Australian Cotton Production Manual

2016

Brought to you by

The Australian cotton industry's CottonInfo Team

CottonInfo

Best Practice

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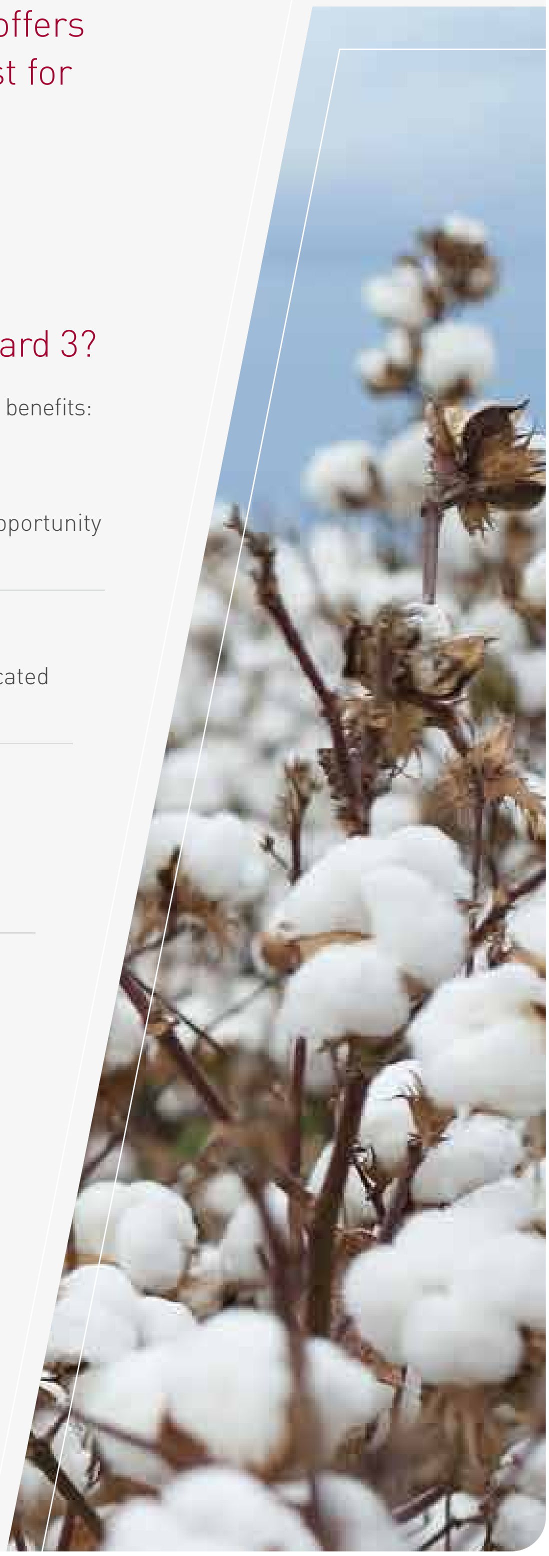
All growers must complete their Bollgard 3 accreditation before taking delivery of seed, even if they have previously completed the Bollgard II accreditation. To organise a time contact your Technology Service Provider or Monsanto Regional Business Manager.



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Cover photos courtesy Melanie Jenson.
Photo this page courtesy Ruth Redfern.

Meet our team

Led by CottonInfo Program Manager Warwick Waters (0437 937 074, warwick.waters@crdc.com.au), the CottonInfo team of Regional Development Officers, Technical Specialists & *my*BMP experts are all here to help!

Regional Development Officers

Regional Development Officers provide cotton research outcomes and information directly to growers, agronomists, consultants and agribusinesses in each region. Contact your local Regional Development Officer for the latest research, trials and events in your area.

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Technical Specialists

Technical specialists are experts in their fields and provide in-depth analysis, information and research to the industry, for the benefit of all growers. Contact the technical specialists to learn more about water use efficiency, nutrition, soil health and much, much more.

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*my*BMP team

The *my*BMP team run the industry's best management practice program, *my*BMP. Contact the *my*BMP team to learn more about - or to participate in - *my*BMP.

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Foreword

By **Susan Maas** (CRDC), **Ruth Redfern** (CRDC & CottonInfo) **& Annabel Twine** (CottonInfo)

The *2016 Cotton Production Manual* is a key reference tool for best management practices in cotton. The manual is one of a series of publications proudly brought to you by the Australian cotton industry's extension team, CottonInfo, with the support of industry and researchers to help you make on-the-ground management decisions for your crop and your farm.

The manual has been divided into 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 and 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.
- **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 based on the latest in cotton industry research, and is designed to help Australian cotton growers increase their input efficiencies and improve their yield; help the industry proactively manage issues that affect all of us; and ensure our cotton remains at a very high quality.

On behalf of the CottonInfo team, we hope you find this year's Cotton Production Manual a valuable and informative reference. Remember, the CottonInfo team of regional development officers, technical specialists and *my*BMP experts are standing by to assist you with all your cotton information needs. You can find our contact details on page two of this manual.

You can also find further information on the topics covered in the Cotton Production Manual at the CottonInfo website www.cottoninfo.net.au, and specific best practice information for your farm at the *my*BMP website www.mybmp.com.au.

Finally, on behalf of the CottonInfo team, thank you to the industry representatives and researchers who contributed to this edition.

ISSN 2206-0081 (Print)
Published by Cotton Research and Development Corporation
Production by Greenmount Press, July 2016 (Ph: 07 4659 3555)

The Australian cotton industry

By **Ruth Redfern** (CRDC)

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 modest beginnings, the industry has expanded, with today's growing region stretching from Hay and Griffith in southern NSW to Emerald in central Queensland, with occasional plantings in the Ord, WA, and the Burdekin, QLD.

Australia's 1500 cotton growing families are considered world leaders, growing the highest yielding, finest quality cottons in the world.

Cotton makes a vitally important contribution to Australia's society, economy and environment: providing employment for some 8000 people across 152 communities, contributing $2.3 billion in farm gate value to the economy, and growing more cotton using fewer natural resources, like land and water, than ever before.

Australian cotton growers produce yields almost three times the world average, and compared to 10–15 years ago, use 30 per cent less land and 40 per cent less water to produce one tonne of cotton lint. Thanks to the significant contribution of cotton research and development, Australian cotton growers have reduced their insecticide use by 95 per cent over the past 15 years, and increased their water productivity by 40 per cent over the past 10 years.

Two cotton species are grown in Australia, *Gossypium hirsutum* and *Gossypium barbadense*. *Gossypium hirsutum* (called 'Upland') represents more than 90 per cent of Australia's, and the world's, cotton production due to its productive nature and fibre properties suitable for modern textile production. *G. barbadense* (known as Pima, Egyptian, Peruvian, Sea Island and others) have very good fibre properties, demanding a significant price premium from spinners for manufacture of fine garments. However it has lower yield and narrower climate requirements – requiring specific management – and thus in Australia, Pima production has been limited to western NSW locations such as Bourke, Hillston and Tandou.

Australia is the third largest exporter of cotton in the world, and over 99 per cent of our raw cotton is exported. The majority of Australian cotton goes into high quality yarns for use in the woven and knitted apparel section 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.

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 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 research and development (R&D), 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 development officers, technical specialists 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.net.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 lobbies extensively on a wide range of political issues confronting growers, defends the industry from the impact of new legislation 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 lobbying 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) invests in research, development and extension projects for the Australian cotton industry. A partnership between the Commonwealth Government and the Australian cotton industry, CRDC exists to support the performance of the cotton industry: helping to increase both the productivity and profitability of growers.

CRDC is funded through a research and development (R&D) levy, which all growers pay (the levy equates to $2.25 for each 227 kilogram bale of cotton), with the Government matching the funds dollar-for-dollar. Over the past 25 years, more than $280 million has been invested in over 2100 cotton R&D projects by growers and the Government – and it is estimated that the return on investment for growers is $7 in benefits for every $1 invested.

This year, growers and the Government will co-invest more than $20 million into cotton R&D. Two of the greatest success stories for the cotton industry – water use efficiency and pesticide use reduction – are the result of R&D, but the successes do not stop there. Research is currently being conducted across the full scope of cotton production: pathology, biosecurity, insects and weeds, spray application, insecticides, Bt stewardship, energy use, nutrition and water use efficiency. There is work constantly underway to make cotton more productive, and profitable, for Australian cotton growers.

Importantly, connecting growers with this research is also a key focus for the CRDC, who are joint partners with Cotton Australia and CSD in the industry extension program, CottonInfo.

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 supplied quality cotton planting seed to the cotton industry for nearly 50 years. CSD was formed through the vision of Australia's foundation cotton growers and remains committed to the success of today's growers.

CSD is a major investor in cotton breeding and research and development, having developed a long and successful partnership with the CSIRO Cotton Breeding Program. CSD's objective is to deliver to the cotton industry elite varieties that are specifically bred and adapted to suit local growing conditions by delivering yield and quality outcomes to keep growers 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. CSD provides industry wide extension services focused on cotton production and agronomy.

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 CottonInfo in the Australian Cotton Production Manual – as well as many other programs – are:

- Cotton Australia
- Cotton Research and Development Corporation
- 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
- 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 1.6m and its tap root can reach depths of 1.8m. 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.

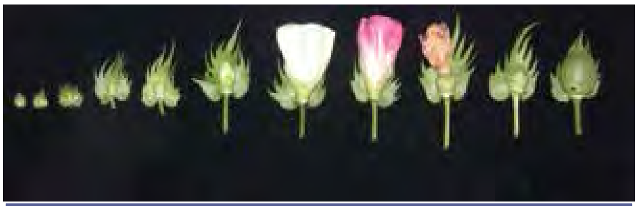
DD is described by the following equation:

$$\mathbf{DD = (Maximum\ Temp. -12 + Minimum\ Temp. -12) \div 2}$$

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

$$\mathbf{DD = (Maximum\ Temp. -12) \div 2}$$

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.



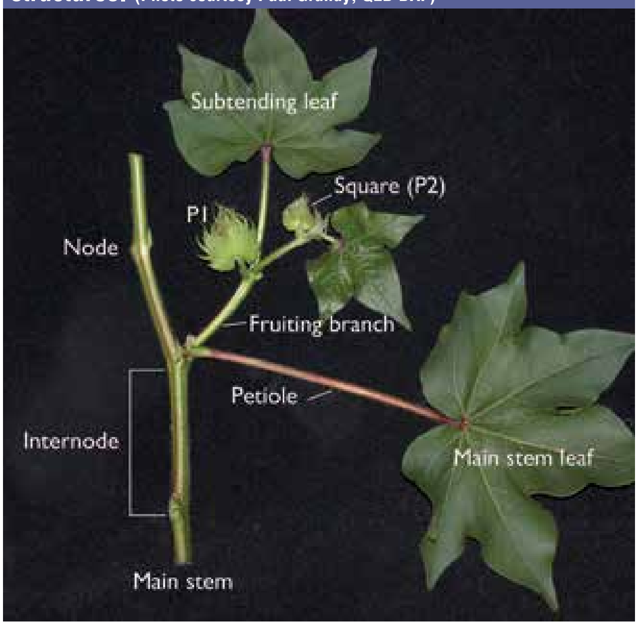
The cotton plant develops from a tiny flower bud or 'square' which continues to grow until it flowers. The flower desiccates after about 3 to 4 days, exposing a small green boll. This boll will continue to grow until it matures. **(Photo courtesy Paul Grundy, QLD DAF)**

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.

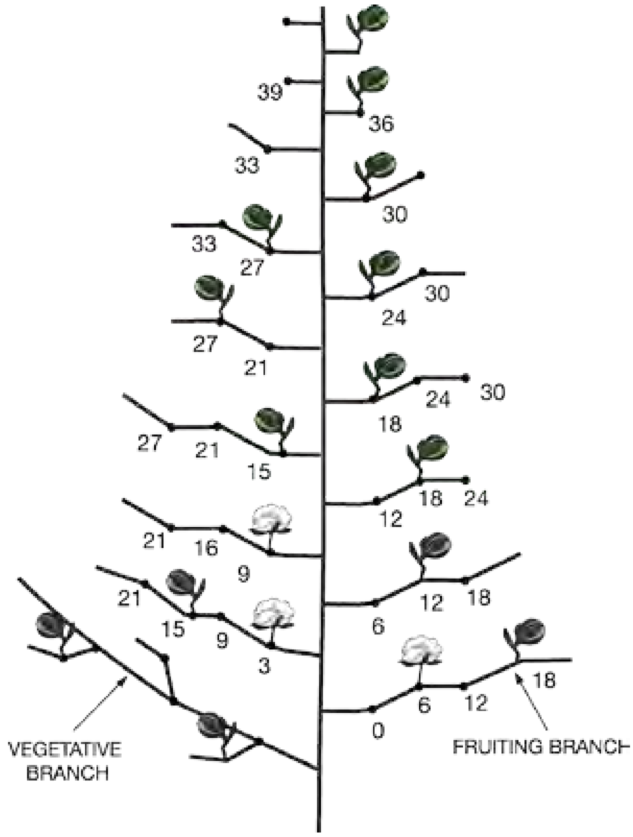
During crop growth certain growth parameters (eg. node production and fruit retention) should be measured and recorded to help with management decisions for maximum yield. The Cottassist Crop Development Tool can help with these measurements.

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.



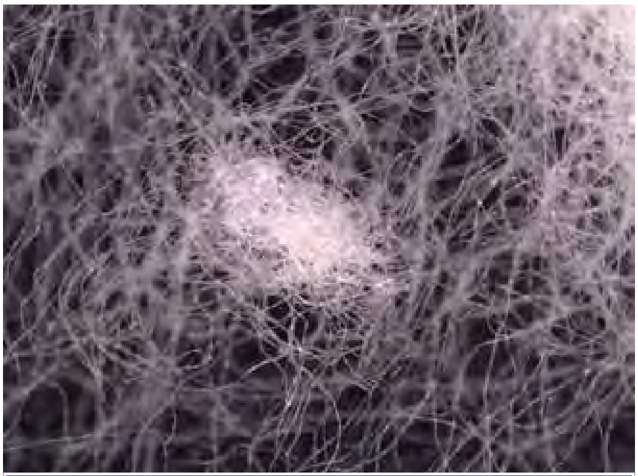
In some situations where there is plenty of water and nutrients, excessive vegetative growth can occur. Growth regulators such as Mepiquat Chloride can help manage this growth. Measuring Vegetative Growth Rate (VGR) is an effective technique used to assist with these decisions. See Managing crop growth 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.

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



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)

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.net.au and www.mybmp.com.au

- **FIBREpak**
- **CottASSIST Crop Development Tool**

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 lobbying. 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 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. 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). For more on minimising spray drift and maximising efficient spray application, refer to Chapter 18.
- **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 hail 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 (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 below:

Useful resources:

Local Cotton Grower Associations
www.cottonaustralia.com.au/contacts/cotton-growers-association

Cotton Australia
www.cottonaustralia.com.au/cotton-growers/resources/new-growers

CottonInfo team (page 2) or www.cottoninfo.net.au

***my*BMP information www.mybmp.com.au**

Agronomic adviser/consultant www.cropconsultants.com.au

Cotton Seed Distributors www.csd.net.au

Planning

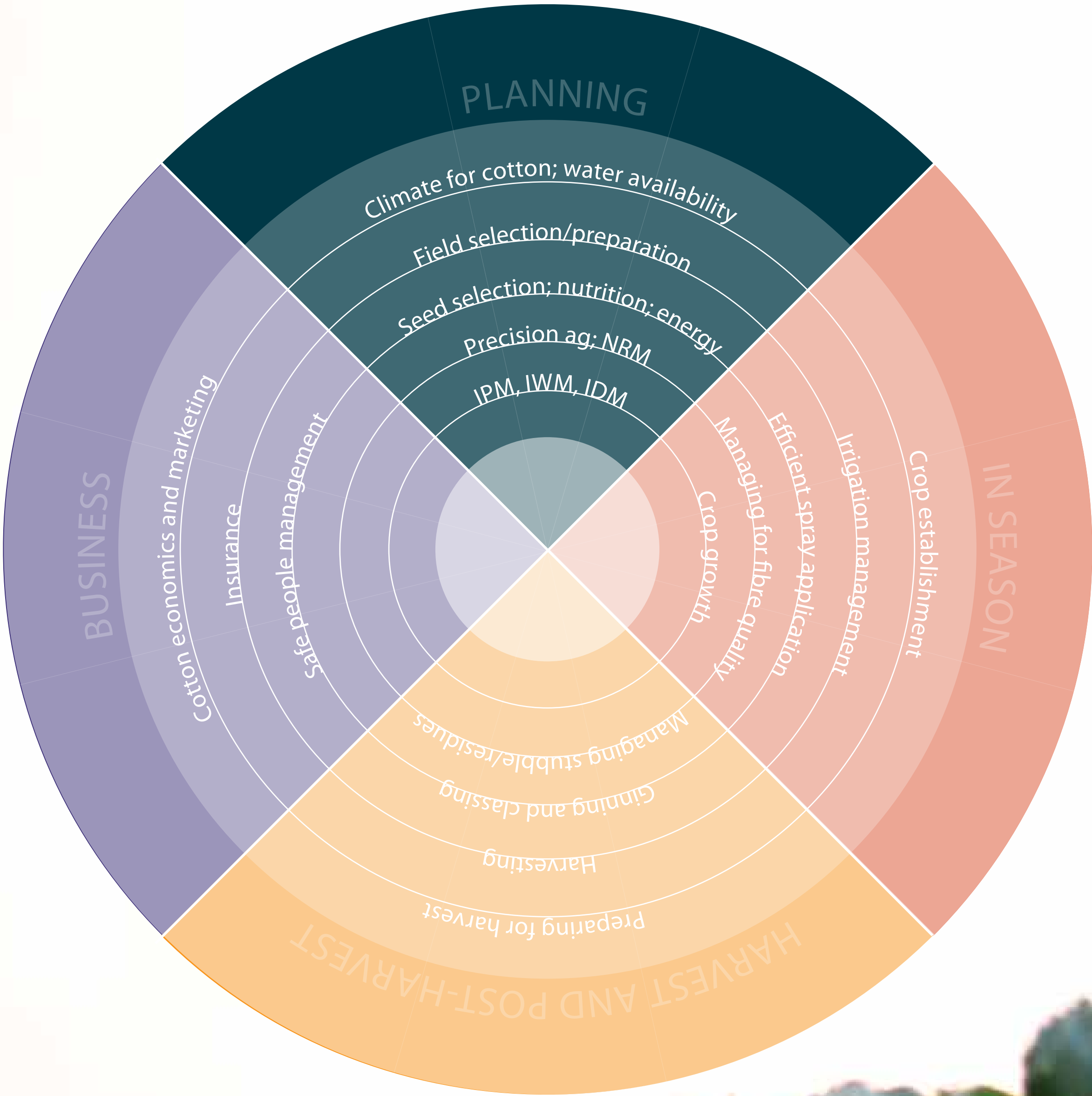


Photo courtesy Alan Redfern

Climate for cotton growing

By **Jon Welsh** (CottonInfo team)

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, particular with regards to 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

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.

Southern Annular Mode

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.

Using General Circulation Models (GCM's) for planning

With the vast majority of information presented to users in the form of dynamic computer generated colour charts or General Circulation Models (GCM's), it is useful to identify accuracy and inputs of these models. Three categories of GCM 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.

Best practice…

- **Best practice climate risk management is to survey the Australian BOM, plus the IRI (US) and ECMWF (UK) seasonal (3 monthly) models. Alignment of these results can aid in confidence levels when making critical on-farm investment decisions.**
- **When we are in neutral ENSO conditions consider using temperature predictions as a guide. Rainfall variability will increase during ENSO neutral years. Droughts are a combination of reduced rainfall and high temperatures, and temperature predictions are normally more accurate than rainfall predictions.**
- **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
Always survey temperature outlooks together with rainfall	Temperature predictions are based on air pressure and have greater accuracy. These also help us to determine evaporation losses
Always survey more than just the BOM seasonal outlook	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
Benchmark GCM outputs with raw indicators	As users of GCM's we have no transparency on the inputs to these models. For added confidence we should always check that indicator values are aligned with model output results
















- Seasonal outlooks display rainfall and temperature guidance for the following 3 months. These models are refreshed by research agencies usually once a month. Statistical and ensemble predictions also compliment GCM outputs.

Moisture Manager surveys all model outputs at critical periods throughout the year.

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.

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

Seasonal outlooks (3 monthly) from the Bureau of Meteorology should be benchmarked against outputs from at least 2 other credible international research agencies. Consensus between forecasts will lead to greater confidence levels (a suite of international models are surveyed in the cotton industry fortnightly climate summary: Moisture Manager). Climate models simulating Australian seasonal conditions will be heavily weighted with the state of ENSO; La Niña/Neutral/El Niño. When the ENSO is showing a strong signal towards El Niño or La Niña, the winter and spring seasons forecasting models will normally be attached with higher "skill" or confidence levels in predictions. Some tips for using seasonal GCMs for planning ahead for your next crop are shown in Table 1.

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;

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.

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

	Cotton Production Cycle											
	Boll fill		Harvest		Fallow				Planting		F/F	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.

First flower/bollfill/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 is 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 Plant Industry, 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.

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; and,
- Better economic returns due to production costs being reduced more than the yield relative to solid planted cotton.

Best practice…

- **Soils with a greater plant available soil water holding capacity reduce risks associated with 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.**

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 Plant Industry. Some assumptions used in this study were:

- Cracking clay soils storing 200mm or 250mm of available soil moisture in 1.5m profile. A full profile at sowing.
- Siokra (Bollgard II) variety.
- Crops sown on the 30th October.
- Row spacing set at 1m.
- 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 II sowing window restrictions.

A sowing opportunity was considered to occur when there was:

- 25mm (1") of water in top 100mm (4") soil; and,
- 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.

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

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 1m plant configurations. They generally show that when yields of solid configurations are high, skip row configurations have a penalty; but when yields of solid configurations are low the difference in yield between skip rows and solid configurations are small. 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.

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.

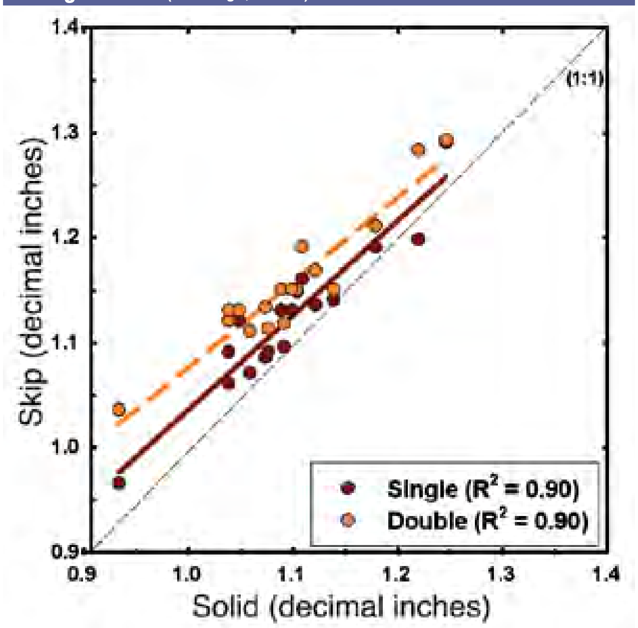


TABLE 2: Probability of failing to sow based on the sowing opportunity for different periods starting 15th September.

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

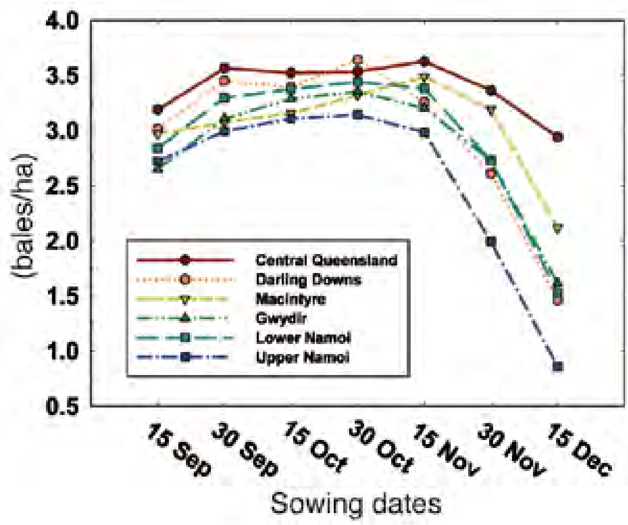
In Tables 3 and 4 the average potential yield from three different row configurations (solid, single and double) is presented on a regional basis along with the associated 'Probability of exceedence' values. Probability of exceedence is used to indicate yield variability that exists with different seasonal 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 (200mm vs. 250mm).

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

FIGURE 2: 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 200mm.



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 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 2). 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
- 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 for more information.
- An integrated approach to insect, weed and disease management is important in ensuring cotton remains profitable. While biotechnology provides many benefits to the industry, it is important that the stewardship responsibilities, such as requirements for pupae busting are understood, see Chapter 11 for insecticide and Bt stewardship, and Chapter 12 for herbicide stewardship.
- 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.

Sources of information:

Whopper Cropper risk management software can compare the effects of different management options to help farmers to better manage production and economic risks. www.backpaddock.com.au

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.mybmp.com.au

More information: www.drylandcotton.com.au

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	200mm Plant Available Soil Water			250mm 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	200mm Plant Available Soil Water			250mm 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


AgEagle

Irrigated or semi-irrigated cotton

Contributing authors:
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Jim Purcell (Aquatech Consulting)

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). Improving water use efficiency 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.

For more information: WATERpak 1.2 Water use efficiency, benchmarking and water budgeting pg 18. Available at www.cottoninfo.net.au.

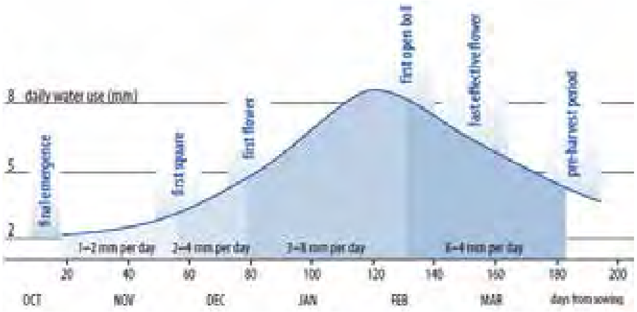
Seasonal Crop Water Requirements: Understanding crop water requirements (ETc) is crucial for planning your mix of crops, the area to be planted and how irrigation is managed. Table 1 shows the water requirements for a variety of crops.

