels of ≤12% to prevent downgrading of fibre and seed.

Guidelines for module placement, construction, tarping and transport

Irrespective of which harvesting method is used the key considerations for module production to maintain quality are module placement, construction, tarping, storage and transportation to the gin.

Typically harvesters with basket systems require module builders to produce conventional (traditional) modules that have a maximum size of 2.4 x 3.0 x 12 metres. These modules can weigh 12-16,000 kg which produces an average of 24 bales. In contrast harvesters with on board module building capacity produce round modules which weigh 2,000-2,600 kg which produce an average of 4 bales.

Module placement

Incorrect placement of modules has the potential to contribute to significant losses caused by moisture damage as well as contributing to contamination. The following guidelines should be considered when choosing a site for module placement:

- Module pads should have enough space to allow easy access for the equipment and trucks.
- Located on a well-drained field road and avoiding areas where water accumulates.
- Surface of site is free from gravel, rocks, stalks, and debris such as long grass or cotton stalks.
- Smooth, even and firm compacted surface that allows water to drain away.
- Accessible to transport and inspection in wet weather.
- Away from heavily travelled and dusty roads, and other possible sources of fire and vandalism.
- Clear of overhead obstructions, especially power lines.

Round modules

The introduction of the John Deere harvester with on board module building capacity, offer labour and efficiency gains (due to non-stop harvesting and the elimination of in-field unloading to boll buggies and processing in module builders) have been rapidly adopted. This is especially true in Australia where these machines have harvested in excess of 95% of the total crop for the past 4 to 5 years. These harvesters, which have been described as a hybrid of a cotton harvester and an oversized round hay baler, produces round modules which are covered with an engineered polyethylene film that both protects the seed cotton and provides compressive force to maintain the module density. Despite the

Round module pickers have almost entirely replaced the more traditional picking machinery, allowing a more manageable and safer approach, with less casual labour. Growers utilising these pickers should consider, soil compaction and round module handling.
(Photo courtesy of Ruth Redfern)

advantages of these harvesters some concerns have been raised regarding seed cotton moisture, contamination, soil compaction and the potential effect on yield of subsequent crops, variability in quality, as well as the high cost of the plastic wrap.

As this harvester can harvest without stopping to unload, the operator needs to decide where and when to drop the module that has been completed and 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 anywhere within the field. This action has no impact on the operation of the harvester, but stalks may puncture or tear the plastic wrap.

Module staging (method used to place modules together for transport)

The modules must be picked up from where they were dropped in the field, and staged together for pickup. The most common system is a mast-type tractor mounted implement that holds the module with the axis parallel to the tractor rear axle. Because the round modules can weigh up to 2600 kgs, a large tractor is required for staging:

- Transport speed of the tractor with a module on the handler should be kept to a safe speed to suit current conditions and not exceed 16 km/h (10 mph).
- When transporting modules through harvested rows, the module should be carried high enough to minimise contact with those rows.
- Gap between the underside of the module and the ground should be sufficient and never be less than 15 cm during module staging to prevent drag and tearing of underside of wrap.
- Modules should be staged only in well drained areas of bare soil, such as turn-rows. If the soil is wet, wheel slip by the truck can cause the loading chains to tear the plastic wrap.
- Modules should be staged on a high flat surface. Staging on well defined flat driveways or a flat disked surface is optimal. Modules will take the shape of the surface they are placed on. Setting on beds or uneven surfaces requires digging into the ground with the module truck chain to safely get under the entire surface of the module.
- If possible, avoid staging in areas where the truck cannot access the modules if rain occurs.
- Do not allow module ends to touch, as this will cause water to enter the modules rather than to run off down the ends. The modules should be aligned so that the centrelines are within a +/- 13 cm band.
- Stage round modules for transport as per transport operators required method. The two typical staging types are “Sausage” (end to end) and “Wagon Wheel” (at 90° deg from end to end). The “Wagon Wheel” is more common for loading by articulated loaders and transport by flat top trucks. The “Sausage” staging is for the more specialised self loading chain-bed trailers. But development of a self loading trailer for Wagon Wheel loading is being pursued. Modules staged for sausage chain-bed module truck pickup must have gaps between 102 mm and 203 mm at module cores. Too little gap can cause tearing as modules travel up module truck incline due to interference with adjacent modules. Also, having module ends contacting each other during long-term storage can increase chances of mould growth. Gaps between modules allow ventilation.
- Significant wrap tears must be repaired in the field before module truck pickup to prevent further wrap damage and ginning problems.
- Loose outer tails must be secured with a high strength spray adhesive (3M™ 90) or lint bale repair tape.

Conventional modules

Module construction

A module builder compacts seed cotton to a density of about 190 kg/m^3. A tighter module better sheds rainfall on the sides and less cotton is lost during storage, loading and hauling.

Build modules in a straight line to assist the carrier in avoiding misalignment of modules on the trailer resulting 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. Module builders should not be elevated with blocks as this can lead to oversized and overweight modules. Only build module weights which are appropriate to the transportation system. Do not exceed 16 tons if chain beds are to be used, with flat top trucks able to handle more weight.

The top of the module should be rounded to allow the top of the module when covered to shed water. In addition a well compacted module will help reduce freight costs to the gin.

Good communication is needed between module-builder operators, picker and boll buggy drivers to allow appropriate time for modules to be built and to avoid spillages. Cotton that is spilled from modules should be carefully added back into the module avoiding contamination whilst following strict WHS guidelines. A constant lookout for oil leaks on both cotton pickers and module builders is needed to prevent contamination. Oil leaks on builders should be repaired as soon as they are noticed. Oil contaminated cotton needs to be removed from the module as soon as it is identified.

Module tarping

Use of a high quality tarpaulin on modules is important to avoid moisture affecting quality as well as avoiding significant contamination of the cotton from the tarpaulin itself. Before using tarpaulins inspect them for holes, tears and frayed edges and that they repel water.

Tarpaulins should be chosen taking into consideration their tensile strength to avoid tearing, resisting puncturing and abrasion, adhesion of coatings, UV resistance, and cold crack temperature. If tarpaulins have seams they should be double stitched, with a minimum number of stitches. Centre seams (unless heat sealed) should be avoided as it is a potential weak point to allow water to enter the module. All these factors should be weighed up in light of the overall cost of the tarpaulin and its life expectancy. The tarpaulins should be kept in a dry, vermin free store to ensure their quality and longer life expectancy.

To avoid contamination and fibre quality losses tarpaulins need to be securely fastened to the module. For best performance of tie-down type module covers use all loops and grommets provided. Cotton rope is the most appropriate fastener to limit contamination and synthetic rope should never be used. Ensure rope has enough strength to endure strong winds. Belly ropes should be avoided if possible as they may break. A tarp should be large enough to cover at least half to two thirds of the ends of the module.

Keeping good module records

Identifying when and where each module is produced can help with producing better fibre quality outcomes as the grower can discuss with the ginner the quality of the cotton of each module and thus tailor the ginning process to suit. The grower can also use these records to better understand the variability that exists within a field to refine management practices for that particular 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 picked. Any records or numbers assigned to modules should be as permanent as possible. Permanent marker pens should be used on cards attached to modules in a sealable plastic bag.

This may not be necessary if the Radio-frequency identification (RFID) tags that are embedded in the module wrap of the round modules are utilised as these tags are able to document 11 of the most important data points during module formation to improve traceability of cotton modules as they move from the field to gin lot and through the ginning process.

Module transportation

The safe loading and transport of cotton modules (round or conventional) is vitally important in preventing injury to module transport operators, other road users and preventing damage to property. The Cotton Australia Module Restraint Guide has thus been drawn up to provide cotton growers and transport operators with practical information and advice to help meet relevant legal compliance and avoid unnecessary accidents and/or penalties through the safe loading, restraint and transport of cotton modules on Australian roads where flat-top open sided trailers are used.

The Guidelines can be downloaded at www.cottonaustralia.com.au/uploads/resources/CA_Module_Restraint_Guide_2012_Edition.pdf

Work health & safety at harvest

It is vital that all contractors and farm staff go through a safety induction at cotton harvest. The key to managing farm safety during harvest is to involve all staff in identifying potential hazards and implement a plan to manage these safety risks. This process is equally important for contractors as well as farm staff. Developing a set of procedures of how you would like the picking operation to progress will ensure that all involved are aware of correct and safe operation of equipment.

The following are examples of procedures:

- Read and understand the operation manual and the basic safety procedures which are provided with the picker.
- Establish procedures and picking patterns and then train and re-train all staff/contractors on how picking machinery will be serviced and operated.
- Wearing appropriate clothing and using protective equipment where necessary can reduce the risk of an accident occurring.
- Keep windows and mirrors clean for good visibility.
- Keep all lights and alarms in proper working order.
- Ensure walkways and platforms are free of tools, debris or mud.
- Travel at safe speeds around ground staff and equipment and limit unnecessary traffic around pickers and builders.
- Ensure everyone is out of danger way before emptying or moving a picker or plant.
- Emphasise 'look up and live' to avoid contact with overhead obstacles such as power lines, trees or sheds.
- If work continues during the night, workers must take extra care and be aware of the position of other workers. Workers should wear reflective clothes or safety vests and audible warning sounds on machinery should be activated.

For further information on WHS please refer to Safe people management chapter.

Quality issues

Moisture considerations

Cotton that is picked wet will result in cotton being twisted on the spindle (spindle twist – roping that occurs when spindles are partially doffed) which may lead to seed cotton being more difficult to process in the gin. The harvesting operation itself will also be interrupted as picker doors are blocked more often when cotton is too moist and efficiency declines as a result of poor doffing efficiency. Doffers and moisture pads on pickers can also be damaged.

Studies have shown that, irrespective of the harvesting method, seed cotton moisture has a significant influence on fibre quality. Increased moisture results in a microbial/bacterial action which leads to colour degradation (spotting) and discoloration which affects the colour grade (as measured both visually and by instrument), with the fibre becoming yellower and less bright with trash adhering to the lint. Modules are generally stored for 3 months prior to ginning and seed cotton with high moisture content can increase the risk of the module self-combusting and also emits a strong unpleasant odour. Other fibre properties such as micronaire, length, strength and elongation can also be affected. Seed cotton moisture also has a significant influence on seed quality, with an increase in moisture content resulting in a decrease in germination and vigour, due to an increase in free fatty acid content and aflatoxin level. Increased moisture content also leads to increased mechanical damage to the seed, resulting in an increase in the quantity and weight of seed coat fragments and mote. Furthermore, during ginning, increased moisture also leads to increased gas usage, reduction in production, blockages and the possibility of fires.

Typically cotton in Australia is too moist for harvest at dawn but cotton can be picked well into the night provided relative humidity remains low. Moisture monitoring using moisture measuring equipment or dew point charts/calculators need to be used more frequently at each end of the day as the change in moisture can be quite abrupt, eg. moisture can increase abruptly 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. It must be remembered that up to 2% moisture is added to seed cotton by the spindles to keep them clean and to enhance the adherence of the fibre to the spindle and allow for its removal by the doffer. Furthermore round modules are smaller in size in comparison to traditional modules, resulting in less dilution of the cotton from across different picking times and moistures.

The last round module picked each night will have significantly higher moisture than those picked in the middle of the day. From a ginners perspective this is an issue as they are unable to respond to rapidly changing moisture levels to gin efficiently. Round modules are very compact and wrapped in plastic, which is impractical and difficult to remove and replace, which limits the rate of moisture transfer to the atmosphere, which can affect fibre and seed quality if stored for an extended period prior to ginning. Round modules clumped tight in sausage formation will also limit airflow between modules. Isolation for express ginning of high moisture round modules can be difficult, as they can be lost in the multitude of modules produced in a shift. Cartage of several (5–6) round modules can also make isolation of these modules at the gin difficult. Modules during storage on-farm and in the gin should be monitored every five to seven days for temperature rises. A rapid temperature rise of approximately 8 to 11 °C or more in 5 to 7 days signifies a high moisture problem and that module should be ginned as soon as possible. Modules that have temperatures rising to 43 °C need to be ginned immediately. The temperature of modules harvested at safe storage moistures will not increase more than 5.5 to 8 °C in 5 to 7 days and will level off and cool down as storage period is extended.

Assessing moisture content

Some rules of thumb to consider relating to moisture on cotton to be harvested include:

- Install moisture measuring equipment on the harvester, or use hand held moisture meters.
- Moisture measuring equipment should be calibrated to ensure correct readings.
- Note that hand held moisture meters are usually ± 1% accurate
- Take reading from previously constructed modules.
- If moisture is present on vehicles while harvesting it is most likely that the cotton is too wet.
- The seed should feel hard (cracks in your teeth).
- When a handful of cotton collected in the palm of your hand is squeezed into a ball and then released, the moisture content is acceptable if the seed cotton springs back to near its original size.
- If you can feel moisture on the cotton it is too wet.
- Moisture is added to the spindles to keep them clean and to enhance the adherence of the fibre to the spindle and allow for its removal by the doffer. Consider that machine picking can also add 2% moisture to seed cotton.
- The addition of green leaf will add moisture.
- A symptom of moist cotton is frequent blocked doors, throwing cotton out the front of the picking heads.
- If cotton is being expelled into the basket in dense blobs and is not fluffy it may be too moist.
- Suitable picking conditions late into the night are rare.
- Notify your ginner of modules that may be moist so that they may be ginned first, or at least monitored in the module yard.

