



NORpak – Ord River Irrigation Area

Cotton production and management guidelines for
the Ord River Irrigation Area (ORIA) 2007

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Compiled and edited by Stephen Yeates, Geoff Strickland, John Moulden and Andrew Davies

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This publication is designed as an information source to enable the sustainable production of dry season cotton in the Ord River Irrigation Area (ORIA). The information has been prepared from research studies and grower trials with specialist input from researchers, extension staff and private companies. While the authors provide comprehensive coverage of regional cotton production issues, they do not purport to address every eventuality that may arise during regional cotton production.

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Foreword

Recurring droughts in established cropping regions and the unprecedented success of new agricultural biotechnologies have triggered renewed interest in farming in northern Australia, where the reliability of rainfall and availability of water for irrigation seems more secure and plentiful.

Previous attempts to establish cropping industries in some northern regions have been spectacularly unsuccessful, primarily due to unrecognised limitations of the local environment, application of inappropriate production and management systems, combined with excessive, uneconomic and environmentally unpalatable pest control regimes based on broad-spectrum insecticides.

The arrival of genetically modified cotton varieties, which are less reliant on conventional insecticides and herbicides, has revolutionised pest control and weed management, opening a window of opportunity previously denied to northern Australia.

Crucial to the modern cotton management system in the Ord is pest avoidance. Insect pests proved unmanageable in the summer production system attempted previously, so these days cotton is grown as a winter crop, ideally planted during the transition from wet to dry season (March to April) and picked before significant rainfall commences during the transition back to the wet (September to October). This is virtually a reverse timetable to that operating in major southern cotton growing regions.

Since transgenic cotton varieties became available in the mid-1990s, the Cotton CRC and its partners have been engaged in an intense research effort to identify, analyse and understand the dynamics of both pest and beneficial insects associated with winter grown cotton in the Ord, and to devise an integrated pest management (IPM) based approach to insect control.

This has required the development of a new farming system and the characterisation of cotton's agronomic performance in the northern dry season. The result is that a sustainable cotton industry, with yields embracing 9.5 to 10.5 bales/ha, is possible in the Ord and adjacent regions, including the Northern Territory.

Northern research demonstrates that low insect population densities can be maintained and managed; that soils can be protected rather than degraded; and that a globally attractive quality cotton product can be produced to earn valuable export income and provide significant employment and infrastructure investment opportunities in remote northern regions. The culmination and application of successful research has allowed consistent, reliable, economic, and environmentally acceptable cotton production to be both feasible and sustainable in northern Australia.

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This has been an extensive 10 year research program. This document summarises the main points for people interested in growing cotton in conjunction with other crops in northern Australia. By providing farmers another crop choice in their mixed cropping systems, it will provide for the best economic and environmental outcome for the region.



Guy Roth
Chief Executive Officer
Cotton Catchment Communities CRC

Introducing NORpak for the Ord River Irrigation Area (ORIA)

The information contained in this document is a distillation of results from research, conducted over the last decade, which investigated dry season cotton production in the ORIA. An intense effort has been made to understand the dynamics of both pest and beneficial insects associated with winter grown cotton in the region, and to devise an integrated pest management (IPM) based approach to insect control which avoids the major pests. This has required the development of a new farming system and the characterisation of cotton's agronomic performance in the northern dry season.

Previous commercial cotton production in the ORIA eventually failed due to poor fibre quality and insecticide resistance. This failure, although unfortunate, stands testament to the folly of imposing a production system that, in hind-sight, failed to recognise its environmental limitations. Such a flawed production system left other legacies too; residues of DDT and other chlorinated hydrocarbon insecticides applied to cotton and other crops in the ORIA in the 1960s and 70s are still found today in local soils, riverine sediments and fauna.

Genetically modified cotton varieties became available for experimental production in the early 1990s. Early GM cotton varieties (INGARD®) contained a single insecticidal gene from the bacterium, *Bacillus thuringiensis*, and were selectively active against the serious cotton pests *Helicoverpa* spp. This technology, which is not reliant on conventional insecticides, provided the breakthrough needed to underpin a sustainable IPM cotton production system in tropical Australia, and related research soon followed.

Recent advances in GM technology have led to the commercial release of cotton varieties containing two insecticidal genes (Bollgard II®), and genes for resistance to the herbicide glyphosate (Roundup Ready® and Roundup Ready Flex®). These traits have further revolutionised pest control, and also weed management, in established cotton growing regions of Australia, and provide even greater options for sustainable production systems in the ORIA.

NORpak is essentially a 'work in progress'. It is based on results from research carried out in the ORIA, and provides a foundation for future successful and sustainable cotton production in the region.

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The rationale for dry season cotton cropping

The climate of the Ord Valley is classified as semi-arid (or monsoon) tropics (Williams et al. 1985), where the growing season for cotton is not determined by temperature as it is in temperate climates, but by rainfall patterns, irrigation water availability, and relative insect pest densities.



> October 1997 the first cotton module of the current era.

A winter (dry season) growing system for cotton production is ideal for the ORIA, and other areas of Australian semi-arid tropics where average monthly night temperatures are unlikely to fall below 12°C. Winter cropping avoids environmental extremes experienced in tropical summers, allowing application of a less risky, more manageable production system. This is a major departure from traditional practice in established cotton production areas, where temperatures are only high enough for cotton cropping in summer. The new winter growing system is also a major departure from the previous Ord cotton growing experience.

Cotton is ideally planted during the transition from wet to dry season (March to April) and picked before significant rainfall commences during the transition back to the wet season (September to October).

FACTORS CONTRIBUTING TO THE FAILURE OF THE OLD ORD COTTON INDUSTRY (1963 TO 1974)

Cotton was grown from 1963 to 1974 during the summer (wet) season (November to April) with irrigation supplementing rainfall to finish the crop early in the dry season (April to June). Despite achieving yields similar to south eastern Australia during the same period, cotton production became uneconomical due to poor fibre quality and resistance of heliothis (*Helicoverpa armigera*) to insecticides, which caused excessive pesticide usage and control failures.

Poor fibre quality and uncontrollable insects were the result of a production system that in hind sight failed to recognise the ecological limitations of the environment.

During the first six years of commercial production, a sequence of cultural changes led to improvements in yield and quality, but these caused the flowering period to become extended and picking was delayed. The delays eventually caused severely weathered cotton (UV light and rainfall) and an extended period requiring insect protection using broad spectrum insecticides. *Helicoverpa armigera* became uncontrollable due to resistance and the industry collapsed soon after.

The history of the early ORIA cotton industry has been reviewed in detail previously (Hearn 1975; Wood and Hearn 1985; Michael and Woods 1980).

Important issues involved with dry season cotton production

- Sowing time (March to April) is critical as the crop must mature and be harvested before the wet season (see *Sowing date and planting*, page 24).
- Extreme care is required in the management of the crop canopy using growth regulators (see page 25).
- Crop management decisions during the coldest time of the season (June to July) are critical to yield (see *Agronomy*, page 21).
- Preservation of active leaf area is vital to maintain photosynthesis (see *Insect pests*, page 11, and *Disease*, page 29).
- Varieties perform very differently in winter production systems (see *Varieties*, page 27).

Cotton yields of 9.5 to 10.5 bales/ha can be reliably achieved in the ORIA. These yields are comparable with south-eastern Australia and well above the world average. Recent extremely high yields (15 bales/ha) occasionally achieved in temperate growing regions are unlikely in the ORIA. This is because, with current varieties, the shorter winter day lengths limit photosynthetic capacity and hence yield potential (see Figure 1).

Advantages of dry season cropping

- Regular water supply enables consistent and reliable cotton production every season, forward selling at higher prices, and production capacity matched to capital investment.
- Important insect pests, including heliothis (*Helicoverpa armigera*) and cluster caterpillar (*Spodoptera litura*), are considerably less abundant relative to the wet season, and damage from pink bollworm (*Pectinophora gossypiella*) is avoided completely.
- Fields are easily accessed and cropping operations not hampered by boggy ground from persistent rain. Fields are often inaccessible for long periods during the wet season.
- The crop is not subjected to the damaging effects of waterlogging.
- Achievable fibre quality is superior to that of wet season cotton provided the crop is planted at the optimum time and picked prior to early rains.
- Timing of critical growth stages is easy to predict due to the relatively stable growing environment.
- Irrigation scheduling is similarly predictable and rarely affected by in-crop rainfall.



- > A dry season cotton crop in 2005, which yielded 10.1 bales/hectare.

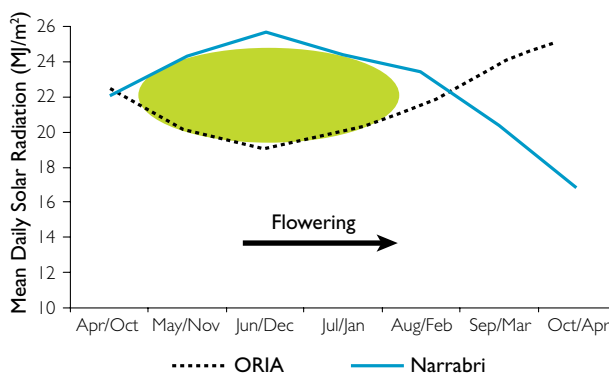
Disadvantages of dry season cropping

- Flowering and boll growth occurs during shortening days and relatively low solar radiation.
- Low night temperatures can produce cold shocks, which may impact on boll growth, yield and fibre quality.
- The risk of storm damage late during crop development increases if crop planting is delayed.

Solar radiation limitations

Solar radiation (the energy from sunlight) is required for photosynthesis to drive plant growth. The monsoon tropics are characterised by less variable rates of solar radiation between summer and winter than more temperate climates. During the wet season in the tropics, solar radiation can be highly variable, due to cloud cover; and when combined with high night temperatures (roughly 23°C to 29°C), the potential yield of most annual crops (e.g. maize, sorghum, and rice) is reduced compared to summer cropping in temperate climates.

Dry season cotton in the ORIA (15°S) receives about 20% less solar radiation during flowering and boll development than cotton grown during summer at temperate latitudes (30°S). This is illustrated in Figure 1.



- > **Figure 1.** Comparison of mean daily solar radiation between a temperate summer growing season at Narrabri (October to April) and the tropical winter (dry) growing season in the ORIA (April to October). The likely flowering period for both regions is indicated by the arrow. The shaded area represents the difference between the two climates in daily solar radiation during the flowering and boll filling period in their respective growing seasons.

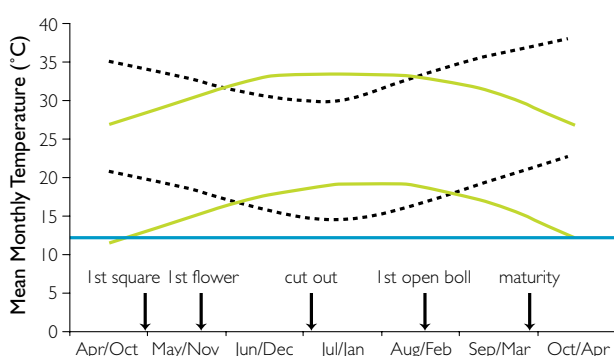
Temperature limitations

Temperature profiles during crop development in the ORIA are exactly opposite those experienced in the main southern production regions (Figure 2). Early season temperatures are relatively high and favourable to cotton crop establishment and growth. However, the relatively cool dry season conditions during flowering and boll fill are limiting factors for very high cotton yields in the ORIA (Figure 2). Temperatures rise rapidly again at the end of the dry season, ensuring rapid boll opening and effective defoliation. The increasing temperature ensures that the crop matures quickly.



> Stunted boll growth resulting from cold night conditions.

In 50% of years, there are 14 nights below 12°C and eight nights below 11°C during the dry season, and temperatures below 5°C are possible. Cotton flowers exposed to such cold nights produce smaller bolls and in extreme cases flowers will abort. Provided leaf integrity is maintained, cotton plants have the ability to compensate for cold weather losses by producing new bolls once temperatures increase. Sowing in March largely avoids low temperatures during flowering.



> **Figure 2:** Average growing season mean monthly temperatures for Narrabri (October to April, solid lines) and the ORIA (April to October, dashed lines). Approximate critical growth stage dates for a March sown cotton crop in the ORIA are marked with arrows.

FLOWERING IS AN IMPORTANT PERIOD FOR DRY SEASON COTTON

The cotton plant must convert squares (flowerbuds) into bolls during the coldest months of the year, when radiation is lowest. Avoiding stress (e.g. waterlogging, nutrient problems, weeds, pests and diseases) during this time is critical for maximum yield. Regular monitoring combined with quick remedial action, if necessary, is essential during this phase of growth.

Optimising cotton growth during the dry season

High yielding crops

- Usually retain about 60% of first position (P1) bolls.
- Have 30 to 50% of all bolls on the second (P2) and third (P3) fruiting branch positions.
- Maintain a steady rate of fruit set with the effective flowering period (nodes above white flower – NAWF > 4.5) lasting for at least 30 days for high retention crops in above average temperatures, and around 42 days for lower retention crops exposed to lower than average temperatures.
- Effective plant nutrition and varying the irrigation interval can achieve the best balance between vegetative and fruit growth in cotton crops. Slightly extending the irrigation interval can improve fruit retention (usually early in flowering) and prevent rank growth, while reducing the irrigation interval, provided waterlogging is avoided and nutrition is adequate, can help extend the flowering period. Close crop monitoring is essential when attempting to manipulate growth by irrigation.



> Rank cotton growth occurs if irrigation intervals are too short when the temperature is relatively high.

The cropping calendar for dry season cotton

> **Table I:** Typical timing of crop stages for dry season cotton production in the Ord River Irrigation Area.

Stage/Operation	Jan/Feb	March	April	May	June	July	August	Sept	Oct	Nov/ Dec
Cover crop/Land preparation										
Planting										
Emergence – 1st flower										
1st flower – Cut-out										
Cut-out – Defoliation										
Defoliation – Picking										
Picking – Cover crop										

Cotton farming operations in the dry season system recommended for the ORIA are almost exactly six months out of synchrony with the farming system used at Narrabri, NSW.