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 – www.cropwateruse.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 (IrriSAT app reference: 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 dryer 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
		ETO = 6mm	ETO = 8mm	ETO = 10mm	
Barley**	350 to 500	6.9	9.2		Shot – blade to lateflowering
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.
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 900mm (9 ML/ha) of water. Historical figures indicated that the median rainfall during the season for this location is 350mm (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 to 6 ML /ha of water supply is required. Refer to Table 3.3.1 WATERpak, pg 265 for more information.

Useful resources:

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

WATERpak Chapter 1.2 Water use efficiency, benchmarking and water budgeting, pp 18-21.

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.

Best practice…

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

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.

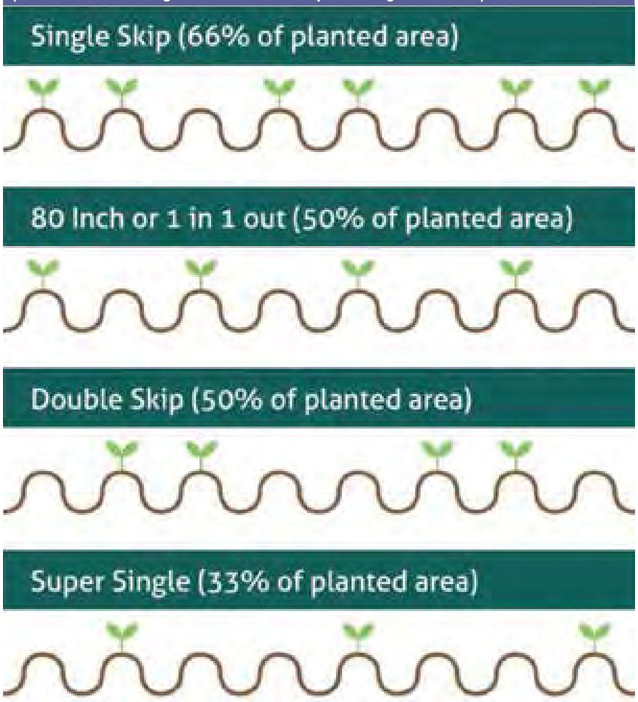
Row configurations and semi-irrigated cotton

There are a range of different configurations being used by growers across the cotton industry in semi-irrigated situations. These include single skip, 1.5m and 2m (60 and 80 inch), double skip, super single and some non-uniform configurations (refer to Figure 1).

The reasons for using skip-row include:

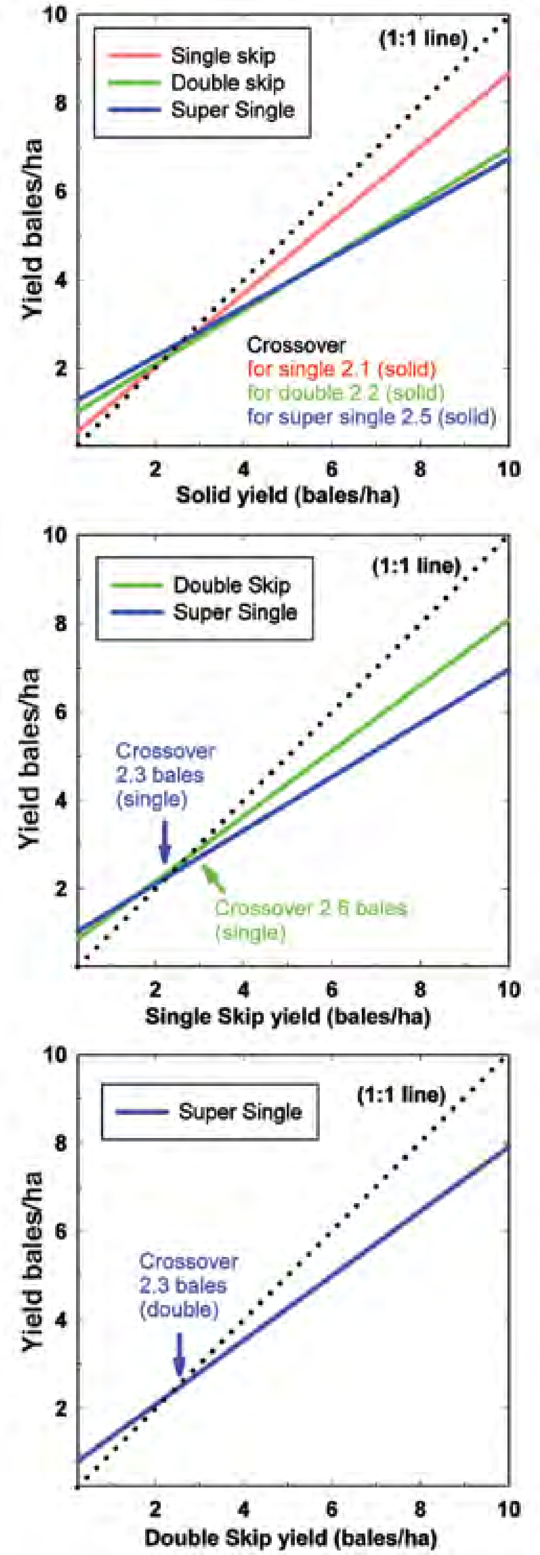
- Reduced risk of crop failure
- Buy time to get rainfall or irrigations
- Spread the irrigation interval.
- Make better use of in-crop rainfall
- Reduce variable costs

FIGURE 1: 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 2: 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 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; and,
- 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 2), 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 50cm 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 (1.5m or 2m)** 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.

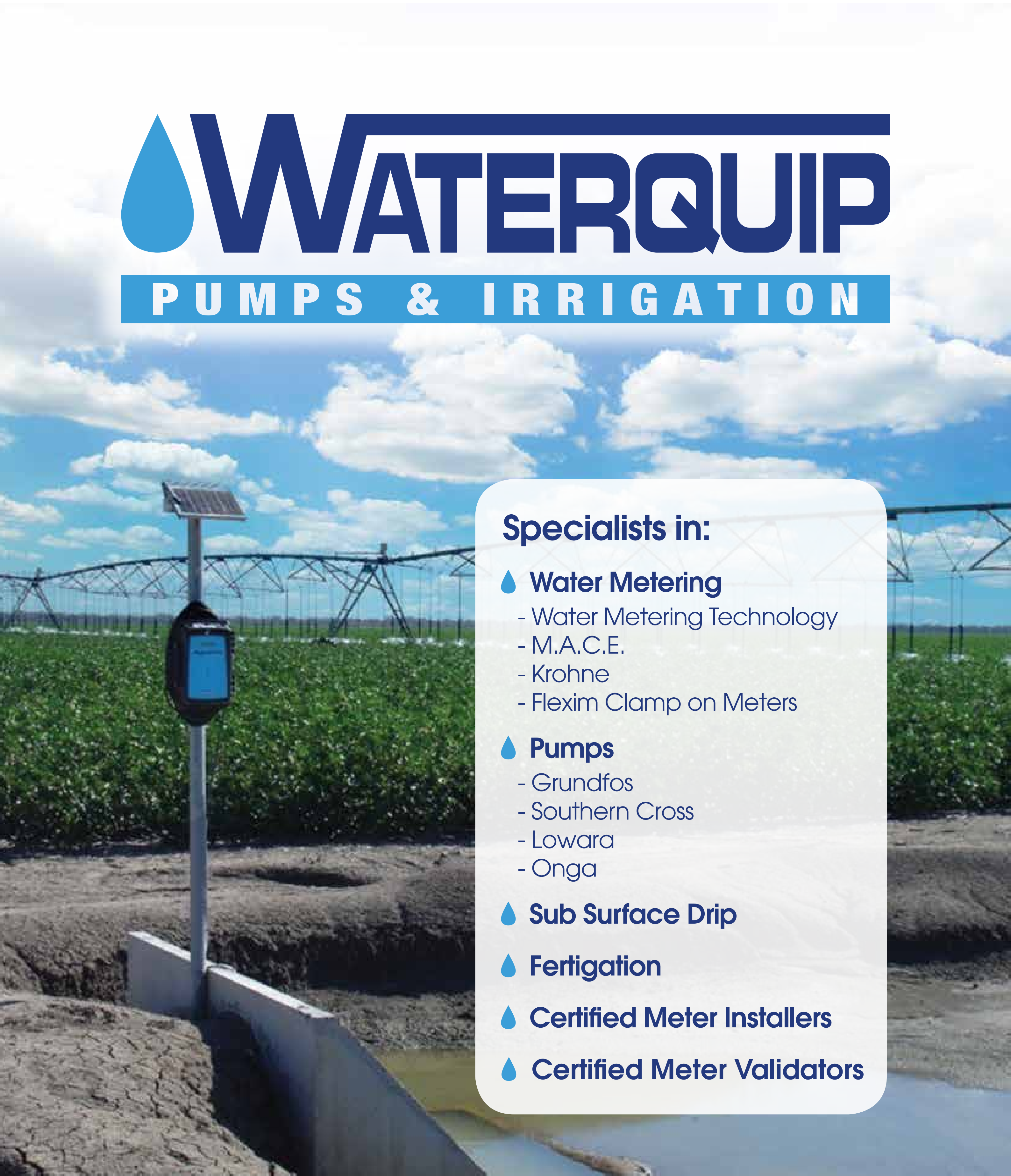
Double Skip provides more insurance against lower yields when compared to single skip especially when conditions are less favourable. Having a plant row 50cm one side and a 1.5m skip row to the other, this configuration provides the benefits of 'partial root zone drying' which toughens the plant up. 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 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.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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.

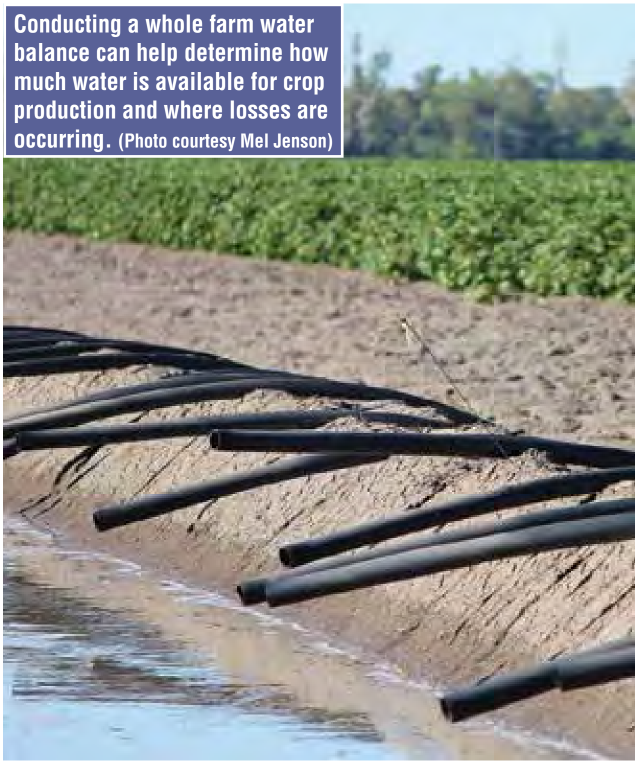
Taking this into account, a lower yielding wider row configuration crop can at times give a better gross margin than a higher yielding crop on a closer configuration. In many ways growing skip row cotton really emphasises that gross margin is not just a function of the yield produced, but very much a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

Useful resources:

'Getting the most out of skip row irrigated cotton', Cotton Seed Distributors www.csd.net.au

Read 'Row configuation' WATERpak 3.3, pg 266.

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)



Monitor to manage – whole farm water balance

By **Jim Purcell** (Aquatech Consulting)

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?).

The tools for whole farm water balance have progressed greatly in the past 10 years. The use of 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:

Phase 1

- Measure and record the basics.
- Complete a simple seasonal whole farm water balance
- Review the results.
- Fix the easy stuff.
- Repeat until happy.

Phase 2

- Stop at Phase 1 if you are happy with your WUE or move to daily water balance. Daily water balance allows prediction forward of water requirements before and during the season.

Phase 1 – Seasonal whole farm water balance

Step 1 – 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 tailwater and buffer storages are included. Storage surveys can now be done with water in the storages!
- 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

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.**

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). 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 is now standard with information available by internet (read your storage volume, depth and surface area with your mobile phone or laptop 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. Aquatech™ 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. Default values are available without measurement as a start.

Step 2 – Record keeping

The next step is basic record keeping. The aim is to record enough basic information to calculate 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 water did I lose and how much could I save and use 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.
- Harvested water volumes (land surface diversions) measured using the storage meter records.
- Rainfall on fields.
- Field number or name and area.
- Crop yield.
- Reference Evapotranspiration for each day during season based on weather data (automatically provided in WaterTrack™ from SILO).
- 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.

Step 3 – Seasonal water balance

The whole point of completing a whole farm water balance is to find out where water is being lost, whether those losses are OK and what is required to reduce the losses and increase production.

The Seepage and Evaporation Assessment with an Aquatech™ Meter allows the calculation of soil seepage losses from storages, channels and drains. Similarly, the measured evaporation characteristics from the same measurement allow calculation of evaporation from storages, channels and drains. If a farm has two different soil types, then it “may” be necessary to complete a second Seepage and Evaporation Assessment in each soil type.

Calculation of actual crop water requirements is based on daily Reference Evapotranspiration (Eto) values for 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 to provide the farm latitude and longitude from Google Earth.

Step 4 – 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™ will complete a simple seasonal water balance and provide Water Use Efficiency Indices required for *my*BMP and Water Management Plans.

Irrigation consultants can advise whether the losses are typical, good or bad and can advise on the type of works and costs to reduce losses. WaterTrack Divider™ even provides a basic economic calculator. This can determine if the proposed capital works are economic and how long the pay back period is from the extra production.

Step 5 – Repeat seasonal water balance next season and so on, until happy with the reduced losses and water use efficiency performance

For more detailed accuracy and predictions undertake Phase 2.

Phase 2 – Daily whole farm water balance

Step 6 – Comprehensive daily whole farm water balance

Rather than waiting until the end of the season to check how water management went, it is also possible to set up the daily water balance model, WaterTrack Optimiser™.

WaterTrack Optimiser™ models each element of an irrigation farm in sections and in individual fields daily. The computer model replicates each action taken by the irrigator in their daily routine and calculates the losses in each segment of channel and drain, each storage and each field daily.

The results are much more comprehensive than those achieved by completing a seasonal water balance but more effort is required with data collection and data entry. Essentially, every action done with water on the farm is also done on the computer.

The value of the extra effort is the ability to manage water for each irrigation and make changes then, rather than waiting until next season. WaterTrack Optimiser™ also allows forward prediction at any time to check whether there is enough water available (including losses) to completely irrigate those fields in production.

Typically, prediction for a cotton crop is done:

- Before planting.
- Mid November or early December to decide which fields shall remain irrigated.
- As many times as required in February to determine which fields shall be finished.

The effort required to complete this modelling can result in very significant profit increases by maximising the yield potential of the remaining water. Most irrigators use commercial consultants to complete this modelling. The consultant is then able to work with the irrigator on alternative strategies.

Useful resources:

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

Aquatech Consulting Ph 02 6792 1265

www.aquatechconsulting.com.au

www.watertrack.com.au

Irrigation systems

Furrow Irrigation

Furrow irrigation remains the dominant irrigation method used by the Australian cotton industry. Typically about 60–70 per cent of the water that reaches the field is used by the crop, and 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. When optimised under appropriate conditions this method can produce high levels of performance. In fact 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 may increase water use efficiency significantly.

There are however a range of factors inherent in siphon irrigation that have driven efforts to develop alternative options. Competition for labour and water resources, and increased yields, are principal drivers. Increased automation, the ability to deliver precise amounts to meet crop demand in a timely manner, and energy efficiencies underlie most ongoing efforts to develop alternatives irrigation systems.

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 & 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).**

Useful resources:

CottonInfo fact sheet: Key Factors to consider when improving furrow irrigation. www.cottoninfo.com.au/publications/furrow-irrigation-fact-sheet

WATERpak 5.2 Developing a surface irrigation system pg 355

Waterpak 5.3 Surface irrigation performance and operation pg365

Mongtomery J. & Wigginton, D. 2007. "Evaluating furrow irrigation performance – results from 2006-07 season" http://www.cottoninfo.com.au/publications/water-evaluating-furrow-irrigation-performance

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

Case study: Water management from an irrigator's perspective, www.cottoninfo.com.au/publications/case-study-water-management-irrigators-perspective

Centre Pivots/Lateral Moves (CPLM)

There has been increasing interest in Centre Pivot (CP) and Lateral Move (LM) irrigation systems in the Australian cotton industry. More recently the Australian government's water reforms have heightened irrigators thirst for new irrigation technologies that require less labour and achieve water savings. 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.

Before replacing a current surface irrigation system with a CPLM system you should assess the performance of the existing system, to be sure the change is warranted. A well performing surface system can be as efficient as a CP or LM irrigation system. Optimisation of an existing furrow system could significantly reduce potential gains expected from investment in an alternative system.

It is not possible to make a 'rule-of-thumb' statement that the investment in CPLMs is or is not profitable – every farm business differs and so do the water savings and yield benefits for the many crops that can be grown with these machines.

A 'with' and 'without' scenario analysis approach 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 steady state profit analysis at the whole farm scale for the current farming system (the 'without' scenario) and the one with the CPLM investment (the '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.

Growers considering purchasing CPLMs should look, listen and learn from those with experience with these machines. One of the most consistent messages is the importance of obtaining a 'site specific' system design – CPLM designs must be tailored to match the environment (eg. soil characteristics, topography) in which it will be operating.

A well designed CPLM should:

- Maximize 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; and,
- Have minimal energy and labour inputs.

A range of tools has been developed to assist grower's initial decision making process, to verify system performance, and to plan ongoing machine operation.

Irrigating CPLM fields is very different to the process of irrigating furrow fields and requires a completely different mindset. While CPLM irrigation systems are capable of giving higher returns per ML of water applied, management in terms of crop agronomy and water management largely influences the benefits obtained by these systems. You have to manage the whole irrigation system, not just the machine.

Water savings depend on the performance of the previous irrigation system. While savings of 30 per cent have been found where CPLM machines have replaced surface irrigation, these savings can be offset by higher energy and capital costs.

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

Four main observations arose from the 2011-12 survey:

- Around half the survey participants would be 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 a general recognition 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 CPLM 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.

From the report the following recommendations should be considered by growers interested in investing in CPLM systems:

- System capacity is critical. Managed system capacity in particular needs to be high enough to satisfy peak crop demand and your irrigation management, while minimising capital and operating costs.
- It is important to ensure that operating pressure is minimised while still allowing optimum system performance. Energy costs are an increasing component of operating costs and may affect the financial viability of these systems.
- Expect it will take several years before you get the best performance out of a CPLM system. There will be a significant time investment in planning and setting up the system and learning to manage it.
- Carefully plan the system to ensure it suits the soil type and performs as required without excessive capital or operating costs.
- 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.

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. Available at www.cottoninfo.net.au

WATERpak Chapter 5.5 Centre Pivot and Lateral Move Systems pg 392

A comprehensive CPLM training package, developed and delivered by the National Centre for Engineering in Agriculture (NCEA) with funding from CRDC and the CRC-IF.

A Centre Pivot and Lateral Move one day workshop available through Growcom.

Video: Growers Guide to Centre Pivots and Lateral Moves. Available on youtube: www.bit.ly/1OMUreO

OVERsched – an on-line CPLM management tool for visualising soil moisture deficits and irrigation scheduling options.

www.irrigationfutures.org.au/OVERsched/OverSchedv1-0.html

Irrigation training: NSW DPI ProWater Irrigation Series www.dpi.nsw.gov.au/agriculture/profarm/courses

Subsurface Drip Irrigation (SDI)

SDI is an alternative irrigation system for improving water use efficiency. SDI is the application of water below the soil surface through emitters with a discharge equivalent to crop water requirements – to meet the crop evapo-transpiration demand. It is a low pressure, low volume irrigation system that uses buried drip tubes. SDI tape is laid permanently and has been documented lasting 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.

Capital investment and labour costs are, therefore, low compared to surface drip where tape needs to be placed, removed and then replaced after each crop. It has a number of potential benefits over furrow irrigation:

- 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 labor demands.
- Field operations possible even when the irrigation is turned on.

As was the case with CPLM, historically SDI irrigated cotton systems provided disappointing results. Their failure to produce the anticipated improvements in yield and water use efficiencies (which had been critical components in the initial decision to outlay the considerable required installation capital) may be attributed to a range of factors. Again, as with early CPLM installations, poor design or adherence to design at installation, and insufficient operator expertise, so often associated with application of any new technology, did little to produce expected outcomes. Just as a high performance engine behaves atrociously when out of tune, SDI systems perform poorly if not operated correctly, even if their design is excellent.

TABLE 2: Example of comparative irrigation costs for different irrigation systems.
(Source: Adapted from NSW DPI ProWater Irrigation training series)

Irrigation system	Capital costs/Ha	Irrigation efficiency	Expected life	Labour requirement	Assumed pumping head	Electricity costs per kWh	Diesel costs per litre ($)		
	($/ha)	(% approx.)	(years)		(m)	10c	30c	120c	150c
Furrow	2500–3000	50–80	10+	High	10	4.52	13.57	15.17	18.96
Furrow (Bore)	2500–3000	50–80	10+	High	45	20.36	61.07	68.26	85.32
Lateral Move (gravity fed channel)	2500–5000	80	15+	Low (1/5 furrow)	30	13.57	27.14	45.50	56.88
Centre pivot with pump, motor and mainline	2500–5500	80	15+	Low (1/10 furrow)	60	27.14	81.43	91.01	113.76

Trials conducted by the Cotton Catchments Communities CRC, in collaboration with a tape manufacturer and three irrigators on three sites, (see Table 3) showed a range of yield impacts of drip irrigation on cotton. The average yield decreased with the use of drip at one site (although here drip out-yielded furrow irrigated cotton in the first year of installation), and increased at the second (a 10 per cent yield increase on average over furrow irrigation with 1m drip) and third sites (where yield increases ranging from 20 to 34 per cent for drip over furrow irrigation were recorded). The average reduction in applied irrigation for drip irrigation over furrow irrigation ranged from 15 to 31 per cent across the three demonstration sites.

TABLE 3: Impact of drip irrigation on Water Use Efficiency Indices (bales/ML) on three Darling Downs drip irrigation demonstration sites.

	Gross Production Water Use Index (GPWUI)		Irrigation Water Use Index (IWUI)	
	Furrow	Drip	Furrow	Drip
Site 1 (1m drip)	0.84	1.11	1.58	2.60
(2m drip)	0.84	1.04	1.58	2.41
Site 2 (solid)	1.22	1.30	2.20	2.80
(skip)	1.32	1.50	2.19	2.66
Site 3 (60')	1.13	1.82	1.66	2.69
(skip)	0.92	1.15	2.24	3.17

The impacts of the yield increases and reduction in water use, as captured in the Water Use Efficiency Indices (IWUI – bales/ML), showed significant improvements in water use efficiency from the investment in drip irrigation. However, for an increase in profitability from the installation of drip, the water savings must be significant enough to enable an expansion in cotton area and an increase in yield sufficient to increase profits over the existing furrow irrigation system. A seven year research trial also identified that oxygation could boost SDI yield by 10 per cent.

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.

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.

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

Articles discussing SDI can also be accessed at www.cottonandgrains.irrigationfutures.org.au

WATERpak Chapter 5.6 Drip Irrigation: Design, installation and management pg 426

Bankless irrigation systems

Bankless channel irrigation systems are designed to remove the need for siphons, with the field split into bays. The field is designed to be watered at a high flow rate with all furrows in a bay irrigated at once.

Bankless irrigation systems are being used by broad acre irrigators seeking to improve farm efficiencies. The main motivation being labour savings.

Two main design approaches are currently being used for bankless channel irrigation systems.

The conventional form of bankless channel consists of a series of terraced bays with a vertical separation of between 0.1 to 0.2m. 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 flatplanted. All bays are connected by a bankless channel.

The second design approach of bankless channel irrigation systems uses the same approach as the conventional form to deliver water to a bay in that water spills from the bankless channel into the adjacent bay. However, in contrast to the conventional form, approximately 20 metres from the bankless channel, the bay slope changes from a positive field slope to a conventional negative field slope. This design is also know as GL bays, where the water advances down the field in a similar way to siphons. 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: GL Bays are a particular design for bankless channel irrigation systems. The design was developed by Glenn Lyons, GL Irrigation Pty Ltd, St George.

Pros

- Reduced labour requirements through removal of siphons.
- Improved machinery efficiency – no need for traditional management operations such as rotobucking and driving through ditches for spraying and harvesting operations.
- 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.
- Irrigation performance of bankless channel irrigation is difficult to measure and hence aggregated performance benchmarks have not been produced
- Need suitable slopes.
- Installation costs – suited to properties in the developmental phase as opposed to converting old siphon fields to bankless systems.

Useful resources:

WATERpak Chapter 5.4 Bankless Channel Irrigation Systems pg388

More Profit per Drop Bullamon Plain Case Study www.moreprofitperdrop.com.au

CottonInfo Fact Sheet Turkey Lagoon Case Study www.cottoninfo.com.au/publications/case-study-bankless-channels

Naylor M. (2014) Some Comments on Bankless Furrows in Bay Irrigation Systems, Paper presented at the 17th Australian Cotton Conference, Gold Coast. www.crdc.com.au/publications/17th-australian-cotton-conference-research-papers-e-summaries

Field selection, preparation & rotation

By **Susan Maas** (CRDC)

Acknowledgements: Dallas King (Western Rivers Ag), Nilantha Hulugalle (DPI NSW), Tracey Leven (formerly CRDC) & Tim Richards (MCA Goondiwindi)

Cotton soils

When planning to grow cotton it is important to select fields with adequate Plant Available Water (PAWC). 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. Under raingrown conditions, if the profile starts out full, large values of PAWC 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 vigorous 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 to any of these soils, due to excessive traffic or tillage at high moisture contents, may create large platy clods. Such damage restricts permeability. While the root zone should be permeable, the deep subsoil should be almost impermeable; excessive deep drainage may cause water tables to rise. Irrigation management and crop rotation should aim to minimise the amount of water draining to the deep subsoil.