Contamination

Contamination of cotton with foreign substances lowers the value of the product and often causes problems and increased costs for those processing the cotton at both the gin and the spinning mill. Australian cotton is recognised as one of the least contaminated cottons in the world and receives a premium. Any 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.

By far the largest contribution to contamination occurs during harvesting and module building and if a module is suspected of having a contaminant, clearly identify it, and notify the gin when delivering the module of the potential problem

The most prevalent contaminants found in Australian cotton are pieces of fabric and string made from woven plastic and plastic film (including module tarps, round bale plastic wrap, plastic shopping and fertiliser bags, agricultural mulch film, plastic twine and irrigation tubing).

Other contaminants include:

Natural – Such as rocks, wood, leaf, bracts, bark, green leaf, burrs and grass. As well as honey dew which are produced by aphid/ whitefly which cause a sticky sugary substance and causes problems in ginning and spinning.

Man-made contaminants – Oil, hydraulic oil, grease, pieces of metal and equipment as well as food wrappers, drink bottles, mobile phones and cleaning rags etc can also find their way into a grower's module. Trial markers (pink tape etc.) are a source of contamination and should be removed prior to 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 putting down a module can prove very useful. Rocks and dirty and discarded cotton is a common form of contamination and can be avoided if an inspection is carried out. All workers should be trained to watch out for contaminants. Make them aware of the potential problems and provide them with the facility to clean up and isolate rubbish, for example provide garbage bins in which all waste is thrown and use only white cotton cleaning rags.

Useful resources:

***my*BMP (www.mybmp.com.au)**

FIBREpak (www.cottoninfo.com.au)

Beyond the farm gate

Ginning

By **René van der Sluijs** (CSIRO)

Acknowledgements: Michael Bange, Greg Constable, Stuart Gordon and Robert Long (CSIRO)

The ginning industry in Australia is relatively modern, with higher throughput gins compared with other countries. The principal function of the cotton gin is to separate lint from seed and produce the highest total monetary return for the resulting lint and seed, under prevailing marketing conditions. Current marketing quality standards most often reward cleaner cotton and a certain traditional appearance of the lint.

A ginner has two objectives:

- To produce lint of satisfactory quality for the grower's classing and market system.
- To gin the cotton with minimum reduction in fibre spinning quality so the cotton will meet the demands of its ultimate users, the spinner and the consumer. 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.

Best practice…

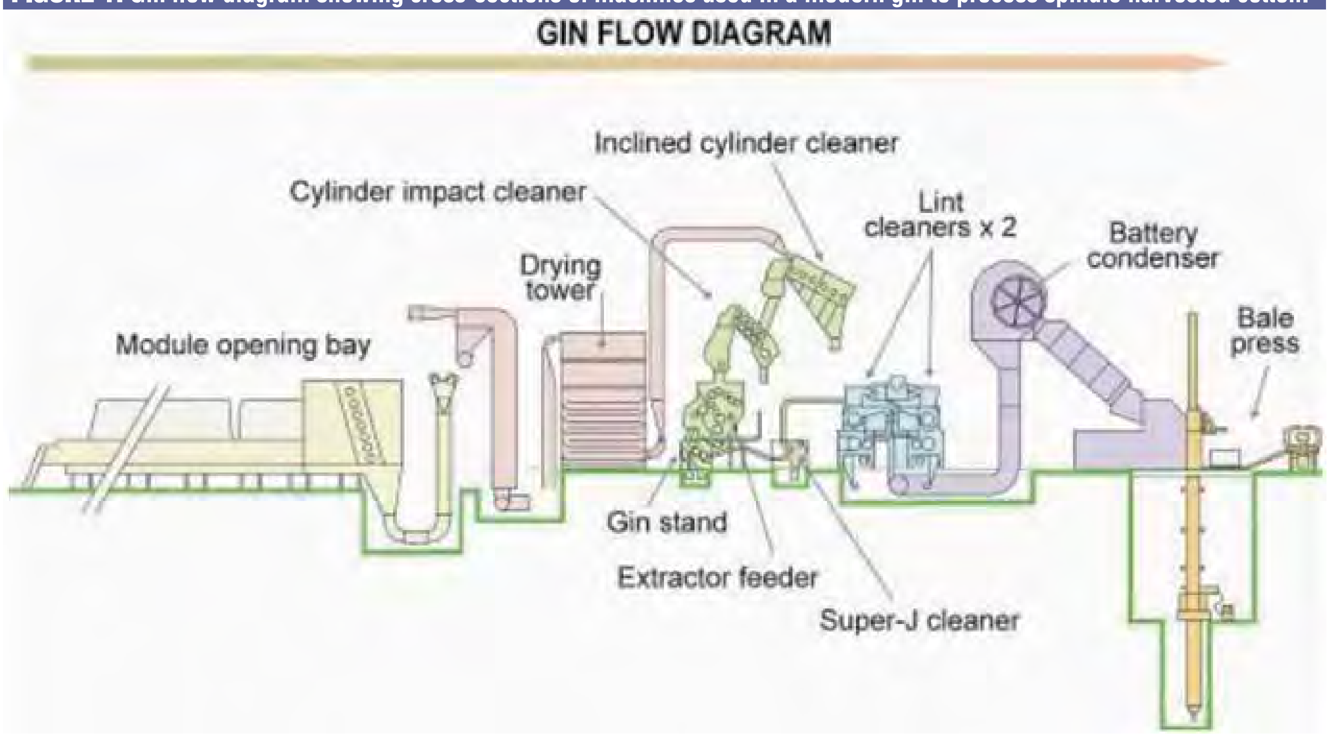
- **The main concerns during the ginning process are to maintain quality, optimise lint yield and contain the costs of ginning.**
- **Appropriate ginning and handling practices post-harvest are important to maximise returns for growers and maintain the industry's reputation for high quality cotton.**
- **Good communication between growers and ginners is a key factor in assisting this process (see Table 1).**

The challenge for the ginner is therefore to balance the amount of cotton produced (turn-out), the speed at which it is ginned and the effects that the various cleaning and ginning components have on the fibre quality. Particular settings in a gin for speed or heat can exacerbate nep and short fibre content. The use of lint cleaners, while removing trash, also increases

TABLE 1: Summary of key post harvest decisions for optimising fibre quality.

Objectives	At the gin
Maintaining fibre length	In the gin, fibre length can be preserved and short fibre 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 should be closer to 7 per cent than 5 per cent; but fibre moisture at either point should not exceed 7 per cent. Lower combing ratios between feed rollers and the saw of lint cleaners also reduces the amount of fibre breakage.
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, eg. 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	Clean gravelled module storage yards. Frequent inspection of tarps and plastic wrap on modules. Storage and handling of bales to avoid damage.

FIGURE 1: Gin flow diagram showing cross-sections of machines used in a modern gin to process spindle harvested cotton.



the number of neps and short fibres. Whilst not included in existing classification systems for cotton, the presence of neps and short fibre seriously affect the marketing ability. The ginner must also consider the weight loss that occurs in the various cleaning machines. Often the weight loss to achieve higher grade results in greater removal of lint as well, which results in a lower total monetary return to growers and ginners as they are both paid on a per bale basis.

Cotton quality after ginning is a function of the initial quality of the seed cotton, and the degree of cleaning and drying it receives during ginning; the exact balance between turn-out and grade will depend upon the particular premium-and-discount (P&D) sheet applied to the cotton in question. For every P&D sheet there will be a point in the balance between turn-out and grade that maximises the return to the grower.

Given this need to balance competing considerations, it is essential that growers seek to:

- Ensure defoliation and harvest practices limit trash.
- Contamination is limited.
- The moisture during harvesting and hence in the module is ≤12%.

Ultimately it is important that growers communicate with ginners these aspects of their harvest prior to the start of the ginning season. An understanding of the issues that were faced in the field may give the ginner insights on how the cotton can be handled to optimise turn-out and quality together.

Modern gins are highly automated and productive systems that incorporate many processing stages. Gins must be equipped to remove large percentages of plant matter from the cotton that would significantly reduce the value of the ginned lint, according to the classing grade standards. Figure 1 shows the cross-section of a gin with machines that are typical of those found in a modern gin, although it is noted that most Australian gins typically have more pre-cleaning stages. This gives them the flexibility to process both spindle harvested cotton and stripper harvested, which requires more pre-cleaning.

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. But in Australia the moisture addition at these points is not common. After ginning, fibre travels by air to one or two lint cleaners for further cleaning and preparation. At the lint cleaners, moisture content is critical to prevent cotton from significant damage (neps and short fibres). Cotton that is too dry (< 5.5 per cent moisture content) will be damaged to a greater degree during the lint cleaning process.

This information has been adapted from FIBREpak chapter 13 – post harvest management.

Classing

Cotton, being a natural agricultural product, differs widely from growth to growth, crop to crop, lot to lot, bale to bale, within a bale and even fibre to fibre. In view of this and the important effect which variations in fibre properties have on processing performance and cost and product quality, it is of crucial importance that such variations in fibre properties be determined and quantified. Once cotton is ginned, and while it is being baled, a sample (minimum of 200g) is taken from both sides of every bale and bulked together and sent to the classing facility for classification.

Originally, cotton was 'classified' by a classer's subjective assessment of fibre length as well as colour and leaf using the United States Department of Agriculture (USDA) Universal Upland Grade Standards and American Pima Grade Standards. These grade standards specify colour and leaf. There are twenty five official colour grades for Upland cotton and five categories of below grade colour. Universal Upland Grade Standards are valid for only one year with the Pima Grade Standards valid for two years. Cotton classers are skilled in visually determining the colour, trash and extraneous matter and then assigning such cotton to a certain established standard grade.

USDA Universal Upland Grade Standards and American Pima Grade Standards.

As the 'Classer' was not able to assess various important textile quality related fibre properties, such as strength, elongation and fineness, a number of instruments were developed which measure the required 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 those 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.

Currently in Australia. classer's grade is still used to describe colour, leaf, extraneous matter (any substance other than fibre and leaf, such as bark, grass, seed coat fragments, oil etc.) and preparation (degree of smoothness or roughness of the cotton sample). There are moves underway to replace the visual determination of colour and leaf by instrument and measured by HVI.

The quality of cotton can be expressed by a number of different measurements which are performed by cotton classers. These measurements are described in a wide range of grades (Figure 2), and affect the final price that is paid for a bale of cotton.

The price received for cotton is dependent on the quality of each bale of cotton. Cotton prices are quoted for 'base grade' 31-3-36, G5 (refer to Figure 2). Base grade refers to the grade of cotton that is used by cotton merchants as a basis for contracts, premiums and discounts

Premiums and discounts apply for higher and lower grades respectively. These pricing adjustments reflect the change in suitability for the spinning and dyeing process (see Chapter 19, Table 1 'Consequences of poor fibre quality' right column). For this reason, variability in any

Best practice…

- **Classing is a complex process, whilst this chapter gives an overview, a more detailed understanding can be gained from visiting your nearest classing facility.**

quality characteristic may influence the price. Some of the key quality characteristics are outlined below:

- Colour.
- Leaf.
- Preparation.
- Staple Length.
- Micronaire.
- Strength.

Colour

Colour can be classed either visually by a trained cotton classer or by a High Volume Instrument (HVI). When cotton is classed visually, the classer compares the sample to a standard lint sample of known grade provided by the United States Department of Agriculture (USDA). The colour grading of Upland cotton takes into account 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 currently 25 official physical color grades for Upland cotton and five grades for below grade color. Table 2 lists the official colour grades applied to Upland cotton.

TABLE 2:

Designation		White	Light spotted	Spotted	Tinged	Yellow stained
Good middling	GM	11	12	13	—	—
Strict middling	SM	21	22	23	24	25
Middling	M	31	32	33	34	35
Strict low middling	SLM	41	42	43	44	—
Low middling	LM	51	52	53	54	—
Strict good ordinary	SGO	61	62	63	—	—
Good ordinary	GO	71	—	—	—	—
Below grade	BG	81	82	83	84	85

The colour of cotton as measured by HVI is determined by a colorimeter and defined in terms of the Nickerson-Hunter colour model, in terms of brightness (Rd) and yellowness (+b).

Leaf

Also known as 'trash', is a measure of the amount of leaf material (from the cotton plant) remaining in the cotton sample. Whist the gin removes the majority of trash, some remains in the sample which is removed in the spinning process resulting in a reduction in lint yield and increases cost.