Operational issues

Both transitions from wet to dry (March to April) and back to the wet season (October to November) are critical for cropping operations in the ORIA (see Table I), as they coincide with sowing and harvest for cotton and rotation crops, and crucial cover crop management periods. Rainfall is unpredictable at these times of year. Timely management of the cover crop, if any, is especially important, as delays to cotton sowing will increase the risk of late picking when the chance of rain is higher.

Conservation tillage systems that reduce the number of machinery passes and provide soil cover to prevent run off and erosion are the best way to ensure timely operations during seasonal transitions.



> Minimum till cotton sown in permanent beds in the ORIA.

Pest management

The pest management strategies described here aim to ensure sustainability and profitability while avoiding the potential problems of insecticide resistance and environmental contamination that plagued the earlier industry. This is achieved by using pest resistant genetically modified (GM) cotton varieties and Integrated Pest Management (IPM) principles tailored to regional requirements, to minimise reliance on conventional insecticides for insect pest control.

INTEGRATED PEST MANAGEMENT (IPM) PRINCIPLES

IPM strategies use numerous insect pest management tools, rather than placing sole reliance on broad spectrum insecticides for insect pest control. Insect pest management tools include trap crops to attract insect pests away from cotton; avoidance of seasonal insect pests; use of insect tolerant cotton varieties and selective chemicals that target specific insect pests when necessary; applying cotton damage thresholds to insect pest control decisions; and fully utilising the impacts of natural enemies on pests to achieve biological control. Broad spectrum insecticides are used only as a last resort in IPM systems. Detailed information is available in the Cotton CRC publication, 'Integrated Pest Management Guidelines for Cotton Production Systems in Australia', which is also on the Cotton CRC website.

The compact production area in the ORIA lends itself to the adoption of IPM on an area-wide basis. Local farmers presently collaborate to implement the local insecticide resistance management (IRM) strategy and this group could successfully expand to implement area-wide IPM systems across the region.

Key pest control features of this production guide

- Dry season cropping to avoid key insect pests, some of which are most abundant through the wet season.
- System based on Bt transgenic cotton varieties (minimum two gene – currently Bollgard II®).
- Minimal insecticide use, only when necessary as indicated by pest abundance and plant damage thresholds.
- Insecticides selected according to IPM compatibility (e.g. specificity to target pests).
- Minimal environmental and non target impact (e.g. select insecticides with little negative effect on predators or parasites of pests, and which have low persistence in the environment).
- Total avoidance of endosulfan, parathion and related insecticides which represent particular environmental risks.
- Use of ground-rig spraying whenever possible to reduce costs and reduce the risks of drift.
- Use of refuge and companion crops to support IPM cotton production and contribute to a more diverse farming system and increased biodiversity.



- > IPM has assured minimal pesticide usage hence little chemical runoff from fields.

Insect pests

- > **Table 2:** Insect pests of cotton in the ORIA.

Principal pests	Occasional/possible future pests
1. <i>Helicoverpa</i> spp.	1. Cluster caterpillar <i>Spodoptera litura</i>
2. Aphids (mainly <i>Aphis gossypii</i>)	2. Spider mites <i>Tetranychus</i> spp.
3. Mirids <i>Creontiades dilutus</i>	3. White fly <i>Bemisia</i> spp.
	4. Leafhoppers <i>Austroasca</i> spp.
	5. Redbanded shield bug <i>Piezodorus</i> spp., green vegetable bug <i>Nezara viridula</i>
	6. Redshouldered leaf beetle <i>Monolepta australis</i>

Cotton is attractive to a large number of insects but only a few are economically damaging. Most arthropods found in cotton are either relatively harmless to the crop or are beneficial species that help control pests. A primary aim of IPM is to maximise the role of beneficial species so that dependence on insecticides is minimised.

Pests at planting

Early plantings (March) perform well agronomically, but can be attractive to grasshoppers, caterpillars and sucking insect pests such as mirids, which may occur at greater densities closer to the end of the wet season. For this reason, seed dressings of thiodicarb, fipronil, imidacloprid and thiamethoxam are recommended for early season sucking pest control, combined with regular monitoring for all insect pests.

Sowing into poorly prepared cover crops or weedy fallows increases the risk of seedling damage from soil dwelling and chewing insects that may transfer from the crop or weeds onto cotton, although they are not normally cotton pests. Following cover crop spray-out, these insects are deprived of food and, if the period between spray-out and cotton sowing is too short, will sometimes persist long enough to feed on newly emerged cotton seedlings. Seed dressings (listed above) will assist in controlling soil insect pests in this situation, but above ground pests may require specific control if large numbers of seedlings are threatened. Planting in late April or early May avoids some insect pest activity, but increases the risk of yield and quality penalties and harvest complications due to possible rain at the end of the season, so is not recommended.



> Pre flowering cotton crop showing early vigour.

Heliothis management (*Helicoverpa*)

Bollgard II® effectively controls most lepidopteran cotton pests and greatly reduces the need to use conventional insecticides for heliothis control. However, regular monitoring remains important, especially when large numbers of heliothis eggs are deposited on cotton crops.



> Adult *Helicoverpa punctigera* (left) and *Helicoverpa armigera* (right). Note light coloured 'window' in hind wing of *H. armigera*. Both species occur in the ORIA, but *H. armigera* is the more serious pest, as it has developed resistance to a range of chemical insecticides.



> Mature *H. armigera* larva attacking a cotton boll. Bollgard II® technology has largely controlled this pest in cotton. [Photo: C. Mares, CSIRO]

Tipping out and square shedding (see Appendix 1, page 34) may be caused by either heliothis or mirid feeding (see page 14 for mirid insect pest information), although in Bollgard II® crops, mirids are currently the main source of damage. Medium to large squares damaged by heliothis show characteristic 'flaring', whilst mirid damaged squares simply turn black and fall off the plant. Some square loss up to first flower should not cause concern, unless special circumstances exist that require the earliest possible crop finish. As a guide, square retention on the top five nodes should be maintained at 50 to 60% prior to first flower. Aim for close to 100% retention if earliness is paramount; however a trade off for slightly earlier maturity is that yield can be reduced due to early cut-out when total retention is too high (e.g. PI retention exceeds 80% of fruiting sites).

For Bollgard II® crops, heliothis is generally well controlled and tip damage is unlikely unless extremely high larval density is encountered or if the plants are failing to express Bt proteins adequately. Plant stress situations, such as temperature extremes or waterlogging, can lead to poor Bt protein expression.

Cotton plants shed squares for reasons other than insect damage, generally producing far more squares than they could ever retain and support to produce bolls (only 35 to 50% of squares produced become harvestable bolls). Typical of indeterminate plant types, cotton plants shed fruit readily in response to luxuriant and rank growth; or to adverse environmental conditions such as waterlogging, extreme temperature events, lack of solar radiation, high winds and other factors. It is important to note that not all square loss is caused by insects.

CottonLOGIC is currently recommended as the model for determining heliothis control thresholds, but some qualification is required in northern Australia. Specifically, it is recommended not to spray on 'egg thresholds', except in extreme cases when large and sudden egg lays (>100 eggs per metre) are encountered. High levels of egg parasitism by the minute wasp, *Trichogramma* (see *Beneficials*, page 18), make eggs per metre of row an unreliable predictor of eventual heliothis larvae per metre.

Generally, heliothis control thresholds determined by CottonLOGIC are adequate for use in northern Australia, although 'cumulative larval day thresholds' developed for INGARD® cotton can provide superior yields, sometimes with fewer sprays (Strickland and Annells 2002). Cumulative thresholds take into consideration low level but protracted periods of larval densities that do not reach the critical value of two larvae per metre. Thus the cumulative threshold approach can change the timing of sprays, but not necessarily the number of sprays.

THE FORMULAE DEVELOPED FOR CUMULATIVE HELIOTHIS THRESHOLDS ARE:

Y Cumulative Larvae/m =

$[(\# \text{ eggs found today} * \text{DR}) + (\# \text{ eggs found on Day 3 of the previous check} * \text{DR})] +$

$[(\# \text{ vs larvae found today} * \text{DR}) + (\# \text{ s larvae found today} * \text{DR}) + (\# \text{ vs \& s larvae found on day 3 of the previous check} * \text{DR})] +$

$[(\# \text{ m larvae found today} * \text{DR}) + (\# \text{ large larvae found today} * \text{DR}) + (\# \text{ m \& l larvae found on day 3 of the previous check} * \text{DR})]$

Where DR = Damage Rating which is 0.05 for eggs, 0.1 for very small larvae, 0.5 for small larvae, 1.0 for medium larvae and 1.5 for large larvae.

Where Y = threshold required (i.e. 10 larvae per metre or 5 larvae per metre)

Y Cumulative Larvae/m with correction for retention is = x + $[(\ln(\text{RN}/100) * x)]$

where x = formula for Y cumulative larvae/m as above and RN = Percentage Retention of first position fruits

There is insufficient experience with Bollgard II® cotton to know whether cumulative thresholds designed for INGARD® would provide any benefit to growers. However, if heliothis survival increases in the future and growers wish to validate the model on their properties, they may contact the Entomologist, Department of Agriculture and Food, Kununurra, for assistance in using dynamic thresholds in a simple spreadsheet application based on the above formula.

> **Table 3.** Recommended heliothis thresholds for cotton production.

Heliothis larvae size	Phase 1	Phase 2	Phase 3
Very small & small	2 per metre	2 per metre	3 per metre
Medium & large	0.5 per metre	1 per metre	1 per metre
Total larvae	2 per metre	2 per metre	3 per metre

Several trials aimed at developing a post cut-out (see Appendix 1, page 34) control threshold for heliothis have been conducted with INGARD® cotton. No yield difference was found between cotton crops sprayed at thresholds from zero up to 4 heliothis larvae per metre after cut-out (G. Strickland, unpublished data). This suggests that a threshold of around 4 heliothis larvae per metre is tolerable for post cut-out cotton in the ORIA.

It is important to remember that northern cotton matures in hot dry conditions so boll opening can be relatively quick. Boll opening rates of 4% per day are typical and therefore the boll protection period after cut-out can be relatively short.

Cluster caterpillar (*Spodoptera litura*)

Spodoptera was a major insect pest in the original wet season based ORIA cotton industry (Michael and Woods 1980), but modern dry season production generally avoids high populations of this insect pest. Commercial *Bt* sprays, including the *Bt kurstaki* strain, have proven a poor control option for *Spodoptera* generally (Polanczyk et al. 2000), and Bollgard II® provides only partial suppression of *Spodoptera* (Strickland et al. 2006). *Spodoptera* have been observed feeding on leaves, flowers and bolls in dry season cotton crops, and insecticidal control on INGARD® crops was necessary on occasion. There are no established control thresholds for *Spodoptera*, but, as their larvae can be potentially damaging to cotton, they should be scouted separately and heliothis larval thresholds applied. CottonLOGIC does not have thresholds for *Spodoptera* so it is recommended that the standard heliothis threshold of two larvae per metre be used as an interim measure.



> Cluster caterpillar (*Spodoptera litura*) feeding damage on cotton plants.

Mirids (*Creontiades dilutus*) and dimpling bug (*Campylomma austrina*)

Mirids inject pectinase when they feed on cotton and this causes terminal growth to blacken and die (Lei et al. 2002). Research conducted in the ORIA demonstrated that, provided cotton plants are able to grow out of early tip damage (e.g. damage occurring at or before 5 nodes), yield is unlikely to be affected. Early tip damage, even up to 95% of plants, has not reduced yields in northern Australia (Lei and Gaff 2003). Nevertheless, mirid control is necessary to prevent multiple and continuous plant tip damage. Before flowering, square retention is a good guide when considering the use of insecticides to control mirids. Retention should be maintained at at least 55%. If mirid numbers are erratic or increasing and cotton square retention is dropping below 60%, control is recommended. Tipping can delay cotton crop maturity (Lei et al. 2002), so potential yield loss to mirid damage is important to consider when crops are already 'behind' due to late sowing or some other circumstance.



> A green mirid (*Creontiades dilutus*) adult.
[Photo: C. Mares, CSIRO]

Mirids can be damaging to cotton throughout fruit development. Research at Katherine, in the Northern Territory, demonstrated relatively high mirid densities after first flower caused serious yield losses in cotton crops. Trial results specifically demonstrated that 1.7 mirids per metre caused a 60% cotton yield reduction (Ward 2005). The ORIA is warmer on average than Katherine (14 versus 27 'cold shocks', respectively) so may have a slightly higher tolerance to mirid damage due to a greater capacity for compensation. However, conservative mirid control thresholds are recommended, especially when plants may be physiologically stressed during the colder months (June and July). A provisional threshold of 0.5 mirids per metre is recommended.



> Apple dimpling bug (*Campylomma liebknehti*) adult.
[Photo: C. Mares, CSIRO]

Dimpling bugs probably have both a pest and beneficial role in cotton, depending on the crop growth stage and the presence of other insects, as they are considered omnivorous. Dimpling bugs are known predators and may exert some control of mites and thrips, but, in the ORIA, it has been customary to treat them as cotton pests due to their frequent high population densities.

When insecticidal control of sucking insect pests is necessary, selective chemical options such as fipronil or imidacloprid should be used according to label recommendations, in preference to organophosphates or pyrethroids, to reduce the degree of disruption to the developing IPM system.

Aphids

Aside from heliothis, the cotton aphid *Aphis gossypii* is the major pest insect species attacking cotton. The same species feeds on cucurbit crops where it transmits several important viruses that drastically reduce yield and quality. For this reason, *A. gossypii* is frequently targeted by horticultural producers and high levels of resistance to conventional aphicides such as organophosphates and the carbamate pirimicarb are common (Herron et al. 2001).