Soil compaction

Soil compaction can significantly reduce cotton yields by restricting root growth, which in turn reduces water and nutrient uptake. Refer Figure 1. Some compaction is an inevitable consequence of machinery use throughout the season, or 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.

Best practice…

- Crop growth will be easier to manage in a field with a uniform soil type.
- Fix problems associated with land forming before planting cotton
- Favour fields that have most recently grown a crop other than cotton, where stubble has been retained and there is low risk of herbicide residues
- Consider alternative irrigation systems ie. would lateral moves or pivots be more appropriate on lighter soils than flood irrigation.
- Consider suitable run lengths not just for cotton but possible rotation crops.

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.

Ideally field traffic in 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 was significant occurrences of soil compaction beneath all wheels. Significant compaction was further observed to depth (0.8 m) for 50% of the soils, with conditions conducive to long-term formation of a compaction pan beneath the tillage zone.

A dry harvest also provides the widest range of options for preparation and improvement of cracking clay soils (provided that heavy rain does not follow soon afterwards). Cultivation, and particularly deep tillage should only be attempted when the soil is either at plastic limit or drier than plastic limit. Clay soils may be cultivated when dry, but non-swelling soils

Soil moisture has a large impact on compaction. Photos show treatments in trial where delayed defoliation was used to draw down profile resulting in greater pore distribution and more friable soil (right), compared with standard defoliation practice (left) where platy soil structures are evident in the 40-70cm. Both soil pit face photos are under inner wheel traffic furrow and tape measure in the image has units in metres.
Image reference: Roberton and Bennett (2016) "Efficacy of delaying defoliation to mitigate compaction risk at wet harvest" In: An impact assessment framework for harvesting technologies in cotton: Management considerations for the John Deere 7760. Eds: Bennett, J.McL., Jensen, T.A., Antille, D.L., Baillie, C. National Centre for Engineering in Agriculture Publication 1004960/16/1, USQ, Toowoomba.

containing higher amounts of loam or sand can be damaged if cultivated when too dry as the soil structure is more easily broken down. Controlled Traffic Farming (CTF) is one efficient way of dealing with the compaction problem by constraining to defined tracks through the field. However 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 and can require cracking by rotation crops, and/or deep tillage to improve the yields and profits of future crops. Compaction in clay soils may also be remediated by subsequent crops, where cycles of wetting and drying during the growing period, and deep drying by the crop after the last irrigation can crack the soil and improve structure to a point where deep tillage may not be necessary.

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

A vital component of any farming system is the inclusion of a rotation phase. Planning should take into account a range of issues, including weed, insect, disease, water use, and soil structural issues, to maximise the advantages and minimise the disadvantages at a field and whole of farm basis. Rotation crops can be used as a tool within the farming system. For example there is evidence of improved cotton yields after a corn crop which is most likely due to increased organic matter and better soil structure.

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 (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**

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

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.

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.

When soil properties within a field are variable, it usually is impossible to deliver the required inputs to all sub-sections simultaneously when flood irrigation is used. Some parts of variable fields, therefore, will have lint yields that are lower than the field's potential, and product quality for the whole field will not be uniform.

In practice, it is unlikely to ever be economically feasible to completely remove across-field soil variability. Gilgai micro-relief, once levelled, can have former mound and depression sites giving differing crop performance which may persist for many years.

Good quality soil survey information provides the opportunity to minimise the impact of soil variation within each management unit.

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.

Surface drainage and tail drains must be designed to minimise flooding during heavy rain, the consequences of which may be disastrous during the seedling stage. Furrow-edge compaction and water application rates need to be matched so that the root zone does not become waterlogged due to excessive water intake. Slopes that are too steep create erosion hazards.

Land forming of cotton fields often creates soil problems that should be dealt with before cotton is grown. The main issue is the exposure and spreading of unstable subsoil.

Subsoil exposure is usually unavoidable because of the need to provide an even slope in irrigated fields. Even drip irrigated fields have to be land formed because of the need to quickly dispose of runoff water after heavy rain. At best, the exposed subsoil will have inadequate organic matter. At worst, it will be sodic, depleted of mycorrhiza, have a high pH and perhaps be saline.

Where sodic subsoil is exposed, the scraped material also has poor physical properties. It may be spread thinly over low lying areas which previously had a favourable soil structure. Therefore it is desirable to stockpile the original topsoil, landform the subsoil, and then replace the topsoil.

If stockpiling and replacement of the topsoil is not possible, the exposed sodic soil will have to be reclaimed by the use of gypsum, and perhaps by the growth of a well-fertilised cereal crop (eg. Barley). Zinc fertiliser may need to be added.

It can be difficult to reshape fields at the recommended soil water content, particularly when there is a mix of soil types. A well fertilised crop such as wheat should be grown just before land forming to maximise the chances of the soil being dry enough.

Selecting the seed

By **Robert Eveleigh** (CSD)

There are a range of varieties that can be selected and grown. Varieties are generally selected on yield, quality and disease resistance characteristics. But other traits such as determinacy, leaf shape and season length may also be important. Varieties containing Bollgard II technology will be phased out from 2016 and will not be available for the 2017 planting season. Left over seed can be planted. Initially 4 new varieties containing the Bollgard 3 technology will be available for planting in 2016 (see below). 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. In initial testing Sicot 714B3F has demonstrated exceptional yield performance in a wide range of environments. Sicot 714B3F is also the best choice for growers in regions with shorter seasons such as the Upper Namoi and southern NSW. Sicot 746B3F and Sicot 748B3F are full season varieties that perform best in full season environments. They have similar yield, quality and disease tolerance. Sicot 748B3F is more vigorous than Sicot 746B3F. Sicot 748B3F should be selected for fields that generally produce shorter cotton that struggles to achieve row closure.

Dryland production systems require varieties that yield well in water limited situations. The best dryland varieties are generally very indeterminant and have robust fibre characteristics. The new Sicot 748B3F is expected to become the dominant variety in mainstream dryland environments while Sicot 714B3F is the best choice for eastern regions.

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 their results in variety trials. Historically cotton growers change varieties rapidly to grow the higher yielding replacements. Cotton varieties bred in Australia have demonstrated a 1.8 per cent 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.**

TABLE 1: New BG3 variety summary.

Sicot 714B3F	Sicot 746B3F	Sicot 748B3F	Sicot 754B3F
A mid to full season, normal leaf variety with excellent yield potential.	A full season, normal leaf variety with excellent yield potential.	A full season, normal leaf variety with excellent yield potential.	A full season, normal leaf variety with excellent yield potential.
Suitable for irrigated and dryland growing scenarios.	Suitable for irrigated and dryland growing scenarios.	Suitable for irrigated and dryland growing scenarios.	Suitable for irrigated growing scenarios.
Foliage is dark green.	Foliage is dark green.	Foliage is dark green.	Foliage is lighter green compared to other varieties.
A compact growth habit. Avoid stress early in flowering period	An intermediate growth habit depending on boll load and seasonal conditions.	A vigorous growth habit depending on boll load and seasonal conditions.	A vigorous growth habit.
A large boll size and a tendency to fruit earlier in the season, more suited to shorter season growing areas.	A large boll size and a tendency to fruit late into the season, careful management post cut-out is desired to reach full yield potential.	A large boll size and a tendency to fruit late into the season, careful management post cut-out is desired to reach full yield potential.	A medium to large boll size and a tendency to fruit late into the season, careful management post cut-out is desired to reach full yield potential.
Care at planting should be taken to ensure the correct plant population is established to ensure optimum yield.	Seed density is lower than Sicot 714B3F, so care at planting should be taken to ensure the correct plant population is established to ensure optimum yield.	Seed density is lower than Sicot 714B3F, so care at planting should be taken to ensure the correct plant population is established to ensure optimum yield.	Higher fibre qualities especially length offers opportunity in the marketing of this variety
Resistant to Bacterial blight. Similar Fusarium and Verticillium Wilt disease resistance to current commercially available varieties.	Resistant to Bacterial blight. Similar Fusarium and Verticillium Wilt disease resistance to current commercially available varieties.	Resistant to Bacterial blight. Similar Fusarium and Verticillium Wilt disease resistance to current commercially available varieties.	Seed density is lower than Sicot 714B3F, so care at planting should be taken to ensure the correct plant population is established to ensure optimum yield.
			Resistant to Bacterial blight and leading resistance to Fusarium wilt. Similar Verticillium Wilt disease resistance to current commercially available varieties.

Quality

Australian cotton quality is regarded as some of the best in the world. Fibre characteristics have been improved by breeding. Fibre length has been increased significantly in the past few years. Fibre strength has also been increased and micronaire values adjusted down to the premium range. Some varieties such as Sicot 754B3F have exceptional quality and may achieve premiums. Pima have the best quality and generally command 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 the hotter regions selecting varieties with lower relative micronaire may assist in minimising discounts and achieving premiums. In dryland situations selecting varieties with the best fibre length will reduce the chance of length discounts. Variety selection can also impact on grades. Okra leafed varieties sometimes achieve slightly lower grades than normal leaf varieties due to the leaves 'catching' on the plant 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 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. 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 will replace the current Bollgard II technology by 2017. Bollgard 3 technology adds to the existing Bollgard II resistance management strategy by stacking the Vip3a protein with the 2 existing BT proteins in Bollgard II. One of the key benefits of Bollgard II and 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 will reduce but not eliminate the continued threat insect resistance poses to the Australian cotton industry. Continued vigilance and adherence to the approved resistance management plan is still essential. However the new Bollgard 3 technology does provide a more relaxed resistance management strategy. This includes an amended refuge requirement, a wider planting window and a modified pupae busting protocol.

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 in a few years.

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
BRF = Bollgard II stacked with Roundup Ready Flex
RRF = Roundup Ready Flex (no Bollgard)

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 'Technology User Agreement' (TUA). The TUA forms the basis of the relationship between the grower and the technology company.

The primary purpose of the TUA is to clearly define the terms and conditions associated with use of the technology 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 **Jon Welsh** (CottonInfo)

Acknowledgement Oliver Knox (UNE), John Smith (NSW DPI), Brendan Griffiths (UNE) and Duncan Weir (QLD DAF)

Ensuring the crop has adequate nutrition is critical to maximizing yield, but with crop nutrition making up the largest cost line item in the irrigated cotton gross margin , nutrient efficiency is a key management consideration.

Long-term farm management and fertiliser strategies should ensure that soil nutrient levels remain in adequate supply for continued high levels of production.

Maintaining the 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.

Cotton crop nutrition does not occur in isolation, but in association with 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/ exploration; and,
- Water availability (irrigation or starting soil moisture levels in raingrown production).

Nutrient removal

A significant amount of nutrient is removed from the cropping system in the harvested seed-cotton (Table 1). 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.

Nutrient supply

The supply of nutrients for a cotton crop is dependent on the soil nutrient reserves and nutrients added as fertiliser. A fundamental requirement in meeting the nutritional needs of a cotton crop is determining nutrient level in the soil before planting and estimating the mineralised N in-season. Routine soil analysis, as part of crop management, can provide an indication of the fertility level in your soil at that point in time. Decision support tools to better account for soil mineralised N are currently being developed by the CRDC.

Once soil nutrient levels are determined and a nutrient budget is generated, then fertiliser requirements can be more accurately calculated. The nutrient budget takes 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 here.

There is much 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). With two major implications; firstly you need to ensure adequate nutrition by the start of flowering because plant uptake increases dramatically during this period and levels of being adequate to being deficient can occur quickly; and secondly late application of nutrients can have little impact on plant development and yield.

Best practice…

- **Fertilise fields for their own merit, based on yield expectation 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.**
- **Making the most of nutritional inputs relies on good irrigation, disease and weed management.**

Nitrogen

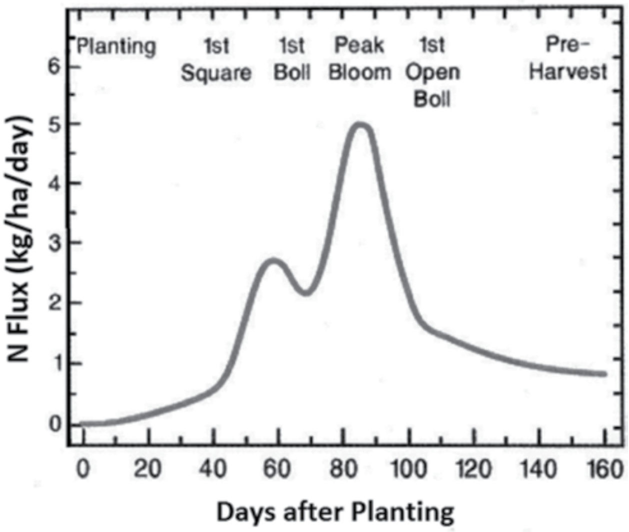
Cotton sources most of its N as nitrate-N from the mineralisation of soil organic matter. Mineralisation is a biological process within the soil that results in the release of nutrients in a form that are available for crop uptake. About 2/3 of the crop's N needs comes from soil N while the remaining comes from N fertiliser. The N fertiliser applied is critical to maximising production. Fertiliser N also ends up as nitrate-N in the soil.

The cotton plant uses N throughout the entire growing season, with the greatest requirement during the flowering stage (Figure 1). Insufficient nitrogen supply during this period will reduce yield, however, excess 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. All these impacts have considerable economic costs associated with them and result in reduced yields, quality down grades, increased production costs, higher fertiliser costs and reduced N efficiencies.

Matching N supply to crop N requirements requires a degree of management because N availability is affected by a range of physical, chemical

The CottonInfo team conducted regional nutrition trials in 2015-16 and included soil analysis on in-crop mineralised N. To find out more or participate in future trials contact your Regional Development Officer. (Photo courtesy Ruth Redfern)

FIGURE 1: Daily nitrogen flux patterns at yield of 10 bales/ha. (Adapted from http://cals.arizona.edu/crop/soils/azncotton.pdf)



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 and lost to the environment. 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 types or forms of fertiliser that can be used i.e. Manures and composts, granular fertilisers, anhydrous ammonia (gas), and liquid fertiliser. Anhydrous ammonia (82 per cent N) and urea (46 per cent N) are the two major N fertiliser used in the cotton industry. The type of fertiliser may be limited by the capacity to apply it. Composts and manures need to be spread and incorporated, anhydrous ammonia (gas) needs to be applied at a depth of at least 15cm by trained staff using specialized equipment. Studies have shown effectiveness of water-run anhydrous ammonia can be poor due to uneven distribution and substantial losses due to volatilisation . Urea has the advantage of being able to be applied using different application methods and at different times. However, it does need to be timed with a rain event or incorporated quickly after application to prevent significant losses through volatilisation.

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

In-crop mineralised N can vary greatly in irrigated cotton. A nil strip can help understand soil function and assist in future nutrient budgeting. (Photo courtesy Kieran O'Keeffe)

TABLE 1: Nutrient removal at various yield levels in bales/ha (1 bale = 227kg). 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	0.15	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.

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:

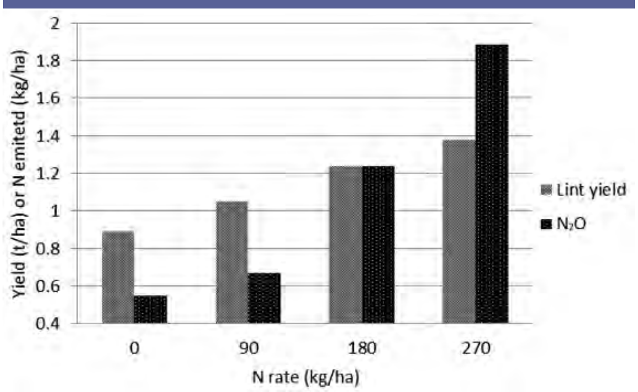
- Determine soil nutrient status using pre-season soil testing (ideally to a depth of 60–90cm).
- Calculate expected crop nutrient requirement taking into consideration expected yield, in-crop mineralisation, cropping history, cropping system and nutrient losses, crop use efficiencies, plant nutrient recovery and uptake, soil condition and characteristics – decision support programs such as NutriLOGIC can assist here.
- When finishing the crop, foliar N application may be an alternative to water-run urea to meet the nutrient requirements and avoid large losses of N in hot conditions.
- 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. Results of a study on the Darling Downs based on an irrigated wheat/cotton rotation shows production of nitrous oxide (resultantly N losses) increasing exponentially with N rate. Figure 2 shows the relationship between lint yield and nitrous oxide emissions in response to variable rates of nitrogen application,

FIGURE 2: 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)



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 after July to reduce the risk of substantial losses through denitrification and leaching.
- Allow sufficient time after application 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.
- 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 may impact on the ability to apply fertiliser in-crop in a timely manner, increasing the risk of crops being nutrient deficient during high demand periods (e.g. 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.

Right place

Most fertilisers (other than foliar) are applied to the soil, pre-plant, at depth (preferably 300mm) 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 15cm 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 e.g. 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 in the previous crop within the rotation.

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. 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 especially under low oxygen conditions such as during water-logging where nitrate N is converted into a nitrogen gas and lost to the atmosphere.
- **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.

- **Volatilisation –** Particularly important when solid fertilisers are applied and are not incorporated properly or in a timely manner on soil with high pH (>7), free lime (Calcium carbonate) is present or where plant residues are retained on the soil surface. Nitrogen in the form of ammonia is lost to the atmosphere.
- **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 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.

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

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 realising that N is only one factor that determines final yield and working out what the other manageable 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, however gradual that may be.

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. Table 1 provides an estimate for removal in cotton crops over a range of lint yields.

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 some 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 nutrient content 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[1], with the remaining P requirement coming from other sources of P in the soil of which fertiliser application in previous years has contributed.

There are several pools of phosphorus in the soil. It is important to understand these and the soil test methods that relate to them. For simplicity they can be classified into 2 pools:

- The 'labile' or fast release pool of P 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' method of soil phosphorus measurement.
- There are also slower release pools of P in the soil, it is these that generally hold the compounds formed in our cotton growing soils such as 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. We measure this pool using the 'BSES' method of soil phosphorus measurement, in the surface 0-10cm, and to some depth, 10-30cm.

With our fertiliser P strategies 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 we apply P fertilisers to treat the largest volume of soil possible (i.e. broadcasting prior to pupae bust), to ensure maximum root interception, and to some depth if practical.

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 have been attributed to long fallow periods or after non-mychorrhizal crops, such as canola, causing long fallow disorder, however in-field evidence generated for the CRDC and CRC debunked these myths. Wetting and drying cycles in the prolonged absence of any plants and tillage are the main contributor to low AM populations.

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 on clay particles and not readily available to plants. While most soils have large amounts of K but only a small proportion (less than 2 per cent) is available to plants. Despite large amounts in the soil, plant uptake can be limited because K is taken up through diffusion and has limited mobility.

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 sulphate is the most effective and inexpensive form to apply zinc to soil or the crop as a foliar spray. 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.

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 can be managed through both foliar and soil applications.

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.net.au and www.mybmp.com.au
NUTRIpak
FIBREpak
SOILpak
Vetch Fact sheet
Nutrients removed in harvested seed-cotton
CottASSIST Nutrilogic
[1]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 chemical and physical properties. While there are no hard and fast rules about when to do this a good start would be to do 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.

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, high or low pH, waterlogging and erosion. 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.

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 way:

N mineralisation (kg N/ha) = *0.15 x Organic C (%) x Growing Season Rainfall (mm)*

Organic matter losses

Organic matter can be quickly depleted if soils are not managed carefully. Soil organic matter losses result from excessive 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. 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 addition of organic materials with their decomposition, by either adding more organic matter (crop residues and other organic materials) and/or reducing the loss of carbon from the soil.

Inputs of organic materials can be increased by:

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

Losses can be reduced by changing management practices:

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

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

Some of these practices have conflicting impacts. For example, retaining crop stubble on the surface reduces build up of Fusarium innoculum, 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. But 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 but 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.

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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. There are reductions in the infiltration rate of the soil, the hydraulic conductivity of the soil and the plant available water capacity of the soil meaning that 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. The soils become increasingly hard setting and have greater susceptibility to waterlogging. Finally, there is only a narrow band of ideal conditions for plant growth between the soil being too wet and then becoming too dry and a physical barrier of hard soil for root penetration.

Sodic soil can be ameliorated by applying calcium. 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 can also help to reduce the effects of soil sodicity. Organic matter helps hold the soil aggregates together, stabilises soil chemistry, reduces dispersion and improves soil structure. It is difficult to get sufficient organic matter deeper into the soil.

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

Saline soil

Salinity and sodicity are separate issues. A soil can be sodic without being saline, 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; lime or gypsum. 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 restricts 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.

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.net.au and www.mybmp.com.au
WATERpak
NUTRIpak
SOILpak

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 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) and comparing that to the 'ideal' in CottASSIST, 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 up to 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.

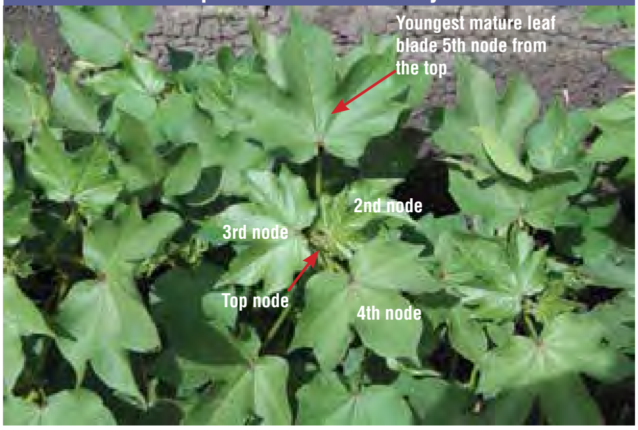
Leaf analysis can be used to monitor all nutrients including micronutrients. Sampling leaf tissue twice (at flowering and cut-out) produces the most useful information. Follow sampling directions carefully, results are only as good as the sample provided.

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 2).
- 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).

FIGURE 2: Identification of youngest mature leaf blade used for leaf and petiole nutrition analysis.



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

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

NutriPAK

SoilPAK

CottASSIST 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- and post-cotton soil tests, tissue tests and generate an N budget for your system. If there is lots of N unaccounted for then it has been lost to the environment so reconsider your approach and use the current low prices to investigate changes that may work for you to improve your fertiliser efficiency.
- **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, as the plants draw solution P from the soil. This pool is most strongly correlated to the 'Colwell' method of soil phosphorus measurement. There are also slower release pools of P in the soil and you measure this pool using the 'BSES' method of soil phosphorus measurement. With our fertiliser P strategies 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 66 per cent of your crop N, so you need enough soil biology there to do this effectively.
- **Cover crops make sense and don't dry your soils out.** A cover crop's roots allow for better water infiltration, provide more carbon to feed your soil biology and protect your top soil from the ravages of heavy rain, wind and UV degradation.
- **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 in which it is growing and the environment of the season. Avoiding any kind of stress is the key to getting and maintaining bigger 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 prone to conversion to nitrate and from there it can be lost. When denitrification (biological processes in the soil resulting in gaseous N losses) occurs nitrous oxide is emitted into the atmosphere. 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.
- **What you apply does not matter as long as you follow the 'rules'.** Grab your copy of NUTRIpak and SOILpak and make sure you know what the rules are and accommodate them in your management. You want higher yields more often, so 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.

III

Energy use efficiency

By **Jon Welsh** (CottonInfo), **Janelle Montgomery** (NSW DPI and CottonInfo), **Gary Sandell, Joseph Foley, Craig Baillie** (NCEA) **& Phil Szabo** (formerly NCEA)

Energy inputs are one of the fastest growing cost inputs to primary producers generally, and this trend is predicted to continue. This is particularly true for cotton, which is a highly mechanised production system that relies on direct energy inputs (ie. diesel and electricity). Conducting an energy audit may be one of the fastest, simplest and most effective ways to save money and reduce energy demand. Reducing energy demand also makes significant reductions in Greenhouse Gas (GHG) emissions. Reducing GHG emissions are important in maintaining the 'clean and green' image of the Australian cotton industry, and this helps to market our product.

To understand the range, costs and contributions of energy use to cotton production and greenhouse gas emissions, the National Centre for Engineering in Agriculture (NCEA), with funding from the Cotton Research and Development Corporation (CRDC) has studied on-farm energy use via numerous case study cotton farms. These farms represent small to large growers, cover different farming systems and located from Emerald to Victoria. The results from this work show that energy use varies depending on the cropping enterprise and the farming system and that there are significant opportunities to reduce energy and costs. In order to manage on-farm energy use irrigators should measure energy use across their farm.

Monitoring to manage – assessing on-farm energy use

An energy assessment determines where and how efficiently energy is being used within an enterprise. The main purpose of conducting energy assessments is to identify opportunities for significant energy savings (which will also reduce GHG emissions). For example, energy savings through fuel switching, tariff negotiation and managing energy demands are all possible outcomes of an audit.

Best practice…

- **Record farm energy usage to identify how efficiently energy is used and where the most energy is consumed.**
- **Explore ways to reduce energy use by focusing on high energy input areas and investigate opportunities to reduce energy inputs by changing practice or by doing the same operation more efficiently.**
- **Maintain machinery and equipment and ensure any modifications do not affect their efficiency.**
- **Consider impact on energy use efficiency when making any changes to farm practices or new investments.**

An energy audit is not necessarily complicated. Work within the industry and with *my*BMP has developed tools to make this process super-easy for growers. For example, EnergyCalc Lite is a simple and functional app, preloaded with industry standards and benchmarks, which can be downloaded from iTunes to easily provide a snapshot of your energy use. Alternatively, monitoring energy use can be as simple as collating fuel and electricity costs and tracking them over time. As growers start to look at energy use they will find that the more information collected will help to identify opportunities to produce more crop per unit of energy. The concept of energy assessments is relatively new in the cotton industry.