Hence, cotton with high levels of trash attracts a discount. Leaf grades range from 1 (lowest amount of trash) to 7 (highest amount of trash), with level 3 as 'base grade'.

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 of importance to the spinning industry as longer fibres allow finer and stronger yarns to be spun.

Length is measured on a sample of fibres either by pulling a hand staple or by the HVI machine by passing a beard of parallel fibres through an optical sensing point. Australian cotton is all classed using HVI measurements and is reported in 100ths and in 32nds of an inch. Under raingrown (dryland) conditions, staple length tends to range from similar to irrigated cotton (1 1/8 inches) down to very short (1 inch or less). Base grade is 36 or (1 1/8"). Table 3 gives an indication of both 32nds and 100th of an inch.

TABLE 3: Upland length conversion chart.

Length (32nds)	Length (Inches)	Length (32nds)	Length (Inches)
24	0.79 & shorter	36	1.11 – 1.13
26	0.80 – 0.85	37	1.14 – 1.17
28	0.86 – 0.89	38	1.18 – 1.20
29	0.90 – 0.92	39	1.21 – 1.23
30	0.93 – 0.95	40	1.24 – 1.26
31	0.96 – 0.98	41	1.27 – 1.29
32	0.99 – 1.01	42	1.30 – 1.32
33	1.02 – 1.04	43	1.33 – 1.35
34	1.05 – 1.07	44 & +	1.36 & +
35	1.08 – 1.10		

Micronaire

Micronaire is measured by placing lint in a chamber, compressing it to a set volume and subjecting it to a set pressure. The reading, when related to a variety, is an approximate guide to fibre thickness and has been used as a measure of fibre maturity. Other, more accurate, fibre maturity testing methods and devices are now available, but for now the general guidelines below still apply:

- Low (<3.5) Micronaire indicates fine (but possibly immature) lint.
- High (>4.9) Micronaire indicates coarse lint.

The premium range is 3.7 to 4.2 and the base range is 3.5 to 4.9 (G5) and discounts apply for cotton with a micronaire outside the base range. Discounts for low micronaire can be substantial.

Micronaire results are grouped on the schedule for premiums and discounts. Common causes of low micronaire include:

- Cool temperatures during fibre wall development.
- Potassium deficiency.
- Dense plant stands.
- High nitrogen.
- Excess irrigation/rainfall.
- Favourable fruit set and high boll retention.
- Early cut-out due to frost, hail, disease or early defoliation.

Common causes of high micronaire include:

- Poor boll set.
- Small boll size due to hot weather or water stres.
- Variety.

Ginning has little or no effect on micronaire although low micronaire cotton is more susceptible to buckling and entanglement which creates neps which can effect preparation and subsequently grade. Raingrown cotton normally falls into the acceptable micronaire range; but under hot, dry conditions some varieties are prone to produce high micronaire. Late planted crops are susceptible to low micronaire and heavy discounts sometimes apply.

FIGURE 2: Interpretation of Base Grade: 31–3–36, G5.

BASE GRADE: 31 – 3 – 36, G5

Colour – Leaf – Staple Length, Micronaire

Colour	
Descriptor	**Code**
Good Middling (GM)	1
Strict Middling (SM)	2
Middling (MID)	**3**
Strict Low Middling (SLM)	4
Low Middling (LM)	5
Strict Good Ordinary (SGO)	6
Good Ordinary (GO)	7
Below Grade (BG)	8

Discount applies (codes 4–8)

Colour	
Descriptor	**Code**
White	**1**
Light Spotted	2
Spotted	3
Tinged	4
Yellow Stained	5

Leaf	
Descriptor	**Code**
Level 1 (least)	1
Level 2	2
Level 3	**3**
Level 4	4
Level 5	5

Staple Length	
Measurement	**Code**
1 inch	32
1 1/32"	33
1 1/16"	34
1 3/32"	35
1 1/8"	**36**
1 5/32"	37
1 3/16"	38
1 7/32"	39

Micronaire	
Measurement	**Code**
≥5.3	G7
5.0–5.2	G6
3.5–4.9	**G5**
3.3–3.4	G4
3.0–3.2	G3
2.7–2.9	G2
2.5–2.6	G1
≤2.4	G0

Management practices that open immature bolls such as pre-mature 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 per cent bolls open lowers micronaire (reduced fibre maturity) and increases neps (Bange et al. 2009).

Fibre strength

Fibre strength is highly dependent on the variety, although environmental conditions can have a small effect. Raingrown 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 (premiums or discounts) may be made for other undesirable quality characteristics including (but not limited to):

- Grass or bark in the sample.
- An un-uniform sample.
- Contamination.
- Sugars (honeydew).
- Neps.

A number of other fibre characteristics measured by HVI instruments which, whilst of increasing importance to spinners, currently do not have a direct impact on price, include:

- Uniformity Index (UI).
- Elongation (EL).
- Short fibre (fibres shorter than 12.7mm or 0.5 inch).
- Maturity.

Cotton grade and price

The price received for cotton is dependent on the quality of each bale. Cotton prices are quoted for 'base grade' 31-3-36, G5 (refer to Figure 2).

Premiums and discounts apply for higher and lower grades respectively. Cotton merchants generally present actual classing results in an easy to read report displaying the AUD $/bale premiums or discounts.

These pricing adjustments are calculated using their 'Premiums and Discount (P&D) Schedules' or 'Differential Sheets'. Australian merchants P&D schedules are formatted similarly and the adjustments are generally quite similar, but there may be some differences. P&D schedules often change between seasons and sometimes within the season; the merchant will generally set the seasons P&D around ginning time. From this time they can be requested from your merchant.

Premiums or discounts may be displayed in either USD $/lb or USD points/lb. There is 100 points in a cent. For example a 300 point discount is equivalent to -$0.03. To convert from per pound to per bale, multiply by 500. To convert into Australian dollars, divide by the USD/AUD exchange rate (ask your merchant the exact exchange rate which is applicable).

For example: A total discount of 800pts/lb = -$0.08/lb

$$= \frac{-\$0.08 \times 500}{.85}$$

= AUD -$47.06/bale

Multiple adjustments may apply to one bale of cotton. One adjustment for colour – leaf – staple length, while all other characteristics have their own adjustments.

For more information talk to your merchant or their classing facility.

Refer to the following websites:

Australian Cotton Shippers Association (www.austcottonshippers.com.au/)

FIBREpak (www.cottoninfo.com.au)

Managing cotton stubble/residues

By **Steve Buster** (NSW DPI)

Acknowledgements: Sharna Holman (QLD DAF & CottonInfo), Ngaire Roughley (CSD)

The destruction of crop residues is the first step towards preparing a field for the next crop, as well as being an important aspect of managing insects, pests and diseases.

The industry encourages zero tolerance of ratoon cotton (cotton that has regrown from leftover root stock from a previous season) and volunteer plants (cotton that has established unintentionally) as these provide a 'green bridge' to enable pests and diseases to carry over between seasons.

Post harvest crop residue management

Returning cotton stubble to the soil enhances nutrient cycling, by providing a source of energy for microbial organisms, which in turn helps the breakdown of stubble and maintains the supply of nutrients to the crop. Organic matter boosts the health of the soil, by improving water infiltration and internal drainage, as well as reducing wind and water erosion.

However there are difficulties involved in retaining crop stubble. Crop stubble has the potential to encourage volunteer cotton plants and may block cultivation equipment or irrigation channels if not incorporated effectively. There is a number of tillage and operation options available to ensure crop residues are managed appropriately.Some are discussed below.

Ploughing or the use of off-set discs

A one pass operation to incorporate standing crop stubble is the use of off-set discs. The advantage of this operation is that in one pass, residual crop residue is incorporated into the soil and pupae busting is done at the same time. The disadvantages are numerous and include the destruction of the hill or bed which will require another pass to re-hill, the moisture content of soil needs to be on the drier end to ensure smearing and compaction is minimised and off-set discs do not normally cut up stalk fine enough to breakdown quickly. This stubble management method is less preferable due to the required subsequent field operations and the possibility of moving the cotton plant hill into a furrow line creating further issues with compaction.

Pull, rake and burn

Another method that the cotton industry used in the 1990's was to 'pull, rake and burn'. Cotton plants were pulled out of the ground with a rubber tire stalk puller, raked into windrows and then burnt. While this method removed most stalk from the field it also resulted in a major movement of nutrients into the burn lines which showed up as green lines across the rows every 100 meters in the field. The obvious advantage is the removal of the majority of crop residue. The major disadvantages were the transfer of nutrients into lines across a field and into the air; the removal of organic matter that can help water infiltration and nutrient cycling; and issues with field access once winter rains started and trash lines had not been burnt. Very little of this method is still used by the industry except when the field may need re-laser levelling.

Standard slashing

This practice focuses on the slashing of crop residue and allowing other operations to take care of the cotton stub and root system. Standard slashing is not recommended for crop residue due to the issues associated with ratoon cotton. It can be used when going into a cereal rotation crop where broadleaf herbicides can kill the ratoon cotton that emerges from the standing stalk.

Best practice…

- **The destruction of plants and incorporation of crop residues should generally be performed by a root cut and mulch operation, followed by tillage.**
- **Pupae destruction is an important component of the Bt Cotton Resistance Management Plan and requirements should be followed.**
- **Pupae bust all Bt cotton fields regardless of defoliation date.**
- **Remove cotton volunteers and ratoon plants from all cropping and non-cropping areas to reduce carryover of pests and diseases and to reduce resistance risk.**
- **Where possible, all tillage operations (including picking) should be performed when soil is dry to reduce compaction risk.**

Photo 1 (top) – how a field's trash content should look like after only 2 workings (once mulched they were centre busted and then trace listered). Photo 2 (bottom) – large piles of trash left on the field can causes blockages and other management issues.

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Mulching and root cutting

The Australian cotton industry now promotes the practice of mulching/slashing the stalk above ground and cutting the root below cotyledon height, preferably two to five centimeters below the top of the bed. Crop residues are then incorporated into the surface soil. This 'mulch and root cut' system can improve the amount and quality of soil organic matter and avoid implement blockages in future cultivation/planting operations if crop residue can be sufficiently buried into the hill or bed. As the cotton plant is quite 'woody' it is preferable to break up the stalk into the smallest of pieces as possible to help the material break down in the soil and reduce the possibility of bridging across subsequent tillage and cultivation equipment. Stalks that are too long can cause problems in following operations. Mulching at slower speeds aids the potential reduction of stalk particle size as does the use of additional flails if available and mulch bars across the drum of the mulcher.

The efficiency of root cutting is maximised when machinery is run at a greater speed. However it is important that the machines are set up properly (with GPS systems being helpful) otherwise ratoon cotton can become an issue in guess rows. Depending on the depth of root cut, some preliminary pupae control can also be achieved. The advantage of mulching and cut-off is the retention of stubble to help soil conditions and retention of existing hill or bed in situ. The disadvantages are dependent upon the soil type and moisture conditions as the ability to work the mulched stubble can be variable. Stubble is difficult to incorporate in light, dry soils and tends to 'float' to the top of the hill. Further trash management passes/implements may be needed to handle the stubble.

Crop residues should be managed to minimise carryover of pathogens into subsequent crops. If Fusarium wilt is known to be present in a field, residues should be slashed and retained on the surface for at least one month prior to mulching, in order to disinfect the stalks through UV light exposure – immediate stubble incorporation is likely to aggravate the fusarium problem. In all other circumstances (including the presence of Verticillium wilt and other diseases), crop residues should be incorporated as soon as possible after harvest to afford a host-free disease period (for more information refer the Integrated Disease Management chapter).

Volunteer cotton

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. It is important to monitor and control volunteers located outside of the field, including roadsides, fence lines, channels, culverts, around sheds and other infrastructure.

For more information on volunteer cotton plants in the farming community visit www.youtube.com/cottoninfoaust

Ratoon cotton

Ratoon cotton plants (regrowth/stub cotton) that have survived crop destruction can be difficult to control, having developed a large root system and small leaf surface area. As part of an integrated weed management strategy, recent research has identified three herbicide options for the control of large volunteer or ratoon cotton plants in fallow. There are now registrations in place for controlling large 15 to 30 node volunteer cotton and ratoon cotton in fallow. Please refer to the Comet 400® label for further information. The product user must be in accordance with the label instructions. It is important that ratoon and volunteer cotton is managed as part of an integrated weed management strategy, with these plants providing a high risk for disease and pest carryover. Refer to the Cotton Pest Management Guide for information about volunteer and ratoon control.