> Severe aphid infestation causing cotton leaf distortion and production of sticky honeydew.
[Photo: Lewis Wilson, CSIRO]

In cotton, severe aphid infestation causes leaf distortion and production of sticky honeydew. Control thresholds in CottonLOGIC are considered to be too high and not adequate for aphid management in northern Australia. While the CottonLOGIC aphid control threshold is 95% of plants infested, the level and duration of infestation must be considered in the ORIA as serious yield and maturity penalties occur when aphid populations are left uncontrolled. Aphid feeding damage directly reduces leaf photosynthesis and the development of sooty mould on aphid honeydew further exacerbates photosynthetic reduction (Annells et al. 2004). Aphid populations, especially those coinciding with short day lengths and cold weather in June and July, should be controlled if more than 30% of plants are infested.

Leafhoppers (*Austroasca* spp.)



> Leafhopper (*Austroasca* spp.) adult. [Photo: C. Mares, CSIRO]

Leafhoppers, which occasionally build up to high densities on cotton, are sap feeders that prefer the lower and mid canopy foliage of cotton plants. Leafhopper feeding causes white speckling on the leaves and, in extreme situations, may make the canopy take on a bleached appearance. Following sustained, high density leafhopper feeding, cotton leaves may also develop a reddish purple discolouration, especially on leaf margins and inter-vein areas.



> Red leaf symptoms of high density leafhopper attack on cotton.

The impact of leafhopper feeding damage on cotton yield has not been extensively examined, but if leaf photosynthetic capacity is reduced then the ability of cotton plants to fill bolls is impaired. An interim threshold of 50 leafhoppers per metre is suggested.

Other sucking pests

In addition to mirids, pentatomid bugs such as green vegetable bug and redbanded shield bug can be extremely damaging to cotton yield during boll development.

> **Table 4.** Recommended control thresholds for some cotton sucking pests.

Sucking bugs	Phase 1	Phase 2	Phase 3
Green vegetable bug	>2 per metre	1 per metre	1 per metre
Redbanded shield bug	>2 per metre	1 per metre	1 per metre
Cotton stainer	>10 per metre	5 per metre	5 per metre

Thrips do not cause significant damage to fast growing cotton seedlings in the ORIA and control has not been necessary to date.

Mites (*Tetranychus* spp.)

Mites are not often a problem in cotton crops, but sometimes appear late in the season. It is recommend that no control is needed after 10% open bolls as pickable bolls will be very close to maturity and defoliation not far away. However, prior to 10% open bolls, control action should be considered if greater than 30% of cotton leaves are mite infested, especially if top bolls are vital to yield.

Redshouldered leaf beetle (*Monolepta australis*)

Redshouldered leaf beetle is a swarming insect that congregates on cotton and other crops, occasionally causing isolated patches of almost total defoliation. By releasing an aggregation pheromone, beetle swarms combine so that high populations can develop relatively quickly. Fortunately, the initial attack is usually on the crop edge so detection is relatively easy. Spot spraying of redshouldered leaf beetle swarms, which can become increasingly difficult to control if unmanaged, usually prevents substantial congregation in cotton and so avoids their possible spread and associated leaf damage.

Redshouldered leaf beetle larvae feed on grass roots and it seems likely that sugarcane is a suitable host. Anecdotally, cotton in close proximity to large sugarcane crops appears to be more at risk of redshouldered leaf beetle attack than cotton crops at a distance.



> A redshouldered leaf beetle (length ~ 6 mm).
[Photo: S. Eyres, WADAF]



> Redshouldered leaf beetle damage to seedling cotton.
[Photo A. Annells, WADAF]

Insect monitoring

Regular and accurate sampling of pest and beneficial insect species, and monitoring of the crop's growth and fruiting, provides essential data on which pest management decisions can be based. The CottonLOGIC program, developed for established cotton growing areas in south eastern Australia by the Cotton CRC, is recommended as a suitable decision support tool, but has some minor limitations in northern Australia. Where appropriate, these limitations will be discussed for each of the major insect pests. It is intended that a decision support tool will be developed specifically for northern Australia prior to industry commencement.

Management options

Integrated Pest Management (IPM) aims to use multiple tactics to control pests rather than relying on routine applications of insecticides to solve pest problems. IPM tactics include conserving the natural enemies (of pests), using biological control, using selective chemicals to target specific pests and growing crops and varieties with tolerance or resistance to pest attack. 'Calendar' spraying with broad spectrum insecticides must be avoided to prevent disruption of naturally occurring control processes.

Extensive IPM cotton research has been conducted in northern Australia, especially at Kununurra. Local farmers have participated in large scale IPM trials with Bollgard II® and its predecessor, INGARD®. In total about 3,000 hectares of IPM cotton grown in the north has demonstrated the robustness of the system. Key features of the IPM system include:

- winter cropping – this strategy avoids peak abundance of many key pests, especially pink bollworm, looper caterpillars, *Spodoptera* and locusts;
- companion crops;
- encouraging beneficial species; and
- a Resistance Management Plan to minimise the likelihood of pests becoming resistant to Bollgard II® varieties.

Some management strategies included in the IPM package are discussed in the following.

Companion crops

Companion crops, sometimes called 'trap crops', act as a 'sink' for pests and a nursery for beneficial insects in IPM systems. Companion crops for INGARD® cotton were examined over several seasons in the ORIA. Results demonstrated cotton

grown with companion crops required slightly fewer insecticide sprays and also tended to produce a modest yield improvement (Annells and Strickland 2003). The likelihood of obtaining benefits from companion crops will depend on individual farm location and enterprise mix. For example, a property with several enterprises, such as horticulture, grain crops and trees, is likely to have established reservoirs of beneficial insects. However, if a cotton crop is surrounded by a crop monoculture, such as sugarcane, increasing local insect species diversity with companion crops is more likely to deliver pest control benefits. On average, 2.5 to 5% of total cotton crop area is sown to a companion crop, which may have no intrinsic commercial value, but indirect economic and environmental benefits.



> A well managed lucerne companion crop. Companion crops like this can be a permanent feature in a cropping system.

Companion crops must be well managed to be of value in a cotton production system, and are most effective if attractive to insect pests early in the season (Annells and Strickland 2002). On black soils this can be difficult to achieve because cotton also needs to be planted as soon as possible after the end of the wet season. To overcome this problem, consideration should be given to establishing permanent companion crops such as beds of lucerne, or planting a companion crop the season before and maintaining it through the wet. To be most effective, companion crops must maintain vigorous growth that is continuously attractive to insect pests.

The selection of a suitable companion crop is dependent on several factors including cost, ease of maintenance and effectiveness. Appropriate companion crop species will vary between farms.

There is the possibility that companion crops could act as a source of mirids, which are important insect pests of cotton. If mirid densities in companion crops become high (>5 mirids per metre), application of a selective insecticide to both the companion crop and the first six immediately adjacent rows of cotton may assist in controlling mirids before they move into the adjacent cotton. Vigorously growing lucerne is more attractive to mirids than cotton, and must be maintained in this state to remain attractive.

Species of companion crop

Both lablab (*Dolichos lablab*) and lucerne (*Medicago sativa*) are excellent companion crops for cotton in the ORIA.

Lucerne is slow to establish and needs to be established well ahead of the cotton crop. This can cause difficulties if early cotton planting is imperative. Alternatively, lucerne can be managed as a permanent crop from season to season, but weed control in the companion crop becomes an important consideration. Lucerne generates more beneficial insects than any other species of companion crop. The value of lucerne as a source of beneficials can be maintained by slashing at intervals through the season and encouraging new growth.

Lablab establishes readily and grows more rapidly than lucerne. It can be planted at the same time as cotton, and is a very effective companion crop. Slashing half the strip of lablab in the late flowering stage will prevent seed set (volunteers can cause problems in subsequent years) and ensure vigorous vegetative growth is maintained to attract insects.

Companion crops should be about 12 metres wide (6 'beds') and spaced at 300 metre intervals.



> A well managed lablab companion crop.

Beneficials

Many beneficial arthropods can help control insect pests. 'Beneficials' are either predators, such as spiders, lady beetles and hoverflies that feed mainly on aphids and small caterpillars, or parasitoids that use host insects for reproductive purposes. The small *Trichogramma* wasp that

breeds within heliothis eggs is the most common and important parasitoid in the cotton cropping system.

The value of beneficials can be maintained or enhanced by a) the use of companion crops that act as nurseries for beneficials, which may then move into the cotton crop, and b) by avoiding the use of disruptive broad-spectrum insecticides.



> An adult female *Trichogramma* wasp parasitising a heliothis egg. [Photo: Courtesy Dr Brad Scholz, QDPI]

Trichogramma larvae devour the contents of host eggs as they develop, so parasitised heliothis eggs never hatch. *Trichogramma* thus reduces the number of heliothis caterpillars exposed to Bt cotton and is an important component of Bt resistance management. Parasitised heliothis eggs turn black as the wasps develop and adult *Trichogramma* usually hatch after about 10 days. The rate of parasitism by *Trichogramma* (percentage of host eggs parasitised) can be measured by randomly collecting heliothis eggs from across a field and monitoring development. If many of the collected eggs are parasitised, then it is reasonable to conclude that heliothis larval hatch is actually below that predicted from normal egg counts (see *Heliothis management*, page 12). *Trichogramma* are especially active early in the season and are susceptible to most insecticides (see Appendix 10, page 43) so careful consideration regarding their value within the IPM system is required if insecticide application is necessary.



> Beneficial insects common in cotton production. Clockwise from top left: big eyed bug, hover fly, lacewing adult, ladybeetle adult, ladybeetle larva, predatory shield bug. [Photos: D. A. Ironside, QDPI, C. Mares, CSIRO]

Encouraging beneficial species into the cotton IPM system

- Growing a summer cover crop to provide continual habitat for spiders and other predators.
- Adoption of a minimum tillage system. Farming systems that feature a long period of bare fallow can reduce numbers of beneficial species.
- Planting of a companion crop to increase on farm biodiversity and beneficial numbers.
- Tolerance of early season pest damage, within limits (maintain >50% square retention), which reduces early season spraying that may disrupt establishing beneficial populations.
- Application of insect attractants (food sprays) to attract beneficials from companion crops and surrounding vegetation into the cotton crop.
- Minimising broad-spectrum insecticide use.
- The utilisation of insect resistant varieties (currently Bollgard II®).
- Preferential choice of IPM compatible insecticides when chemical control is necessary (effective against the target pest but with low negative effects on beneficials).

Detailed information on conserving beneficial species in cotton crops can be found on the Cotton CRC website in publications including 'Cotton Insect Pest and Beneficial Guide', 'Integrated Pest Management Guidelines for Cotton Production in Australia 2nd Edition', and in the 'Australian Cotton Best Management Practices' manual.

Bt resistance management

In Australia, the introduction of genetically modified (GM) cotton with lepidopteran insect protection traits has been highly successful. Farmers have adopted the technology readily and in 2005/06, ten years after the first INGARD® crops were planted, more than 80% of farmers grew Bollgard II® cotton, which expresses two genes from *Bacillus thuringiensis* (Bt), for caterpillar pest control (Monsanto, unpublished data).

The risk of pests, especially *Helicoverpa armigera*, developing resistance to the Cry1Ac and Cry2Ab genes expressed in Bollgard II® plants, was recognised prior to the commencement of commercial production and Resistance Management Plans (RMPs) put in place to mitigate against this concern. For example the early plantings of INGARD® were limited to 10% of the total cotton crop area in each production region and allowed to increase gradually to a final 'cap' of 30%.

RMPs were based on theoretical and experimental data published by resistance management experts including Roush (1997), Gould (1998) and Tabashnik (1994). Key strategies for delaying resistance development were:

- 'stacking' or 'pyramiding' insecticidal genes in plants rather than deploying them individually; either sequentially or concurrently in a mosaic;
- delivering a high dose likely to control >95% of heterozygous resistant individuals;
- utilising 'refugia' crops to produce populations of non-Bt selected moths; and
- deploying transgenic crops within an IPM system that will further reduce the survival of resistant insects.

Refuge crop options for Kununurra have been researched extensively and suitable crops selected (Strickland et al. 2006). A draft RMP developed by TIMS has been submitted to the APVMA and can be seen in Appendix 12, page 45.

Cotton regrowth and volunteer seedlings must be controlled following harvest in the ORIA.

Unlike in established growing areas, northern conditions after picking are highly favourable for cotton regrowth and volunteer seedling establishment. Prompt and determined actions are therefore required to prevent regrowth populations from establishing. This is especially important in black soil areas where access problems can arise if there is an early wet season. Full details of the Bollgard II® resistance management plan can be found in Appendix 12, page 45.

Post-season recommendations for cotton crop management

A major difference between traditional cotton growing regions and winter production systems in northern Australia is the post-season climate. Cold weather follows picking in traditional areas whereas rain and hot summer conditions occur in northern Australia. Preventing carryover of cotton plants is essential to the Bollgard II® resistance management plan and to prevent disease build-up. The following recommendations highlight important management differences between traditional growing areas and the ORIA.

Stubble destruction

Mulch and blade plough. If regrowth occurs, apply fluroxypyr at 300 grams per hectare (Starane® at 1.5 L/ha). Volunteers can be managed during ground preparation and sowing of cover crops. The cover crop should have the capacity to smother cotton seedlings, so densely planted grass species are desirable. Fluroxypyr or other broad leaf selective herbicides (e.g. bromoxynil) can be applied as per label recommendations if significant numbers of cotton plants become established in the cover crop.

No pupae busting

Heliothis diapause is rare in the ORIA and pupae busting is not generally a recommended action in northern Australia.

Cover crops

Little research has been conducted in the ORIA regarding the role cover crops play in influencing insect pest densities in following cotton seasons. Crops that could possibly act as nurseries for major insect pests should be avoided (see Table 2). In general, grasses are preferred as cover crops because they tend to harbour few cotton pests, allow for broad leaf weed management with selective herbicides, and can be removed relatively easily at planting.

The current recommendation for cover crops in a cotton production system is hybrid millet or forage sorghum sown late November and killed mid January. Irrigation will usually be required for crop establishment and to supplement dry spells.

Agronomy

Irrigation type

Furrow irrigation on Cununurra clay soils

Furrow is the favoured irrigation method for broad acre crop production on the clay soils of the ORIA. Beds are typically formed 1.8 metres wide and 0.16 metres above the furrow. Fields are lasered to a slope of between 1:800 and 1:2,000. Furrows are rarely longer than 500 metres and are often only 200 metres long. Irrigation heads (the height between the water surface in the supply channel and the tumble area of the furrow) are low, typically in the range 100 to 250 mm. Siphon diameter ranges between 25 mm and 50 mm depending on field length and water supply.