Level 1 or overview assessment

(Overview of the total energy consumption on-site, whole farm approach)

A Level 1 assessment is total fuel plus electricity consumed per bale and per hectare. It is the simplest and cheapest form of assessment that provides an overview of the total energy consumption across the farm. A Level 1 assessment benchmarks farm performance for comparison over time, and with other enterprises. The process is reasonably simple: Firstly, calculate your total direct energy consumption. Take the total litres of diesel purchased for the season and multiply by 38.6 to convert from litres of diesel to megajoules of energy. Add to this, total kWh of electricity purchased, multiplied by 3.6 (to convert to megajoules) plus any other significant energy consumption from other sources. Total energy consumed will, of course, depend on farm size. Dividing the total energy by the number of bales produced gives a more meaningful number to compare with others. Similarly, total energy can be divided by hectares. Often, total megajoules are divided by 1000 to give total gigajoules (GJ) per bale and per hectare.

TABLE 1: On-farm energy use benchmarks for cotton production.

	Energy (GJ/ha)	Energy (GJ/bale)	GHGs (kg CO_2/ha)	GHGs (kg CO_2/bale)	Energy Cost ($/ha)	Energy Cost ($/bale)
Irrigated	10.9	1.18	1,091	119	310	34
Supplementary	3.6	0.43	247	30	101	20
Raingrown	3.1	0.71	212	49	87	12

The CottonInfo team has been involved in a project to collect this data from a number of irrigated cotton farms using the web-based tool "EnergyCalc" to compile the data and generate benchmarking reports. A summary of results to date is presented in Table 1.

Without properly assessing energy consumption it is difficult to accurately identify and quantify the savings that can be made. Growers interested in assessing their own energy consumption can also use 'EnergyCalc Lite'. Refer to CottonInfo website for more information.

Level 2 or itemised assessment

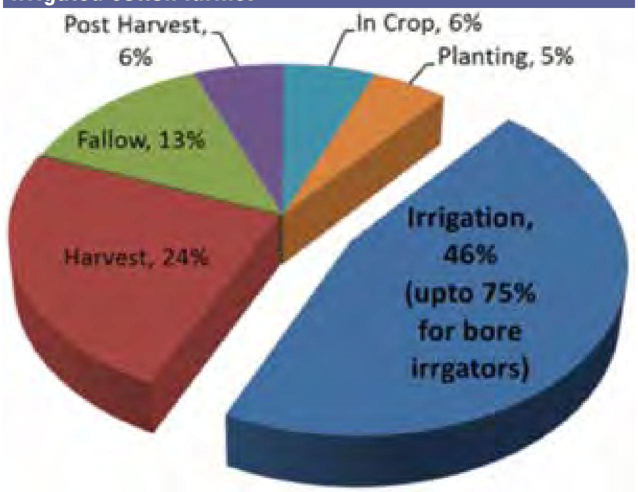
(Itemised farm approach, practice or management based)

A Level 2 assessment 'breaks down' or 'itemizes' total energy use into the energy used in key farming processes and individual operations. While this takes a little more work than a Level 1 assessment, it does provide powerful information that allows you, as the grower, to better investigate the big energy uses in your system. A Level 2 analysis can also be used to benchmark your operation in detail, against other growers over time. In short, a Level 2 analysis allows you to evaluate your farming system, pumping costs and more.

Because this process can be time consuming and can suffer from lack of data, the NCEA, in conjunction with the CRDC and *my*BMP have developed EnergyCalc Lite (available from the Apple iTunes Store). This is an iPad app that allows growers to easily itemize their energy use and compare themselves with the rest of the industry. EnergyCalc uses information such as fuel bowser and electricity meter-box readings and other farm records. Often, it is not known exactly how much fuel went into each tractor. For this reason EnergyCalc has in-built calculators for specific farming practices based on machine size and other site specific information including electric motor sizes, pumping equipment and vehicles which are collated to calculate energy use. A Level 2 assessment provides much more detail and aims to have a greater accuracy than a Level 1 assessment.

Figure 1 indicates the typical results collected from irrigated cotton farms, this itemised benchmarking helps to identify operations that require further investigation and in this case highlights irrigation as a significant energy consumer. EnergyCalc Lite also converts direct energy inputs into greenhouse gas emissions and includes cost information. For more information go to www.cottoninfo.com.au/energy-use-efficiency

FIGURE 1: Itemised energy consumption across irrigated cotton farms.



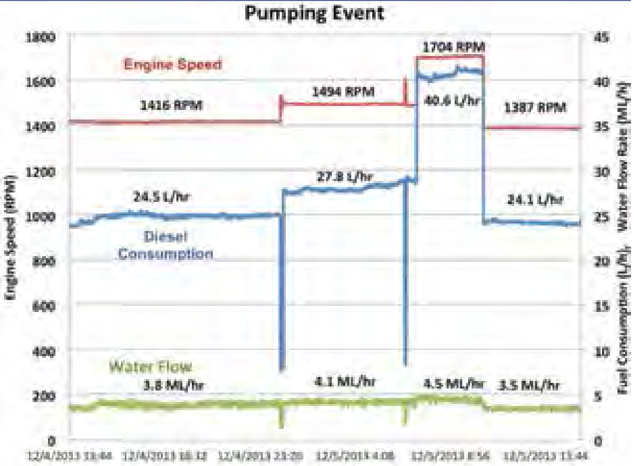
Level 3 or specific operation assessment

A Level 3 assessment closely investigates one particular operation and involves taking measurements to find ways to improve the efficiency of that operation. A Level 3 assessment might investigate pumping performance or look at tillage efficiency, for example. This will usually involve the application of a range of different sensors to measure performance and generally requires specialised advice. The NCEA have developed the Pump Efficiency Monitor (PEM) which monitors pump performance over time. The PEM pump performance monitoring to date has obtained more useful data than a simple spot check.

A Level 3 assessment is compared to a standard benchmark of energy use. In the case of a pump assessment, for example, the measured energy consumption would be compared to benchmarks of energy per megalitre of water per metre of lift to evaluate the performance of a pump against other irrigators. This type of assessment will determine performance and identify optimal machine settings. Importantly, it can also be used to build a business case for new capital investment.

Figure 2 presents a three-day pumping event from a diesel engine driving a 26HBC-40 China pump.

FIGURE 2: Results from a pumping event.



The task for the pump was to lift tail water back into the supply channel across a consistent Total Dynamic Head of 8m. The grower was concerned that the pump station wasn't performing efficiently when operated at high engine speeds 'as the engine sounds over stressed.' The data collected illustrates the diesel consumed for the amount of water moved at four different pump speeds. The importance of proper pump set-up and operation is highlighted by the drastic increase in fuel consumption, from 28 L/h to 41 L/h, when increasing the engine speed from 1494 RPM to 1704 RPM for only a modest increase in water flow rate of 0.4 ML/h. Reducing engine speed to 1494 RPM requires an additional 2.3 operating hours each day to accommodate for the slight reduction in water flow and will save 242 L of diesel each day. This is a 25 per cent reduction in operating cost. While at times it might be necessary to pump at a higher flowrate (and pump speed), alternative pulley ratios could be explored to better match the engine and the pump. Performing the pump test has provided the grower with the knowledge on how efficiently the pump station is operating plus the tools to allow for better management of the pump station.

Understanding the performance and cost of an operation can also allow an assessment of the cost and benefit of possible energy savings devices or different operating set ups.

What level of assessment do I use?

An energy audit can be started at any level. Often a Level 2 audit will be performed and this is used to target Level 3 investigations, but this is not always the case. The level of audit that is appropriate to you depends on what you want to get out of it and how much resources you have at the time.

Assessing greenhouse gas emissions (GHGs) from direct energy inputs

With increasing community concern about global warming and climate change, more of our cotton customers are demanding that their products are clean and green and are produced responsibly. This is particularly important for cotton because the direct energy consumption of the highly mechanised production systems contribute a significant portion of total GHG emissions. Other sources of GHG emissions in cotton production are from biologically generated soil emissions and from indirect emissions use. Indirect emissions are those related to the production of the fertilisers (particularly nitrogen) and chemicals used in production. Calculating GHG emissions may have strategic use to the cotton industry in the future through product labelling or where a carbon price is introduced. Fortunately, estimating GHG emissions for direct energy consumption is an easy process because diesel, electricity and all other energy sources have standard conversion factors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that convert litres or kWh into GHG emissions. These factors are built into EnergyCalc and are reported automatically. EnergyCalc uses the conversion factors published in the National Greenhouse Emissions Reductions Technical Guidelines, published by the Department of Climate Change & Energy Efficiency for direct energy use to greenhouse gas emissions.

On-farm energy use and GHGs

Work by the NCEA shows that on farm energy use ranged from 3.7 GJ/ha for raingrown to 15.2 GJ/ha for irrigated cotton, costing $80 to $310/ha. Diesel energy consumption ranged from 95 to 365 litres/ha, with most farms using between 120 and 180 litres/ha. Farms included in that study covered a range of farming regions and farming practices (eg. conventional tillage, minimum tillage, dryland farming, and irrigation across NSW and Queensland). GHGs emitted with this direct energy use were estimated to be between 275 and 1404 kg CO_2-e /ha. Raingrown cotton production is expected to be at the lower end of this range. It is important to note that these calculations only relate to GHGs from direct energy use, and have not included the (biological) effect due to soil tillage/disturbance and applications of nitrogen fertiliser which can be determined by the Cotton Greenhouse Gas Calculator. For irrigated cotton, average direct energy related greenhouse gas emissions can be equivalent to the emissions from fertiliser use. A focus on improving on-farm energy use efficiency can be as important in irrigated cropping systems as improving nitrogen use efficiency. For example, data contained in the Australian government's submission to the UN Framework Convention on Climate Change May 2010 (Australian Government, 2010) suggests that, in irrigated cotton, average direct energy related costs and greenhouse gas emissions (0.712 t CO_2-e/ha) appear to be equal to average costs and emissions from fertiliser use (0.67 t CO_2-e/ha).

Energy saving practices

In irrigated cotton enterprises, pumping water is often the operation that consumes the majority of on-farm energy (50 to 70 per cent). Significant efficiency gains can be made by optimising pump performance to provide reductions in diesel consumption. In some cases improved pump efficiency can lead to increased water flow rates. More timely irrigation and improved crop yield can result from assessment of in-field irrigation performances completed as part of this process.

It has been shown that moving from conventional tillage to minimum tillage offers saving of around 10 per cent of the fuel used on the farm, plus other production advantages. It has also been found that energy use associated with picking is also significant and may contribute 20 to 50 per cent of the total direct energy use (more so in dryland cropping systems). Ensuring equipment is well maintained and operating efficiently is particularly important for these high energy use operations. In studies monitoring tractor performance, the NCEA has found that by changing gear selection up and engine speed down, you can reduce energy use by about 30 per cent for the same power requirements. The integration of diesel–gas systems to reduce reliance on diesel fuel also shows considerable promise. In this system, LPG is injected into the diesel stream and this improves the efficiency of the fuel burn in the engine, resulting in fuel, cost and GHG savings.

For more information refer to:

The energy and greenhouse gas module in *my*BMP (www.mybmp.com.au).

CottonInfo and NCEA fact sheets and case studies on energy use efficiency, available from www.cottoninfo.net.au

References: CRDC – Spotlight Magazine winter edition 2009 – www.crdc.com.au

Australian Government (2011), National Greenhouse Accounts Factors, Department of Climate Change and Energy Efficiency.

Australian/New Zealand AS/NZS 3598:2000. Energy Assessments.

Precision ag

By **Claire Welsh** (Sustainable Farming Systems)

Acknowledgements: Andrew Smart and Brooke Sauer (Precision Cropping Technology)

Precision Agriculture (PA) refers to the integration of information, computing and sensing technologies to production-based agricultural systems. PA application enables increased detail (spatial resolution) and/or automation of agronomic and management practices; resulting in improved production efficiencies and profitability, whilst reducing input costs and minimising the unintended impacts on the environment.

The evolution of Australian cotton production systems to incorporate varying scales of PA based concepts, solutions and products, is considered by many as the "new normal". PA utilisation has provided producers with the objective information necessary to maximise the production potential and efficiencies gained via concurrent mechanical, chemical and biotechnology developments.

Development has resulted from commercial PA applications leveraging the availability, convergence, and widespread uptake of enabling technologies such as: The Global Positioning System (GPS), Geographic Information Systems (GIS), widespread 3G/4G internet access, smartphone operating systems, wireless sensor networks, cloud computing capacities, and automated systems including tractor and machine (M2M) communication controls.

With regards to cotton crop production, PA can be divided into two main areas:

1. **Spatial Control.** This includes implement guidance utilising GNSS (ie GPS), as well as remote monitoring and control.
2. **Site Specific Crop Management (SSCM).** Referring to the analysis of spatial agronomic and production data which is decision based.

Spatial Control products have been widely adopted; implementation is reasonably straightforward and benefits are easily quantifiable. Site specific crop management (SSCM) is PA applied to field and irrigated row crop production scenarios and requires a change of focus from managing average field conditions, to addressing within-field variations in yield limiting features.

SSCM aggregates multiple agronomic and production data sources, enabling the agronomist and/or manager to build knowledge and optimise crop production decisions, based on quantified in-field variability.

Where to begin?

Successful on-farm implementation of SSCM is a staged process and requires competencies above and beyond the application of spatial control technology. Implementation involves;

1. **OBSERVATION:** Deployment of GPS and sensor technology to locate, measure and capture data (production, climate, soil, topographic and as-applied data sets).
2. **ASSESSMENT:** Integration of multiple layers of collected sensor and location data, utilising GIS software to analyze data sets and make objective, agronomically sound management decisions.
3. **STRATEGIC RESPONSE:** Implementation of a timely, site specific management response, including quantification of results.

> **Best practice…**
>
> • **Talk to your agronomist about how precision ag could improve profitability for your enterprise.**

OBSERVATION: Understanding 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 metre of a 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, known as yield levers or yield limiting factors, and to comprehensively understand what site-specific combinations are present. Although not definitive, variation in yield quantity and quality across a field can be influenced by the following measurable agronomic, climatic and landscape factors:

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

OBSERVATION: 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.

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 dryland systems) and the identification of subsoil constraints and deep drainage or leakage areas.
- **Remotely sensed multispectral 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.
- **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.
- **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 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.

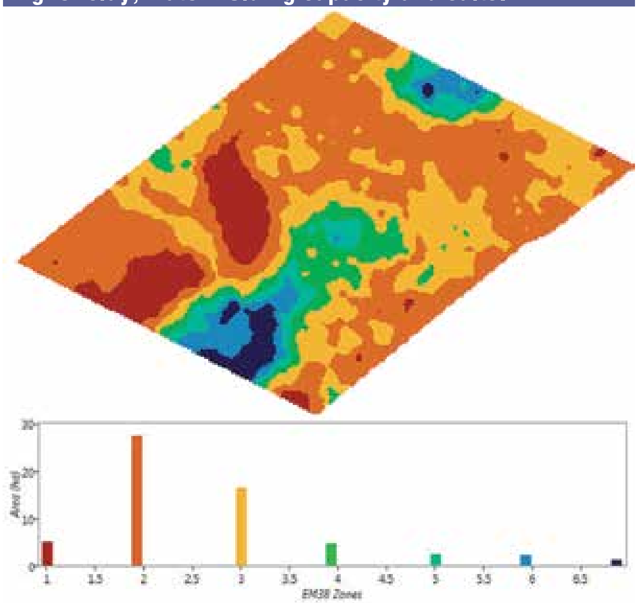


FIGURE 3: Airborne imagery captured on 15th December 2002 where the relative PCD values on the X axis indicate the amount of biomass: Red = low biomass and blue = high biomass. NB. At this time in the season this map is mainly used for in-crop growth management.

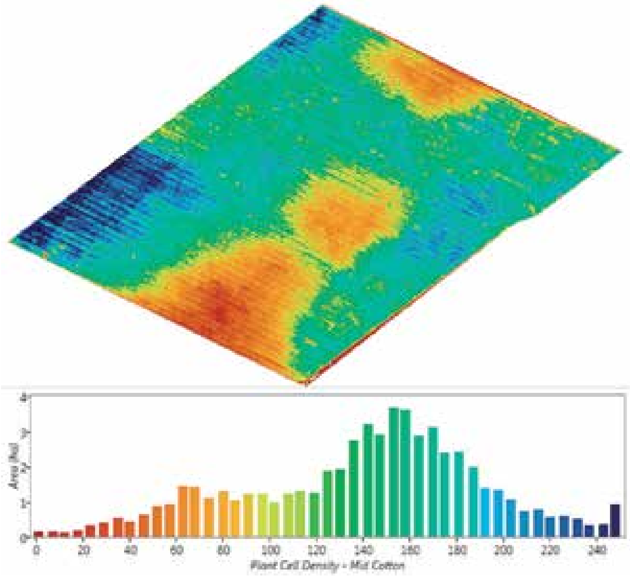


FIGURE 4: Slope% map created from an RTK tractor steering system where the X axis shows soil level above or below a "plane of best fit (0)" as a percentage (ie.15ha of this field is 0.05 per cent above the plane).

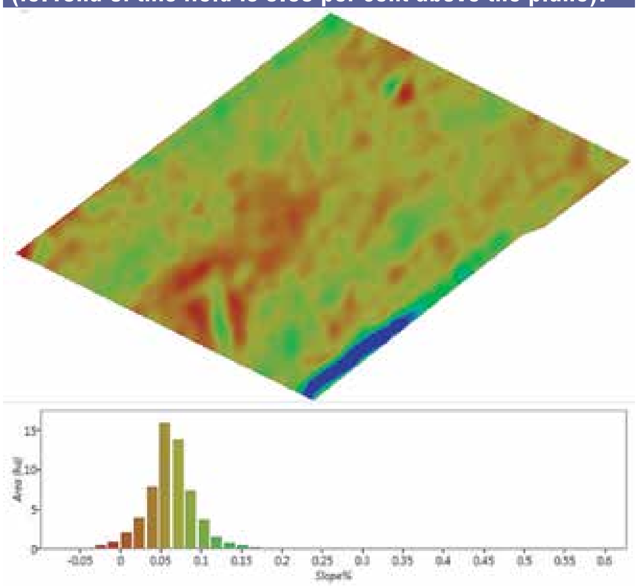
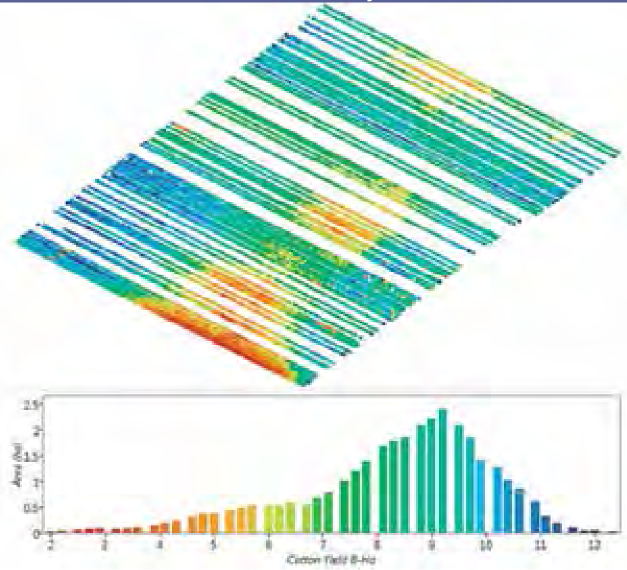


FIGURE 5: Cotton yield from an actual cotton yield monitor, where the x axis shows yield in ba/ha.



ASSESSMENT: Data considerations

Spatial data quantifying variability in both crop production and associated yield levers can be collected on a varying spatial scale from whole field to management zone and grid based sampling techniques. The value of such data can only be exploited once it has been processed and a meaningful (optimised) production decision has been made. The survey scale utilised (refer to Figure 6) will be largely dependent on the cost/benefit associated with an increased resolution of investigation.

Spatial data quantifying variability in both crop production and associated yield levers, can be collected on a varying spatial scale from whole field to management zone and grid based sampling techniques. The survey scale utilized (refer to figure 6) will be largely dependent on the cost / benefit associated with an increased resolution of investigation.

The value of crop production and associated data can only be exploited once it has been aggregated, stored, processed and analysed, to enable a meaningful or optimised production decision. Resultantly, a growing emphasis exists around the standardization & inter-operability of such data, usually collected across differing equipment manufacturers and often delivered by specialized third parties, to enable objectivity of analysis & decision making.

FIGURE 6: Spatial resolution of data sampling.

Assessment: Decision support and management zones.

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 (including "on-the-go" processing) or the division of a field into broader sub-units (eg. "management zones"). Use of spatial information layers for management decisions will reflect:

- The machinery and associated hardware/software 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).

Currently, industry consideration of the most practical approach is the identification and assessment of management classes within a field using relevant layers of information.

STRATEGIC RESPONSE: Creating and effecting differentiated management solutions

The adoption of a more intensive crop management strategy will have costs associated. In the following generalised adoption pathway (see Table 1), implementation has been structured to ensure maximum benefit is gained from the least additional cost, as each step involves new tools and techniques to be acquired and/or applied:

STRATEGIC RESPONSE: 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, dryland):** 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 & software suppliers (PCT, PrecisionAgiculture.com, BackPaddock, SST Software, AgWorld).

- Independent crop consultants (Crop Consultants Association).
- Machinery and specialist telemetry equipment retailers.

Acknowledgements: With recognition of the ideas and resources contributing to the development of this chapter by; Andrew Smart (Precision Cropping Technologies, Narrabri NSW), Brook Sauer (McGregor Gourlay Ag Services, Moree NSW), Mark Pawsey (SST Software, Brisbane QLD), Brett Whelan (ACPA USyd, Sydney NSW) and Tim Neale (PrecisionAgriculture.com.au, Toowoomba QLD).

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 analyze data layers.** Determine the major causes of variability in multi-year yield output, or for in-season crop growth.	• Analyze 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.

Integrated Pest Management & resistance management

By **Sally Ceeney** (CottonInfo),
Sandra Williams (CSIRO and CottonInfo) **&**
Susan Maas (CRDC)
Acknowledgements: Paul Grundy (QLD DAF), Grant Heron (NSW DPI), Lewis Wilson (CSIRO)

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.net.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 has been approved for commercial release in the Australian market. Bollgard 3 builds on the current 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 as the industry moves towards Bollgard 3, effective resistance management will continue to be critical to ensure the efficacy of this technology is maintained, both now and into the future.

The Bollgard II and Bollgard 3 RMPs

Bollgard II and Bollgard 3 are grown under separate and distinct RMPs. 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. In theory 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 for Bollgard 3 crops. In central and southern regions, the planting window has been widened to 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 both Bollgard II and Bollgard 3 crops in these regions sets specific planting dates (refer to each individual RMP for

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

full details). The RMPs in Central Queensland include requirements for all Bollgard II, Bollgard 3 and associated trap crops to be destroyed by a set date (refer to the RMP for details in *The Pest Management Guide*).

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. This strategy works because 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 (2016/17) RMP options for irrigated Bt refuges are:

- 100 per cent sprayed conventional cotton,
- 10 per cent unsprayed conventional cotton or
- 5 per cent pigeon pea (relative to the area of Bt cotton grown).

The current (2016/17) RMP options for 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).

In recent years almost 70 per cent of refuges grown have been pigeon pea. 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 growers ensure that 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 the 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 become exposed to the Bt proteins at a later growth stage when they can survive to produce offspring. This will lead to an increase in the frequency of resistant individuals in the population.

The same risk to resistance from increasing exposure to the Bt technology applies not only to Bt volunteers within refuge areas but also 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 excluded. 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 are destroyed and cultivated to kill the remaining larvae and 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.

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 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


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

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.net.au

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

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.


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

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.net.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 chapter.

Refer to the Cotton Rotation Tool. Available from www.cottoninfo.net.au

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.

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

WeedPAK

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 northern 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.

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

Vigorous, 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.

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 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.

A 'zero tolerance' approach to cotton volunteers between crops is an important IPM strategy

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.

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 chemical handling application management plan (CHAMP). Developing a CHAMP 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 CHAMP makes everyone involved in a pesticide application aware of their responsibilities.

A CHAMP 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 CHAMP. 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.

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

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.

Determining whether crop growth is optimal

Cotton development can be predicted using daily temperature data (day degrees). The CottASSIST Crop Development Tool (CDT) uses this knowledge to enable crop managers to check the vegetative and reproductive development of their cotton crops compared to a potential rate of growth and development. A crop manager can use this information as a prompt to further explore why the crop may not be on track, and manage the crop accordingly.

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.

Useful resources:

Collecting and recording data about insect pests is described in the Insects chapter of the 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.net.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, 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

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 and whitefly 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 efficacy can be 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, 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; and,
- 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.net.au

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: Dr Grant Herron, NSW DPI, 02 4640 6471

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

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

Defoliation

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 busting

In NSW and southern Queensland, *Helicoverpa* spp. spend the winter in the soil as pupae and emerge as moths in spring to mate and lay eggs. 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.

Chapter 12 sponsored by – eChem crop protection

Integrated Weed Management

By **Susan Maas** (CRDC)

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

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

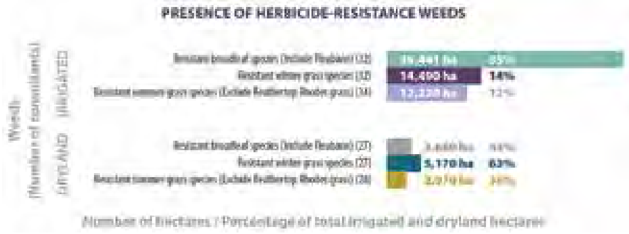
Herbicide resistance is normally present at very low frequencies in weed populations before the herbicide is first applied. Using the herbicide creates the selection pressure that increases the resistant individuals' likelihood of survival compared to 'normal' or susceptible individuals. The underlying 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.

Herbicide resistance has been confirmed in 39 grass and broadleaf species in Australia, across 11 distinctly different herbicide chemical groups (croplife.org.au) refer to Figure 1. Cases of multiple resistance have also been commonly reported. 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. In response to this issue the Australian cotton industry has developed a Herbicide Resistance Management Strategy. Refer to the Cotton Pest Management Guide for more information.