Ten reasons why ratoon and volunteer cotton must go:

1. **Mealybugs survive from one season to the next on these food sources, infesting crops earlier in the following season.**
2. **Cotton aphids with resistance to neonicotinoids survive between seasons on these plants, reducing insecticide effectiveness.**
3. **Bunchy top disease can be transmitted by Cotton aphids from infected ratoons to new cotton crops.**
4. **Silverleaf whitefly survive between seasons on these plants, resulting in earlier infestation in the following season.**
5. **They provide a winter host for Pale cotton stainers and solenopsis mealybugs.**
6. **Inoculum of soil-borne diseases such as Black root rot, Fusarium and Verticillium builds up in ratoons, as does the population of parasitic nematodes such as *Rotylenchulus reniformis*, the reniform nematode.**
7. **Ratoon and volunteer plants place extra selection pressure on Bt.**
8. **Fields with ratoons from Bt cotton are unsuitable for planting refuge crops, as the refuge cannot be effective if contaminated with Bt cotton plants.**
9. **Removing ratoons may be a costly exercise, but it is cheaper than the costs of dealing with the problems resulting from not removing them.**
10. **They are a biosecurity risk. Ratoons harbour pests and are a potential point of establishment for exotic pests.**

Pupae control

Pupae destruction is a key recommendation for conventional cotton under the Insecticide Resistance Management Strategy (IRMS). Bollgard 3 provides growers with more flexible pupae busting requirements depending on crop location and timing of defoliation. Refer to the Bollgard 3 RMP for further details at www.monsanto.com.au, or the Cotton Pest Management Guide.

Useful resources:

***my*BMP at www.mybmp.com.au**

CottonInfo at www.cottoninfo.com.au

Business

Photo courtesy Melanie Jenson

Best Practice

The business of growing cotton

By **Janine Powell** (AgEcon)

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 financial advice see your accountant or agribusiness manager.

For many cotton growers, 'Business Manager' and 'Chief Financial Officer' are two of the many roles taken on by default. This chapter aims to summarise some of the key business aspects of growing cotton include budgeting, marketing, finance and insurance.

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 may be guided by the 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. GM budgets do not take into account risk, timing, overhead costs (such as depreciation, council rates and permanent labour) and do not calculate farm profit.

A well prepared GM budget will give an indication of management operations involved and may also help to understand the cash flow requirements of an enterprise.

Table 1 shows a simple example of a GM budget for 1ha of irrigated Bollgard3® cotton. The budget lists income sources, cost items and totals, with gross margin calculated as the total income less total variable costs. These figures are an indication only and can be used as a guide to create your own budget by applying your operations, yield and pricing estimates.

For detailed cotton gross margin budgets, see: www.cottoninfo.com.au/publications/australian-cotton-industry-gross-margin-budgets-2017-18

Enterprise gross margins are sensitive to both yield and price, however a GM budget does not consider price and yield risk. The GM's in the above link also include sensitivity analysis to illustrate the effect that changes in lint yield and cotton prices have on gross margins. The final cotton price is achieved through marketing; a comprehensive overview of cotton marketing can be found later within this chapter.

You can use published budgets as a guide when developing your own GM budgets, altering costs and operations as necessary. The degree to which budgets reflect actual crop returns will be influenced not only by general factors common to all farms, such as prices and season conditions, but also by the individual farm or field characteristics such as soil type, crop rotation and management. Consequently, it is strongly recommended that published GM budgets be used as a GUIDE ONLY and should be changed to take account of movements in crop prices, changes in seasonal conditions and individual farm characteristics.

Within the example gross margin (Table 1) the operations towards the end of the crop (defoliation, picking, cartage, ginning and levies) represent approximately 40 per cent of the total variable costs. Understanding the timing of costs is particularly important if short-term finance is going to be utilised. A brief overview of crop finance options can be found later in this chapter.

Gross margins need to be used carefully when used as a guide to deciding the farm's overall enterprise mix. As overhead costs are excluded, it is advisable to only make comparisons of gross margins between enterprises that use similar resources (ie. labour).

An understanding of overhead and operating costs is essential to understand the profitability of a farm business. Gross margin budgets do not show gross farm profit because they do not include fixed or overhead expenses such as depreciation on machinery and buildings, interest payments, rates, taxes or permanent labour. These costs are usually discussed at a business level, as they are costs that have to be met regardless of enterprise size or crop mix. The Australian Cotton Comparative Analysis is an industry benchmark from an accounting (or profit) point of view that includes overhead costs (details can be found in this chapter).

If major changes are being considered, more comprehensive budgeting techniques (that include overhead costs) are required and consultation with financial advisors is recommended, to estimate the range of expected profitability.

Best practice...

- **Prepare your own gross margin budget using published budgets as a guide.**

Marketing

Acknowledgments: David Lindsay & Ross Brown (Namoi Cotton)

The aim of this section is to give a general overview of the cotton pricing components and marketing alternatives available to Australian

TABLE 1: Example gross margin budget.

Irrigated Bollgard3®, Roundup Ready Flex®

Income	$/ha
11 bales lint/ha @ $485/bale	$5335
Cotton seed @ $65/bale (combined lint and seed price $530/bale)	$715
TOTAL INCOME (A)	**$6050**
Variable Costs	**$/ha**
Fallow management	$90
Farming: Pre-planting	$30
Nutrition	$360
Planting and in-crop farming	$145
Irrigation 9.6 ML (C)	$480
Insurance	$110
Crop protection, application and licence fee	$740
Defoliation	$145
Picking, cartage and ginning	$1095
Farming: Post-crop	$80
TOTAL VARIABLE COSTS (B)	**$3275**
GROSS MARGIN/HA (=A-B)	**$2775**
GROSS MARGIN/ML (=(A-B)÷C)	**$289**

cotton growers. It is strongly recommended that growers seek advice from a reputable merchant about the alternatives suitable for their specific situation.

Variability in the Australian cotton price is caused by fluctuations in the underlying futures prices, foreign exchange rates and basis levels. This variability can create major uncertainties (or risk) for cotton growers when deciding whether or not to plant cotton and when to sell. It is important that growers understand the components of the cotton price, associated risks and available marketing options before they begin marketing their crop.

The ability to 'lock in' a price for some or all of a crop before harvest is a key feature of the Australian cotton marketing system and can be a major advantage for cotton growers. However, fixing prices before harvest can be risky due to uncertain production levels. Therefore, to understand the different marketing alternatives it is necessary to first understand the risks.

Risk

Risk is the effect of uncertainty on objectives. In this case, returning a profit from the cotton crop is the objective and the primary areas of uncertainty (or risk) are production (quality and quantity of the cotton produced) and price (ie. adverse price changes such as an increase in input costs or a decrease in commodity prices). These risks are complex and vary between growers and over time, however, marketing is one method for managing these risks.

Production risk is separated into quantity (yield and area) and quality. With the ability to enter into forward contracts before the crop is planted, there is uncertainty with both the area to be planted (due to seasonal conditions) and the yield that will be achieved. Yield risk also exists when a contract is entered into after planting, but before harvest. Variable yields may result in a grower under or over producing against contracted commitments. If production exceeds the commitments made, and the contract price is higher than the spot or market cotton price, then the grower has an opportunity loss. If the grower under produced a fixed bale contract, then the grower may be obligated to fill the contract at market rates, which could result in a financial loss to the grower.

Varying quality is managed by merchants with all forward contracts priced on 'base grade'. Once the cotton is ginned and classed, the final price paid to the grower is adjusted with a premium when the grade is higher than 'base', or a discount in price when the grade is inferior. These pricing adjustments can be found on a merchant's corresponding premium and discount (P&D) sheet. P&Ds may change between, and sometimes during, seasons. At times there may be considerable variance between merchants P&D's (for more information about quality see the Managing for fibre quality Chapter).

Ring around and get copies of the merchants P&Ds prior to selling cotton each season and make a mental note of key differences.

Price risk, in relation to a cotton grower, is when all or a portion of the crop is not priced and the value is reduced due to decreases in the cotton price. There are three components of the Australian cotton price that cause day-to-day changes, each of these represent a different risk to the grower if they move against them. The three components of price are:

1. ICE Cotton Futures.
2. The Basis.
3. The AUD/USD foreign exchange rate.

Cotton is internationally traded and priced in US Dollars (USD), using the Intercontinental exchange (ICE) Cotton No 2 contract, previously managed by the New York Board of Trade.

Australian growers generally receive their income in Australian dollars (AUD), so the USD price is converted into local currency using the AUD/USD exchange rate. This may not be the spot exchange rate, rather 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

FIGURE 1: Australian Cotton Price, AUD $/bale, 15 years.

at any point in time. Basis is expressed in US c/lb (the same units as the futures price, where lb is pounds), it accounts for location and quality and is affected by local supply and demand conditions. Basis may be negative or positive and in recent times has ranged from -10 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

$$\text{An example of pricing elements for AU\$500/bale} = \frac{(0.68 + 0.08) \times 500}{0.78}$$

All three price elements can and do change on a daily basis. The price of cotton in Australian dollar terms is therefore subject to daily volatility. The major merchants in Australia publish their daily prices online or communicate their prices via email and text message. To be kept up-to date with pricing movements, contact the merchants and ask to be added to their daily price lists. See Figure 1 for AUD/bale pricing.

Figure 1 depicts cotton pricing over a 15 year period. Of note is that in the past 5 years prices have only momentarily dipped under $400/bale. In the past 12 months, supported by positive fundamentals – firm futures have combined with a more moderate dollar to achieve prices about $100 AUD/bale higher than the 15 year average.

Marketing options

Australian cotton growers are well serviced by a number of 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 5 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.

Merchants will offer growers a range of marketing options which allows the grower the opportunity to create a marketing strategy that best suits their production plan, business needs and hopefully maximise their profit. However, despite intense competition in the Australian market, not all merchants will offer every style of contract listed below. The most commonly utilised forward marketing options are:

AUD Fixed cash price: This is the most simple and by far the most common method of marketing cotton in Australia and is generally known as the 'cash price' (refer to Figure 1). This is a forward contract for delivery of a fixed number of bales of a given crop year (ie. 2017-18) and potentially month (i.e April-July) after they are ginned. Growers accept a fixed price in AUD for the bales which protects them from adverse movements in all three components of the cash price, but in turn the grower creates production risk by committing to deliver a set number of bales in the future. There may be financial penalty should a grower not be able to deliver the specified number of bales in the correct delivery period.

Be cautious with fixed bale commitments. As a general rule – don't market more than 80% of your conservative yield estimate before picking… also ginning delays may affect your ability to deliver into contracted months.

USD Fixed cash price: This is similar to the AUD Fixed cash price, however, in this contract the grower is leaving the foreign exchange component of their price unhedged. 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 have the view that the AUD/USD exchange rate is going to fall in the future and enhance your AUD/bale return.

Basis On-Call: This marketing option involves the grower agreeing to deliver a fixed number of bales of a particular crop year at a set basis. The price will be expressed in US c/lb on (or off) a particular futures contract month, for example 5.50 US c/lb on May 2018 ICE Futures. In this case both the futures and foreign exchange components of price are left floating, or 'on-call', to be fixed by the grower at a later date. In this case, the grower should have a view that the futures price will increase and the AUD/USD exchange rate will decrease in the future.

Closely monitor on-call contracts as you've only protected yourself against one of the three components of price risk to which you are exposed.

Fixed bale pool: This is a commitment to deliver a specified number of bales to a 'pool' of bales with a particular marketing organisation. Both price and yield risk are borne by the grower, but the price risk is managed by the marketing organisation. Most pools have an indicative price attached and often once that price is no longer achievable, the pool will be closed. As with all pools, payment is spread over a period of time as delivery of cotton from growers and sales to mills proceed.

Other pools may be offered by merchants to mirror the pricing profile of the fixed bale contracts above. Some pool contracts may have a guaranteed minimum price (GMP), with potential (but limited) upside risk. For these contracts, the grower bears production risk and some price risk. Due to the hedging requirements for the merchant to guarantee a certain minimum return, these contracts usually come at a discount to the cash market.

Hectare contracts: These contracts are quite rare in the cotton industry today. In a hectare contract, the grower commits a particular acreage, and all cotton produced from that area is covered by the contract. In this case, the production risk is borne by the merchant, and as such a minimum and maximum yield will often be specified.

Balance of crop (BOC) is a contract where the grower commits their remaining unpriced bales. These contracts are generally available towards the end of the season when the grower can make a reasonable estimate of their yield. Often, the merchant will require the grower to commit to a minimum and/or maximum delivery rather than bearing the entire production risk for the grower.

Force Majeure (FM) means 'compelling force, unavoidable circumstances'. When an 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.

True BOC and FM contracts are a good way to reduce production risk towards the end of the season… ensure you understand the contract conditions.

Who to sell your cotton to?

In recent years, a number of new merchants have entered the Australian market, creating more competition and choice for growers. While higher competition can result in higher $/bale there are some other considerations when selling your cotton:

- **Counterparty risk: Is there a chance of default – i.e not being paid as per the contract?**
- **Contract term:**
  - **Delivery months: Watch out for penalties on late delivery and consider your gin/processors ginning timeframes**
  - **P&D sheet: There is currently a considerable variance in the discounts being applied to below grade cotton. A $10/bale gain on the contract, may result in a net loss when discounts are applied.**

Seek advice from a reputable cotton merchant to understand your marketing options for both cotton lint and seed.