Use the first irrigation to 'tune' the paddock and adjust siphon size to ensure all furrows flow at the same rate. Slow running furrows may be supplied with larger diameter siphons, or the siphons can be doubled up.

Drip irrigation on levee soils

There is limited experience growing cotton using tape on light soils in the ORIA. A summary of research that examined drip irrigation on levee soils during 2005 is presented in Appendix 5, page 38.



> Drip irrigated cotton crop grown on a levee soil in 2005.

Irrigation scheduling

Rainfall during the cotton growing season is rare, so water requirements must be met by irrigation. Humidity is consistently low during the dry season and irrigation scheduling can be based on accumulated pan evaporation.

The ORIA is exposed to high daily evaporation rates early and late in the growing season. Evaporation is lowest mid-season, during flowering and early boll filling, but it is important to note that large plants can rapidly reduce soil water reserves at this time. Early season irrigation must aim to ensure effective crop establishment and prevent damage to seedlings caused by high temperatures, mid-season irrigation must avoid waterlogging, while late season irrigation requires a balance between rapidly increasing crop water use and the need for dry soil at defoliation. Irrigation scheduling is therefore critical throughout the entire growing season. The guidelines for irrigation scheduling are summarised in Table 5.

Timing of irrigations

> **Table 5.** Furrow irrigation timing for ORIA cotton crops.

Irrigation timing	Pan evap* (mm)	Approximate interval – days	Comments
Water-up		Immediately following sowing	Water-up is preferred because it permits earlier sowing**
2nd irrigation	130–190 mm	21–28 days	If irrigation extended towards 28 days then side dress nitrogen immediately prior to this irrigation
2nd irrigation to first flower	120–130 mm	18–24 days	Excessive vegetative growth can be managed by lengthening irrigation intervals and treatment with Pix® during this period (see <i>Growth regulation</i> , page 27)
First flower to cut-out	70–90 mm	12–18 days	Soil water depletion should preferably not exceed 50% of plant available water and must not exceed 60%. Care must be taken to avoid waterlogging at this growth stage (see below)
Cut-out to final irrigation	90–120 mm	12–18 days	Calculate final irrigation date at this time
Final irrigation	25–30 days prior to predicted defoliation		Assume 800 DDS (45 to 70 days) from cut-out (NAWF < 4.5) to picking

*This is the accumulated class A pan evaporation since the last irrigation.

**Water-up is preferred, but consider pre irrigating when:

- (1) there is a large seed bank of difficult to control weeds
- (2) the soil is dry and temperatures are high

Timing the last irrigation

The last irrigation needs to be planned to allow the crop sufficient time to begin natural senescence and the soil to dry without affecting yield or quality. On typical Cununurra clay soils, a cotton crop can extract 75% of plant available water (140 mm) prior to picking without affecting yield or quality. This generally takes 25 to 30 days during August to early October. If the soil has not been adequately dried there is a risk the crop will re-shoot following initial defoliation, but before picking, and so require an additional defoliation.

The date of the last irrigation should be planned at last effective flower. The following method is used to calculate the last irrigation date

- Record the date of last effective flower i.e. when NAWF falls below 4.5 and is still falling a week later.
- Using long term temperature averages, calculate 800 DDS (see Appendix 2 for calculation method) forward from last effective flower to give the predicted picking date.
- Plan to apply the last irrigation 25 to 30 days prior to the picking date.

Duration of irrigation

It is important when irrigating cotton to get water on and off the field quickly to reduce waterlogging. When watering, wet to the plant line about 30 metres above the tail drain (at least above any back up from the tail). Ideally, an irrigation should not exceed 10 hours using channel heads, siphon diameters and paddock lengths typical of ORIA stage 1. However, run times can be reduced where larger heads and diameters are available. See WATERpak for more details on application techniques for cotton. As a general guide, after irrigation the centre of the bed from about 30 metres above the tail drain (where the water backs up) should be dry enough to walk on without sinking.

Avoiding waterlogging during cool weather is critical. Waterlogging can occur in poorly lasered fields, or when irrigation times are too long.

Irrigation water use efficiency

The following is a guide to the irrigation water requirements of dry season grown cotton.

- Supply required at the field = 7 to 9 megalitres per hectare.
- Achievable field application efficiency = 70 to 80%.
- Achievable irrigation water use index = 1.1 to 1.3 bales per megalitre.
- Achievable cross production water use index = 1.0 to 1.2 bales per megalitre.

Water use in excess of these guidelines is wasteful, may be detrimental to yield, and may lead to excessive deep drainage. Refer to WATERpak for a full discussion of the principles of water use efficiency.



> The M1 irrigation supply channel in the ORIA.

Soil refill points

Research is currently evaluating neutron probe and capacitance tools to determine soil refill points. During flowering, irrigation after about 50% (range 40–60%) depletion of plant available soil water appears optimal. The maximum plant available soil water (to 1.3 metres) of a Cununurra clay is approximately 180 mm. See Appendix 6, page 39.

Cover crops and wet season field management

Field management over the wet season will have a significant influence on the success of the following cotton crop.

Options for wet season field management

- Bare fallow with complete weed control. Requires complete bed preparation and formation prior to planting the cotton crop, because bed edges slump during the wet season.
- Weed fallow (ensuring no seed is allowed to set).
- Managed cover crop on 'permanent' beds.

Possible benefits of a cover crop

- Earlier cotton sowing as the field may dry faster and require less cultivation than a bare fallow.
- Erosion and soil loss during the wet is reduced.
- Bed structure is maintained over the wet season.
- Weed control may be incorporated into the cover crop management plan.
- The cover crop can be managed to provide mulch with weed control benefits during the cotton season.
- Less fuel for land preparation and crop establishment.



> A cotton crop incorporating minimum till into a cover crop with a lablab companion crop.

For more details on research into minimum-tillage and cover crops (see Yeates et al. 2006).

Factors to consider when growing a cover crop

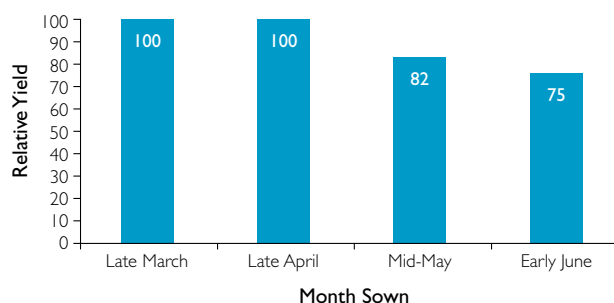
- Possible allelopathic effects on cotton crop (known for pigeon pea and may be a factor with sorghum).
- Beds must be properly formed prior to planting the cover crop to obtain full benefit.
- An irrigation may be required to establish the cover crop.
- The cover crop must be managed (slashed and sprayed if needed).

Sowing date and planting

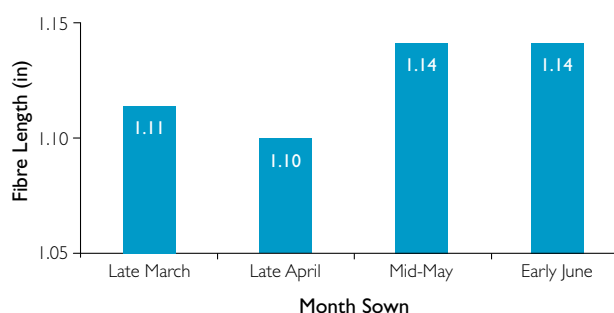
Sowing date

March sowing is recommended, as it provides the best compromise between maximising yield and fibre length (Figures 3 & 4) and avoidance of rain at maturity (Figures 5 & 6).

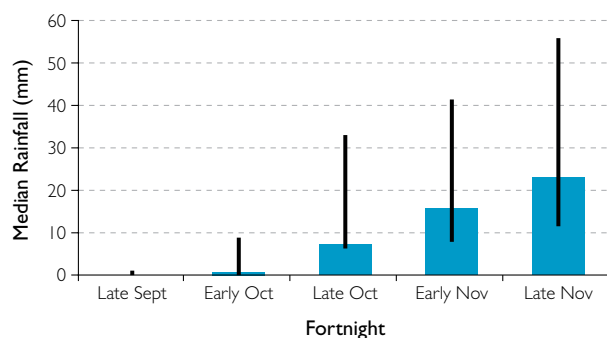
ORIA cotton sown in March is defoliated in early September (Figure 6) and picking commences 10 to 14 days later when the chance of rainfall is still low (Figure 5). In contrast, sowing in mid-May pushes the start of picking to late October, when the chance of rain is much higher (Figures 5 & 6).



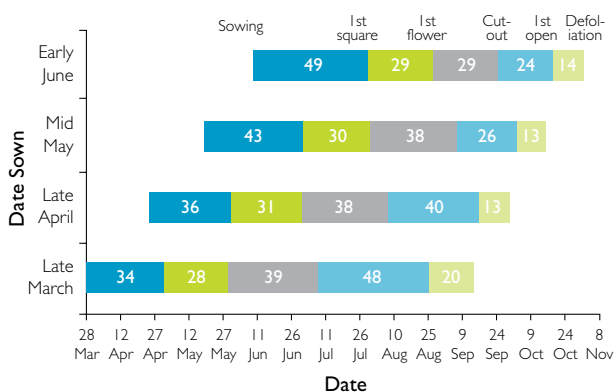
> **Figure 3.** Effect of different sowing dates on relative cotton yield in the ORIA. Yield is average for three years and two varieties.



> **Figure 4.** Effect of different sowing dates on cotton fibre length in the ORIA. Fibre length is average for three years.



> **Figure 5.** Median fortnightly rainfall during the transition from dry to wet season in the ORIA. Vertical bars denote the range for 10 to 90% of seasons.



> **Figure 6.** Effect of different sowing dates on the average time from sowing to defoliation (60% open bolls) for ORIA cotton. The average duration (in days) and occurrence date (x axis) of each crop growth phase (top) is given.

Planting prior to 1 March is not recommended.

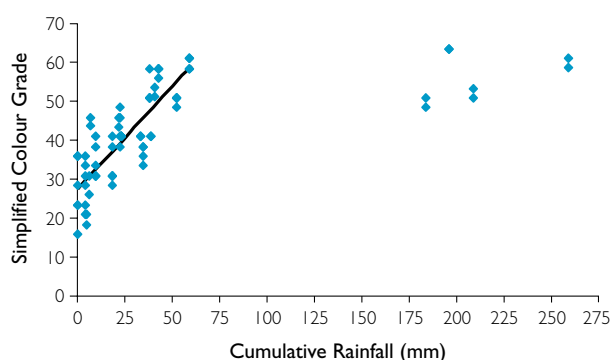
The recommended planting period for cotton is between 1 March and 30 April, with the earliest possible date within this window preferred. In some years, an opportunity to plant cotton in January or February may occur, but is not recommended.

Planting cotton in January or February is not recommended because.

- The crop will be exposed to unnecessarily high numbers of insect pests.
- High soil temperatures can damage emerging seedlings.
- Early vegetative growth may be difficult to control.
- The current Bollgard II® resistance management strategy (Appendix 12, page 45), which must be adhered to, dictates a five week planting window. This means that the entire district's crop must be planted within five weeks of the first crop being planted. The likelihood of further rain in January and February may prevent the entire crop from being planted within five weeks.
- There is a greater risk of waterlogging.
- There is a greater likelihood of prolonged periods greater than 35°C during boll growth, which can reduce boll size.

The effect of rain at maturity on fibre grade (colour) and yield

Research has found that lint is easily discoloured by rain in the tropical climate. A reduction of approximately one colour grade occurred for every 15 mm of rain on open bolls (Figure 7). Exposure to as little as 30 mm of rain could therefore result in significant price discounts (Grade 41 – Strict Low Middling) and exposure to about 60 mm of rain could result in severely discoloured lint (Grade 61 – Strict Good Ordinary).



> **Figure 7.** The effect of cumulative rainfall on open boll simplified colour grade for ORIA cotton.

In addition, most rain in the ORIA occurs as intense storms, which dislodge lint from cotton bolls and reduce yield.



> Lint dislodged from mature cotton plants following intense November storms in the ORIA. Cotton regrowth is rapid following rain due to high temperatures.

Planting density

An established population of 7 to 10 plants per metre of row is recommended. To achieve this, aim to plant 10 to 13 seeds per metre of row. Research has found that cotton yield is largely independent of planting density within the range 4 to 15 plants per metre of row on a typical 1.8 metre twin row bed (i.e. 0.9 metre row spacing).

Densities as low as 4 plants per metre of row are unlikely to cause yield reductions provided plants are uniformly spaced. Densities above 12 plants per metre of row can produce tall plants possibly reducing picking efficiency.

Refer to Appendix 13, page 48, for the experimental basis of these recommendations.

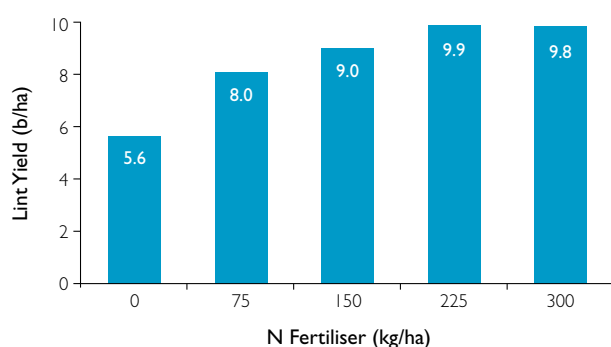
Nutrition

Cununurra clays are inherently low in nitrogen (N), phosphorus (P), zinc (Zn) and sulphur (S), so expect to apply the following nutrients in most seasons:

- nitrogen 200 kg per hectare;
- phosphorus 40 kg per hectare;
- zinc 5 kg per hectare; and
- sulphur 20 kg per hectare.