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.**

FIGURE 1: Herbicide resistance is a growing problem in both dryland and irrigated systems.
(source CCA 2014/15 qualitative survey)



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?

If you suspect herbicide resistance and require further information please refer to the Cotton Pest Management Guide or discuss with your agronomist or your regional CottonInfo team member.

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

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.

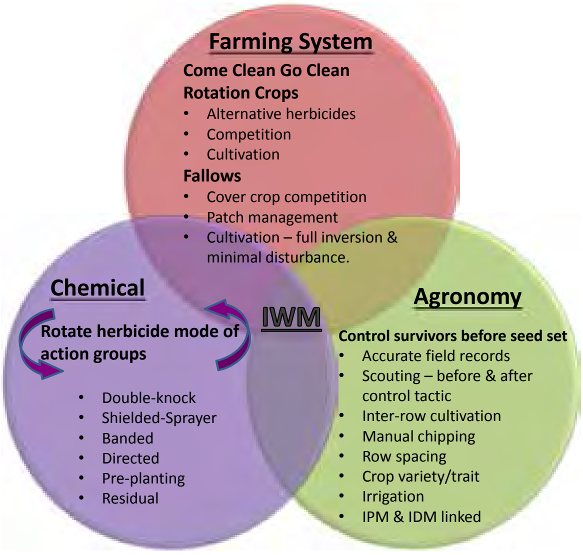
There are five principles in developing a successful long term approach to weed management:

- 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 prevent 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 below.

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.

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



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.

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

Identify and closely monitor areas where machinery such as pickers and headers breakdown. Weed seeds are often inadvertently released when panels are removed from machines for repairs. 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 reinfestation 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. For all fields, maintain records of cropping history and weed control methods and their effectiveness after every operation. Consider the records from past years in this year's decisions, particularly in relation to rotating herbicide modes of action and safe plant back periods for residual herbicides.

Timely implementation of tactics

Often the timeliness of a weed control operation has the 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.

TABLE 1: Guide to the critical period for weed control to prevent 2 per cent yield loss.

Weed Type	Weed Density/ 10m 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)

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 1 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.

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. 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.

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.

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 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, especially control of all weed survivors will be critical to 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

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Often the timeliness of a weed control operation has the largest single impact on its effectiveness. Early scouting and identification of weeds is important. Flaxleaf fleabane seedling.
(Photo courtesy of G.Charles, NSW DPI)

will fail to germinate once row closure occurs, and many small weeds will not receive enough light to compete with cotton plants and 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.

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 evolution 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 can be unsuitable to apply post-emergence, as very little herbicide gets to the roots.

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 nonselective 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 or short duration residual herbicides can be used to control germinating weeds while they are young and actively growing.

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 WeedSeeker technology should refer to APVMA permit PER11163 for allowable uses. A total of 30 different herbicides are listed on the permit, some being non-residual and others with short or longer term activity in the soil. Seven different herbicide mode-of-action groups are represented, enabling growers to effectively rotate their chemistry.

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, and so usage should consider potential weed species and density for at least the previous 12 months.

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, 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

Tillage & cultivation

Inter-row cultivation

Inter-row cultivation can be used mid-summer to prevent successive generations of weeds from being targeted by post-emergent herbicides.

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 & 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 to ease weed pressure in-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 (1–3cm) 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 20mm. 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

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

seed, chipping has been shown to be a cost effective means of preventing survivor seed set.

Bury seed of surface-germinating species

Use strategic cultivation to bury weed seeds and prevent their germination. Some weed species, such as common sowthistle (milk thistle), Feathertop Rhodes grass and flaxleaf fleabane, are only able to germinate from on or near the soil surface (top 20mm). 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 20mm 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 2).

TABLE 2: 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

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.**

Come Clean Go Clean

To minimise the entry of new weeds into fields, clean down boots, vehicles, and equipment between fields and between properties. 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 look out 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.

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) and Ngaire Roughley (formerly QLD DAF and CottonInfo)

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.

Best practice…

- **If an exotic pest or disease is suspected, contact your State Agriculture Department or the Exotic Plant Pest Hotline 1800 084 881.**
- **Follow good farm hygiene practices (Come Clean Go Clean) to minimise the movement of pathogens onto and off your farm and spread of diseases on farm.**
- **Conduct effective monitoring, and mapping of diseases and disease trends across the farm.**
- **Where possible, select disease resistant varieties.**
- **Control volunteer and ratoon cotton plants at all times throughout the year to minimise disease carryover.**
- **Incorporate appropriate cultural and agronomic management tactics specific to the diseases present on the farm.**
- **Be aware of insect vectored diseases and the management of these insects is performed according to industry thresholds.**

Sowing date/temperature

Sowing in cool and/or wet conditions favours disease. Where possible, delay planting until soil temperatures are at least 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.

Australian upland cotton are completely resistant to Bacterial blight, however some old Pima varieties are still susceptible.

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

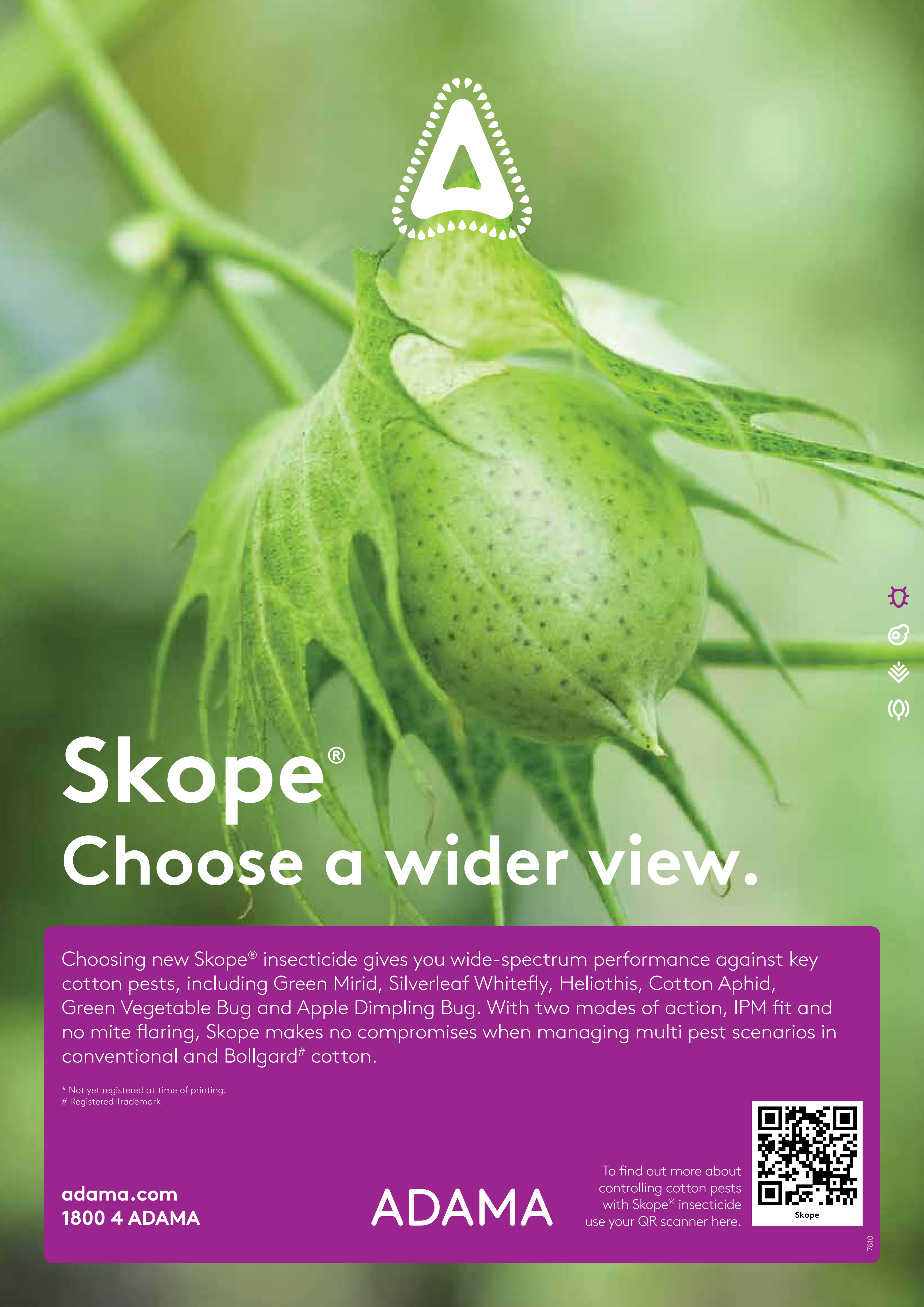
Fungicides

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 Pima cotton.

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

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


Skope®
Choose a wider view.
Choosing new Skope® insecticide gives you wide-spectrum performance against key cotton pests, including Green Mirid, Silverleaf Whitefly, Heliothis, Cotton Aphid, Green Vegetable Bug and Apple Dimpling Bug. With two modes of action, IPM fit and no mite flaring, Skope makes no compromises when managing multi pest scenarios in conventional and Bollgard# cotton.
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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.

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. Excess nitrogen 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 and where they occur by conducting a disease survey in November and February of each season. Monitor and record to allow comparison over time of disease presence in fields (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 disease strain.

QLD DAF pathologist, Linda Smith – (07) 3255 4356 or 0457 547 617.

NSW DPI pathologist, Karen Kirkby – (02) 6799 2454 or 0428 944 500.

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

- 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

- 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 disease 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 40cm) 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/sites/default/files/tools/cottonRotation/index.html.

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.

Come Clean Go Clean

Minimise the risk of moving diseases on or off your farm, from field to field or farm to farm by considering vehicle movements within the farm and having a strategy for ensuring clean movement of vehicles 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.net.au and www.mybmp.com.au

CottonInfo youtube video: Keep your farm free from pests, weeds and diseases: Come Clean Go Clean https://www.youtube.com/watch?v=gR8hf8-hYOA

Best practice...

- **Ensure that a wash-down facility is available.**
- **All machinery, vehicles and equipment are inspected for any soil and plant debris, cleaned in the wash-down facility before moving on and off your property.**
- **A sign-posted designated parking area is provided for visitors and contractors 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. These pests will impact on your business so you need to make sure that Come Clean Go Clean is part of your business.

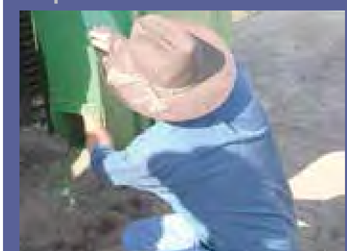
Step 1: Wash-down

Park on a clean wash down pad where contaminants can be trapped. Apply 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: Decontaminate

Apply decontaminant (eg. 10 per cent water dilution of Farmcleanse (Castrol) or Bio-Cleanse (Queensland Cleaning Solutions)) liberally to all surfaces especially areas that were dirty including mats, tools and footwear. Leave the decontaminant to work for 10 minutes unless directed otherwise by the label. (Photo courtesy Susan Maas, CRDC)

Step 3: Final Rinse



Rinse decontaminant. Clean all mud off the pad with high pressure water so it is clean for the next person and that mud & debris isn't picked up by wet tyres. Where equipment has not been cleaned down on farm, thoroughly inspect to ensure cleanliness. (Photo courtesy Susan Maas, CRDC)

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 technical specialist Sharna Holman – disease & volunteer/ratoon cotton management (0477 394 116).

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	Airborne 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.	Airborne and waterborne spores, infected crop residues.	Airborne or waterborne spores, infected crop residues, seed borne dispersal.	Airborne or waterborne spores, infected crop residues.	Waterborne spores (including rain splash onto bolls), infected crop residues.	Airborne 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	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.	Non-host	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.	Non-host	Increases risk	Increases risk
Cotton (ie. back to back)	Non-host	Survives in crop residues. Incorporate infected residues early.	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 variety V rank. Incorporate infected residues early. Fields with long history of cotton at higher risk.	Increases risk	No resistant varieties available, increases risk.
Faba beans	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.	Non-host	Increases risk	Decreases risk when resistant varieties are grown
Long fallow	N/A	Decreases risk if crop residues incorporated.	Decreases risk in weed free fallows	Decreases risk if 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 nematode can survive for long periods in dry soil
Maize	Decreases risk	Decrease	Non-host	Decreases risk	Non-host; repeated use may decrease	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Decreases risk	Decreases risk	Non-host

Continued page 76

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.	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.	Non-host	Increases risk	Increases risk
Pigeon pea	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.	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.	May increase – listed as a host in QLD	Increases risk	Non-host
Sorghum	Increases risk	Decreases risk	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.	May increase risk – listed as a host in QLD.	Increases risk	Decreases risk when resistant varieties grown
Sunflower	Increases risk	Decreases risk	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.	May decrease with resistant varieties.	Increases risk	Increases risk
Vetch	Planting into freshly incorporated, unweathered residues may cause allelopathy.	Survives in crop residues. Incorporate infected residues early.	Non-host	Decreases risk	Biofumigant when incorporated	Increases risk in crop residues – a saprophyte. Incorporate infected residues early.	Non-host	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.	Non-host	Decreases risk	Non-host

Red shaded box = Potential disadvantage. Green = Generally positive interaction. Yellow = Cautionary note.

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. 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.

Loss of groundcover and species diversity favours the establishment of weeds. Many of the annual broadleaf weeds of cropping, such as

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.**
- **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)

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.

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.

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. 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.

Consider the impact of water quality on irrigation equipment as well as soils. (Photo courtesy of Cotton Australia and Tim Haffey)

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 & 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).

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

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.

Monitor groundwater levels

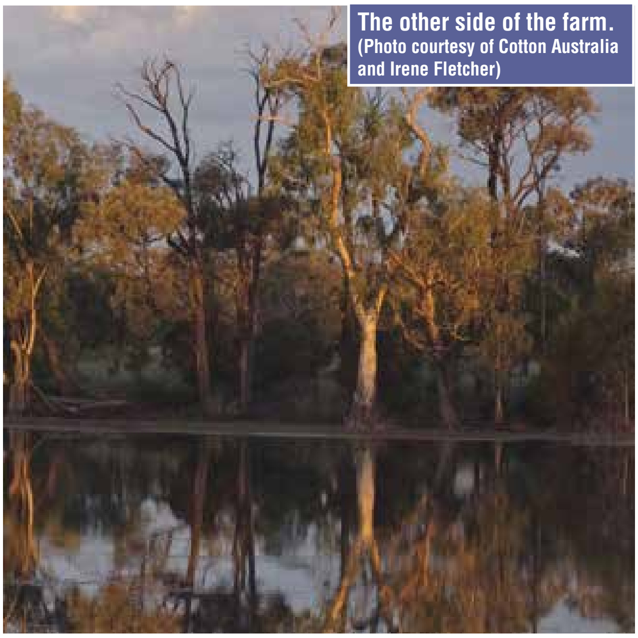
Groundwater levels can change over time, where an aquifer may either gain or lose water, with local influences often overriding regional trends. Falling groundwater levels have significant implications for farm and catchment water availability, whereas rising water tables pose significant salinity risks.

Reducing the risk of deep drainage

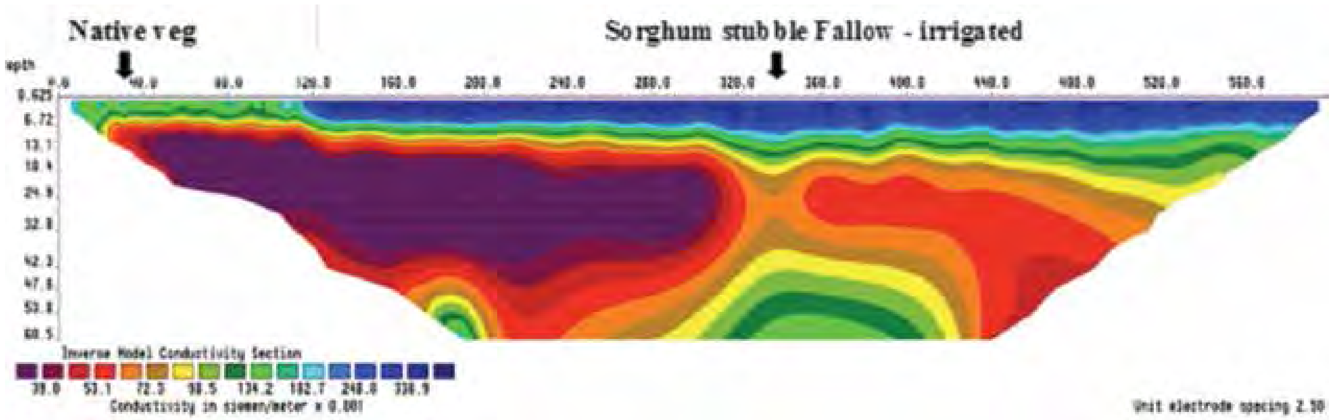
Deep drainage is the movement of water beyond the root zone of crops. It varies considerably depending on soil properties and irrigation management, and is not necessarily 'very small' as believed in the past. Rates of 100 to 200mm/yr (1–2ML/ha) are typical, although rates of 0 to 900mm/yr (0.03 to 9ML/ha) 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; and,
- Raising of water levels in shallow groundwater systems.



The other side of the farm. (Photo courtesy of Cotton Australia and Irene Fletcher)



Electrical resistivity tomography transect running from native vegetation into fallow irrigated paddock in the Central Condamine Alluvia (tail drain at 120 m). Blue colour indicates highly wet and conductive clay layers. (WATERpak 1.5 Deep-drainage)

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 minimize 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.net.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 (https://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

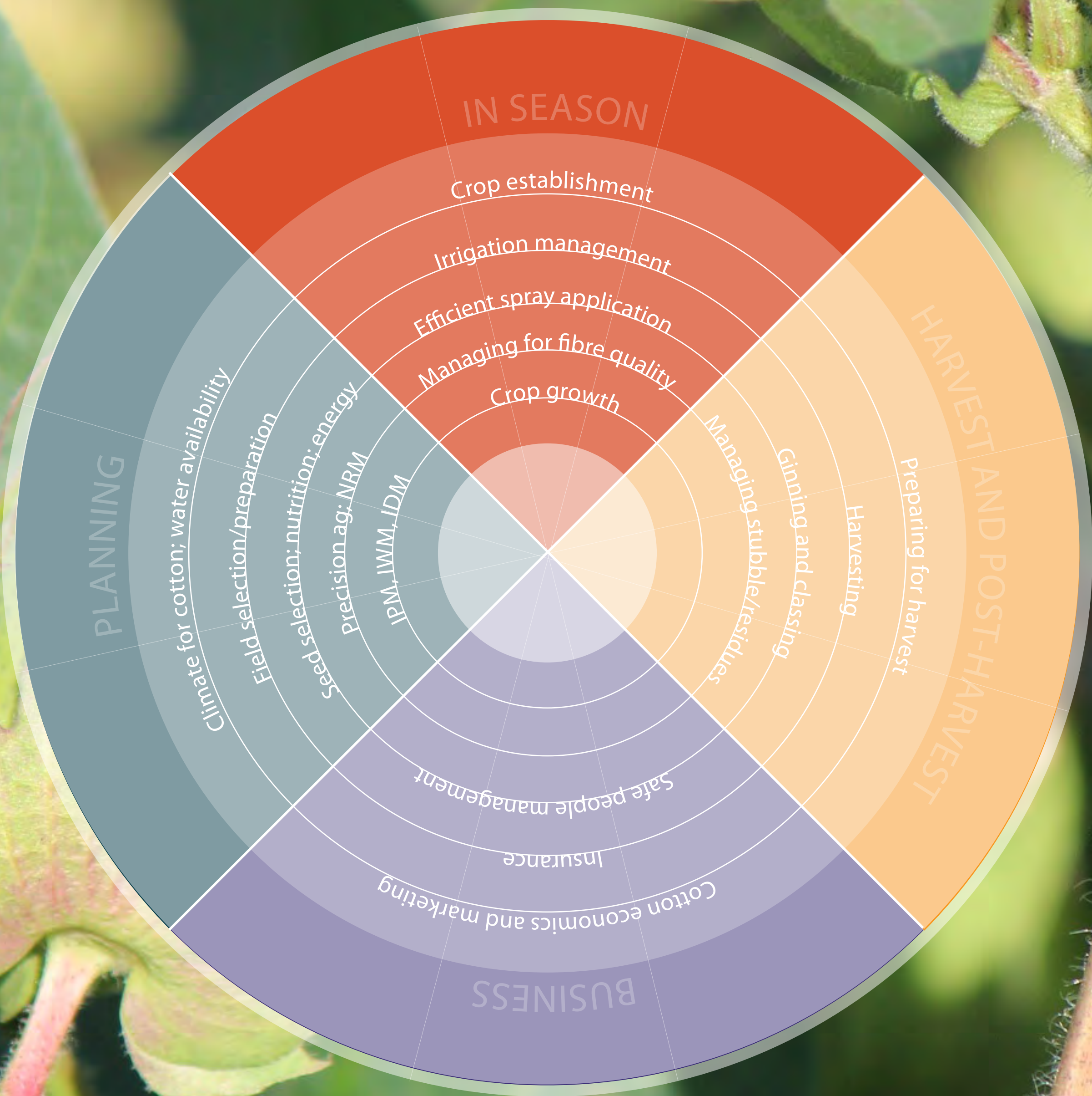


Photo courtesy Ruth Redfern

Chapter 15 sponsored by – DuPont Pioneer

Crop establishment

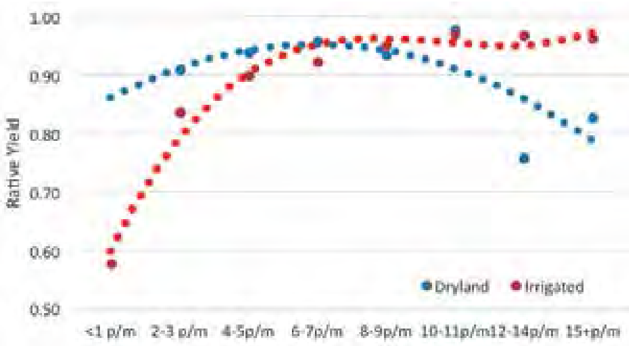
By **James Quinn** (CSD)

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 dryland 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 (28 trials) and Dryland (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 dryland or marginal conditions.
- Where you normally grow a larger plant size that can compensate well into gaps in the plant stand (e.g. in wetter, warmer climates and good soil types).

Best practice…

- **Planting outside the ideal conditions and the planting window for your district may require special management.**
- **Some varieties have lower seedling vigour 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 average seeds/kg for each variety is printed on the bag and also available on the CSD website.

Germination data: All CSD seed has a minimum germination of 80% at the point of sale. Germination data both Warm and Cool Test Data for individual lots are available on the CSD website or contacting CSD's E&D 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 CSD 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 50cm – 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

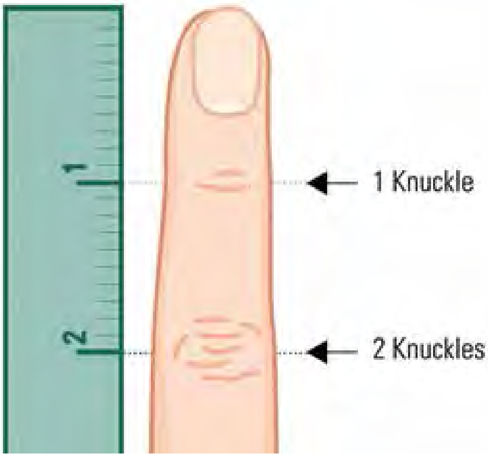
Ensure planter is well serviced and operational well before planting time because breakdowns in the field can rob you of time and allow surface soil moisture to further dry away:

- 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.



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

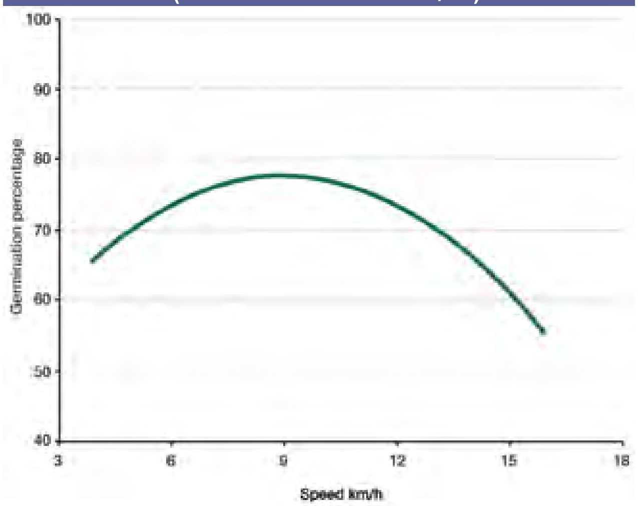
- This method has advantages in hot climates, because it cools the soil and crop establishment is rapid. However, consider pre-irrigating when:
  1. There is a large seed bank of difficult to control weeds.
  2. The soil is very dry and temperatures are high.
- Any shallower than 2½cm and the plant doesn't 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).



PROVEN:
INCLUDING CORN IN YOUR COTTON PROGRAM INCREASES YOUR COTTON YIELD

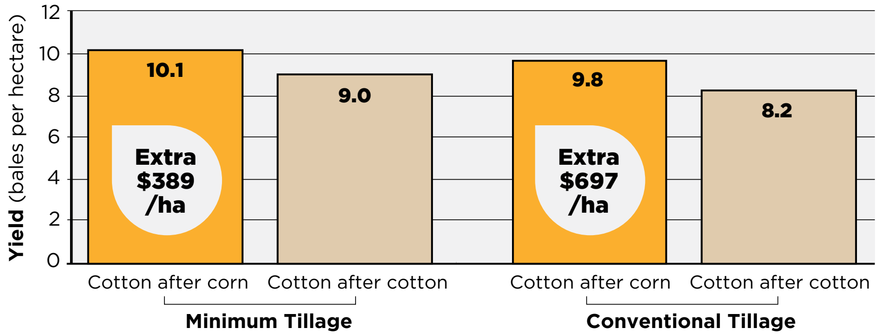
> Research conducted by NSW Department of Primary Industries using Pioneer® brand corn has highlighted the benefits of including corn as part of a cotton rotation.