Timing of payment for cotton lint depends on the type of contract. Cash contracts are generally paid within 14 days of ginning, while 'pool' contracts may pay up to 75 per cent in July (after ginning) with further payments in September and December.

Confirm with your accountant and merchant the best payment structure for your business prior to entering into any contracts.

Cotton seed

The value of cotton seed can be a significant component of the income from a cotton crop. Cotton seed is priced through the ginning company which may not be the same organisation the cotton lint is sold through. Cotton seed is usually priced in bales (based on the amount of seed that is produced in the ginning process of one bale, and depending on the variety, this varies between 220–300 kg of seed), given current varieties most gins work on a yield between 230–250 kg. Traditionally the price of cotton seed has been strongly correlated with feed grains and fluctuates with supply and demand. In recent years, high exports of cotton seed to China have supported domestic pricing.

In the past, cotton seed has been worth up to $125/bale (approx. $500/t), and as little as $30/bale (approx. $120/t), with the latter not enough to cover ginning costs, however a price closer to $65/bale (approx. $260/t) has been more common.

When seed is priced at the same level as the cost of ginning (ie. $65/bale), this is known as 'net ginning for seed', which means the income from the seed covers the ginning cost. The ginning organisation may quote the seed price as 'net of ginning and seed' (ie. $65/bale = 'gin for seed', seed at $70/bale is 'Plus $5 back to grower', indicating the seed price covers the $65/bale cost of ginning, with $5 paid to the grower; an example of seed priced below the ginning cost, (seed at $60/bale) is '$5 payable by grower'). Talk to your preferred ginning organisation about current cotton seed pricing.

For further information on marketing your cotton, talk to a merchant or you can find comprehensive marketing notes on the following website:

Australian Cotton Shippers Association: www.austcottonshippers.com.au/downloads/Grower_Marketing_Risk_Handbook.pdf

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 with which you deal.

Crop credit is available through some agricultural resellers (ie. chemical resellers) and allows growers the option of deferring costs until after picking. Interest is charged at current short term money market rates (eg. bank bill rates).

At picking, pre-ginning loans (module advances) are available from most ginners and merchants. Details can be discussed with your merchant.

Most cotton growers have debt. Whether it is a seasonal overdraft or a long-term loan, it is important to understand the capability of your business to repay the loaned amount.

There are many ways to assess the financial sustainability of a business. The five indicators below are a good place to start, as these are some of the aspects that a financial institution will assess in a loan application.

- Debt levels.
- Ability to service interest.
- Net operating expenses.
- Interest expense.
- 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 on how to calculate any of the five financial measurements above or have any other questions, it is recommended that you speak to a financial advisor for more information and advice on how these measurements impact your individual business financial assessment.

Australian Cotton Comparative Analysis

By **Phil Alchin** (Boyce Chartered Accountants)

Acknowledgement: Sam Bacigalupo (Boyce Chartered Accountants)

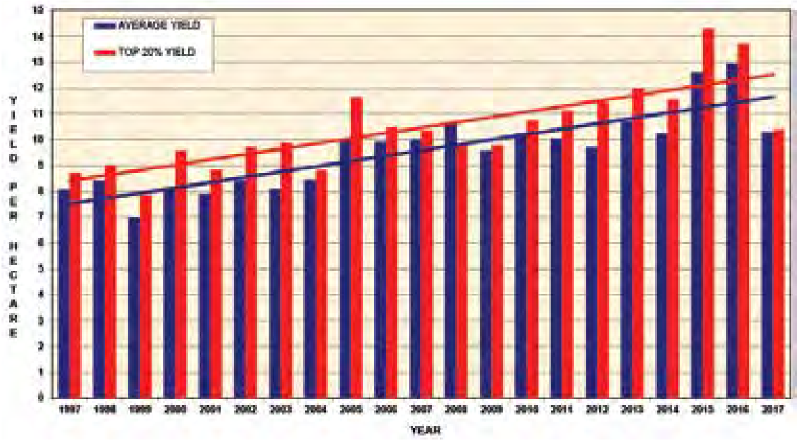
The Comparative Analysis is a joint initiative of the Cotton Research & Development Corporation (CRDC) and Boyce Chartered Accountants to produce the industry benchmark for the economics of cotton growing in Australia. The primary purpose of the Comparative Analysis is to show the income and expenses of growing fully irrigated cotton on a per hectare basis. The reports are posted on the web pages of Boyce Chartered Accountants (www.boyceca.com) and CRDC (www.crdc.com.au).

Financial analysis using comparative statistics helps farmers identify relative strengths and weaknesses. Accompanying budgets and long term business plans will then focus on ways to overcome weaknesses and build on strengths. In other words, this Comparative Analysis is a management tool to implement change and to identify where effort should be directed on a day to day basis. Obviously, this analysis does not provide all the answers – it is a benchmark or a standard to strive for. It is up to management to develop and implement specific action plans based on improved knowledge to set and achieve new goals. The reliable, independent figures in the Comparative Analysis provide the starting point for farmers to develop "best practice".

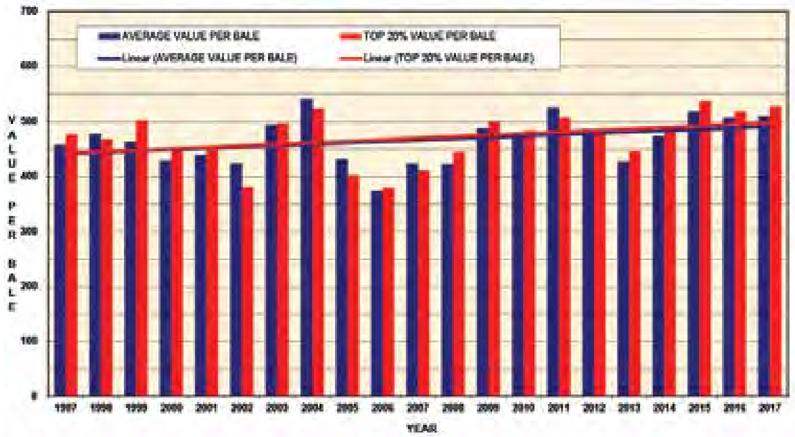
The reports show that over many years cotton farmers have been able to achieve top-class results, even in years when seasonal or financial circumstances were less than favourable. The analysis includes the average results compared with top 20 per cent, the average results of those farmers who achieved the highest operating profit (after using an average cotton price for all growers); and the average results compared with best "low cost" farmers, average results of those farmers who had the lowest farm operating expenses (before interest).

The most recent information on the Australian Cotton Comparative Analysis can be downloaded from www.boyceca.com or contact Phil Alchin, David Newnham or Paul Fisher on 02 6752 7799.

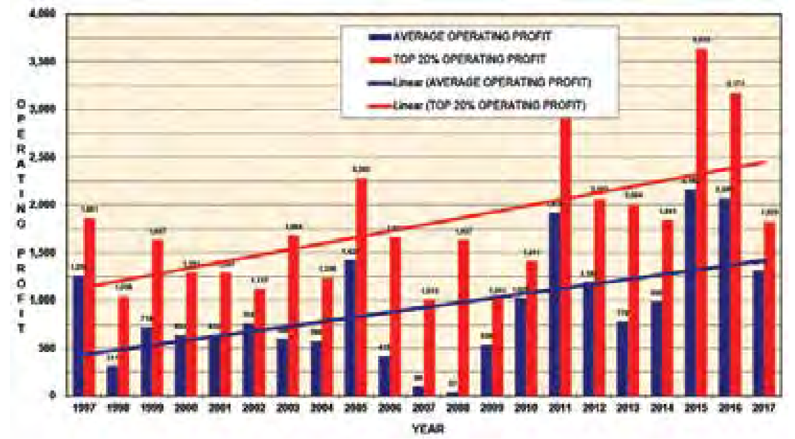
Comparison of the yield for the average and the top 20% for landholders



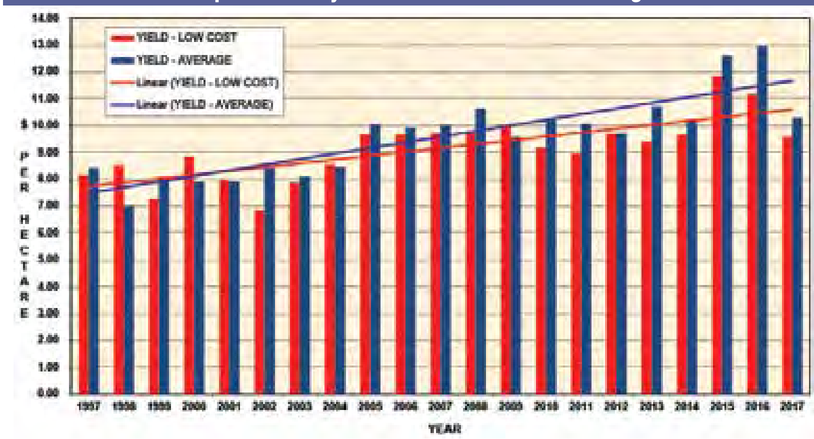
Comparison of the value per bale for the average and the top 20% for landholders



Comparison of the operating profit for the average and the top 20% for landholders



Comparison of yield for low cost and average.



Insurance

By **Deidre McCallum** (AgriRisk)

Acknowledgements: John van der Vegt (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 see your preferred insurance specialist.

Cotton farming operations are exposed to a variety of risks and hazards on a daily basis. 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 generally accepted as an effective tool to transfer risk and there are many types of insurance policies specifically designed for farming operations. From an insurance perspective, products are generally designed to:

- **Protect your assets:** Including farm (machinery, buildings etc) 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 are required by law such as workers compensation and third party personal injury insurance which is purchased in conjunction with your vehicle registration. Some insurances are imposed by others such as banks or financiers that require insurance is taken on machinery or crops where finance arrangements exist.

When operating your business, many companies will require evidence of public liability insurance. So whilst there are situations where insurance is mandatory, imposed or necessary, most insurance just makes good business sense to safeguard your operations from financial losses that could impact on the viability of your business.

Insurance is available via 2 different distribution channels:

- Either directly with the Insurer or through their Agents; and by,
- Insurance brokers.

The difference between agents and brokers is insurance agents act on behalf of the insurer and insurance brokers act on behalf of their clients. This is a very important distinction that impacts on the range of products you will be offered. Generally insurance brokers will have access to a number of Insurers and therefore a broader range of insurance products. They can therefore compare those products and make more meaningful recommendations to their clients. Conversely Agents can generally only access a single insurer and the products they can provide.

Timing of the loss	Types of yield losses	
	Partial losses	Total losses
Within the planting window	Yield loss will be indemnified PLUS any additional expenses	Replant payment PLUS any additional expenses PLUS any yield loss on the subsequent crop will be indemnified
Outside the planting window	Yield loss will be indemnified PLUS any additional expenses	100% yield loss will be indemnified LESS any savings in growing costs, defoliation and harvest costs and licence fees

Growers should seek expert advice in determining what insurance products they require and how they will respond in the event of a loss. Brokers can help in this process as they work for the growers.

Cotton hail insurance

Cotton hail insurance is now a mature product having evolved for nearly 30 years from a simple production cost based coverage to something far more complex today. Now growers can effectively tailor their insurance to their exact requirements from a low level production cost cover to full revenue protection, including cover for various quality related downgrades.

The policies are designed to provide cover for yield losses as a direct consequence of hail damage. The following table highlights how most policies will respond to both partial and total yield losses at different times of the season.

A specialist Agricultural Loss Adjuster will be appointed to quantify any losses. Yield losses will be determined by the Loss Adjuster by comparing the harvested yield to the potential yield of the crop, or in other words what the crop would have yielded except for the hail damage. The yield loss claim will then be indemnified based on the grower's specific coverage parameters.

Whilst today's policies are similar in the way they respond to losses, the grower has the ability to select their yields, bale prices, excess, additional options and cost structures. Changes in these parameters will impact on both the applicable premium rate charged by insurers and the policy response. When comparing products growers should seek specialist advice from their preferred crop insurance specialist.

Other risk tools

Weather derivatives

Over the last few years a number of international reinsurers have become more interested in products that are based on weather statistics rather than historical losses – these are called weather derivatives, and they are not an insurance product.

The reason for their growing popularity is that they can be priced based on weather data that is readily available over an extended time period. Weather derivatives are simple contracts that respond when specific weather triggers are recorded at a specified meteorological station. As a consequence weather derivatives create a basis risk as losses are determined at the meteorological station rather than on farm. Weather derivatives can be structured to financially protect a farm business from:

- Insufficient rainfall during the planting window or growing season.
- Excessive rainfall at harvest.
- Temperature extremes such as excessive heat at critical stages of crop growth.
- Lack of heat units during the vital growth stages of the crop.
- Excessive wind.

Index products

Index products are not an insurance product. They are based on an available independent index generally of yield or weather data. With Index products losses are determined by changes in the index which creates a basis risk as losses are determined according to the index rather than on-farm.