Soil testing to determine paddock nutrient status can be done when practical during February. A typical soil analysis for previously fertilised Cununurra clay can be found in Appendix 7, page 40.

Nitrogen



> **Figure 8.** Three year average yield response of cotton to N fertiliser.

For Cununurra clays, the plant available soil nitrogen is usually low at sowing, with 50 to 110 kg N/ha available in the 120 cm profile, and, because the organic carbon is also low at about 0.6%, cotton crops will require significant amounts of nitrogen fertiliser for high yields. Research over three seasons in the ORIA, where cotton has followed a wet season fallow, found around 200 kg N/ha was required to maximise yields at about 2,250 kg lint/ha (9.9 bales/ha). Yield was reduced by 10% when 150 kg N/ha was applied, and there was no yield increase above that achieved with 225 kg N/ha when increasing to 300 kg N/ha (Figure 8, above).

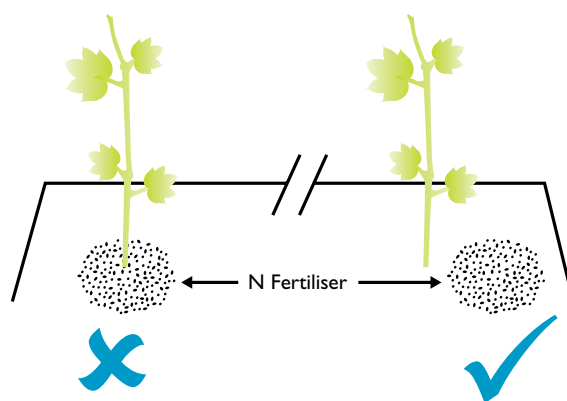
The amount of available soil nitrogen following the wet season is difficult to predict due to variable rainfall and rapid rates of mineralisation, which can leach NO_3 below the root zone. Wet season soil management therefore has a significant impact on soil nitrogen status at cotton planting. Cover crops extract some mineralised nitrogen before it is leached by rain and store it until they are turned into mulch. Nitrogen is then re-mineralised, although the quantity available to the cotton crop will depend on the ratio of carbon to nitrogen in the cover crop, weed growth, rainfall pattern over the wet season, and the time between killing the cover crop and cotton sowing.

Splitting nitrogen applications

Nitrogen can be applied immediately prior to cotton sowing at a starter rate or as the whole amount. Where a starter rate is used, the remainder can be applied up to 40 days after sowing ensuring application is prior to plants being too tall for machinery to pass without causing damage.

Delaying application of all nitrogen fertiliser for up to 40 days allows timely cotton sowing without affecting yield. However, a slight delay in maturity (three to four days) can occur.

Where urea is the nitrogen fertiliser, the field must be irrigated immediately following application, otherwise heavy losses may occur through volatilisation. Sidedressed nitrogen is applied to the furrow side of the cotton plant line at 10 to 15 cm depth and followed with irrigation. Sidedressing can be combined with inter-row cultivation for weed control, prior to the second or third irrigation after planting.



- > Stylised placement of nitrogen fertiliser in cotton beds. Avoiding burning of seedlings is critical when applying high rates of chemical fertilisers. Fertiliser placement to the side of and below seed reduces this risk, as can splitting applications.

Phosphorus

Previously fertilised soil

Phosphorus status can be improved with a fertiliser program that reduces the amount of phosphorus fertiliser required in future seasons. Use of 'stored' soil phosphorus by a crop necessitates maintenance applications in following seasons to replace what has been removed. A crop yielding > 8.5 bales/ha will require a maintenance application of 30 kg/ha of P.

Guidelines, modified from research with cotton (Duggan et al. 2007) and maize (Sherrard 1993) for determining fertiliser requirements from soil available phosphorus are given below.

Soil test (ppm, Colwell)	Phosphorus applied (Kg/ha)
> 29	0
21–29	20–30
10–20	40–50
< 10	60–80

Virgin soil

Research found that the first cotton crop on virgin Cununurra clay will require 80 kg/ha of P for maximum yield (See Duggan et al. 2007).

Zinc

An annual Zn fertiliser program is required for all crops grown on Cununurra clay soils. Critical Zn soil test values have not been determined for ORIA cotton. NUTRIpak can provide a guide to potential requirements, but at least 5 kg/ha of Zn should be applied even where soil test values exceed the critical level.

Other nutrients

It is possible that boron (B), iron (Fe), copper (Cu) and potassium (K) fertilisers may be required for cotton production in some fields in some years. A soil test prior to sowing will provide guidance. At this stage for these nutrients, the same critical values and test methods used in southern Australia are recommended for the ORIA (see NUTRIpak).

Plant analysis

No locally developed guidelines for interpretation of ORIA cotton plant analysis are yet available. Therefore, within season leaf or petiole testing of cotton should follow the methods described in NUTRIpak. The turnaround time for plant analysis must be considered when planning within season fertilisation. If leaf analysis is carried out, the leaves must be separated from the petioles while still on the plant, as errors will occur if the leaf is separated from the petiole after picking.

Fertiliser type

There is no preferred source of nitrogen or phosphorus fertiliser. Acidifying forms (e.g. MAP) may have advantages for availability of other nutrients such as P and Zn, as Cununurra clay and dry season irrigation water are usually slightly alkaline.

Varieties

Cotton development is ongoing and current varietal recommendations may rapidly become obsolete as improved varieties appear. The following comments are valid as of March 2007.

Early maturing Bollgard II® Sicala 40B is recommended for sowings made prior to early April. For an April sowing, the later maturing Bollgard II® Sicot 289B is recommended due to its tendency for rank growth if planted too early and superior fibre length when sown late (Refer to Appendix 8, page 41, for details of cotton variety characteristics). In extreme seasons when cotton is sown in May there is little difference between the varieties and a mixture may spread the picking and boll opening period. There is a high risk of pre harvest rain when sowing occurs in May.

Roundup Ready® varieties are not generally recommended as early season high temperatures shorten the spray window (17 days after planting), seriously reducing the versatility of the technology under local conditions (see *Weed management*, page 28). Roundup Ready Flex® varieties are likely to greatly increase the spray window.

Growth regulation

Excessive early vegetative growth may occur in some varieties (e.g. Sicot 289B), especially when planted early.

Vegetative growth and a tendency to rankness early season in the ORIA can be controlled to some extent by

- judicious application of mepiquat chloride; and
- increasing the interval between irrigations.

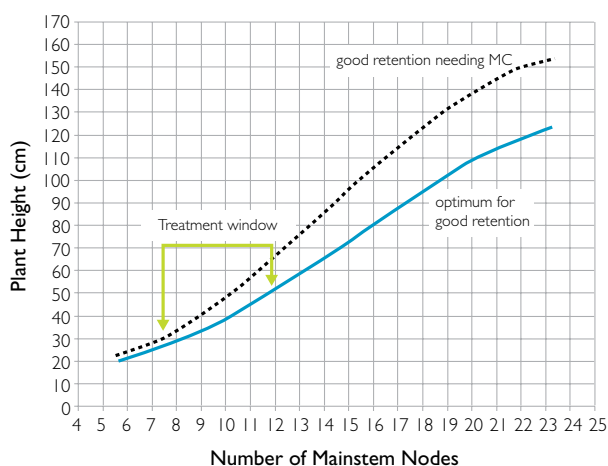
Mepiquat chloride (MC)

Treatment with mepiquat chloride (e.g. Pix®) can be beneficial to crops sown in March and early April. Local research has shown that MC applied at 200 to 400 ml/ha early (between 7 to 12 nodes) reduces the rate of cotton crop elongation in potentially rank varieties. However, yield effects (positive or negative) are unlikely, unless rank growth hampers insecticide penetration or picking efficiency (see Yeates et al. 2002).



> A comparison of ORIA cotton with (left) and without mepiquat chloride treatment (right).

The decision to treat with MC is based on cotton plant height between nodes 7 and 12, and square retention, as shown in Figure 9. MC is unlikely to be beneficial on crops sown after mid-April. Do not apply MC when low temperatures (below 15°C) are expected within the fortnight following application. Cold weather immediately following application of MC, even at low rates (200 to 400 ml/ha), can severely retard cotton plant growth and reduce yield. When square retention is low (less than 40% of total sites) plants will grow taller and treatment with high rates of MC (> 400 ml/ha) can inhibit compensation by the crop. Extending the irrigation interval and using low rates of MC (200 ml/ha) are the best options in this situation.



> **Figure 9.** When cotton plant height is greater than optimal (black line) during the treatment window, Pix® at 200 to 400 ml/ha can be used to limit vegetative growth.

Interval between irrigations

When seasonal factors indicate that excessive early season vegetative growth rates may be expected (early planting date and high temperatures), cotton crop height can be reduced by extending early irrigation intervals. Limited ORIA research results indicate that the first irrigation following watering up can be delayed for up to 28 days without harm to crop vigour.

Weed management

Weed management for cotton in the ORIA aims to minimise the use of residual pre-emergent herbicides. Research is examining the use of chemicals known to have minimal mobility and environmental impact. Rotation of herbicide groups should be practiced for resistance management (see WEEDpak). Common weeds in cotton crops are shown in Table 6.

For dry season cotton production, the ease of in crop weed control is influenced by the success of seed bank management during the wet season fallow, which in turn is related to the seasonal rainfall pattern. Rainfall directly influences timeliness and efficacy (rain fastness) of herbicide applications. Rainfall also necessitates the use of aerial application when the soil is wet. On clay soils, a further impact of rainfall on efficacy is through reduced weed vigour due to waterlogging.

Pre sowing

Good management of weeds over the wet season prior to sowing is essential to reduce the weed seed bank. A competitive cover crop inhibits weed growth over the wet season. Cultivation, combined with the use of knockdown herbicides (e.g. glyphosate and paraquat/diquat) will control weeds in the period between killing the cover crop and cotton sowing.

In crop

Stomp® at 4 L/ha post sowing pre emergence is recommended to control grass and selected broadleaf weeds (e.g. black pigweed). Stomp® can also be applied pre plant, but local experience has shown that this is not as effective as watering up immediately after post-planting application. Inter row cultivation at about first square and chipping of important weeds, such as Chinese gooseberry and hibiscus, may be required. Staple® and Envoke® or selective grass herbicides (e.g. Verdict®) can be applied over-the-top if needed.

Roundup Ready® cotton varieties are not generally recommended for production in the ORIA (Yeates et al. 2006), however, next generation Roundup Ready Flex® technology has the potential to be of great value. Roundup Ready Flex® varieties will allow over-the-top application of glyphosate for weed control throughout the season with no adverse impact on cotton yield. Similarly, Liberty Link® cotton varieties will allow the in-crop application of Basta® for weed control.

Reduced/minimum tillage

Apart from benefits to be gained by achieving early cotton planting due to minimal early season cultivation, reduced tillage, when combined with a cover crop, can provide weed control benefits. Cultivation encourages the germination of weed seeds, and weed problems are often greater in crops that had been cultivated prior to planting. Potential weed

problems can be minimised by planting a cover crop, which is sprayed out, avoiding cultivation, and applying a pre-emergent herbicide with watering up immediately following planting.

Note: these recommendations for chemical weed control are either the result of experiments or are well developed in eastern Australia. Check the registration status of any pesticide before use. There are currently limited herbicides registered for use in cotton in Western Australia.

Common weeds in cotton

> **Table 6.** Common and species names of weeds associated with cotton production in the ORIA.

Weed	Species	Comments
Native Rosella	<i>Abelmoschus ficulneus</i>	Both these weeds are important and difficult to manage. Hard seeded – several germinations
Wild Gooseberry	<i>Physalis minima</i>	
Pumpkin Vine	<i>Operculina brownii</i>	
Black Pigweed	<i>Trianthema portulacastrum</i>	Common but controlled with existing herbicides (Stomp®, Treflan®)
Nut Grass	<i>Cyperus</i> spp.	Only small areas to date
Wild Vigna	<i>Vigna</i> spp.	Channels mainly
Tridax Daisy	<i>Tridax procumbens</i>	Channels mainly – tolerant of glyphosate

Disease

No major diseases have been reported on cotton grown in northern Australia, except *Alternaria* leaf spot. The following is a summary of cotton pathogens known in northern Australia, and other important cotton pathogens that may affect the development of a future cotton industry in the region. The pathogens causing *Alternaria* leaf spot are endemic to northern Australia and their impact and management options are discussed.

1. *Alternaria* leaf spot

Alternaria leaf spot is considered the most prevalent and serious disease of cotton in northern Australia. During recent years, disease severity was high in some crops at Katherine, the ORIA and the Burdekin in north Queensland. Symptoms normally appear mid-season following a prolonged cold spell.

Symptoms

Alternaria leaf spot occurs on cotyledons, leaves, stems, flowering buds and bolls.

- Symptoms begin with small brown necrotic lesions, 1 to 2 mm diameter; surrounded by a purple halo. The lesions may extend up to 2 to 3 cm in diameter in severe cases.

- A marked yellow halo surrounding the necrotic lesion is common in mature leaves.
- Under suitable conditions, leaves take on a black sooty appearance due to the massive sporulation from lesions by the fungi. As the disease progresses, tissue at the centre of the old lesions becomes grey and dry and necrotic tissue may crack and fall out, giving a 'shot-hole' appearance.
- Defoliation of infected leaves is the most noticeable symptom of *Alternaria* leaf spot.
- Heavy leaf infection can completely defoliate plants.



> Left: Early *Alternaria* leaf spot symptoms. Right: Severe *Alternaria* infection.

Cause

Alternaria macrospora and/or *Alternaria alternata*

Sources of infection

- Volunteer crops.
- Cotton residues.
- Alternative host plants.
- Contaminated equipment.

Control

There is limited information about the management of *Alternaria* leaf spot on cotton in Australia, probably because it has not been a major disease in established cotton growing areas. Although the fungicide mancozeb (750 gac/kg) at the rate of 2.5 kg/ha is recommended for the control of *Alternaria* leaf spot on pima cotton, no reports on the management of *Alternaria* leaf spot of upland cotton in Australia are available. Potassium deficiency is considered to be a prerequisite for the development of *Alternaria* leaf blight on cotton in the ORIA.