> Yield increases in the corn rotation ranged from 12 per cent through to more than 21 per cent and added significantly to the gross margin.

> Soil organic carbon was higher after corn than cotton in the surface of on-farm sites AND there was an increase in carbon in the sub-soil at depths of 60cm or more.

> Cotton root systems after corn went deeper and were much more extensive so were able to access extra moisture and nutrients.

CORN IN A COTTON CROP ROTATION



CORN YIELDS HIT 17.38T/HA ON DALBY PROPERTY

James and Dan Hayllor of Dalby, Qld use corn, in rotation with cotton, on the Darling Downs, in Queensland.

Over the past two seasons high yields have been achieved with Pioneer® hybrid P1756 and the corn will be grown next year as well.

"It was amazing. We averaged about fifteen and a half across the paddock but then we did a yield trial for a full half a hectare and got 17.38 tonnes to the hectare."

"We like cotton but we like corn too," Mr Hayllor said. "We use it for the rotation. We grow forty hectares a year just to improve our cotton yield and we are seeing between half to three-quarters, sometimes up to a bale, increased production in the cotton."

"At the yields we've got this year, it is going to be quite interesting to see the bottom line. I'm thinking it's comparable."

Picture: Dan and James Hayllor, of Dalby, QLD, increased their average corn yields by one tonne per hectare with Pioneer® hybrid P1756.

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DRV_J3449

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

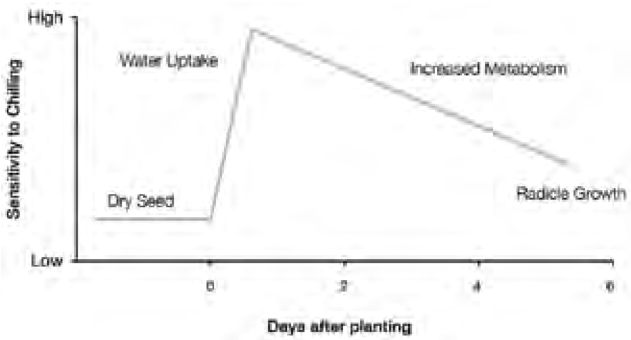
The ideal planting time will vary between seasons and districts.

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 10cm depth, at 8.00am. 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 33 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!**

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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 10cm	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 II and 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)

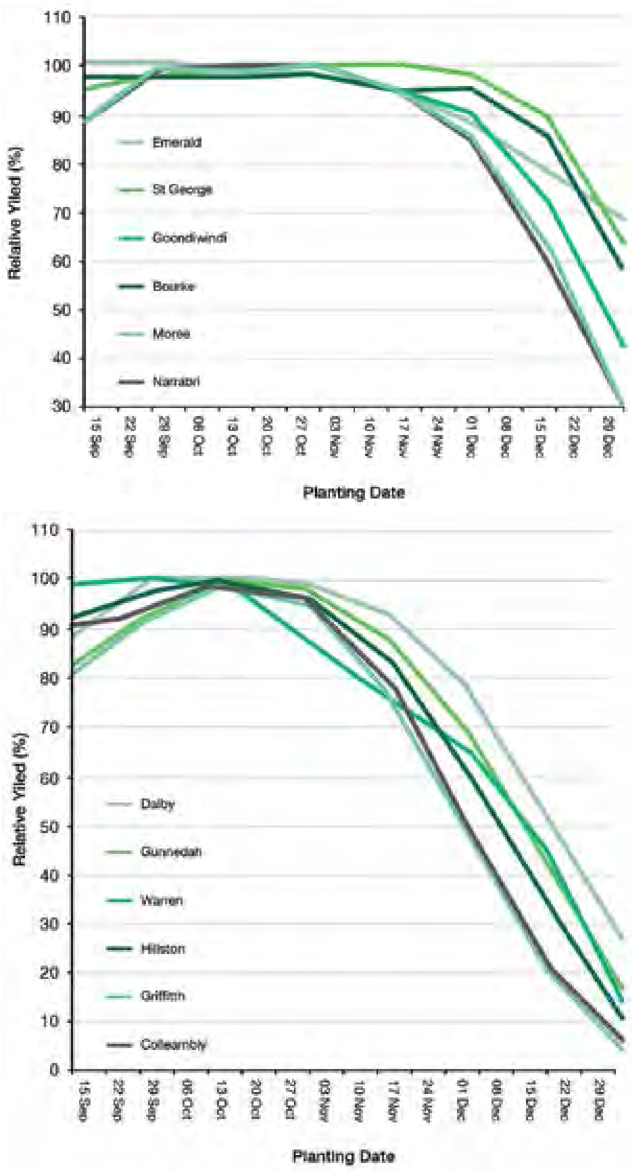
Where season length allows, planting slightly later has a lot of advantages:

- It will increase the likelihood of warm temperatures at planting, resulting in increased seedling survival and vigor.
- 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 II or 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 2.5cm, 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 dryland 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 vigor of the young seedlings need to be monitored closely as an early first irrigation may be required.

Do I need to replant?

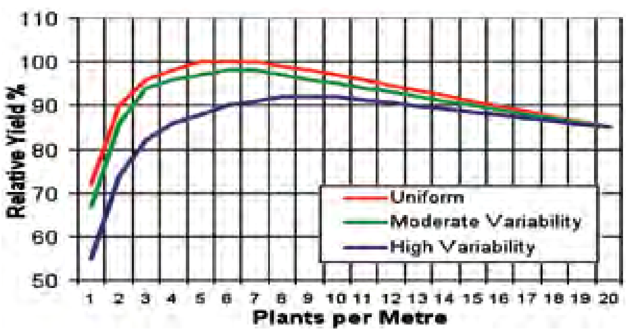
The decision as to whether to replant or not is sometimes a straightforward decision, and other times not. The obvious question is "will I achieve a better result with the plants I've got or should I start again?"

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 50cm 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 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.
- **Fertilizer 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 **Janelle Montgomery** (NSW DPI and CottonInfo), **Lance Pendergast** (QLD DAF) & **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 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. Boll growth exerts large demands for carbohydrates and it is through the balance between boll demand and leaf production that vegetative growth is restricted.

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.

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.**

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)


AS SOLID AS THE
GROUND IT STANDS ON.
valleyirrigation.com
VALLEY

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 does 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 – https://www.youtube.com/watch?v=08vnL2sT3io

WATERpak Chapter 3.4 Impact of waterlogging on cotton

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. Growers can use the crop development tool on the CottASSIST website (www.cottassist.com.au) to track their crop.

Dryland 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

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

current varieties, (eg Bollgard II) 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.

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

Useful resources:

CottonInfo video: First Irrigation – https://www.youtube.com/watch?v=T-aqy2Tr70s

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<5mm/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. Use the Crop Development Tool on the CottASSIST website (www.cottassist.com.au) to help keep track of how the crop is progressing.

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,
- Predicting 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. The Last Effective Flower Tool, available on CottASSIST website www.cottassist.com.au/, will provide the number of days between cut-out and defoliation.

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 mositure.

At the time of first open boll, crop water use may be 5-7mm/day, but this can decline to only 3-4mm/day during the last 2 to 4 weeks prior to defoliation. If roots are extracting to a good depth (at least 1m) 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 150mm soil moisture, which is equivalent to 25 to 30 days water use (5mm/day) with little effect on yield or quality.

Therefore on most cotton soils unless water use is above 5mm/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 – 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.

- Use CottASSIST Last Effective Flower Tool to determine the predicted or desired date of last effective flower (cut-out).
- 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:

WATERpak, Chapter 3.2 Managing Irrigated Cotton Agronomy.

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

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. Growers can use the crop development tool to track their crop.

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.

Useful resources:

WATERpak Chapter 3.1 Cotton growth responses to water stress.

WATERpak, Chapter 3.2 Managing Irrigated Cotton Agronomy.

www.cottoninfo.com.au/sites/default/files/documents/WATERpak.pdf#page=273

Late season irrigation management
www.cottoninfo.com.au/blog/late-season-irrigation-management

Water running short? How do we manage our irrigations? www.cottoninfo.com.au/blog/water-running-short-how-do-we-manage-our-irrigations

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

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) http://weather.irrigateway.net/aws/index.php
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 https://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 IriSAT for irrigation scheduling – https://www.youtube.com/watch?v=ccvJizT4lw0

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:

Webinar: https://www.youtube.com/watch?v=u4MOqBrdkHc

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 > 5mm/day (lower deficits) and improve water use efficiency by reducing the need for irrigation during periods of low evaporative demand, ETo < 5mm/day, (larger 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

IrriSAT http://www.agronomy2015.com.au/951

Crop Canopy Temperature Sensors https://scisoc.confex.com/scisoc/2014am/webprogram/Paper88636.html

Dynamic Deficits www.regional.org.au/au/asa/2012/soil-water-management/8066_brodrickr.htm

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)

Acknowledgements: 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.

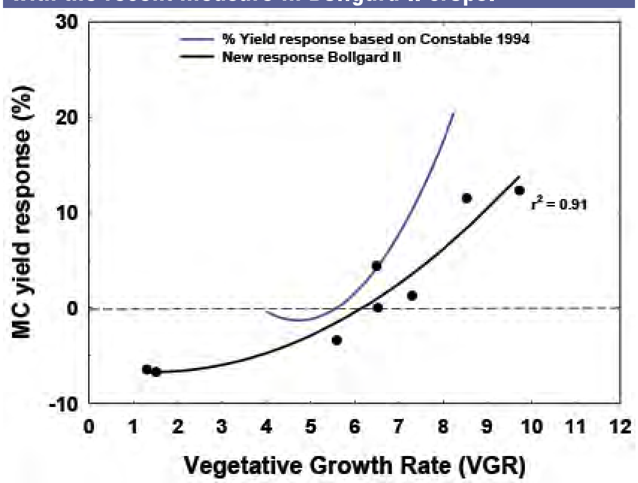
GA belongs to a group of plant hormones, Gibberellins, which are natural growth regulators in plants. They play an important role in stimulating plant cell wall loosening which allows stretching of the wall by internal pressure. This is known as cell expansion and is one mechanism allowing a plant to 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 (refer to Figure 1) 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-Bollgard cotton with the recent measure in Bollgard II crops.



Yield

Recent research has been conducted to investigate the response between Vegetative Growth Rate (VGR) at early flowering and % yield response to MC in Bollgard II cotton. Our results have shown a positive yield response to applying MC 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 Bollgard II have been more severe than previously measured on non-Bollgard 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:

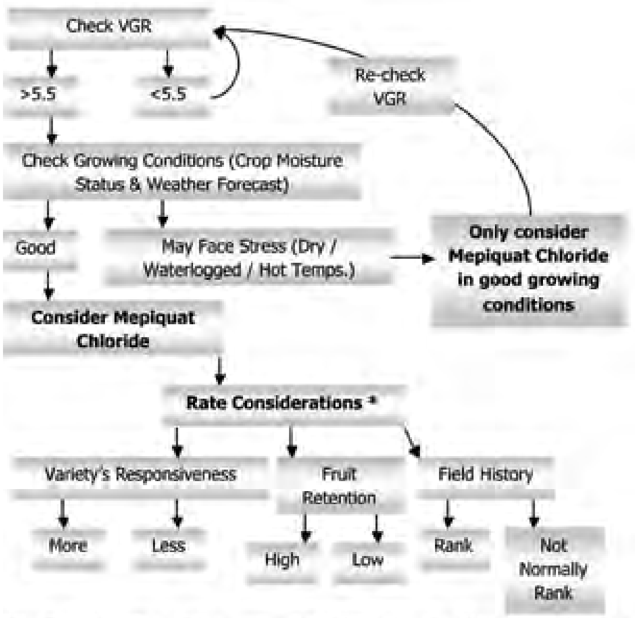
- Ensuring a timely harvest to avoid adverse weather conditions;
- Allowing an effective defoliation to reduce trash content; and,
- Reducing the amount of immature bolls that may increase the incidence of neps.

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. These dates can be predicted for all locations across Australia using the last effective flower tool on CottASSIST (www.cottassist.com.au).

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.

Plant height and node information can be entered into the CottASSIST Crop Development web tool which calculates the VGR and compares this number to the ideal range for the crops growth stage.

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

Mepiquat Chloride manages excessive vegetative growth by shortening internodes and reducing leaf area to restore the balance between reproductive and vegetative growth.

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.

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 Bollgard 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. Refer to the Crop Development Tool on CottASSIST site.

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.

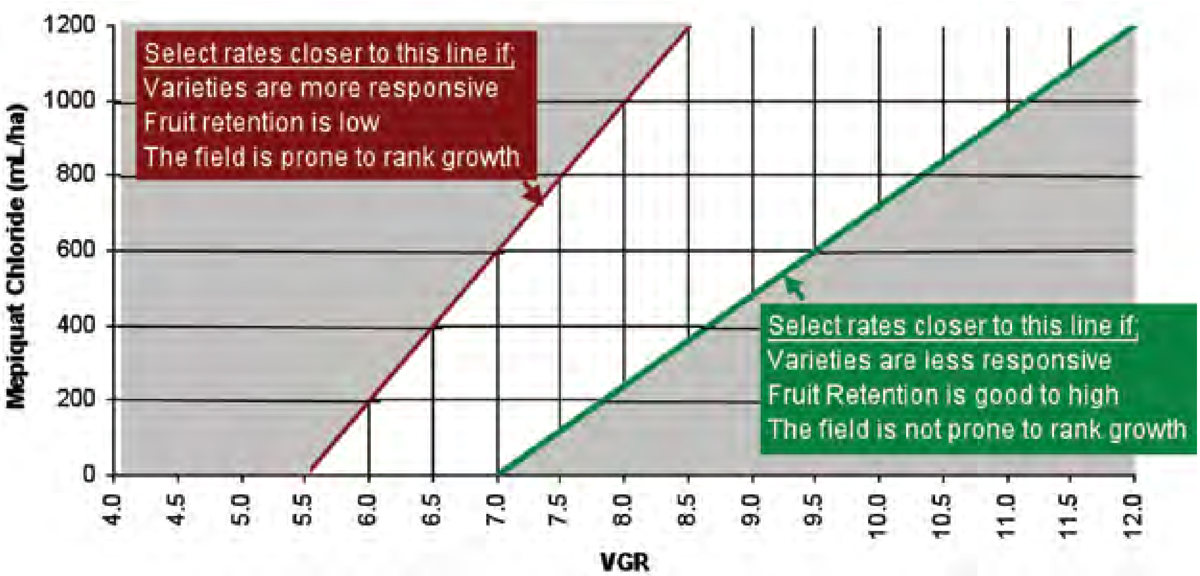
Variety

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

FIGURE 2: Mepiquat Chloride requirement graph incorporating VGR and other factors. Rates assume Mepiquat Chloride formulation of 38 g/litre. (Source: CSD)



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 600–1000mL/ha).

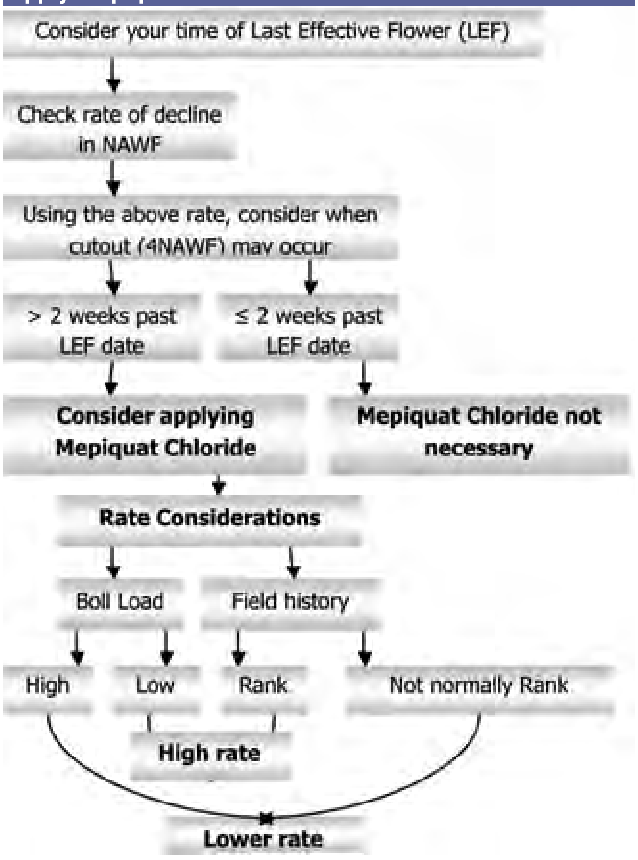
Example two: A crop has a VGR of 6, good fruit retention, the field has no history of rank growth and information from the seed company has indicated that the variety is not greatly responsive to Mepiquat Chloride, therefore using Figure 2 applying Mepiquat Chloride may not be a benefit, although monitoring 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. These decisions are generally made in late January for most regions or about 3 weeks before the last effective flower (LEF) date. The LEF date can be determined by using the CottASSIST Last Effective Flower Tool (LEFT) or from local experience (refer to Flowchart 2).

FLOW CHART 2: Cut-out Decision Tree – This cut-out chart is designed to help with late season decisions to apply Mepiquat Chloride.



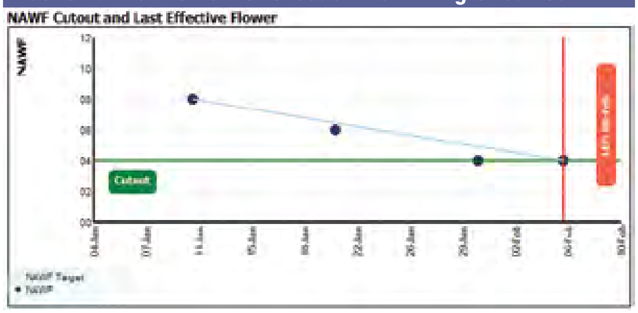
Monitoring NAWF – late season

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.

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. NAWF counts can be entered into the CottASSIST Crop Development web tool to plot the rate of decline on a chart and compare this with the optimal rate of decline.

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. Figure 3 is an example NAWF chart produced by the CottASSIST Crop Development Tool. This chart has been designed to allow users to define their own target line based on measurements and the Last Effective Flower date for their location. In this example, the NAWF measurements 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.net.au, www.mybmp.com.au and www.cottassist.com.au

- **FIBREpak**
- **CottASSIST (Crop Development Monitoring and Last Effective Flower Tool)**

Cothren JT (1995). Use of growth regulators in cotton production. Proceedings of the World Cotton Research Conference – 1: Challenging the future. Brisbane, Australia. Feb 14-17, 1994. GA Constable and NW Forrester (Editors). CSIRO: Melbourne, pp 1-3.

Constable GA (1995). Predicting yield responses of cotton to growth regulators. Proceedings of the World Cotton Research Conference – 1: Challenging the future. Brisbane, Australia. Feb 14-17, 1994. GA Constable and NW Forrester (Editors). CSIRO: Melbourne, pp 6-24.

Kerby, TA (1985). Cotton response to Mepiquat chloride. Agronomy Journal. 77, 515-518.

Kerby, TA, Hake, K and Keely, M (1986). Cotton fruiting modification with Mepiquat chloride. Agronomy Journal. 78, 907-912.

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 **Bill Gordon & Mary O'Brien** (Cotton Australia)

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. The aim of spray application is to transfer active ingredients through the atmosphere to the target in an effective manner with minimal off-target losses. Application technique needs to be matched to the target and weather conditions.

Always read and follow the label when handling and applying chemicals. Label conditions may specify spray quality, 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.

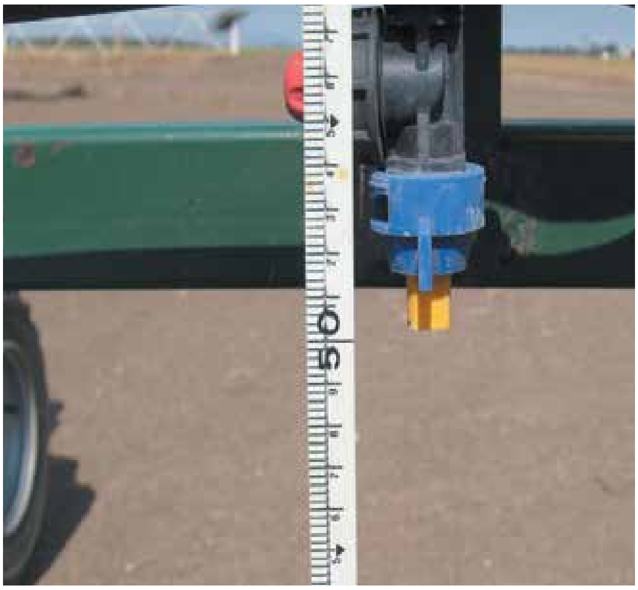
Summary of practices that influence spray efficiency (reduce spray drift)

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 50cm above the target to 1m 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.

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.**



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.**

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.**

FIGURE 1: Effect of atmospheric stability.

Smoke	Condition	Notes	Spray?
	NEUTRAL (e.g. morning)	Cool breeze (4–15 km/h) Optimum spray conditions.	✔
	UNSTABLE (e.g. afternoon)	Hot. Low windspeed, thermal activity. Risk of upward movement of fine droplets.	✗
	INVERSION (e.g. night)	Low windspeed. Hot during day. Risk of significant off-target deposition of fine droplets.	✗
	STABLE (e.g. dusk)	Low windspeed. Risk of off-target spray deposition.	✗

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: Fact sheet Water Quality, Fact Sheet: Spray Mixing Order**

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**

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 to Spraywise Boom Spray Hygiene – cleaning procedures.

***my*BMP resources: Nufarm Spraywise Decontamination Guide**

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 and LI700 can actually reduce drift potential. 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.

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 down 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 lower volatility than the low volatile ester forms. Even products with low volatility are still susceptible to droplet and particle drift.

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 websites at either www.spraywisedecisions.com.au or www.weather.syngenta.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**

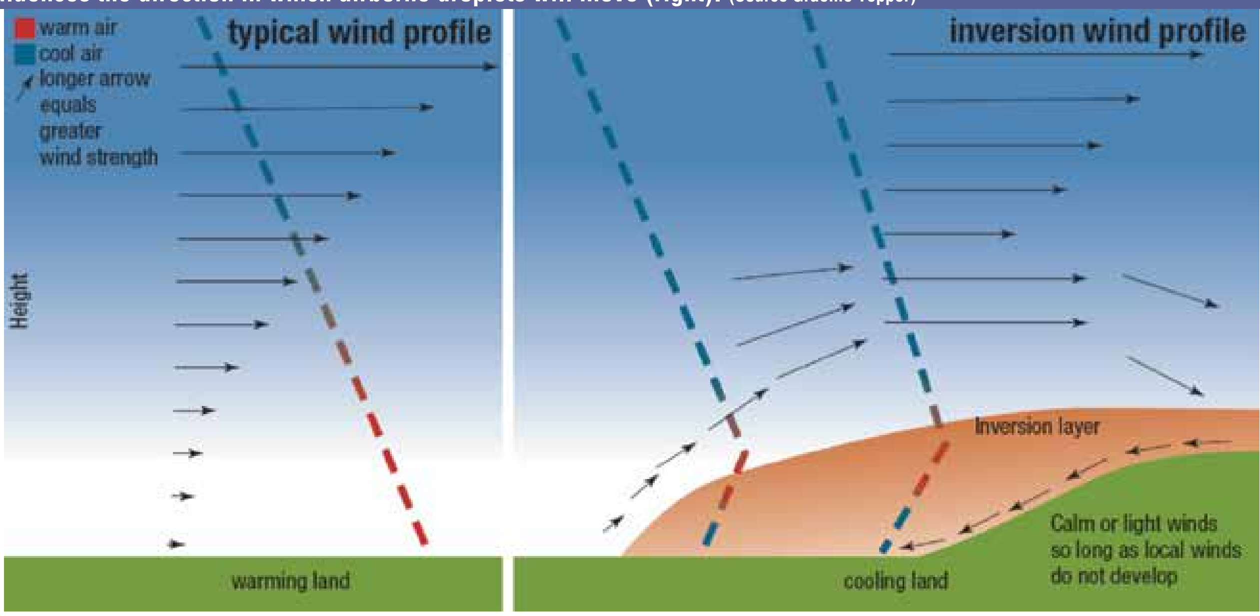
Temperature and humidity

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. 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). Never start a spraying operation when the delta T is below 2 or above 10–12.

***my*BMP resources: Tips for reducing drift fact sheet**

FIGURE 2: 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.

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 2).

Use visual indicators such as moisture, smoke and dust to determine if an inversion is present. Other clues include occurance of mist, fog, dew or a frost or if the wind stops blowing, or is constantly less than 11km/hr in 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 (refer to Figure 1).

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.

Useful resources:

"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 http://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 & 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 0.7m band** ÷ 1m 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 1m row = 0.7m ÷ 3 = 0.23m).

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 1m row spacing (only planted 1 out of every 2 rows), this would be the same as only spraying 12 x 1m rows with a 24m 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 1m row at 100 per cent band would be 1m ÷ 5 = 0.2m.

If you had 4 nozzles per 1m row and a 70 per cent band, then the average sprayed width would be 0.7m ÷ 4 = 0.17m.

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.net.au**
- **GRDC fact sheets on:**
  - **Spray Mixing Requirements**
  - **Spray Water Quality**
  - **Preseason 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**
  - **www.weather.syngenta.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**

Spraywise Boom Spray Hygiene – Cleaning Procedures

Always check labels for specific cleaning and decontamination procedures.