While Weather Derivatives and Index Products are relatively new to the Australian agribusiness sector, growers need to be aware of these risk management tools particularly in cases where the traditional insurance market has failed to provide a solution.

Please note that Weather Derivatives and Index Products are not insurance products and special licencing is required to provide advice in this area. If you are interested please seek professional advice from an appropriately licenced organisation.

Safe people management

Work health & safety (WHS)

By **John Temperley** (Australian Centre for Agricultural Health and Safety, University of Sydney)

Acknowledgement: Primary Industry Health & Safety Partnership (PIHSP)

While many accept that the most valuable asset for a business is its people, the question that should still be considered is "are we properly managing the safety of our farms and human resources?" At least, in terms of optimising the value that our employees contribute to the farm business and meeting relevant legal compliance.

This section is focused on just one critical aspect of human resource management for cotton growers; that is 'Work Health and Safety' (WHS). It aims to provide a quick overview of key legal requirements and advice on practical support available for growers to manage their WHS responsibilities by Cotton Australia and through *my*BMP.

Safety – a core business value

Managing safety must be accepted as an integral part of the way that we manage our cotton farm businesses. The cost of accidents is not only felt in terms of pain and suffering, but can also result in significant financial loss to growers personally and the farm enterprise. The cost of poor WHS performance may also include:

- Reduced productivity and profits.
- Increased Workers' Compensation insurance premiums.
- Equipment damage, downtime and replacement of injured workers, and
- High cost of injury compensation and civil law claims, prosecutions and the associated legal costs and time spent off farm attending to business with solicitors and/or in courts defending litigation.

WHS risk management

Contemporary WHS legislation in Australia has moved from being prescriptive to a requirement of performance for workplaces to demonstrate a risk management approach to WHS issues. The key steps to WHS risk management on cotton farms include:

Best practice…

- **Make sure you are aware of your WHS legal responsibilities and maintain an effective WHS program that is integrated into all aspects of the cotton business.**

- **Step 1:** Develop your farm's ***Work Health and Safety Plan***. Do this with your employees to give them ownership of the process. This document should cover the issues that you need to address for your farm business and includes links to a number of registers, checklists and guidance materials that can help you to put in place a good safety system. Cotton farm templates are available under the *my*BMP HR and WHS module: www.mybmp.com.au.
- **Step 2:** ***Do it – put the plan into action.*** Remember 'actions speak louder than words'. By planning for health and safety you will get better returns. People are the most valuable asset on the farm.
- **Step 3:** ***Continuously reviewing and learning*** from what you are doing to make sure your plan and actions are working and are appropriate for your operation and then make changes when needed.

Work health and safety law

The Work Health and Safety Act and Regulations in each State outlines the responsibilities of key parties involved in managing health and safety risks associated with workplaces and work activities.

Current WHS legislation refers to Persons Conducting a Business or Undertaking (PCBU) as those that have health and safety responsibilities. The term PCBU includes employers, self employed, growers and businesses operating as partnerships or sole traders including (farm owners), managers of cotton farms, cotton gins and all other work places.

The PCBU's legal responsibilities for WHS include:

- Ensuring a safe workplace for all workers.
- Involving (consulting with) workers to establish and maintain WHS plans.
- Organising safe systems of work, including the use of safety equipment.
- Maintaining work areas, machinery and equipment in a safe condition.
- Ensuring safe use, handling, and storage of plant and hazardous chemicals.
- Providing information, instruction, training and supervision to workers.
- Providing adequate facilities and amenities for the welfare of workers (first aid, eating, toileting, washing and storing personal belongings.
- Planning and being prepared for emergencies.
- Ensuring Workers Compensation Insurance for injured workers and assistance with injury management, rehabilitation and their early return to work.

The definition of 'Worker' includes all people working, contractors and contract workers as well as the PCBU's own employees. Others who can be deemed to be workers, include labour hire workers, students and in some cases volunteers.

Workers also have WHS legal responsibilities. Workers must:

- Comply with any reasonable health and safety instructions of the PCBU.
- Take reasonable care of the health and safety of themselves and others.
- Report hazards and dangers in the workplace.
- Cooperate with reasonable health and safety policy and procedures of the PCBU (the farm owner, manager or employer) in managing safety at work.

WHS Regulations provide information to a person who conducts a business or undertaking (known as a PCBU in current WHS legislation) on what is required to meet their safety obligations.

Grower's safety priority must be to eliminate hazards where it is reasonably practicable, that is, where there is a known and accepted safety solution to a hazard, these controls should be used. Most hazards on farms have known and accepted solutions.

Codes of Practice provide more information on how to comply with these obligations. Codes of Practice will be used by courts to determine

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minimum health and safety performance, and what is considered as reasonably practicable.

If growers are uncertain what to do, solutions can be found in many Safety Guides and resources developed by Safe Work Australia and State Work Health and Safety Authorities.

Some Codes of Practice will refer to Australian Standards and Safety Guides for more detail on how to manage health and safety risk where applicable.

What help is available to manage WHS on cotton farms?

Under the banner of CottonSafe, Cotton Australia is promoting an increased awareness of relevant WHS issues for the cotton growing industry. Delivering to growers and cotton farm workers up-to-date evidence based guidelines, tools and other resources to assist in managing WHS responsibilities and to mitigate injury, legal and financial risks known to be associated with poor WHS performance.

Access to the cotton WHS risk management resources is available through the Cotton Australia website and through the *my*BMP 'Human Resource' module.

Growers are encouraged to visit the Cotton Australia website and CottonSafe section and to utilise the information and resources available on that site.

Useful resources:

QLD WHS Law: www.worksafe.qld.gov.au

NSW WHS Law: www.safework.nsw.gov.au

CottonSafe program (Cotton Australia) www.cottonaustralia.com.au

***my*BMP Human Resources: www.mybmp.com.au**

The CRDC-supported Primary Industry Health & Safety Partnership (PIHSP). Its goal is to improve the health and safety of workers and their families in farming and fishing industries across Australia: www.rirdc.gov.au/PIHSP

Harvest can be a particularly high risk time – refer also to Harvesting and delivering uncontaminated cotton chapter

Safework NSW has a small business safety rebate program in place. For further information and eligibility see www.safework.nsw.gov.au

Best practice...

Ensure you have the required paperwork in place:

- **Farm Safety Plan.**
- **Safety Induction.**
- **Records of consultation with workers (employees and contractors).**
- **Safety Action – Risk assessment and control records.**
- **Emergency plan with contact numbers.**
- **Records of pesticide storage and use.**
- **Safety information and plans for high risk work ie Safe Operating Procedures (SOPS) for working with quad bikes and in confined spaces, electrical safety, working at heights, servicing pumps and guarding pump drive shafts and PTO powered machinery.**
- **Accident/ Injury Record Book.**
- **Training/ Competency Register.**
- **Farm Diary Records.**

Rebates for a WorkCover advisory visit are now available, along with templates: see www.safework.nsw.gov.au and www.worksafe.qld.gov.au

Employee relations

By **Bob Kellow** (Industrial Mediation Services)

Managing employee relations can, as has been identified in previous editions, be one of the most difficult but often overlooked areas of any business. Take for example the very basics of offering a prospective employee employment. Can you be confident that what you have offered and what the employee has accepted truly reflects the contractual relationship, and importantly whether it will stand the test of third party intervention?

The area of permanent full time employment and casual employment is one that has been the root of many problems in the past and continues to be so. With around 10,000 employees in the cotton growing sector and an estimated 33% of these employed as casuals, can you be confident that your casual employees are in fact casual? This question is significant because it will directly affect the ability of an employee to claim entitlements such as annual leave, sick leave, notice of termination and other benefits.

The nature of the industry is such that it is highly unusual for casual employees to be engaged in the traditional sense of casual employment, that is, working irregular hours and days and usually for less than 38 hours per week. There is currently no definition of a casual employee in the Fair Work Act and there have been significant differences adopted by the courts and tribunals when considering whether an employee working the equivalent of full time hours can be a casual employee.

The argument

In 2010 the Federal Court determined that an employee was permanent despite having signed a written contract describing him as a casual employee. The contract further quite explicitly stated that the employee would be paid a casual loading in lieu of all paid leave and other entitlements. It was ruled that the employee who had worked regular hours and did not work for short periods of time or for irregular hours was not, despite the terms of the signed contract, a casual employee.

However in a similar case heard in the Fair Work Commission (FWC) it was ruled that employees who were employed on a regular and systematic basis for a definite period were not entitled to redundancy pay because they were employed as casual employees. The employees were engaged and paid as casuals and the FWC determined that employees who worked on a regular and ongoing basis could still be employed as casual employees.

Best practice...

- **Consider the need for casual employees versus permanent employees, (even for short periods of employment).**
- **Regularly review and monitor the hours of work of casual employees.**
- **Consider offering permanent employment to longer term casual employees.**
- **Review and update contracts or letters of offer.**
- **Maintain awareness of award changes relating to casual conversion and other variations.**

The Award

The Pastoral Award 2010 is not particularly helpful in determining whether a casual employee can work on a regular and ongoing basis and still be considered a casual employee. There are however a number of indicators that might be helpful to employers.

Clause 10.4 of the Award in dealing with casual employment provides the following requirements:

- A casual employee is an employee engaged as such and paid by the hour. An employer when engaging a casual must inform the employee that they are employed as a casual, stating by whom the employee is employed, their hours of work, their classification level and their rate of pay.
- A casual employee other than a casual pieceworker must be paid per hour at the rate of 1/38th of the weekly rate prescribed for the class of work performed, plus 25%.
- Casual employees must be paid at the termination of each engagement, but may agree to be paid weekly or fortnightly.
- Subject to clause 10.4(g), on each occasion a casual employee, other than a casual pieceworker, is required to attend for work, the employee is entitled to a minimum payment of three hours' work at the appropriate rate.

As can be identified from the Award, there are different conditions that apply and are specific to the employment of casual employees, certainly the condition around the payment of casual employees is one which many employers do not consider in the course of engaging such employees.

Useful resources:

Employers can access the following government websites for copies of awards and/or a range of industrial relations matters:
Fair Work Commission, www.fwc.gov.au
or the Fair Work Ombudsman – www.fwo.gov.au.

Employers also have access to the *my*BMP management tool that provides general Human Resources information.

For further information please contact Bob Kellow, Industrial Mediation Services, 0427 667 344.

People in Ag website

In December 2016, a new resource – the People in Ag website – was launched, to offer compliance support for employers, promote agriculture as a career choice, and provide a platform for information sharing. It breaks down questions commonly asked by Australia's farmers around employment law and staff management, and provides access to information on employment opportunities, entitlements and career management in agriculture. In cotton, it is designed to complement the resources available in the HR and WHS modules of *my*BMP, with links to the new site from *my*BMP. It was developed by CRDC and other agricultural bodies, and is supported by Cotton Australia. Visit: www.peopleinag.com.au

Glossary & acronyms

Glossary

Adjuvant Any substance added to a spray mixture to enhance its performance or overcome an inhibiting factor. This includes, wetting agents, 'stickers', thickeners and buffering agents. Always check the label to ensure the adjuvant is compatible with the pesticide, formulation and application method being used.

Allelopathy is a biological phenomenon where one plant inhibits the growth of another.

Alluvium Refers to sediment that has been deposited by flowing water, such as a flood plain.

AM Arbuscular Mycorrhiza (formerly known as VAM). A partnership between soil borne fungi and most crop plants, including cotton (but not brassicas). AM fungi colonise the roots of the plant without causing disease. AM fungi act as an extension of the root system and transfer extra nutrients, especially phosphorus, from the soil to the plant. In return the plant provides the fungi with sugars as a food source.

Aphid colony 4 or more aphids within 2 cm on a leaf or terminal.

Area Wide Management (AWM) Growers working together in a region to manage pest populations. AWM is a cotton industry vehicle driving adoption of on-farm IPM.

At-planting insecticide Insecticides applied in the seed furrow with the seed during planting. The insecticide may be applied as a granule or as a spray into the seed furrow.

BDI Beneficial Disruption Index – Is a score for each insecticide for the entire cotton season, of the impact of each insecticide on beneficial insect populations. The BDI helps benchmark the 'softness' or 'hardness' of an individual fields' insecticide spray regime.

Beat sheet A sheet of yellow canvas 1.5 m x 2 m in size, placed in the furrow and extended up and over the adjacent row of cotton. A metre stick is used to beat the plants against the beat sheet. Insects are dislodged from the plants onto the canvas and are quickly counted.

Beneficial insects Predators and parasitoids of pests.

Biological insecticides Insecticides based on living entomopathogenic (infecting insects) organisms, usually bacteria, fungi or viruses, or containing entomopathogenic products from such organisms ie. Gemstar, Vivus and Dipel (BT).

Biomass Plant biomass is the total dry weight of the crop.