2. Other potential disease threats

Table 7 summarises disease threats to cotton in the ORIA. For more detail see Appendix 14, page 49, and 'Cotton Integrated Disease Management' published by Cotton Catchment Communities CRC and CRDC.

> **Table 7.** Potential disease threats to cotton.

Type of infection	Disease(s)	Control issues ORIA
Seedling	<i>Rhizoctonia solani</i> (AG 4)	Use fungicide treated seed and good farm hygiene. Avoid incorporation of residues of rotation crops prior to cotton.
	<i>Pythium</i> spp.	As above
	<i>Fusarium</i> sp.	As above
	Anthraxnose caused by <i>Colletotrichum</i> sp.	As above
Stem and root	Fusarium wilt <i>Fusarium oxysporum</i> f.sp. <i>vasinfectum</i> (Fov)	Prevent entry on seed, soil and machinery.
	Verticillium wilt <i>Verticillium dahliae</i>	As above, except not seed borne.
	Charcoal rot <i>Macrophomina phaseolina</i>	Manage to reduce soil temperatures.
Foliar	Tropical cotton rust <i>Phakopsora gossypii</i>	May require resistant varieties/fungicides.
	Bacterial blight <i>Xanthomonas campestris</i> pv. <i>malvacearum</i>	Resistant varieties.

To promote effective defoliation, cotton crops need to begin the maturation and desiccation process naturally. Leaves should be aged (not young and green) and fruit mature prior to defoliation. Dry down fields as much as possible prior to treatment.

Cotton should be defoliated once 60% of bolls have opened naturally. A mixture of ethephon (Prep® – 500 to 1300 ml/ha) and thidiazuron (Dropp® – 50 to 100 ml/ha) is recommended. Relative rates and application timing for mixtures will vary with the maturity of the cotton crop, its height and leafiness, and the intended picking date. Defoliation will also be influenced by seasonal differences causing variation in thickness of leaf waxy cuticle. Two defoliations, one week apart, are usually required. Prep® may be omitted from the second defoliation if boll opening is satisfactory.

Effective defoliant application is critical. Ensure even coverage and avoid high temperatures and strong wind during application (morning is best). Minimum water carrier volumes are 30 L/ha by air and 150 L/ha by ground rig. Spraying the first defoliation along rows avoids striping.

At relatively high temperatures, cotton regrowth can be very rapid (one week) when soil moisture is available. Prompt picking when regrowth is likely is essential otherwise there is a difficult choice between the risk of green stain to lint or the cost of another defoliation.

Prompt picking also avoids down grading of lint due to rain and UV light exposure. Research at the ORIA estimates a drop of one colour grade for every 15 to 30 mm of rain on open bolls.

It is better to delay defoliation, rather than leave a defoliated field exposed to the weather for long periods without picking because:

- leaves will provide some protection to lint from UV light damage;
- additional defoliant to remove regrowth can be avoided;
- on mature crops, defoliants work quickly in ORIA conditions (8 to 10 days); and
- if rain falls, the field will dry more quickly with green leaves on the bush.

Best Management Practice (BMP)

The Cotton BMP program is a voluntary program based on a process of continuous improvement. It uses a 'plan – do – check – review' management cycle and is best described as a functional Environmental Management System. It involves growers in a repeatable risk assessment and planning process that equips them with the means to address generic and farm specific environmental risks. The BMP Program also includes an audit component that ensures farm practices and procedures are regularly checked, and that any deficiencies are corrected.

The goals of BMP are to see the development of a cotton industry:

1. whose participants are committed to improving farm management practices;
2. whose participants have developed and follow policies and farm management plans that minimise the risk of any adverse impacts on the environment or human health; and
3. which can credibly demonstrate to the community stewardship in the management of natural resources and farming operations.

The BMP Manual and Program was established following a research project investigating the impact of pesticides on the riverine environment (using the cotton industry as a case study), completed in the early 1990s. Following the research, a BMP Program was considered the best means to help cotton growers manage their operations in order to minimise the environmental risks associated with pesticide use.

It is anticipated that a BMP manual, tailored to the ORIA cropping system, will be developed prior to the commencement of an industry.

More information on the BMP program can be obtained from Cotton Australia (www.cottonaustralia.com.au).

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Appendix I: Glossary of terms

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

Boll The fruit of a cotton plant. The woody capsule which contains the cotton lint and seed. Forms immediately after the flower petals have fallen.

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

Companion crop A crop grown in conjunction with a cotton crop. Its purpose is to act as a nursery for beneficial species and a trap for pest insects. Lucerne and lablab are effective companion crops in the ORIA.

Cut-out The date when the last effective flower has formed. Flowers formed after this date will not add to yield. Cut-out can be recognised in two ways:

- nodes above white flower falls below about 4.5 and remains below 4.5; or
- the squares per metre falls below about 50.

Degree day The heat accumulation calculated progressively during the season to monitor the crop's progress. Daily sums are used to predict date of growth stages of cotton crops (see Appendix 2).

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

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

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

Fruiting site The position on a plant where a fruit (square or boll) is formed. Can contain a fruit or an abscission scar.

INGARD® A trademark of Monsanto Ltd. Cotton containing the Cry I Ac gene from *Bacillus thuringiensis*.

Integrated Pest Management (IPM) Pest control based on the integrated use of a range of strategies that can be used to influence pest numbers in a crop.

Irrigation water use index The lint produced per megalitre of irrigation water used. (Note: there is little in crop rainfall in the ORIA)

NAWF Nodes Above White Flower. The number of nodes above the topmost white flower in position 1. Usually the average of 5 plants at a sample point.

PI, P2 etc. Fruiting position along a fruiting branch.

PI is the fruiting position closest to the main stem. A fruiting branch may have up to 5 fruiting positions.

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

Phase The developmental stage of cotton as it affects susceptibility to insect attack:

Phase 1 Germination to 1st flower

Phase 2 1st flower to cut-out

Phase 3 Cut-out to harvest

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

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

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

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

Square The flower bud on a cotton plant. First seen as a triangle of bracts.

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

Vegetative boll A boll which forms on a vegetative branch.

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

Water use efficiency A general term relating to measurements of the efficiency with which available water is used to produce a crop. Includes measures of the efficiency of supply, application and conversion of water to cotton lint.

Appendix 2: Accumulated Degree Days (DDS)

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

The relationship between key growth stages and DDS in the ORIA is shown below:

Stage	DDS ¹²
4 nodes	290±20
6 nodes	380±20
1st square	546±40
1st flower	888±50
Cut-out*	1400±75
1st open boll	1783±75
60% open/defoliation	2040±120
Harvest [#]	2200±120

* Estimate – is affected by fruit load and retention.

Can also be calculated as cut-out + 800 DDS.

From 4 nodes to early flowering (17 nodes) there is a constant 60 DDS for each node, which is similar for most varieties.

Degree days can be calculated using the following formula:

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

where: DD = degree days for that day

max = maximum temperature for that day

min = minimum temperature for that day

(note: when min < 12, then a value of zero is used)

Degree days for a growing season should be calculated and summed from planting date.

Appendix 3: Crop agronomic monitoring calendar

Measurement	Cover crop to planting	Planting to first flower	First flower to cut-out	Cut-out to defoliation	Defoliation to cover crop
Plant height and node number		✓	✓		
Fruit retention (refer App. 4)		✓	✓		
Fruit counts/fruitlet factors			✓	✓	
Soil water/evaporation		✓	✓	✓	✓
Weeds	✓	✓	✓	✓	✓
Nutrient status		✓	✓		
NAWF			✓	✓	
% open bolls				✓	

Appendix 4: Fruit retention

'Retention' is a measure of the percentage of squares that successfully develop into pickable bolls. It is customary to consider PI retention, or the percentage of first position squares that become bolls. Retention is a valuable statistic as it provides insights into the growth of the plant and whether insects or other stress may be causing unacceptable levels of damage.

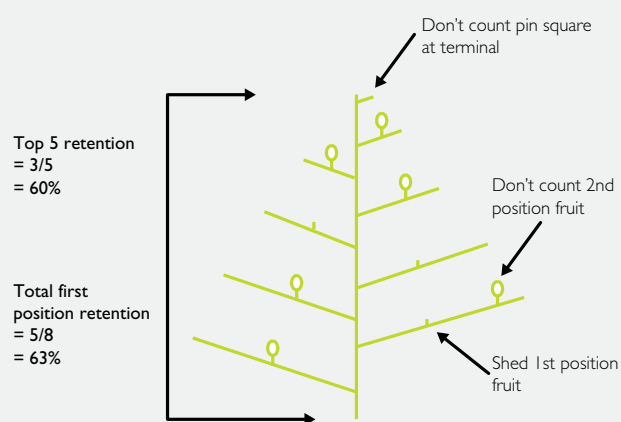
As a general guide, a PI retention of 50 to 60% at harvest represents a good balance between plant growth and fruiting. Retention will vary throughout the growth season.

Low retention (<50% between 1st square and 1st flower)

- May result in excessively tall and vegetative plants (the plant diverts too many resources into vegetative growth).
- Might cause maturity to be delayed.
- May reduce total yield and fibre quality.
- May indicate loss of small squares caused by insect attack (heliothis and mirids).
- Might reduce picking, spraying and scouting efficiency due to tall cotton plants.

High retention (>80% between 1st square and 1st flower)

- Very high retention may cause early cut-out (the plant uses resources to fill early bolls at the expense of vegetative growth, with a reduction in the total number of fruiting sites set).



Measuring 1st position retention

- Only count 1st position squares.
- Monitor plants in 1 linear metre at 5 points per field.
- Monitor tipped and untipped plants.
- Do not include vegetative branches.
- Monitor at least 30 plants per field.
- Monitor weekly and before spray decisions are made.
- Start monitoring the first week after 1st square.

Appendix 5: Drip irrigation on levee soils

Limited experience in the ORIA in 2005 and 2006 indicated cotton crops can be grown with drip irrigation on lighter soils found on the Ord River levee, and, by extension, on areas of similar soil on the Mantinea Plain.

Potential advantages

- Ability to get onto the land earlier in the season (well drained soils).
- Ability to closely control irrigation and fertiliser application (fertigation).
- Higher yields may be possible than on clay soils (levee soil has produced over 12 bales per hectare).
- Infrastructure costs may be competitive.

Potential disadvantages

- Limited areas of suitable land are available.
- Cotton may be seen as an undesirable competitor for other horticultural crops.

The following program was used to produce a crop of Sicot 289B cotton on levee soil at Frank Wise Institute, Kununurra, in 2005. The crop was grown on raised 1.8 metre beds. Drip tape was laid under each row at a depth of 70 mm. The crop yielded 12.8 bales per hectare.

Irrigation

Water was supplied to the crop to replace $E_{pan} \times k_p$

E_{pan} = pan evaporation

k_p = crop factor

Growth stage	DDS	k_p
Sowing to 7 nodes	0–440	0.30
7 nodes to 1st flower	440–800	0.53
1st flower to peak flower	800–1000	0.75
Peak flower to cut-out	1000–1400	0.83
Cut-out to max. bolls	1400–1600	0.75
> max. bolls	1600–1900	0.53

(This was the driest of 3 watering regimes tested in 2005. Greater k_p values produced rank growth)

Nutrition

The fertiliser program aimed to supply 250 kg N and 60 kg P per hectare. Supertrace 4 L, CuSO_4 5 kg/ha and ZnSO_4 5 kg/ha were applied through the tape at the start of the season. No basal fertiliser was used.

Week	DDS	Urea kg	MAP kg
1	136	4	
2	261	20	
3	374	60	40
4	463	60	40
5	549	60	40
6	631	60	40
7	709	60	40
8	785	40	25
9	857	40	
10	925	20	
11	989	20	
12	1050	20	
13	1113	20	
14	1173	20	
15	1236	20	

Ammonium sulphate may be considered as an N source if sulphur is low or acidification is needed. K levels should be checked before the season and monopotassium phosphate or K_2SO_4 included if required.



> Rank growth due to excessive irrigation.

Appendix 6: Scheduling irrigation based on soil water depletion

Soil water depletion relates to the quantity of water removed from the soil by the crop. Plant available water is the maximum volume of soil water available. A decision to irrigate can be made when soil water depletion reaches a critical fraction of plant available moisture (the refill point.)

For a Cununurra clay, the crop should be irrigated when it has extracted about 50% of plant available soil water after first flower. Cununurra clays have about 180 mm of water available to the crop, provided there is no soil compaction or other limitations to root growth.

The fraction of plant available water depleted between irrigations directly affects the balance between vegetative and boll growth of cotton, hence yield. Too frequent irrigation can stimulate leaf and stem growth and produce rank plants that shade lower bolls and are less efficient to pick. Over extending irrigation can reduce yields by inducing moisture stress.

Effect of irrigating at different fractions of plant available water content, from 1st flower to last irrigation, on cotton yield in the ORIA.

Fraction Plant Available Water (%)	Pan evaporation between irrigations (mm)	Relative Yield (% Maximum)
85	44	85 to 100
68	88	100
35	127	98
10	180	70

Measurement of soil water depletion

Soil water depletion can be measured by neutron probe. At a minimum, measurements should be made 7 and 10 days after irrigation and the soil water extraction extrapolated to determine the date when depletion has reached the refill point and irrigation is required.

Pan evaporation is related to soil water depletion and can be used to schedule irrigations (see the table in this Appendix and Table 5 in *Irrigation scheduling*). For example, after first flower, a crop having normal growth (e.g. not rank) should be irrigated after about 90 mm of pan evaporation is accumulated.

N.B. These pan evaporation values may not be valid for soils with poor structure or plants with damaged root systems.

Appendix 7: Typical Cununurra clay chemical analysis

The following values are indicative for virgin Cununurra clay soils and soils that have been in agricultural production for a number of years.