GROUP	CHEMISTRY	PRODUCTS	CLEANING PRODUCT
A	Dims	Sequence	Tank and Equipment Cleaner
	Fops	Nugrass	
B	Imidazolinones	Midas® Arsenal Xpress, Spinnaker Intervix®, Raptor®	Small amount of Tank and Equipment Cleaner or water
	Sulfonyl Ureas	Associate®, Lusta®, Monza® Nugran®, Sempra	Chlorine Bleach
C	Triazines	Nu-Trazine 900 DF Convoy® DF Diuron 900 DF	
		Flowable Diuron, Flowable Simazine	
		Nu-Tron 900 Df, Prometyrn 900 DF, Simazine	
	Benzonitriles	Bromicide 200	
D	Dinitroanilines	TriflurX, Rifle 440	
F	Phenoxynicotinanilides	Paragon, Nugrex	
G	Diphenyl Ethers Trialolinones	Striker, Affinity®, Hammer®	Alkaline Detergent 'Omo®' or 'Spree®'
I	Benzoic Acids	Kamba 500, Comet 200, Conqueror	Tank and Equipment Cleaner
		Invader 600	
	Phenoxy Acetic Acids		
	Mcpa (Dimethylamine)	Agritone 750	Cloudy Ammonia followed by Tank and Equipment Cleaner
	Mcpa (Ethyl Hexyl Ester)	Bromicide MA, Nugrex, Paragon	Tank and Equipment Cleaner
	Mcpa (Iso-Octyl Ester)	Broadside, Agritone LVE	
	Mcpa (Potassium Salt)	Trooper®	
	2, 4-Db	Buttress®	Cloudy Ammonia followed by Tank and Equipment Cleaner
	2, 4-D (Dimethylamine And Diethanolamine)	Surpass 475, Amicide 625	
	2, 4-D (Dimethylamine	Baton®, Kamba M, Surpass 475	
	2, 4-D (Ethyhexyl Ester)	Estercide Xtra	Tank and Equipment Cleaner
	Pyridines	Archer	
J	Thiocarbamates	Avadex® Xtra	Small amount of Tank and Equipment Cleaner or water
K	Chloroacetamides	Bouncer	
L	Bipyridls	Revolver, Nuquat 250	Water
M	Glyphosate	Roundup, Roundup Biactive Roundup CT Roundup PowerMAX®, Roundup Ready Herbicide with PLANTSHIELD, Weedmaster Duo	
Q	Triazoles	Amitrole, Illico®	Small amount of Tank and Water Equipment Cleaner or water
Z	Arylaminopropionic Acids	Mataven 90	

Source: Spraywise Broadacre Application Handbook, Nufarm Australia Ltd, 2008.

Chapter **19** sponsored by – AUSTRALIAN CLASSING SERVICES

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.

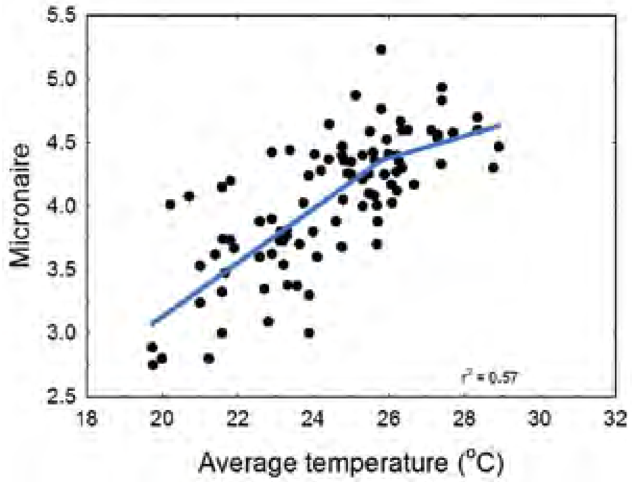
Fibre length and micronaire are significantly affected by agronomic and climate effects, but fibre strength is more influenced by variety choice. Fibre growth and development is affected by most factors which influence plant growth. Since the fibre is primarily cellulose, any influence on plant photosynthesis 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 micronaire. The equation from this linear regression is used in the Micronaire Predictor Tool in CottASSIST (www.cottassist.com.au).

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.



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.

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 different tillage or rotation systems and insect damage causing compensation and 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 Table 2.

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

- **FIBREpak Chapters 7 to 11**

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.**

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 12.7mm.	<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 4.9.	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. For premium fibre >34 grams/tex.	Small premiums for values above 29 g/tex. Discounts appear for values below 27 g/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. 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	Trash refers to plant parts incorporated during harvests, which are then broken down into smaller pieces during ginning.	Low trash levels of <5 per cent	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 process 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 do not absorb dye and appear as '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.

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.		
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.	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

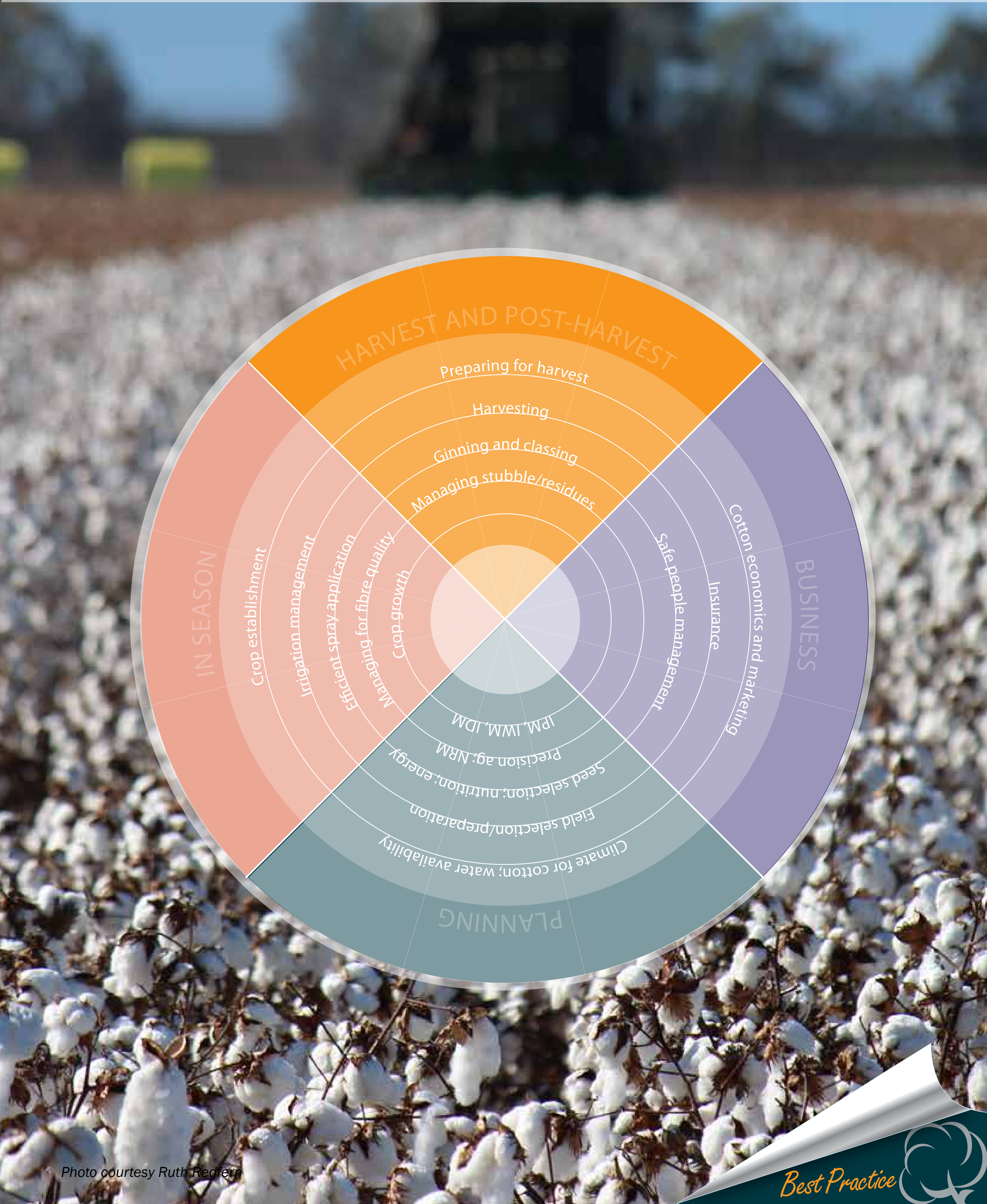


Photo courtesy Ruth Redfern

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. NAWF = 4 to 5 is generally the accepted time of cut-out.

Use the CottASSIST Crop Development Tool to assist you to track your crop's rate of cut-out compared with the optimal rate.

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). This can be determined through the CottASSIST Last Effective Flower Tool. Crops approaching cut-out too slowly can indicate that there has been a loss of fruit and/or plenty of water and nutrition. These crops should be monitored to determine if a growth regulant is necessary. Use the CottASSIST Crop Development Tool to check your VGR (Vegetative Growth Rate). 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.

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 by the CottASSIST Last Effective Flower Tool (www.cottassist.com.au) 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

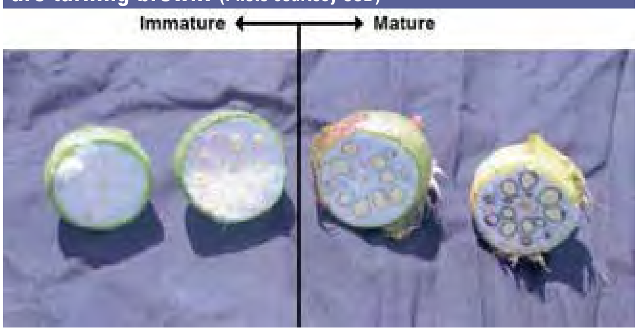
Note that as the date of last harvestable boll is delayed the time for last effective flower is not increasingly delayed. This is especially the case for cooler growing regions.

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.

FIGURE 1: Bolls that are mature have seed coats that are turning brown. (Photo courtesy CSD)



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; and,
- 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 (refer to Figure 1); and when the fibre is pulled from the boll it is stringy (moist but not watery).

See also Timing of Harvest Aids following.

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 can 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.

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.

TABLE 2: Dates of first frost for cotton production.
(Source: http://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

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 or use the last effective flower tool on the CottASSIST website which can be used to identify the timing of first frost for your locality.

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 2). 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) – Desiccants are contact chemicals that cause disruption of leaf membrane integrity, leading to rapid loss of moisture, which produces a desiccated leaf. Desiccants should be avoided as they dry all plant parts (including stems) which can increase the trash content of harvested lint. Sometimes it is necessary to use desiccants if conditions do not enable the effective use of defoliants (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

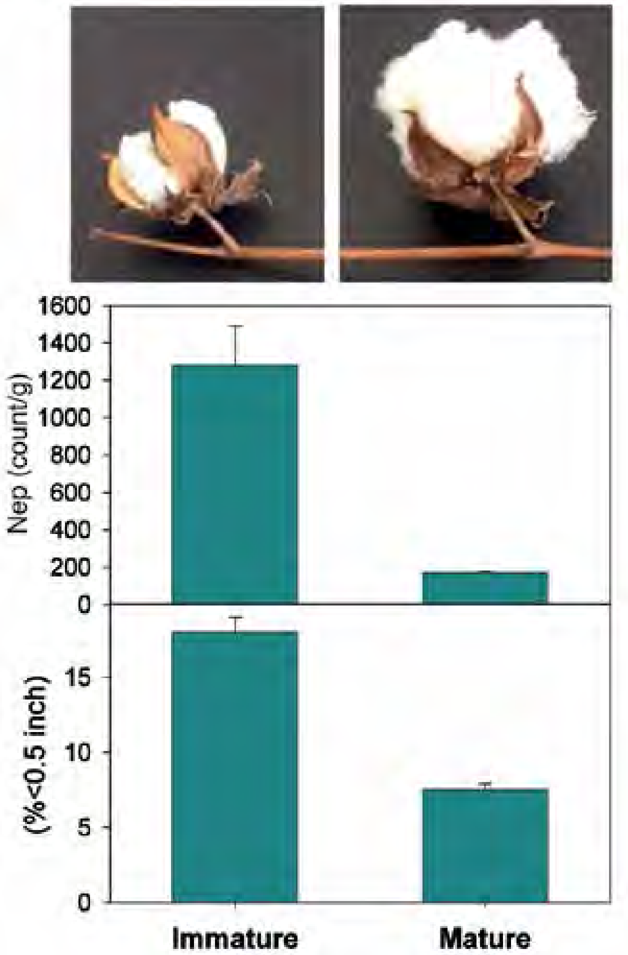
The type of defoliation product is unlikely to impact on fibre quality if timing is correct, but early defoliation can cause a significant reduction in all desirable fibre properties. Too early defoliation will increase the number of bolls (often from the top of the plant) harvested that have immature 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.

FIGURE 2: 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)



- 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.net.au)**
- **CottASSIST (www.cottassist.com.au)**
- **Cotton Pest Management Guide (available from www.cottoninfo.net.au)**
- ***my*BMP (www.mybmp.com.au)**

Harvesting & delivering uncontaminated cotton

By **Rene van der Sluijs** (CSIRO)

Acknowledgement: Geoff Dunlop

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 and 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, a non-selective type harvester, which 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. Plant height should not exceed 1.2m for cotton that is to be picked and 0.8m 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. But many issues will apply to both picked and stripped 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.

(Photo courtesy of Cotton Australia and Joanne Ambrose)

- 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% or less 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 alternative harvesters by Case IH and John Deere with on board module building capacity which 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 the John Deere (JD) 7760; and the recently released CP690 harvesters have harvested in excess of 90% of the total crop for the last 3 to 4 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






John Deere 7760 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 John Deere)

engineered polyethylene film that both protects the seed cotton and provides compressive force to maintain the module density. Despite the 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.

The round modules are covered with an engineered polyethylene film that both protects the seed cotton and provides compressive force to maintain the module density. 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 minimize contact with those rows.
- Gap between the underside of the module and the ground should be sufficient and never be less than 15cm 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.
- Avoid placing the module on cotton stalks, as the movement of the modules on the stalks can puncture the plastic wrap. If possible, avoid staging in areas where the truck cannot access the modules if rain occurs.
- When staging round modules together for transport or for storage at the gin, lift the module 30cm or more above the ground. A lower position can result in stalks tearing the exposed wrap on the bottom.
- When placing modules together for transport, a gap should be left between each module.
- 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 +/- 13cm band. If not properly aligned, the wrap may be damaged by the sidewalls of the module truck.
- 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 102mm and 203mm 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 mold 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 which will assist the carrier to avoid misalignment of modules on the trailer that could cause 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 create 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 the 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 utilized 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 http://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. 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, mean and upper half mean 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.

Typically cotton is too moist for harvest at dawn in Australia 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, e.g. 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 the round modules produced by the JD 7760 and CP690 spindle harvesters and the CS690 stripper are smaller in size in comparison to traditional modules which means that there will be 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.
- 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.
- Seed cotton measured on a moisture meter should be <12%. Note: hand held moisture meters are usually ± 1% accurate
- 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

There are two types of contamination:

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. Many of these natural contaminants can be avoided with careful management and good agricultural practices both prior to and during harvest.

Man made contaminants – Synthetics such as plastic and twine, oil, hydraulic oil, grease, pieces of metal and equipment as well as food wrappers, drink bottles, mobile phones and cleaning rags can also find their way into a grower's module. Mostly these manmade contaminants can be eliminated. Trial markers (pink tape etc) are a source of contamination and should be removed prior to 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 (mybmp.com.au)**

FIBREpak (www.cottoninfo.net.au)

Chapter 22 sponsored by –

Beyond the farm gate

Ginning

By **Rene van der Sluijs** (CSIRO)

Acknowledgements: Michael Bange, Greg Constable, Stuart Gordon, Robert Long and Geoff Naylor (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.

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).**

A ginner has two objectives:

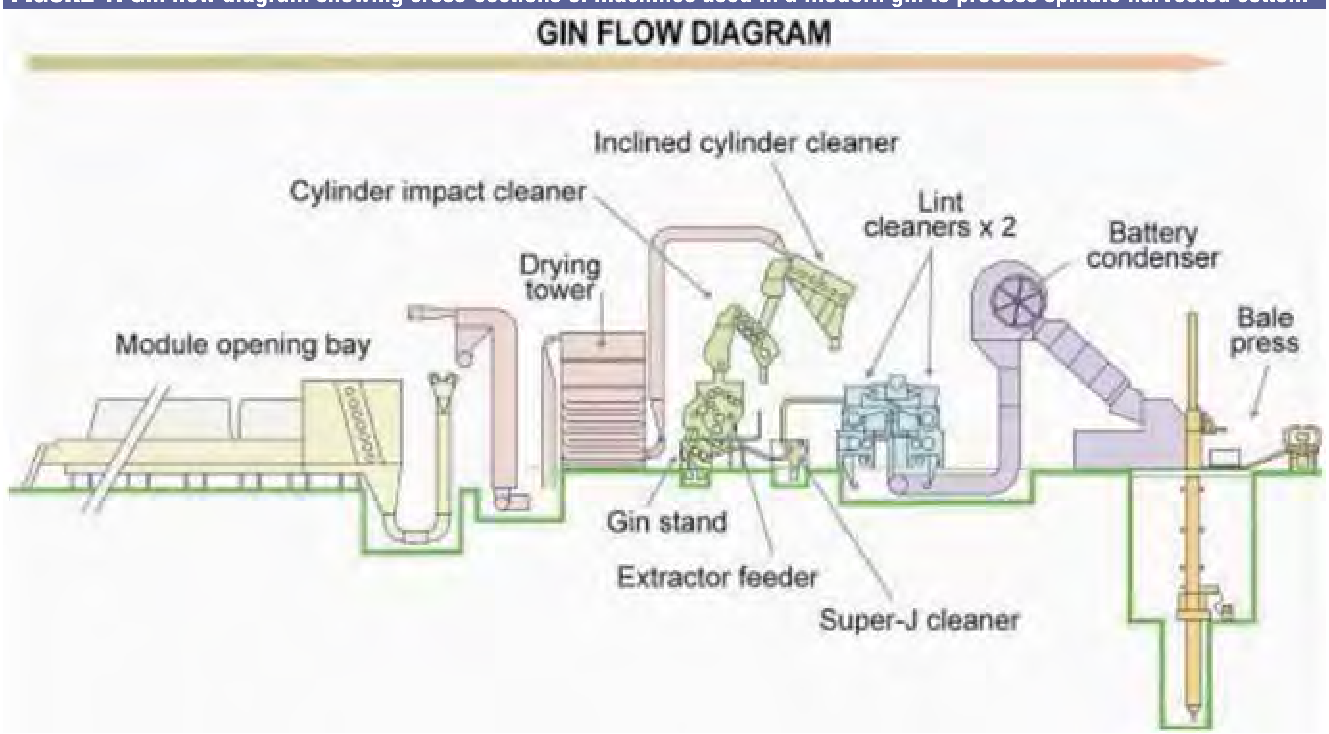
- To produce lint of satisfactory quality for the grower's classing and market system; and,
- To gin the cotton with minimum reduction in fibre spinning quality so the cotton will meet the demands of its ultimate users, the spinner and the consumer. The spinner would prefer fibre without trash, neps 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.

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

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 on modules. Appropriate bale covering/wrap. Storage and handling to avoid damage.

FIGURE 1: Gin flow diagram showing cross-sections of machines used in a modern gin to process spindle harvested cotton.



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 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; and,
- The size and moisture of the module are appropriate.

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

Acknowledgements: Helen Dugdale (formerly CRDC), John Stanley (UNE), Australian Classing Services

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 could 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 which 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.

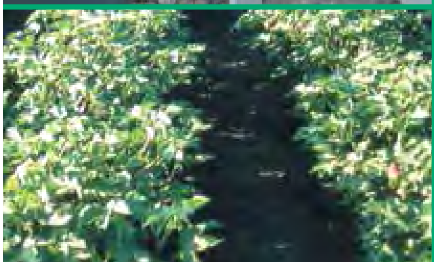
Currently in Australia. classer's grade is still used to describe colour, leaf, extraneous matter (any substance other than fibre and leaf, such

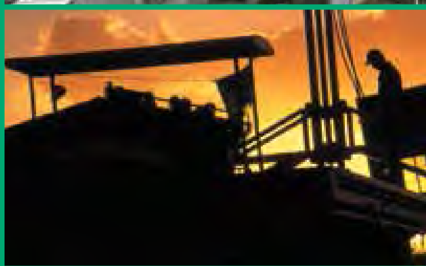
Best practice…

- **Classing is a complex process, whilst this chapter gives an overview, a more detailed understanding can be gained from visiting your nearest classing facility.**








as bark, grass, seed coat fragments, oil etc) and preparation (degree of smoothness or roughness of the cotton sample), with moves underway to replace the visual determination of colour by HVI colour.

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 quality characteristic may influence the price. Some of the key quality characteristics are outlined below:

- Colour
- Leaf
- Preparation
- Staple Length
- Micronaire
- Strength

Colour

The colour of a sample is currently measured visually by a trained cotton classer. The true colour can only be assessed under specific light conditions and via comparison to a 'standard' sample of universal standards provided by the USDA.

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 5 (highest amount of trash), with level 3 as 'base grade'.

Staple length

Length is measured on a sample of fibres known as a 'pull' when hand classing, and is measured to the nearest 1/32 inch. HVI determine length in 100ths and in 32nds of an inch or on a 'beard' or tuft of lint formed by grasping fibres with a clamp. Australian cotton is all classed using HVI measurements. 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").

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; and,
- Early cut-out due to frost, hail, disease or early defoliation.

Common causes of high micronaire include:

- Poor boll set;
- Small boll size due to hot weather or water stress; and,
- 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.

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); and,
- ≥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;

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

- Sugars (honeydew);
- Neps; and,
- Short fibre (fibres shorter than 12.7mm or 0.5 inch).

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 Index (SFI); and,
- 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.net.au)

Managing cotton stubble/residues

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

Acknowledgement: Ngaire Roughley (formerly QLD DAF and CottonInfo)

As well as being the first step towards preparing a field for the next crop, destruction of current crop residues is important for the management of insect 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.

Mulching and root cutting

The Australian cotton industry has moved away from the practices of stubble removal and burning ('pull, rake and burn') and now promotes the practice of slashing the stalk above ground and cutting the root below cotyledon height, and then incorporating crop residues 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. It is important to avoid cutting stalks down too finely, as decomposition and nutrient release may occur too quickly, leading to the loss of nutrients such as nitrogen.

The efficiency of root cutting is maximised when machinery is run at a greater speed, ensuring roots are cut below the cotyledon level. 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. This system is often preferred as residue is more easily broken down and incorporated than slashing, and weather conditions have less of an impact than on rake and burn operations.

The mulch and root cut system has been widely proven and is available in a variety of configurations, but can be costly due to the operation and maintenance cost of extra machinery components, which are often heavy and expensive to run.

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).

Crop residue management is also an important management practice in preparing a suitable seedbed for optimal germination and establishment in back to back cotton crops. Systems that work very well include mulchers operated at a slower speed with extra flails added (used in photo 1) and the

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.**
- **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.

use of rotary hoe machines either before centre/side busting operations or after the fertiliser operations have been completed. This has been shown to further increase the soil tilth and ensure a good seed bed prior to planting.

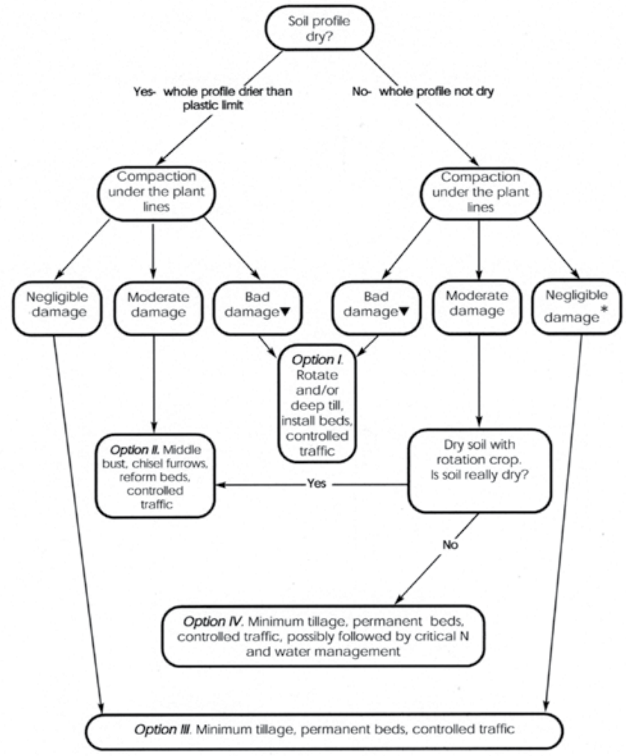
Standard slashing

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.

Pull, rake and burn

Another practice no longer recommended for crop residue control, as raking can spread diseased inoculum. This option is generally only used when growers are looking to re-laser fields and due to minimal cuts are seeking to avoid stubble becoming an issue with the laser buckets. Burning of cotton stalks should be avoided as nutrients and soil carbon will be lost .

FIGURE 1: 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

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, fencelines, channels, culverts and around sheds and other infrastructure.

For more information on volunteer cotton plants in the farming community visit www.youtube.com/cottoninfoaust.

Two youtube videos from CottonInfo: Checking the farm for volunteer cotton – https://www.youtube.com/watch?v=9C2Utf5mUxkRogue cotton plants in the farming community
https://www.youtube.com/watch?v=CJP14_swggE

Ratoon cotton

Ratoon (regrowth/stub cotton) is extremely difficult to control with herbicides as there is a small leaf area for herbicide absorption compared to the large root system available for carbon and nutrient supply. There are no registered products available for control of ratoon cotton, and physical removal, broadacre cultivation or chipping individual plants, is often the only option where 100% destruction has been achieved. These plants are 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 mandatory requirement of the Bollgard 3 Resistance Management Plan (RMP) and a key recommendation for conventional cotton under the Insecticide Resistance Management Strategy (IRMS). Bollgard 3 , however does have a slightly different requirement for pupae destruction depending on the location of the crop. Refer to www.monsanto.com.au for further details. For further information on pupae control refer to the Integrated Pest Management and resistance management chapter.