Boll Cotton fruit after the flower has opened and fertilisation has occurred (after the flower has turned pink). Bolls typically have four or five segments, known as locks, each containing about 6–10 seeds. The lint, or cotton fibre, is produced by elongated cells that grow from the surface of the seed coat, hence the 'seed cotton' in the boll is a mixture of seed and lint.

Bollgard II® cotton Genetically modified cotton variety containing the insecticidal proteins Cry1Ac and Cry2Ab which provides control of *Helicoverpa* spp., rough bollworm, cotton tipworm and cotton looper under field conditions.

Bollgard 3® cotton Genetically modified cotton variety containing the insecticidal proteins Cry1Ac and Cry2Ab and the vegetative insecticidal protein Vip3a which provides control of *Helicoverpa* spp., rough bollworm, cotton tipworm and cotton looper under field conditions.

Broad spectrum insecticide Insecticides that kill a wide range of insects, including both pest and beneficial species. Use of broad spectrum insecticides usually reduces numbers of beneficials (predators and parasites) leading to pest resurgence and outbreaks of secondary pests.

Bt The *Bacillus thuringiensis* protein which is toxic to *Helicoverpa* spp.

Buffer zone A self-imposed area that is not sprayed when the wind is blowing towards a sensitive area to minimise risk of damage or residues from spray drift to areas beyond the buffer.

Calendar sprays Insecticides sprayed on a calendar basis, eg. every Friday, regardless of pest density or the actual need for pest control.

Cavitoma Microbial damage to cotton fibre or the breakdown of the cellulose in fibre by micro-organisms.

Cold shock Is when the daily minimum temperatures fall below 11ºC, delaying cotton growth and development the following day regardless of the maximum temperature reached. Cold shocks have greatest impact on early plant development and increase the susceptibility of plants to diseases.

Consecutive checks Refers to successive insect checks taken from the same field or management unit.

Conventional cotton Strictly a cotton variety that does not contain transgenes (genes from other species), but used in this guide to indicate varieties that do not include genes to produce insecticidal proteins (ie. Bollgard II, Bollgard 3) but which may include herbicide resistance genes ie. Round-up Ready®).

Cotton bunchy top (CBT) A virus spread by the cotton aphid (*Aphis gossypii* Glover).

Cotyledons Paired first leaves that emerge from the soil when the seed germinates.

Crop compensation The capacity for a cotton plant to 'catch-up' after insect damage without affecting yield or maturity.

Crop Development Tool A web tool which allows crop managers to monitor both vegetative and reproductive growth of their crops compared to potential rates of development.

Crop maturity This usually occurs when 60–65 per cent of bolls are mature and open. Cotton bolls are mature when the fibre is well developed, the seeds are firm and the seed coats are turning brown in colour.

Cut-out (or last effective flower) Occurs when the plant's demand for assimilate (products of photosynthesis) finally exceeds supply so that further growth and production of new squares virtually ceases, normally when the plant reaches about 4–5 NAWF. At cut-out no more harvestable fruit is set and the earlier set bolls will start to open.

Damage threshold The level of damage from which the crop will not recover completely and which will cause some economic loss of yield or delay in maturity. Damage thresholds are usually applied in conjunction with pest thresholds to account for both pest numbers and plant growth. For instance a plant which has very high fruit retention (see below) may be able to tolerate a higher pest threshold (see below) than a crop with poor fruit retention.

Day Degrees (DD) A unit combining temperature and time, useful for monitoring and comparing crop development. To calculate your DD, visit the CottASSIST website.

Deep drainage Water from rainfall or irrigation that has drained below the root zone of the crop. A certain amount of deep drainage helps flush salts form the soil, but excess deep drainage means water and nutrients are being wasted.

Defoliation The removal of leaves from the cotton plant in preparation for harvest. This is done by artificially enhancing the natural process of senescence and abscission with the use of specific chemicals.

Denitrification A biological process encouraged by high soil temperatures. Denitrification occurs when there is waterlogging, such as during and after flood irrigation and/or heavy rainfall. The process converts plant available N (nitrate) back to nitrogen gases which are lost from the system.

Dessicant A chemical used as a harvest aid that damages the leaf membrane causing loss of moisture in the leaf, producing a desiccated leaf.

Determinate/Indeterminate Cotton is an indeterminate species which is capable of continuing to grow after a period of stress. Although short season varieties are considered determinate, which terminate reproductive development comparatively abruptly.

Diapause A period of physiologically controlled dormancy in insects. For *Helicoverpa armigera*, diapause occurs at the pupal stage in the soil.

Doffer Doffers unwind and remove the cotton from the spindle so that it can be transported to the basket in an airstream.

Double knock Is the sequential application of two weed control options with different modes of action in a short time-frame.

Double skip A row configuration used in raingrown/semi irrigated situations to conserve soil moisture.

D-vac A small portable suction sampler or blower/vacuum machine used to suck insects from the cotton plants into a fine mesh bag. D-vac samples are collected by passing the tube of the vacuum sampler across the plants in 20 m of row.

Earliness Minimising the number of days between sowing and crop maturity. Within a cotton variety earliness usually involves some sacrifice of yield.

Efficacy The effectiveness of a product against pests or beneficial insects (predators or parasites).

Egg parasitoids They are parasitoids that specifically attack insect eggs, eg. *Trichogramma pretiosum* attacks the egg stage of *Helicoverpa*. The wasp lays its eggs in the egg, and the wasp larvae which hatch, consume the contents of the host egg. Instead of a small *Helicoverpa* larva hatching, up to four wasps may emerge from each host egg. Thus the host is killed before causing damage.

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

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

Flat fan nozzle A spray nozzle with an outlet that produces spray droplet distribution that spreads out of the nozzle in one direction but which is thin in the other direction, much like the shape of a Japanese hand fan.

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

Flush A high volume irrigation carried out in minimal time.

Food sprays Natural food products sprayed onto cotton crops to attract and hold beneficial insects, particularly predators, in cotton crops so they can help control pests. Two types of food sprays are available for pest management. They are the yeast based food sprays which attract beneficial insects and the sugar based ones which retain predators which are already in the crop.

F Rank A rank that each cotton variety is given in accordance with its resistance to the cotton disease Fusarium Wilt.

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

Fruit load Refers to the number of fruit (squares or bolls) on a cotton plant.

Fruit retention Refers to the percentage of fruit (squares or bolls) that the cotton plant or crop has maintained compared with the number it produced.

Fruiting branch Grows laterally from the main stem in a series of segments. Each segment finishes at a node at which there is a square and a leaf. At the base of the square the next segment originates, and so on.

Fruiting factor Is a measure of the number of fruit per fruiting branch. A method to check if the total fruit number produced by the crop is on track. Fruiting factors which are too high or too low can indicate problems with agronomy or pest management which may need to be acted on. To calculate the fruiting factor divide the fruit count made in 1 metre of cotton row by the number of fruiting branches in that area.

Gross Production Water Use Index (GPWUI) Is the gross amount of lint produced per unit volume of total water input (b/ML). The total water input includes irrigation, rainfall and total soil moisture used where the rainfall component can comprise either total rainfall or effective rainfall.

Habitat diversity A mixture of crops, trees and natural vegetation on the farm rather than just limited or single crop type (monoculture).

***Helicoverpa* spp.** refers to species of moth from the genus *Helicoverpa*. In Australian cotton there are two species, *Helicoverpa armigera* (cotton bollworm) and *Helicoverpa punctigera* (Native budworm). Larvae of these two moth species are the major pests of cotton, capable of dramatically reducing yield.

Hill Refers to the risen bed where the crop is planted in a furrow irrigated field.

Honeydew A sticky sugar rich waste excreted by feeding aphids or whiteflies. It can interfere with photosynthesis, affect fibre quality and cause problems with fibre processing.

HVI High Volume Instrument that is able to quickly and accurately determine the fibre properties of a large volume of cotton.

Irrigation deficit Readily available water capacity.

In-furrow insecticide Insecticides applied in the seed furrow with the seed during planting. The insecticide may be applied as a granule or as a spray into the seed furrow.

Insecticide resistance Where a pest develops resistance to an insecticide, the insecticide will no longer kill those individuals that are resistant. This usually results in poor control and may lead to failure of control with the insecticide in the worst cases. The resistant insects develop a mechanism for dealing with the insecticide, such as production of enzymes which break the insecticide down quickly before it kills the pest.

Insecticide Resistance Management Strategy (IRMS) An industry regulated strategy that sets limits on which insecticides can be used, when they can be used and how many times they can be used. This helps prevent the development of insecticide resistance.

IPM Integrated Pest Management (IPM) is a concept developed in response to problems with managing pests, insecticide resistance and environmental contamination. The basic concept of IPM is to use knowledge of pest biology, behaviour and ecology to implement a range of tactics throughout the year, in an integrated way that suppresses and reduces their populations. Conserving beneficial pests (natural predators and parasites) is at the heart of IPM.

Irrigation Water Use Index (IWUI) Is the gross amount of lint produced per unit volume of production water input (b/ML). The production water input includes irrigation water used only and does NOT include rainfall and total 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 A residual herbicide used to control weeds during the growth of the cotton crop.

Larval parasitoids A wasp that lays their egg on or in a larva and uses the lifecycle of the larva in order to reproduce. Parasitoids usually cause the death of their host whereas parasites do not.

Leaching fraction Refers to the portion of irrigation water that infiltrates past the root zone

Lint Cotton fibres. These are elongated cells growing from the surface of the cotton seed coat. See also 'Bolls'.

Listing rig A cultivator used to form cotton beds.

Lodging Towards the end of the season cotton plants with large and heavy boll loads will often fall into each other which is known as lodging.

Main stem leaves Are leaves that are connected directly with the main stem.

Main stem node A point on the main stem from which a new leaf grows. At these points there may also be fruiting or vegetative branches produced.

Management unit An area on the farm that is managed in the same way ie. same variety, sowing date, insect management.

Mepiquat chloride Cotton growth regulator.

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

Mycorrhiza See AM.

NACB The number of main stem Nodes Above the first position Cracked Boll. This is an indication of the maturity of the plant and can be used in making decisions about the final irrigation or defoliation.

Natural enemies Predators and parasitoids of pests.

Natural mortality The expected death rate of insects in the field mainly due to climatic and other environmental factors including natural enemies.

NAWF The number of main stem Nodes Above the first position White Flower that is closest to the plant terminal.

Neps Entanglement of fibres.

Neutron probe An instrument used to measure soil moisture.

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.

Normalised Difference Vegetation Index Is an indicator used to analyse remote sensing measurements to assess whether the observed target contains live green vegetation.

No Spray Zone A legally required unsprayed distance between the sprayed area and a sensitive area that must be adhered to when the wind is blowing towards that sensitive area.

Nursery A crop or vegetational habitat which attracts and sustains an insect (pest or beneficial) through multiple generations.

NutriLOGIC Nutrition management web tool in CottASSIST (www.cottassist.cottoncrc.org.au).

NUTRIpak An information resource for cotton nutrition, including critical levels for soil tests, and interactions between different nutrients.

Nymph The immature stage of insects which looks like the adult but without wings, eg. nymphs of mirids. Nymphs gradually acquire adult form through a series of moults and do not pass through a pupal stage. In contrast, ‘larvae’ are immature stages of insects, such as the *Helicoverpa* caterpillars, that look quite different to the adults, which in this case is a moth.

Okra leaf type Cotton varieties with deeply lobed leaves that look very similar to the leaves on the Okra (*Abelmoschus esculentus*) plant, which is related to cotton and hibiscus.

Oxygation The use of aerated water for drip irrigation.

OZCOT model A cotton crop simulation model that will predict cotton growth, yield and maturity given basic weather, agronomic and varietal data.

P&D sheet Premium and Discount (P&D) sheets are designed to allow a single price representing a base grade to be quoted for growers with variable qualities being deliverable. The P&D sheet represents the market value of various qualities, where premiums are paid for higher than base grade qualities delivered and discounts are deducted for lower than base grade qualities delivered.

Pathogen Refers to the microorganism, usually virus, bacterium or fungus, that causes disease. For example Fusarium Wilt is a disease of cotton caused by the soil inhabiting fungus *Fusarium oxysporum f.sp. vasinfectum* (Fov).

Partial root zone drying The creation of simultaneous wet and dry areas within the root zone. Only part of the root zone is irrigated and kept moist at any one time.

Pest flaring An increase in a pest population following a pesticide application intended to control another species. This usually occurs with species that have very fast life cycles such as spider mites, aphids or whitefly. It occurs following the use of broader spectrum insecticides which control the target pest but also reduce the numbers of predators and parasites. This allows these ‘secondary’ or non-target pests to increase unchecked, often reaching damaging levels and requiring control.

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

Pest damage Damage to the cotton plant caused by pests. This can be either damage to the growing terminals (known as tipping out), the leaves, or the fruit (including squares or bolls).

Pest resurgence An increase in a pest population following a pesticide application intended to reduce it. This usually occurs because the insecticide has reduced the numbers of beneficials, which normally help control the pest, thereby allowing subsequent generations of the pest to increase without this source of control.