	Virgin		Previously fertilised	
	0–15 cm	30–40 cm	0–15 cm	30–40 cm
pH (1:5 CaCl ₂)	6.7	7.1	7.0–7.6	7.1–7.6
pH (1:5 H ₂ O)	7.6	8.0	7.8–8.4	7.9–8.5
EC (1:5 H ₂ O) (dS/m)	0.037	0.03	0.1–0.2	0.1–0.2
Organic carbon (Walkley Black) (%)	0.56	0.43	0.6–0.9	0.4–0.6
Nitrate N (KCl) (mg/kg)	2.1	2.0	9.0–24.0	2.0–20.0
Ammonium N (KCl) (mg/kg)	2.4	2.8	2.0–5.0	1.0–5.0
Phosphorus (Colwell) (mg/kg)	3.2	2.8	26–59	7–40
Potassium (Colwell) (mg/kg)	294	339	270–350	160–270
Sulphur (KCl-40) (mg/kg)	3.8	3.3	3.1–6.6	5.5–10.5
ECEC (meq/100g)	38	39	33–38	35–41
Ca:mg ratio	1.6	1.6	1.6–1.9	1.6–1.8
Copper (DTPA) (mg/kg)	0.8	0.7	0.8–0.9	0.8–0.9
Zinc (DTPA) (mg/kg)	0.8	0.3	2.6–3.5	0.7–2.4
Manganese (DTPA) (mg/kg)	8.6	3.6	6.1–9.7	4.0–7.1
Iron (DTPA) (mg/kg)	12	13	10–20	12–15
Boron (mg/kg)	0.4	0.4	0.6–1.0	0.6–1.0

Appendix 8: Plant type characteristics

Characteristics of a plant type suited to early sowing
e.g. Sicala 40B.

- High rate of early boll set.
- Early cut-out.
- Compact plant.
- Relatively high early retention.
- Large bolls (6 to 7 g) of seedcotton.
- Boll growth during warm weather.

Characteristics of a plant type suited to later sowing
e.g. Sicot 289B.

- Slow early boll set including a capacity to compensate for early fruit loss.
- Late cut-out.
- Large plant.
- Lower early retention.
- Smaller bolls (4 to 5 g) seedcotton.
- Maintains fibre length during relatively cold nights.

Appendix 9: Chemical pest control

Insecticides and miticides

The following insecticides are registered for use on cotton in WA (2006) against the pests shown.

Heliiothis	Mirids	Mites	Aphids	Leafhoppers	Red-shouldered leaf beetle
abamectin	aldicarb	abamectin	acetamiprid	aldicarb	chlorpyrifos
alpha-cypermethrin	alpha-cypermethrin	aldicarb	amitraz	beta cyfluthrin	diazinon
amitraz	beta-cyfluthrin	amitraz	chlorpyrifos	carbosulfan	
beta-cyfluthrin	bifenthrin	bifenthrin	chlorpyrifos-methyl	dimethoate	
bifenthrin	carbosulfan	chlorpyrifos	diafenthiuron	gamma-cyhalothrin	
chlorpyrifos	chlorpyrifos-methyl	diafenthiuron	disulfoton	lambda-cyhalothrin	
chlorpyrifos-methyl	deltamethrin	dicofol	pirimicarb	phorate	
cypermethrin	dimethoate	dimethoate	profenofos		
deltamethrin	fipronil	disulfoton			
emamectin	gamma-cyhalothrin	emamectin			
ethion	imidacloprid	etoxazole			
gamma-cyhalothrin	indoxacarb	methidathion			
indoxacarb	lambda-cyhalothrin	phorate			
lambda-cyhalothrin	phorate	profenofos			
methomyl		propargite			
NPV					
profenofos					
spinosad					
zeta-cypermethrin					

Appendix 10: Impact of pesticides on beneficial insects

(adapted from Wilson, Mensah, Dillon, Wade, Scholz, Murray, Heimoana and Lloyd, 2006)

Chemical pest control

When control thresholds have been breached and a decision has been made to apply insecticides, careful consideration should be given to choosing a treatment that balances effective pest control with minimal adverse impact on beneficial insects and the environment, and is safe for the operator. The following table provides guidance on chemical selection.

Insecticides (in increasing rank order of impact on beneficials)	Target Pest						Beneficials														Pest resurgence ⁹				Toxicity to bees ¹⁴
							Overall ranking ⁷	Ladybirds	Predatory bugs					Lacewing adults	Spiders	Hymenoptera			Thrips	Mite	Aphid	Helicoverpa			
	Total	Damsel bugs	Big eyed bugs	Other predatory	Apple dimpling	Total (wasps)			Trichogramma	Ants															
											Rate	Helicoverpa	Mites			Mirids ⁶	Aphids	Thrips					Persistence ⁴		
Bt ⁸		•					very short	very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL					VL		
NP Virus		•					very short	very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL					VL		
Pirimicarb	250				•		short	very low	VL	L	L	M	VL	VL	VL	H	VL	L					VL		
Methoxyfenozide	400	•					medium long	very low	L	L	L	L	VL	VL	VL	VL	VL	VL					VL		
Spinosad	96	•					medium	low	VL	M	H	H	VL	L	VL	VL	M	H	H	H	+ve		H ¹¹		
Diafenthionuron	350		•				medium	low	M	L	VL	VL	L	H	VL	L	L	H	H	L			+ve	M	
Pymetrozine	150					•	short	low	M	L	L	L	VL	H	M	L	L	M	M	VL				VL	
Indoxacarb ¹⁰	127.5	•		•			medium	low	VH	L	L	L	L	VH	L	VL	L	VH	VH	VL		+ve		H ¹¹	
Abamectin	5.4	^{a3}	•				medium	moderate	VL	M	M	M	M	H	VL	M	M	H	H	M				H	
Emamectin	8.4	•					medium	moderate	VL	H	H	H	H	H	L	M	M	VL	VL	M				H	
Endosulfan (low)	367.5	•		•	•	•	medium	moderate	M	M	M	M	M	L	H	L	M	VL	VH	VH	H			M ¹¹	
Propargite	1500		•				medium	moderate	M	M	VL	VL	VL	L	VL	M	M	H	H	M		+ve	+ve	L	
Acetamiprid	22.5					•	medium	moderate	H	M	H	H	H	M	VH	L	VL	L	VH	VH	VH			M ¹¹	
Amitraz	400	•	^{a5}				medium	moderate	H	L					H	VL	M	M	H	H	M			L	
Fipronil (low)	12.5				•		medium	moderate	L	L	L	L	L	VH	VL	M	M	VH	VH	VH		+ve	+ve	VH	
Chlorfenapyr (low)	200	•	•				medium	moderate	VL	M	H	H	H	H	VH	L	L	M	H	H	M			H	
Thiamethoxam	100					•	medium	moderate	H	M	M	M	M	H	H	M	VL	M	VH	VH	H	+ve		+ve	H
Endosulfan (high)	735	•		•	•	•	medium	moderate	M	M	M	M	M	H	L	M	L	VH	VH	H				M ¹¹	
Fipronil (high)	25				•		medium	moderate	L	M	H	H	L	VH	VL	M	M	VH	VH	VH	+ve		+ve	VH	
Imidacloprid	49				•	•	medium	moderate	H	H	H	H	L	VH	L	L	L	H	H	H	+ve		+ve	M	
Methomyl	169	•					very short	high	VH	M	VH	VH	L	VH	M	M	M	H	H	H	+ve			H ¹¹	
Thiodicarb	750	•					long	high	VH	M	L	L	L	VH	VL	M	M	M	M	H	+ve	+ve		M ¹¹	
Chlorfenapyr (high)	400	•	•				medium	high	L	H	H	H	H	H	VH	L	M	M	VH	VH	M		+ve	H	
OPs ²		•	•	•	•	•	short medium	high	H	H	H	H	H	H	VH	L	M	H	VH	VH	H	+ve		H	
Carbaryl							short	high		H										H				H	
Pyrethroids ¹		•	•	•			long	very high	VH						VH	VH	VH	VH	VH	VH	+ve	+ve	+ve	H	

- Pyrethroids: alpha-cypermethrin, cypermethrin, beta-cyfluthrin, cyfluthrin, bifenthrin, fenvalerate, deltamethrin, lambda-cyhalothrin.
- Organophosphates: dimethoate, omethoate, monocrotophos, profenofos, chlorpyrifos, chlorpyrifos-methyl, azinphos ethyl, methidathion, parathion methyl, thiometon.
- Helicoverpa punctigera* only.
- Persistence of pest control: **short** – less than 3 days; **medium** – 3–7 days; **long** – greater than 10 days.
- Suppression of mites only.
- Mirids: green mirid, brown mirid, apple dimpling bug (not considered a beneficial in the ORIA).
- Impact rating (% reduction in beneficials following application, based on scores for the major beneficial groups): **VL (very low)** – less than 10%; **L (low)** – 10–20%; **M (moderate)** – 20–40%; **H (high)** – 40–60%; **VH (very high)** – >60%.

- Bacillus thuringiensis*.
 - Pest resurgence is +ve if repeated applications of a particular product are likely to increase the risk of pest outbreaks or resurgence. Similarly, sequential applications of products with a high pest resurgence rating will increase the risk of outbreaks or resurgence of the particular pestspecies.
 - Very high impact on ladybirds for wet spray, moderate impact for dried spray.
 - Wet residue of these products is toxic to bees. However, applying these products in the early evening when bees are not foraging will allow spray to dry, reducing risk to bees the following day.
- N.B. The information presented in this table is a guide only. Reference to any product does not necessarily imply that the product is registered for use on cotton in WA. Check that the chemical to be used is currently registered for the purpose before applying.

Appendix I I: Trade names of commonly used active ingredients

The following table lists some commonly used chemicals.
See the annual 'Cotton Pest Management Guide' for full details.

Active Ingredient	Trade Name (s)
Mepiquat chloride	Pix®, Reward®, Reign®
Haloxypop	Verdict®
Pyriithiobac-Sodium	Staple® (not registered in VWA)
Glyphosate	Roundup®
Paraquat + Diquat	Spray Seed®
Pendimethalin	Stomp 330®, Rifle 330®
Ethephon	Prep®, Arvest®, Ethaphon®, Galleon®
Thidiazuron	Dropp®
Fluroxypyr	Starane®, Comet®

Appendix 12: Bollgard II® resistance management plan

Draft Resistance Management Plan for Bollgard II® Cotton: Areas North of 22° South

This is a draft plan – please check current requirements with Monsanto Australia prior to planting Bollgard II® seed.

Developed by the Australian Cotton CRC's northern program and the Technical Group for Northern Australia Resistance Management (TGNARM) in conjunction with Monsanto Australia Limited and TIMS.

OBJECTIVES

- Limit exposure of *Helicoverpa armigera* to Bt proteins in Bollgard II®
- Provide for unexposed *H. armigera* individuals to mate with Bt resistant individuals and effectively dilute resistance genes within the population
- Remove resistant individuals at the end of the cotton season

AREAS APPROVED

Bollgard II® cotton may only be used and planted commercially in the following regions:

- Ord River Irrigation Area, Western Australia;
- Burdekin Irrigation Area, Queensland; and
- Belyando Area, Queensland.

Planting of Bollgard II® in other regions is limited to a maximum of 50 ha per area and a localised resistance management plan must be approved by the TGNARM before it may proceed.

REQUIREMENTS

Growers of Bollgard II® cotton are required to practise pre-emptive resistance management. Requirements for resistance management are set out below. Adherence to the Resistance Management Plan is required under the terms of the Bollgard II® Technology User Agreement and under the conditions of registration (Agricultural and Veterinary Chemicals Act 1994).

Refuges

Each Bollgard II® grower will be required to grow an associated refuge crop capable of producing *H. armigera* moths not exposed to Bt selection pressure in sufficient numbers to dominate matings with Bollgard II® crop

survivors and thus help to maintain Bt resistance genes at low levels within the population.

All refuge requirements have been determined through rigorous scientific research and are based on the equivalent of a 10% unsprayed cotton refuge (determined by relative *H. armigera* production from each refuge option in the region).

For each area of irrigated Bollgard II® cotton, a grower is required to plant a minimum of one or combination of refuges allowed in the planting region.

Irrigated Bollgard II® cotton refuge options

Crop	Conditions	% of Bollgard II®	Regions permitted
Cotton:	Irrigated, unsprayed conventional or Roundup Ready cotton*	10	ORIA, Belyando, Burdekin
Pigeon pea:	Irrigated, unsprayed	5	ORIA
Chick pea:	Irrigated, unsprayed	5	ORIA
Corn:	Irrigated, unsprayed – conditions apply, see box below	10	ORIA

* This does not include 'stacked' Bollgard II®/Roundup Ready® cotton

Note: Unsprayed means unsprayed with insecticides that target *Helicoverpa*.

If the viability of an unsprayed refuge is at risk early-season, with prior approval from the Monsanto Compliance Manager, a non-Bt pesticide can be applied up to the 4th true leaf stage.

IRRIGATED CORN

NB: Special conditions apply to growers who wish to grow corn as refuges. These conditions are:

A minimum of three planting dates. First planting date will be determined by the need for the chosen refuge variety to flower simultaneously with the Bollgard II® crop in your region. Subsequent plantings should then follow at 2-week intervals (three plantings at 2 week intervals = 4 weeks, see a) below).

A single planting of mixed maturity varieties is not acceptable.

The minimum area for each planting should be at least one third of the total area required.

A plan outlining refuge management must be submitted to and approved by the local Monsanto Business Manager before planting.

Periodic monitoring required to ensure the refuge will be attractive to *H. armigera* whilst the Bollgard II® crop is flowering.