Useful resources:

***my*BMP at www.mybmp.com.au**

CottonInfo at www.cottoninfo.net.au

Business

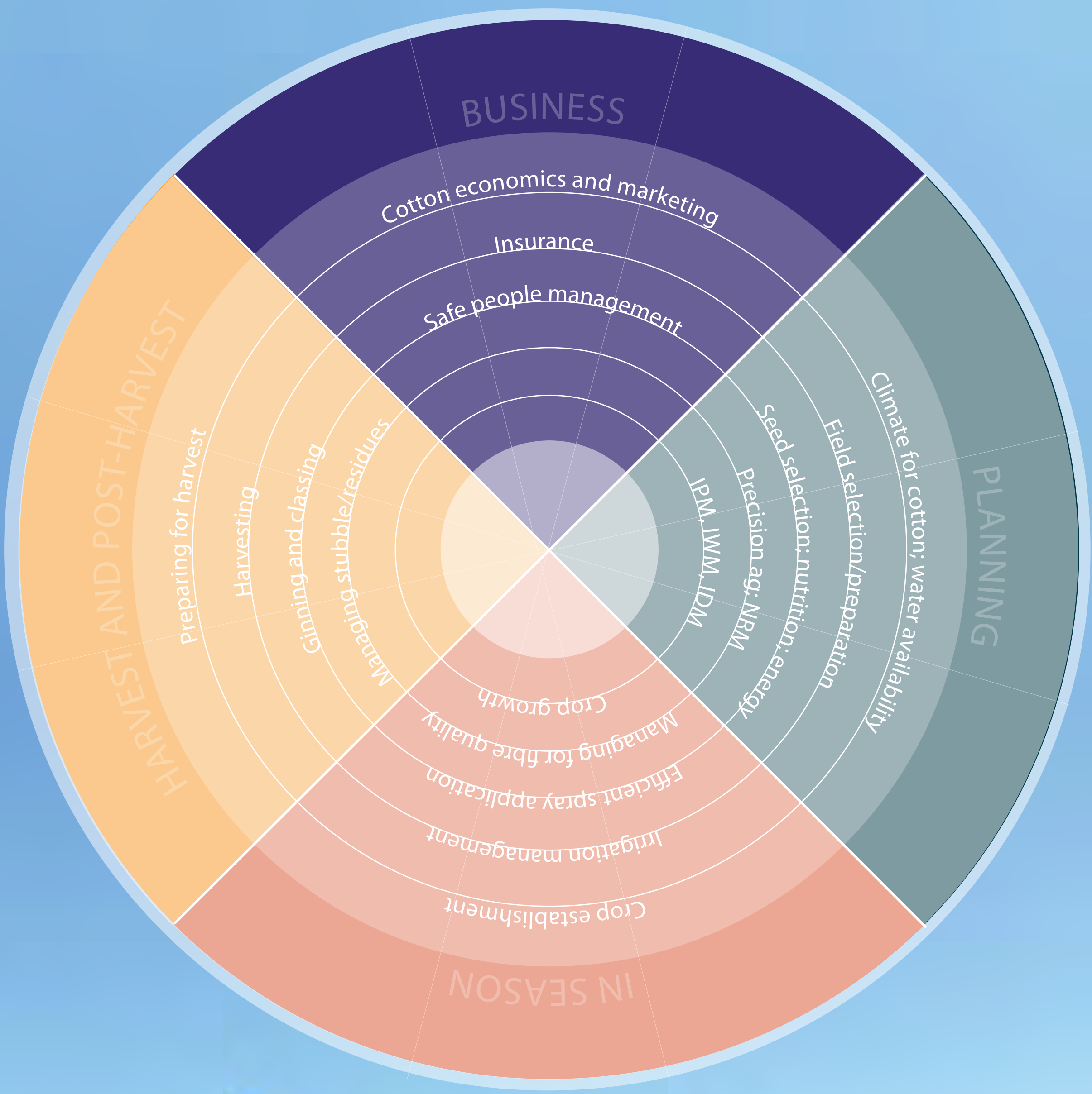


Photo courtesy Ruth Redfern

The business of growing cotton

By **Fiona Scott** (NSW DPI), **Alex Harris** (ECOM Cotton) and **Janine Powell** (NSW DPI)

This chapter covers some of the key business aspects of growing cotton, including gross margin budgets, marketing, finance & insurance.

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.

Gross margin budgets

A gross margin represents the difference between gross income and the variable costs of producing a crop. Comparing gross margins can be a guide to relative enterprise profitability and an indication of management operations involved in various enterprises.

Variable costs are those costs directly attributable to an enterprise and which 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.

Table 1 shows a simple example of a gross margin budget for irrigated Bollgard II cotton. The budget lists income sources, cost items and totals, with gross margin calculated as the total income less total 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.

A complete gross margin budget listing all management operations may also help to understand the cash flow requirements of an enterprise. Within the example gross margin (Table 1) the operations towards the end of the crop (defoliation, picking, cartage, ginning and levies) represent approximately 38 per cent of the total variable costs. Understanding the timing of costs is particularly important if short-term finance is going to be utilised. Note that the example gross margin is for Bollgard II cotton, some of the costs may change slightly when growing Bollgard 3.

Gross margins do not take risk, overhead costs or farm profit into account. Gross margins show the proportion of costs in relation to income, but don't consider price and yield risk. The sensitivity chart shown in Figure 1 helps to illustrate the effect that changes in yield and cotton prices (including both lint yield and seed price per bale) have on gross margins.

Best practice…

- **Prepare your own gross margin budget using published budgets as a guide.**
- **Seek advice from a reputable cotton merchant to understand your marketing options for both cotton lint and seed.**
- **Take the time to consider risk and insurance options. Seek insurance advice from reputable insurance providers/specialist and talk to established cotton growers about their past insurance experiences.**

FIGURE 1: Sensitivity of cotton gross margins to yield and cotton price.

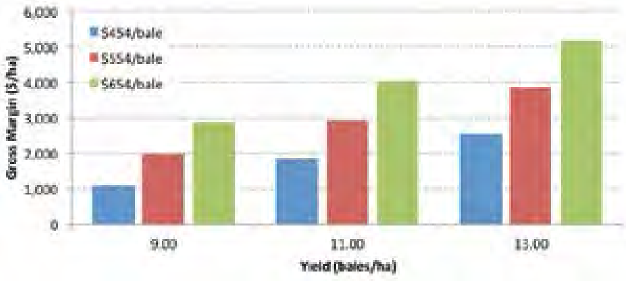


Figure 1 reflects the resulting changes to crop gross margins from a change in both yields and estimated prices. The figure emphasises that the profitability of a cotton crop is highly sensitive to both changes in yield and the cotton price, highlighting the importance of using achievable figures in your budgeting process. For example, a decrease in price of $100/bale results in a 38 per cent decrease in gross margin. Alternatively, a decrease in yield from 11 bales/ha to 9 bales/ha results in a 32 per cent decrease in gross margin. If both price and yield are decreased by these amounts at the same time, a 63 per cent reduction in gross margin occurs. The range of potential yields and prices is much wider than depicted within the figure; however it is the relationship between yield, price and the effect they have on the gross margin which is important.

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 which have to be met regardless of enterprise size or crop mix.

You can use published NSW DPI budgets as a guide when developing

TABLE 1: An example gross margin budget.

(Roundup Ready Flex® Bollgard II®)	
Income	**$/ha**
11 bales lint/ha @ $474/bale	$5214
Cotton seed @ $80/bale (combined lint and seed price $554/bale)	$880
TOTAL INCOME (A)	**$6094**
Variable Costs	**$/ha**
Farming/cultivation	$129
Seed and sowing	$115
Fertilisers and application	$374
Herbicides and application	$ 82
Insecticides and application	$125
Defoliants and application	$103
Irrigation 9.8Ml (c)	$573
Insurance	$110
Consultant	$74
Licence fees	$370
Contract picking	$334
Ginning and levies	$756
Pigeon pea refuge (5% of Bt area)	$31
TOTAL VARIABLE COSTS (B)	**$3176**
GROSS MARGIN/HA (=A-B)	**$2918**
GROSS MARGIN/ML (=(A-B)÷C)	**$298**


ECOM COTTON

ECOM COTTON


your own gross margin budgets, altering costs and operations as necessary. The NSW DPI budgets are calculated using crop yields for the region consistent with the operations given, current commodity and input prices and technical information provided by cotton farmers, agronomists and cotton industry specialists.

The degree to which these 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 characteristics such as soil type, crop rotation and management. Consequently, it is strongly recommended that the NSW DPI gross margin 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.

Gross margins need to be used carefully when used as a guide to deciding the farm's overall enterprise mix. Because overhead costs are excluded, it is advisable to only make comparisons of gross margins between enterprises which use similar resources (i.e. labour).

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.

For more detailed cotton budgets, see the following websites:

NSW DPI Cotton Gross Margins:
http://www.dpi.nsw.gov.au/agriculture/farm-business/budgets/cotton

Dryland Cotton resources (including regional gross margin calculators)
www.drylandcotton.com.au

Marketing

Acknowledgements: Alex Harris, ECOM Cotton

The aim of this section is to give a general overview of the cotton pricing components and marketing alternatives available to Australian 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

A definition of risk: *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 (i.e. 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.

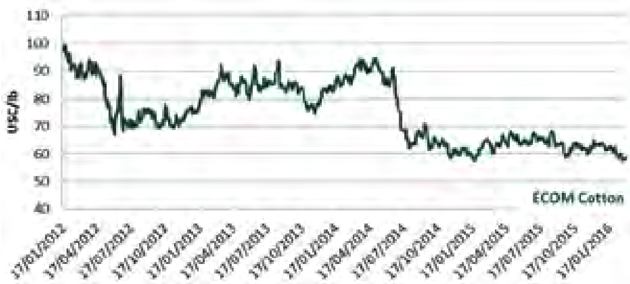
Varying quality is managed by merchants with all forward contracts priced on 'base grade'. Once the cotton is ginned and classed, the final price paid to the grower is adjusted with a premium when the grade is higher than 'base', or a discount in price when the grade is inferior. These pricing adjustments can be found on a merchant's corresponding premium and discount sheet (for more information about quality see the Managing for fibre quality Chapter).

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; and,
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 (refer to Figure 2).

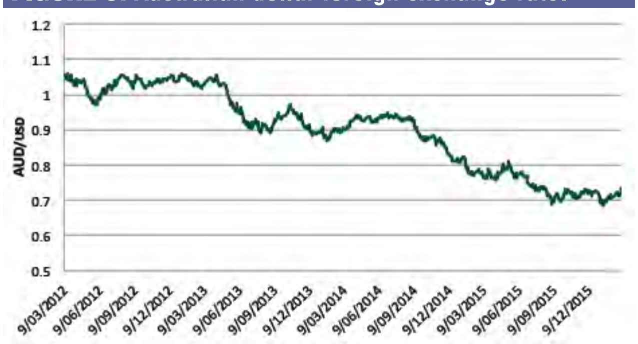
FIGURE 2: ICE Cotton No. 2 Futures.



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 (Figure 3).

FIGURE 3: Australian dollar foreign exchange rate.



The Basis is not traded on a public exchange and is less observable. However, basis can be calculated and is simply defined as the difference between the cash price for a physical bale of cotton and the futures price at any point in time. Basis is expressed in US c/lb (the same units as the futures price, where lb is pounds), which accounts for location and quality and is affected by local supply and demand conditions.

Using these components, the AUD/bale cash price can be calculated as follows:

Top line USD price per bale | **Converts price from pounds to bales**

AUD cash price per bale = (USD$/lb Cotton Futures ÷ USD$/lb Basis) x 500 lbs / AUD/USD exchange rate

Converts price from USD/bale to AUD/bale

An example of pricing elements for AU$500/bale = (0.68 ÷ 0.08) x 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 fax, 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.

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 4). This is a forward contract for delivery of a fixed number of bales of a given crop year (i.e. 2015-16) 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.

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 2016 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. This style of contract needs to be closely monitored by the grower as they have only protected themselves against one of the three components of price risk to which they are exposed.

FIGURE 4: Australian cotton price – A$ bale.

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 maximum delivery rather than bearing the entire production risk for the grower.

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 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 250–290kg of seed). The price of cotton seed is strongly correlated with feed grains and fluctuates with supply and demand.

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 (i.e. $65/bale), this is known as 'net ginning for seed', which means the income from the seed covers the ginning cost. The ginning organisation may quote the seed price as 'net of ginning and seed' (i.e. $65/bale = 'gin for seed', seed at $70/bale is 'Plus $5 back to grower', indicating the seed price covers the $65/bale cost of ginning, with $5 paid to the grower; an example of seed priced below the ginning cost, (seed at $60/bale) is '$5 payable by grower'). Talk to your preferred ginning organisation about current cotton seed pricing.

For further information on marketing your cotton, talk to a merchant or you can find comprehensive marketing notes on the following websites:

Australian Cotton Shippers Association:

http://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 (i.e. chemical resellers) and allows growers the option of deferring costs until after picking. Interest is charged at current short term money market rates (e.g. bank bill rates).

At picking, pre-ginning loans (module advances) are available from most ginners and merchants. Details can be discussed with your merchant.

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 about the best payment structure for your business prior to entering into any contracts.

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 indicators that a financial institution will assess in a loan application.

- Debt levels;
- Ability to service interest;
- Net operating expenses;
- Interest expense; and,
- Equity.

Looking at one indicator on its own may give a false impression of a business's financial health. To get the whole picture, it is important to consider all financial aspects of the business. If you are unsure 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)

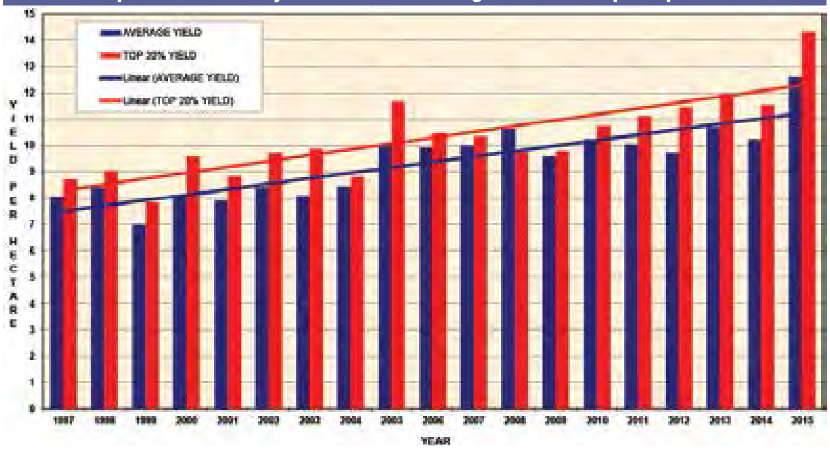
The Comparative Analysis is a joint initiative of the Cotton Research & Development Corporation (CRDC) and Boyce Chartered Accountants to produce the industry benchmark for the economics of cotton growing in Australia. The primary purpose of the Comparative Analysis is to show the income and expenses 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".

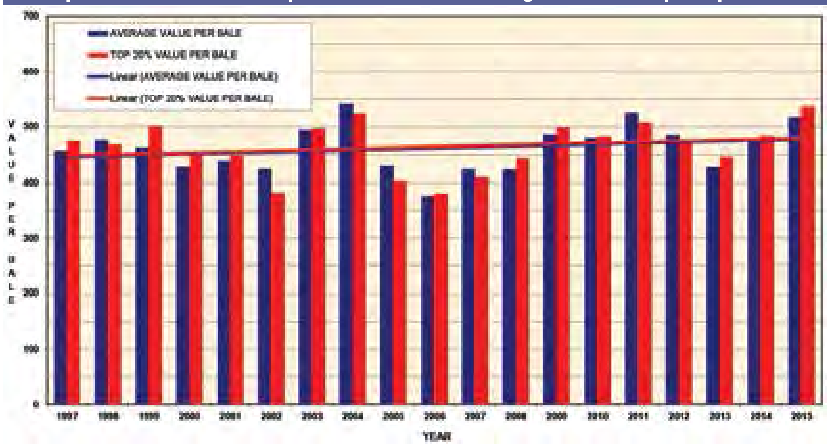
The reports show that over the past fifteen years many cotton farmers have been able to achieve top-class results, even in years when seasonal or financial circumstances were less than favourable. The analysis includes the average results compared with top 20 per cent, the average results of those farmers 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.

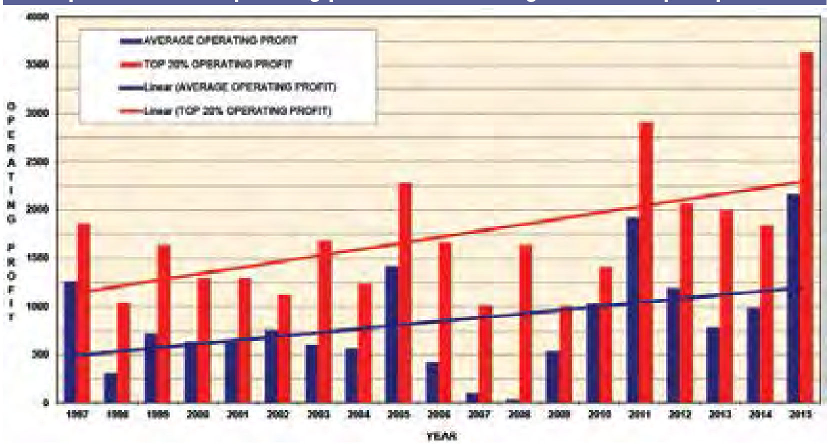
Comparison of the yield for the average and the top 20 per cent.



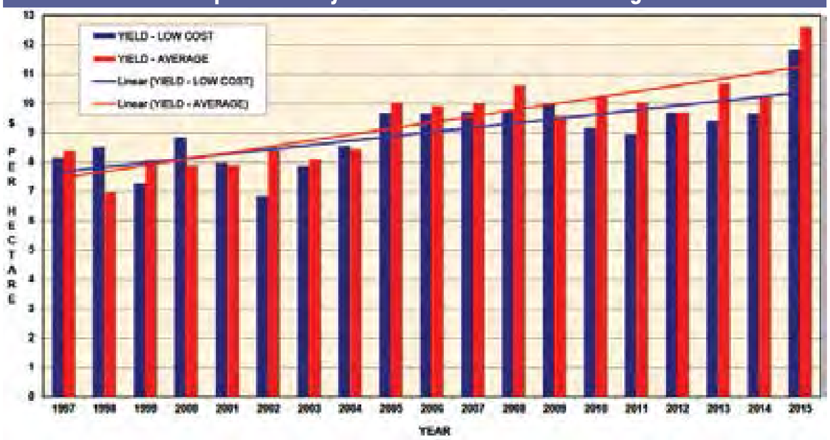
Comparison of the value per bale for the average and the top 20 per cent.



Comparison of the operating profit for the average and the top 20 per cent.



Comparison of yield for low cost and average.



Insurance

By **Deidre McCallum** (AgriRisk)

Acknowledgements: Fred Ghirardello (Goondiwindi Farm Tech), James Hooper (Rural Affinity), Brent Demnar (Agri Business Consulting Group)

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; and,
- **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 financially 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 by the Insurer or through their Agents; and by,
- Insurance brokers.

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.

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 over more than 25 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.

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

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 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 frost at flowering or excessive heat at critical stages of crop growth.
- Lack of heat units during the vital growth stages of the crop.
- Excessive wind.

Index products

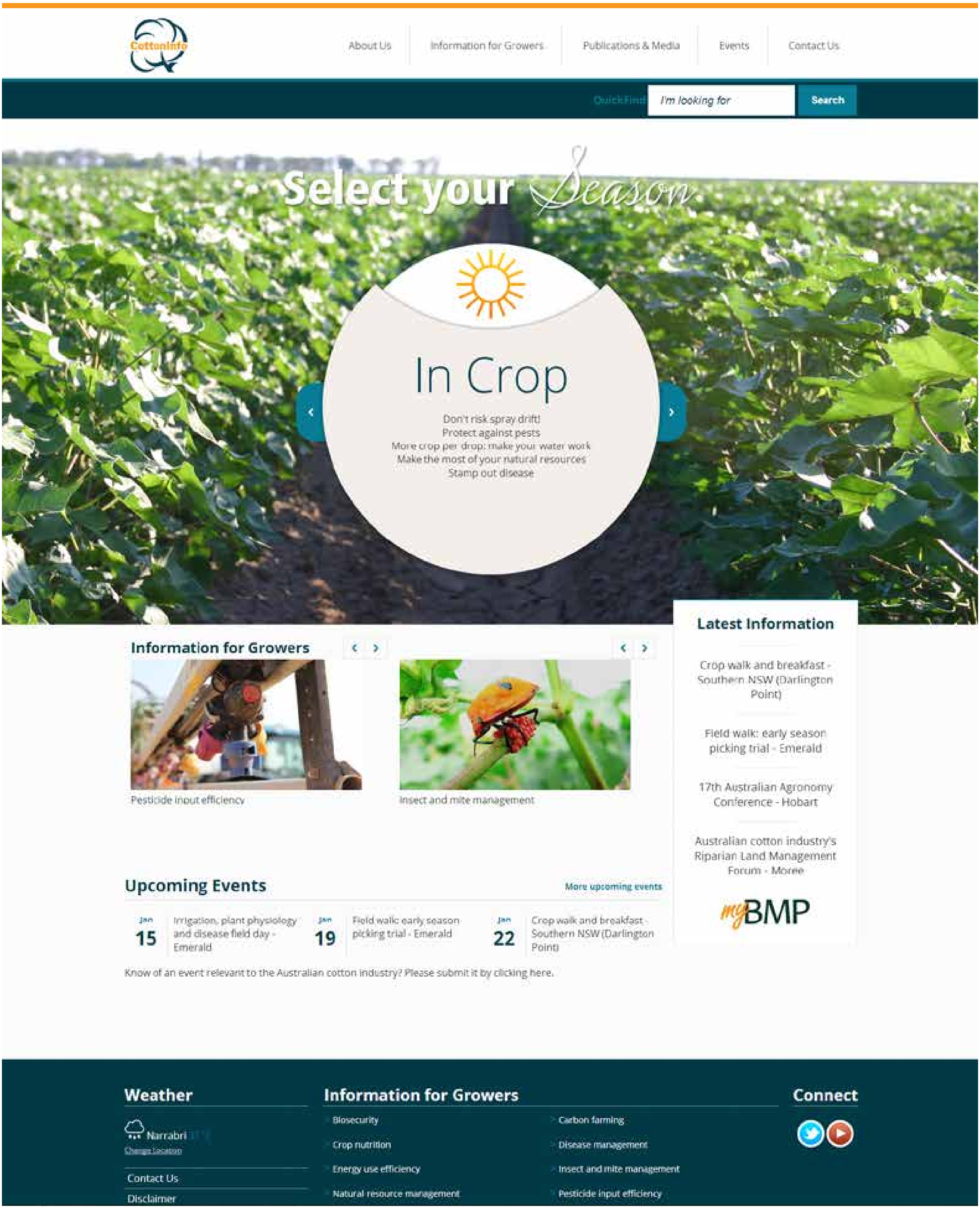
Index products are not an insurance product. They are based on an available independent index generally of yield or weather data. With Index products losses are determined by changes in the index which creates a basis risk as losses are determined according to the index rather than on farm.

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.

What's happening when?

The **CottonInfo website** and the **2016 Australian Cotton Production Manual.** Timely advice for growers throughout the season.
For more, visit us at: **www.cottoninfo.net.au**



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 available at the Australian Centre for Agricultural Health and Safety: www.aghealth.org.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; and,
- 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; and,
- 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 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.workcover.nsw.gov.au

CottonSafe program (Cotton Australia) www.cottonaustralia.com.au

***my*BMP Human Resources: www.mybmp.com.au**

Australian Centre for Agricultural Health and Safety: www.aghealth.org.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

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 in confined spaces, electrical safety, working at heights, servicing pumps and guarding pump drive shafts and PTO powered machiner .**
- **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**

Managing employee relations can often be one of the most difficult but often neglected areas of any business. This is particularly so when setting conditions of employment which not only meets the needs of the employer and employee but also complies with legislative requirements. Employers and employees often want to enter into arrangements that may not strictly comply with what the relevant award states, or what the Fair Work Act allows. Getting this part of the relationship right in the early stages can not only start the relationship off on a good footing but also save the employer from future compliance issues which can result in significant cost for the business.

The right conditions

In addition to the minimum conditions provided by the National Employment Standards (NES) there could be any number of awards that apply to workers in the cotton industry. Depending on whether you employ farm hands, administrative staff, gin workers, mechanics or professional staff such as agronomists will determine the relevant award that applies. Each and every one of these awards will provide for different terms and conditions including rates of pay, how overtime is calculated, what penalties and allowances might apply etc. Determining the correct entitlements is not only a workplace requirement but will assist toward increasing the levels of relationship between the employer and employee.

Flexibility

Many employers and employees would prefer to negotiate their own terms and conditions of employment which may be different to that provided in the awards. Employers should be aware that awards are legislative documents that must be complied with unless such changes are done in accordance with legislation, including the use of individual flexibility agreements. The use of Collective Enterprise Agreements may also be something that employers consider. These agreements are registered with the Fair Work Commission and operate to the exclusion of awards, whilst meeting the needs of employers and employees in that particular business. The message is, that whilst the rules must be complied with, there is the option for flexibility if done correctly.

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 HR (Human Resources) information.

For further information please contact Bob Kellow, Industrial Mediation Services, 0427 667 344.

Best practice...

- **Understand the relevant awards and minimum conditions and the opportunities available to structure these around the needs of your business.**

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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.

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 2cm 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 1.5m x 2m 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®).

CottASSIST A group of web tools developed by CSIRO, Cotton CRC and CRDC designed to deliver the latest cotton research and integrate up-to-date information and assist with cotton management decisions.

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.

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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 20m 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 Chinese or 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 VAM.

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 12.7mm 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.

SOILpak Information about cotton soils.

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 1m 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 60cm deep) attached to a round aluminium frame which is about 40cm in diameter with a handle (1m 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.

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.
CHAMP – Chemical Handling & Application Management Plan.
CRDC – Cotton Research & Development Corporation.
CSD – Cotton Seed Distributors.
CSIRO – Commonwealth Scientific & Industrial Research Organisation.
DAF – Department Agriculture & Fisheries.
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.
GPS – Global Positioning System.
GVB – Green Vegetable Bug.
ICAC – International Cotton Advisory Committee.
ICE – Intercontinental Exchange.
IPM – Integrated Pest Management.
IRMS – Insecticide Resistance Management Strategy.
IWM – Integrated Weed Management.
MIS – Multispectral Imaging System.
NSW DPI – New South Wales Department of Primary Industries.
OGTR – Office of the Gene Technology Regulator.
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.


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