Pest threshold The level of pest population at which a pesticide or other control measure is needed to prevent eventual economic loss to the crop. See also ‘Damage threshold’.

Petiole The stalk that attaches the leaf to the stem.

Pima cotton Is of the *Gossypium barbadense* species. It has an extra long staple and its growth is limited to regions with long growing seasons. Normal cotton is of the species *Gossypium hirsutum*.

Pix See mepiquat chloride.

Plant Available Water Capacity (PAWC) The amount of water in the soil that can be extracted by plants, usually full point (when the soil can hold no more water) minus wilting point (point at which the plant can no longer extract sufficient water from the soil and begins to wilt).

Plant cell density A term used in precision agriculture which is a ratio of infra-red to red reflectance produced from digital imagery.

Plant growth regulator Chemicals which can be applied to the plant to reduce growth rate (see also Rank crop and Pix).

Plant mapping A method used to record the fruiting dynamics of a cotton plant. This can be useful for understanding where the plant has held or is holding the most fruit in order to interpret the effects of factors that may affect fruit load such as pest damage, water stress, heat.

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

Planting window Is a period of time in which you need to plant your cotton. Bt cotton has a planting window which is a strategy used to restrict the number of generations of *Helicoverpa* spp. exposed to Bt in a region.

Plastic limit The water content where soil starts to exhibit plastic behaviour.

Post-emergent knockdown herbicide A herbicide used to rapidly control weeds after they emerge.

Predator to pest ratio A ratio used to incorporate the activity of the predatory insects into the pest management decisions. It is calculated as total number of predators per metre divided by the total number of *Helicoverpa* spp. eggs plus very small and small larvae per metre.

Pre-irrigate Is a pre-irrigation plant establishment method that has advantages when there are weed problems, if the soil is very dry or if planting temperatures are marginal.

Premature cut-out Is when the production of bolls exceeds the supply of carbohydrates too early in the crop’s development and therefore the production of new fruiting nodes stops. This results in a less than ideal boll load.

Pre-plant knockdown herbicide A herbicide used to rapidly control weeds prior to planting.

Presence/absence The binomial insect sampling technique that records the presence or absence of a pest rather than absolute numbers on plant terminals or leaves, depending on the pest species being sampled.

Prophylactic Refers to regular insecticide sprays applied in anticipation of a potential pest problem. Spraying on a prophylactic basis runs the risk of spraying to prevent pest damage that would not have occurred anyway, thereby increasing costs, selection for insecticide resistance and the risk of causing secondary pest outbreaks due to reductions in predator and parasite numbers.

PSO Petroleum Spray Oil – Petroleum derived oil commonly used to control insect pests such as *Helicoverpa* spp., mirids, mealy bugs, aphids, thrips, scales and mites. PSOs can also be used to deter egg lay of some pests such as *Helicoverpa* spp.

Pupae Once larvae of *Helicoverpa* have progressed through the larval (caterpillar) stages they will move to the soil and burrow below the surface. Here they will change into a pupae (similar to a butterfly chrysalis). In this stage they undergo the change from a caterpillar to a moth.

Pupae busting Effective tillage to reduce the survival of the overwintering pupal stage of *Helicoverpa*. Pupae busting is an important tool in reducing the proportion of the *Helicoverpa* population carrying insecticide resistance from one season to the next.

Rank crop A rank crop is usually very tall (long internode lengths) with excessive vegetative plant structures. This can be caused by a number of factors including excessive fertiliser use, pest damage and crop responses to ideal growing conditions especially hot weather. Rank crops can be difficult to spray and to harvest and may have delayed maturity or reduced yield (refer to VGR).

Ratoon cotton Also known as 'stub' cotton, ratoon is cotton that has regrown from left over root stock from a previous season. The control of unwanted cotton in the farming system is an essential part of good integrated pest and disease management.

Refuge The aim of a refuge crop is to generate significant numbers of susceptible moths that have not been exposed to the Bt proteins in Bt cotton. Moths produced in the refuge will disperse to form part of the local mating population where they may mate with any resistant moths emerging from Bt crops, delaying the development of resistance.

Resistance management plan (RMP) A proactive plan for Bt cotton established to mitigate the risks of resistance developing to any of the proteins contained in Bt cotton. Resistance management for Bt cotton is critical due to the season long selection of Helicoverpa spp. to the Bt toxins produced by Bt cotton. Compliance with the RMP is required under the terms of the Bt cotton Technology User Agreement and under the conditions of registration.

Retention Is the proportion of fruiting sites on a plant that are present versus those that have been lost.

Rotation crops Other crop types grown before or after the cotton is grown.

Scouting Checking crops (eg. for insects, damage, weeds, growth etc).

Secondary pests Pests such as spider mites, aphids or whiteflies which do not usually become a problem unless their natural enemies (predators or parasites) are reduced in number by insecticides. See also 'Pest Flaring'.

Seed bed A type of mound on which furrow irrigated cotton is grown.

Seed treatment An insecticide/fungicide used to coat cotton seeds to offer a period of protection during germination and establishment against some ground dwelling pests eg. wireworm and some early foliage feeders such as thrips or aphids.

Selection pressure The number of times insecticides from a particular chemical group are sprayed onto a cotton crop. Each of these spray events will control susceptible individuals, leaving behind those that are resistant. More selection events means that there is greater 'pressure' or chance of selecting a resistant population.

Shedding Describes the abortion and loss of squares and bolls from the cotton plant. Shedding can be due to the plant balancing the supply and demand for the products of photosynthesis, and can be strongly influenced by factors that negatively affect photosynthesis (such as cloudy weather), or in response to pest damage to the fruit. Young fruiting forms (squares) are more likely to be shed than the more developed squares, flowers and bolls.

Short fibre Fibres shorter than 12.7 mm or 0.5 inch

Side-dressing Normally refers to adding an in-crop fertiliser.

Single skip A row configuration used in raingrown/semi irrigated situations to conserve soil moisture.

Sodicity A measure of exchangeable sodium in relation to other exchangeable cations. A sodic soil contains sufficient exchangeable sodium to interfere with the growth of plants.

'**Soft' approach** Managing insect and mite pests using pesticides and other approaches that have limited effect on beneficial insect populations.

Soil water deficit The difference between a full soil moisture profile and the current soil moisture level.

Solid plant A row configuration generally used in irrigated cropping and is normally 1 m row spacing.

Spray adjuvant A substance added to the spray tank that will improve the performance of the chemical.

Spring tickle Uses shallow cultivation to promote early germination of weeds prior to sowing. These weeds can then be controlled with a non-selective knockdown herbicide.

Square Cotton flower bud.

Squaring nodes A node at which a fruiting branch is produced, which is defined as a branch with a square which has a subtending leaf that is fully unfurled and on which all central veins are visible.

Standing stubble Stalks from a crop that has been harvested or sprayed out and left to stand in the field.

Stickers Stickers increase adhesion of a spray mixture on the target and reduce bounce. Check product label for compatibility and specific requirements.

Subbing up An irrigation term referring to the wetting process of the cotton beds.

Subtending leaves Are leaves that are connected directly to a fruiting branch.

Sucking pests Usually from the group of insects known as hemiptera or bugs which have piercing tubular mouthparts which they insert into plant parts to obtain nutrition. Key among these are green mirids, which feed on cotton terminals, and young squares and bolls. Some bugs inject toxins into the plant when they feed, which if bolls are fed on, may cause seed damage and staining of lint.

Sweep net A large cloth net (approximately 60 cm deep) attached to a round aluminium frame which is about 40 cm in diameter with a handle (1 m in length) used to sample insects.

Synthetic insecticides Non-biological insecticides. They may be man-made versions of natural insecticides (ie. pyrethroids are synthetic, light stable versions of naturally occurring pyrethrum) or they may simply be man-made molecules with insecticidal or miticidal (controls mites) activity. In this manual we have used the term to encompass most insecticides with the exception of Bt sprays, virus sprays, food sprays and petroleum spray oils (PSOs).

Terminal The growing tip of a cotton stem, particularly the main stem.

Thickeners Thickening agents increase the viscosity of a spray mixture. Check product label for compatibility and specific requirements.

Tip damage When the plant terminal has been damaged, also known as tipping out.

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

Top 5 retention The percentage of first position fruit maintained on the top 5 fruiting branches.

Trap crop The aim of a trap crop is to concentrate a pest population into a smaller less valuable area by providing the pest with a host crop that is more highly preferred and attractive than the crop you are aiming to protect.

Trap crop – Spring A crop grown to concentrate *Helicoverpa armigera* moths emerging from diapause, usually between September and October. These moths will establish the first generation of larvae in these crops, where they can be killed using biological insecticides (ie. virus sprays) or by cultivation to kill the resulting pupae.

Trap crop – last generation/Summer A crop grown to concentrate Helicoverpa moths emerging late in the cotton season from the non-diapausing component of pupae from the last generation in autumn. These pupae are likely to be more abundant under conventional cotton and will have had intense insecticide resistance selection. The aim is to have these moths lay their eggs in the trap crop where the resulting pupae can be controlled by cultivation.

True leaves Any leaf produced after the cotyledons.

Upland cotton *Gossypium hirsutum* main species grown in Australia.

Vegetative barrier Deliberately planted narrow strips of trees and shrubs designed to protect adjacent sensitive areas (remnant vegetation, waterways, other crops) from spray drift by capturing and filtering airborne spray droplets.

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

Vegetative growth The roots, stems and leaves as distinct from the reproductive growth of flowers and bolls.

Vegetative Growth Rate or VGR Is a measurement of plant height and the number of nodes used to help with decisions regarding early season growth regulators.

Vertisols Clay-rich soils that shrink and swell with changes in moisture content.

Visual sampling Sampling insects in the field with the naked eye without the use of other equipment. See also 'Beat sheets', 'Sweep net' and 'D-vac'.

Volunteer cotton Plants that have germinated, emerged and established unintentionally and can be in field or external to the field (roadsides, fencelines etc). The control of unwanted cotton in the farming system is an essential part of good integrated pest and disease management.

V Rank A rank that each cotton variety is given in accordance with its resistance to the cotton disease Verticillium wilt.

Watering up Planting the seed into dry soil and watering up is a pre-irrigation establishment method that has advantages in hot climates, because it cools the soil and crop establishment is rapid.

Water stress When the demand for water to maintain plant function exceeds the amount available to the plant from the soil.

Water-logging When the plant roots endure a prolonged period under water, the lack of oxygen impairs water and nutrient uptake, both of which will have a direct effect on growth and yield.

WATERpak An information resource for cotton water use and management.

Wetters Wetting agents that increase pesticide coverage by reducing surface tension on the leaf surface so that the droplet spreads over a larger area. Check product label for compatibility and specific requirements.

Acronyms used in the cotton industry

AAAA – Aerial Agricultural Association of Australia.
ACGA – Australian Cotton Ginners Association.
ACRI – Australian Cotton Research Institute, Narrabri.
ACSA – Australian Cotton Shippers Association.
APSRU – Agricultural Production Systems Research Unit.
APVMA – Agricultural Pesticides and Veterinary Medicines Authority.
AWM – Area Wide Management.
CA – Cotton Australia.
CCA – Crop Consultants Australia Inc.
CCAA – Cotton Classers Association of Australia.
CGA – Cotton Growers Association.
CRDC – Cotton Research & Development Corporation.
CSD – Cotton Seed Distributors.
CSIRO – Commonwealth Scientific & Industrial Research Organisation.
CTF – Controlled Traffic Farming.
DAF – Department Agriculture & Fisheries.
DAP – Di-ammonium phosphate.
EC – Electrical Conductivity.
EHP – Environment and Heritage Protection (QLD).
ENSO – El-Niño Southern Oscillation.
EM Survey – Electromagnetic Survey.
EPA – Environmental Protection Authority (NSW).
ESP – Exchangeable Sodium Percentage.
GNSS – Global Navigation Satellite System.
GPS – Global Positioning System.
GVB – Green Vegetable Bug.
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.
MAP – Mono-ammonium phosphate.
MIS – Multispectral Imaging System.
NSW DPI – New South Wales Department of Primary Industries.
OGTR – Office of the Gene Technology Regulator.
PAMP – Pesticide Application Management Plan.
QLD DAF – Queensland Department of Agriculture & Fishery.
RCMAC – Raw Cotton Marketing & Advisory Committee.
RFID – Radio Frequency Identification.
SAM – Southern Annular Mode.
SLW – Silver Leaf Whitefly.
SPAA – Society of Precision Ag Australia.
TIMS – Transgenic & Insect Management Strategy (Committee).
TSP – Technical Service Provider.
TSV – Tobacco Streak Virus.
TUA – Technology User Agreement.
UAV – Unmanned Aerial Vehicle (eg. drones).
ULV – Ultra Low Volume.
VGR – Vegetative Growth Rate.
WUE – Water Use Efficiency.

Meet our team

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*my*BMP team

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