Appendix 12: Bollgard II® resistance management plan *continued*

General conditions for all refuges are:

- a) Refuge crops are to be planted and managed so they are attractive to *H. armigera* during the growing period of the Bollgard II® cotton varieties. All cotton refuges should be planted within 2 weeks of Bollgard II® planting.
- b) When cultivation of a refuge is necessary, the corresponding Bollgard II® cotton crop should be cultivated at the same time (e.g. for weed control).
- c) Preparations containing *Bacillus thuringiensis* may be used on Bollgard II® cotton throughout the season BUT NOT on refuge crops.
- d) All refuges are to be planted within the farm unit growing Bollgard II® cotton. No Bollgard II® field shall lie more than 2 km from the nearest Bollgard II® refuge. All reasonable effort must be taken to plant the refuge either on one side of or next to a Bollgard II® cotton field.
- e) If any sprayed non-Bt cotton is grown on the same farm unit as Bollgard II® then the associated refuge crops must be at least 48 metres wide, and each refuge area a minimum of 2 hectares. If no sprayed non-Bt cotton is grown on the same farm unit as Bollgard II® then the associated refuge crops must be at least 24 metres wide and the total must comprise a minimum of 2 hectares. Different unsprayed refuge options may be planted together as a single unit.
- f) Soil disturbance in refuge crops should not commence until after removal of Bollgard II® crops from the farm unit is complete. Defoliation of cotton refuges should only be carried out after all Bollgard II® cotton fields on the farm unit have been harvested. Defoliation or destruction of aerial parts of a non cotton refuge should only commence following Bollgard II® cotton lint removal (though once corn refuges are mature they may be harvested).
- g) Total cotton is defined as all cotton being grown on a farm unit and includes all Bollgard II®, Roundup Ready® and conventional varieties including cotton refuges. All cotton included as part of the refuge area must be managed as a viable crop and taken through to harvest.

Control of volunteer and ratoon cotton

Volunteer and ratoon cotton within back to back fields (either Bt cotton plants within conventional cotton fields or conventional plants within Bt cotton fields) may impose additional selection pressure on *H. armigera* to develop resistance to insecticidal proteins produced by Bt cotton. Growers must make all reasonable effort to remove volunteer and ratoon plants as soon as possible from all fields being planted with Bollgard II® cotton following a non-Bt cotton crop. All reasonable efforts must also be made to remove volunteer and ratoon Bollgard II® plants from all fallowed and conventional crops in the season following Bt cotton and from post Bollgard II® fields prior to the onset of the Wet.

3. Post-harvest crop destruction

Bollgard II® cotton

As soon as practical after harvest, Bollgard II® cotton crops must be destroyed by cultivation, root cutting or herbicide so that they do not continue to act as hosts for *Helicoverpa*.

Refuge crops

Unsprayed refuges should preferably be left uncultivated for two weeks after harvest to allow emergence of pupating *H. armigera*.

4. Planting windows

Ord River Irrigation Area: All Bollgard II® crops and cotton refuges are to be planted into moisture or watered up in a 5 week window between 1st March and 1st May, in accordance with a 'Bollgard II® Planting Window Variation Notice'.

Burdekin Irrigation Area: All Bollgard II® crops and cotton refuges are to be planted into moisture or watered up in a 5 week window between 1st December and 1st April, in accordance with a 'Bollgard II® Planting Window Variation Notice'.

Belyando Valley: All Bollgard II® crops and cotton refuges are to be planted into moisture or watered up in a 5 week window between 1st October and 31st December, in accordance with a 'Bollgard II® Planting Window Variation Notice'.

Planting windows in other regions will be determined by TGNARM in consultation with local growers and reflected in a regionally amended Resistance Management Plan.

Appendix 12: Bollgard II® resistance management plan *continued*

5. Late summer trap crop

A TGNARM approved 'trap crop' (e.g. chickpea) must be planted to attract any adults emerging from the last developed Bollgard II® on the farm. The Trap Crop must be planted in accordance with the following criteria:

Criterion	Trap Crop
Area of chickpea	1% of Bollgard II® cotton area, min. 2 ha.
Planting time	After last cotton crop is planted on the farm. The crop is to be planted such that it is attractive to <i>Heliothis</i> from 2 weeks prior to defoliation of the Bollgard II® cotton crops until destruction of the trap crop, 2 weeks after the defoliation.
Insect control	Should be monitored and sprayed with insecticide if the larval pressure threatens the viability of the crop.
Irrigation	Same as cotton + 1 irrigation after cotton is finished
Weed control	Keep free of weeds
Crop destruction	Not permitted until 2 weeks after defoliation of the last Bollgard II® cotton on the farm. The chickpeas must be slashed and the soil fully disturbed to a depth of 10 cm across the entire area which was planted to chickpeas.

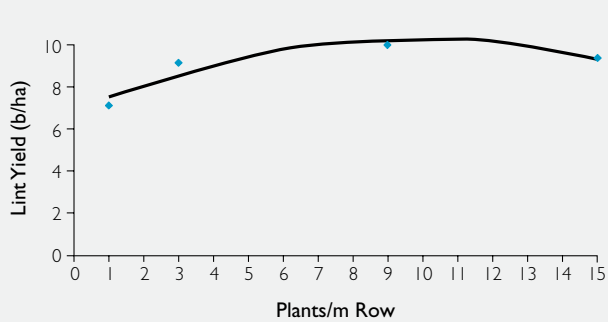
NB: If any grower encounters problems in complying with the resistance management plan, please contact your Monsanto Business Manager.

Appendix I3: Within row plant density research summary – ORIA

Replicated experiments were conducted in 1995 using the variety CS50 and in 2005 using the varieties Sicala 40B and Sicot 289B. The standard ORIA row configuration of 0.8 metres across the bed and 1 metre across the furrow was used (average 0.9 metres).

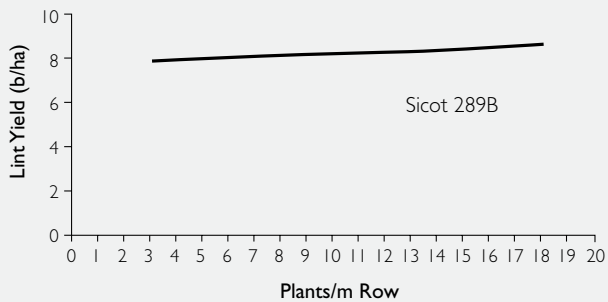
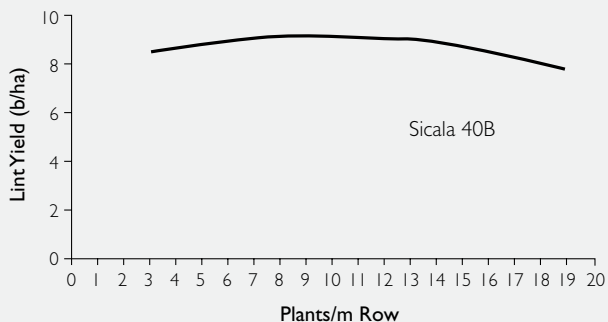
1. 1995

There was no significant difference in yield between 3 to 15 plants per metre of row and yield was optimised at about 9 plants per metre of row.



2. 2005

There was no significant difference in yield between 3 and 18 plants per metre of row for both varieties.



Appendix 14: Potential diseases of tropical cotton

Seedling diseases

Symptoms

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

Cause

- *Rhizoctonia solani* (AG 4).
- *Pythium* spp.
- *Fusarium* sp.
- Anthracnose caused by *Colletotrichum* sp.

Only *Colletotrichum* sp. has been recorded on cotton in northern Australia. *Rhizoctonia solani* (AG 4) was recorded on peanuts in the Douglas Daly area of the Northern Territory. Under suitable conditions, these pathogens may become important seedling diseases. Currently, seedling diseases are not major issues in ORIA cotton production.

Control

- Use seed treated with recommended fungicides.
- Farm hygiene – destroy all debris from previous crops.
- Use resistant varieties if available.

Stem and root diseases

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

Fusarium wilt

Fusarium wilt is an important disease of cotton crops in eastern Australia. Once it is established in a field, fusarium wilt is virtually impossible to eradicate. No incidence of Fusarium wilt has been reported in northern Australian cotton.

Symptoms

- Dull or wilting leaves.
- Chlorosis of leaves, starting on the leaf margin, which eventually becomes necrotic.
- Plants may die from the top down.
- Plants become stunted.

Cause

Fusarium oxysporum f.sp. *vasinfectum* (Fov)

Control

Importation of fuzzy cotton seed from Queensland or New South Wales poses a real threat for the introduction and spread of Fov in northern Australia. Importation of fuzzy cotton seed into Western Australia is illegal.

- Keep farms free from Fov, follow the 'Come clean – Go clean' rule.
- Use treated seed for planting.
- Use resistant cultivars.
- Control weeds which can harbour Fov (especially *Amaranthus*, *Hibiscus* and *Sesbania*).

Verticillium wilt

Verticillium wilt is another important disease of cotton not confirmed from the ORIA. Verticillium wilt is more prevalent in temperate regions, and could possibly impact on ORIA cotton production during June, July and August, due to relatively low seasonal temperatures during these months.

Symptoms

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

Cause

Verticillium dahliae

Appendix 14: Potential diseases of tropical cotton *continued*

Control

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

- Practice good farm hygiene – ‘Come clean – Go clean’.
- Use resistant cotton cultivars.
- Rotate cotton with non-host crops, such as sorghum and other cereals.

Charcoal rot

Charcoal rot is a common disease of cotton worldwide, especially in tropical areas. The disease has been recorded on cotton in Katherine and the ORIA, but is considered to be of minor consequence.

Symptoms

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

Cause

Macrophomina phaseolina

Control

- Use treated seed for planting.
- Avoid seeding at high temperatures.

Foliar diseases

Tropical cotton rust

Tropical cotton rust was first reported in Darwin, the Northern Territory, in 1973 and is common on naturalised cotton at Mataranka, Darwin and Katherine. No tropical cotton rust has been reported on cultivated cotton in northern Australia, but it could be a potential threat since conditions during the dry season are suitable for its development. This pathogen is capable of infecting *Gossypium hirsutum* (upland cotton) and *G. barbadense* (pima cotton).

Symptoms

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

Cause

Phakopsora gossypii

Control

- Use resistant varieties.
- Apply recommended fungicides if required.

Bacterial blight or angular leaf spot

Bacterial blight was reported on cotton in 1962 and 1965 in the Douglas Daly area and from the ORIA in 1966, but has not been reported from Katherine or the ORIA during the current research phase. Resistant cotton varieties and the winter growing season could explain the apparent absence of the disease. Under suitable conditions, this disease can significantly reduce cotton production in susceptible varieties.

Symptoms

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

Cause

Xanthomonas axonopis pv. *malvacearum*

Control

- Use treated seed for planting.
- Grow resistant varieties.
- Destroy residues from previous crops
- Practice good farm hygiene.

Appendix 15: *Alternaria* leaf spot experiments

In 2004, a trial was conducted at Katherine Research Station to determine the impact of foliar applications of potassium on the suppression of *Alternaria* leaf spot. Potassium nitrate (KNO_3) applied at the rate of 13 kg/ha reduced disease incidence, severity and leaf shedding by 1.4%, 7.78% and 13.8%, respectively.

> Mean incidence, severity and leaf shedding due to *Alternaria* leaf spot of cotton at the Katherine Research Station, 2004.

Treatment	Incidence (%)	Severity (0–20)	Leaf shedding (number)*
KNO_3	90.94	9.13	2.39
Control	92.34	9.84	2.72
Differences %	1.4%	7.78%	13.8%
Probability (n=145)	0.048	<0.001	<0.001

*mean number of leaves shed from main stem

In 2005, a trial was conducted at Katherine Research Station to determine the efficacy of mancozeb fungicide against *Alternaria* leaf spot and yield loss due to this disease.

Treatments included

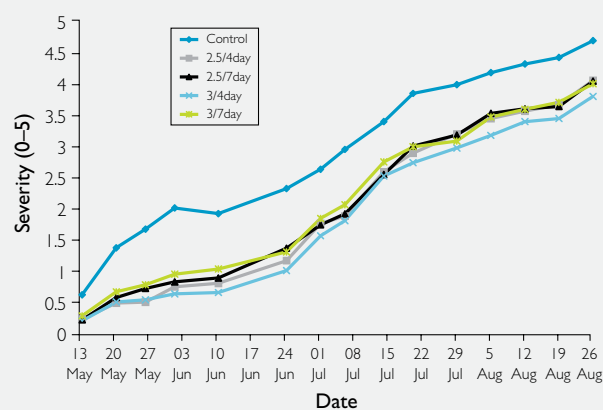
- Unsprayed control.
- Mancozeb 2.5 kg/ha every 7 days (currently recommended for Pima cotton).
- Mancozeb 2.5 kg/ha every 4 days.
- Mancozeb 3 kg/ha every 7 days.
- Mancozeb 3 kg/ha every 4 days.

A similar trial was conducted at the Frank Wise Institute, Kununurra, ORIA.

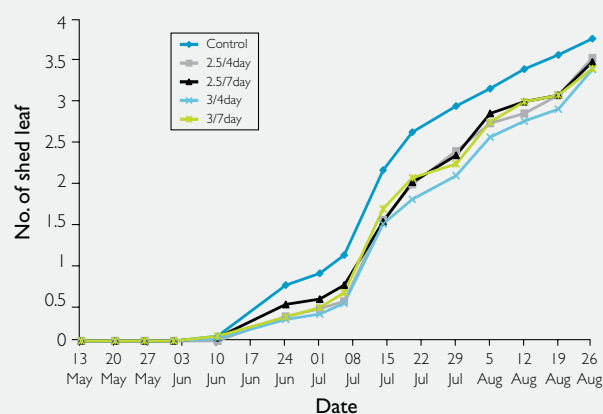
Overall disease incidence and severity was lower in Katherine compared to previous years. In Kununurra, the trial failed due to the lack of disease on the crop.

Results are presented in the figures following

- Yield differences in cotton were not significantly different between the unsprayed control and mancozeb sprayed plots.
- Mancozeb decreased disease severity and defoliation.
- Current fungicide application rate (2.5 kg/ha) with a 7-day spray interval for Pima cotton is adequate to control *Alternaria* leaf blight on upland cotton in Katherine.



> Severity of *Alternaria* leaf blight on cotton sprayed with mancozeb (750 g/kg) at various intervals and rates.



> Number of leaves shed due to *Alternaria* leaf blight by cotton sprayed with mancozeb (750 g/kg) at various rates and intervals.

The above results suggested that more research in various geographical locations needs to be done to determine the efficacy of potassium and/or mancozeb fungicide for the control *Alternaria* leaf spot. Additional fungicides with various modes of action need to be evaluated.

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