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AUSTRALIAN COTTON - IRM AND IPM

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Abstract

Cotton is the third most important agricultural export for Australia, generating approximately 1.5 billion Australian dollars (0.8 billion Euro) annually. Australia grows an average of 450,000 ha or approximately 1 million acres of cotton, equivalent to about 20% of the cotton grown in the US State of Texas. Despite the small area of the crop, consistently high yields and quality make Australia a significant exporter of cotton (the third largest exporter of cotton in the world). The number one limiting factor for Australian cotton production is the availability of water; production has declined in the past 3 seasons due to our most severe drought in 100 years.

Insect and mite pests are the second most important limiting factor for Australian cotton production. For the 160 day growing season, cotton is attacked by *Helicoverpa* spp., sucking pests and two-spotted mites. Traditional insecticide use has represented a significant proportion of variable cost of cotton production, a powerful driver for the selection of insecticide resistance, and of rising environmental concerns associated with the off-target drift of pesticides.

Significant changes are underway in Australian cotton production, a move away from repeated use of older broad-spectrum insecticide groups that typified cotton production in the 1980s and 1990s, towards a more integrated approach. Seventy percent of the Australian cotton crop is now transgenic, containing *Bacillus thuringiensis* (Bt) genes for protection from *Helicoverpa* spp. Integrated pest management (IPM) in both conventional and transgenic cotton aims to integrate all means of managing pest populations while improving environmental and social responsibility and maintaining grower profitability.

The implementation of resistance management and integrated pest management, the availability of transgenic cotton and new selective chemistry with low application rates of active ingredient have enabled growers to continue to grow profitable cotton with reduced inputs of pesticides. Bayer Cropscience, is a leading Research and Development company in Australian cotton and is in the process of building a bridge from its current conventional crop protection chemical business to a future business where conventional and transgenic products are fully integrated.

Introduction

Insect and mite pests impose severe limitations on profitable cotton production in Australia. The Australian cotton crop is subject to a range of insect and mite pests with large variations in seasonal abundance (figure 1).

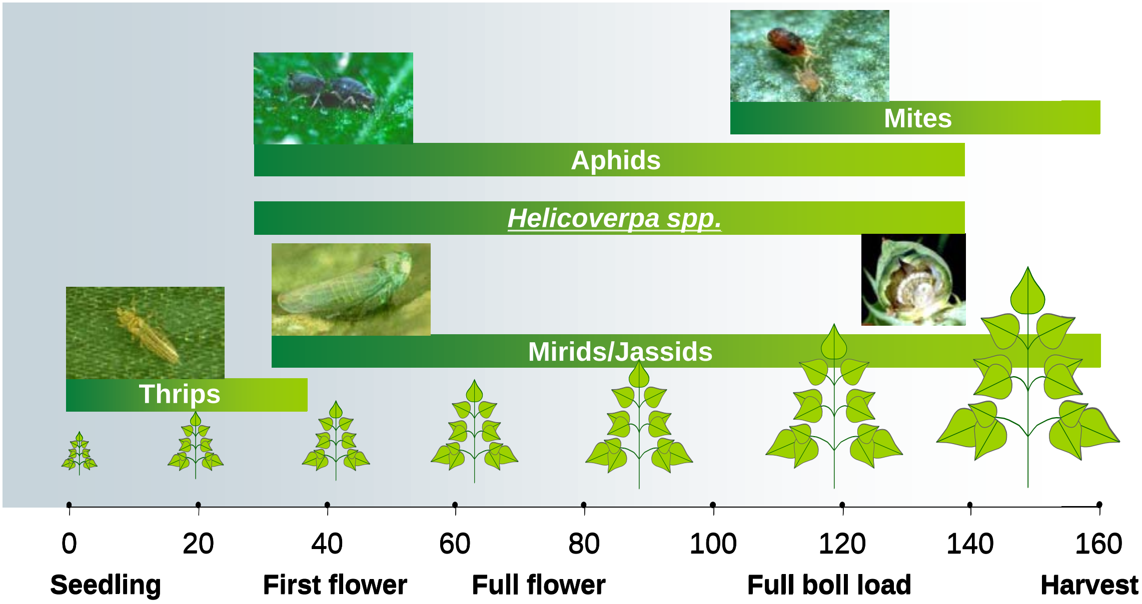


Figure 1. Arthropod pests of Australian cotton.

Key pests are two Heliothine moths, *Helicoverpa armigera* and *Helicoverpa punctigera*, against which between 6 and 10 sprays are targeted on conventional cotton each season. Insect control costs growers an average of approximately A$450 (250 Euro) per hectare per season. This level of pesticide use represents a significant proportion of the variable cost of cotton production, a powerful driver for the selection of insecticide resistance and of rising environmental concerns associated with the off target drift of pesticides. Having said this, the use of foliar applied insecticides will remain an important part of profitable cotton production in Australia in the foreseeable future.

Integrated pest management (IPM) in cotton aims to integrate all means of managing pest populations while maintaining grower profitability. A series of cotton IPM Guidelines released by the Australian Cotton Co-operative Research Centre highlight the first principles of pest management throughout the year, not just during the cropping cycle. This approach seeks to match the choice of cotton variety (both conventional and genetically modified) and its agronomic management to the growing region. It aims to optimise planting windows, scout crops regularly and to take advantage of the compensatory ability of the cotton plant at the beginning of the season. Insecticides are applied only on the basis of realistic thresholds, with more selective products used first to conserve beneficial insect populations. IPM also includes tools for population management of *Helicoverpa* spp., which can be coordinated through area-wide management: the use of refuges for the preservation of susceptible genes, physical destruction of over-wintering pupae and over-wintering weed hosts. Our understanding of many of these components of IPM is growing, but far from complete (Fitt 2004).

The role of IRM in IPM

Australian field populations of *H. armigera* have developed high frequencies of resistance to the pyrethroids, carbamates, endosulfan and organophosphates (Forrester *et al*. 1993). Over the last twenty years, implementation of Insecticide Resistance Management (IRM) strategies in Australian cotton has aimed to slow or reverse the development of resistance to these major insecticide groups. These IRM strategies have relied on extensive voluntary compliance, with use of thresholds, a logical 'window' framework for positioning and restriction of insecticide groups and physical control of over-wintering pupae. Components of the Australian IRM strategy include the separation of the target pest species and insecticide selection pressure in time (alternations, rotations and window strategies) and separation of the target pest species and insecticide selection pressure in space (mosaic and refuge strategies). They include the use of synergists or mixtures where appropriate to overcome metabolic resistance and restrictions in the total number of applications of a particular insecticide group. The success of these approaches depends on the range (and cost) of chemical groups available, their impact on the major beneficial insects and on their resistance status, which needs to be thoroughly monitored. The 2004/2005 IRM strategy for Northern NSW and Southern QLD is shown in figure 2.

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
See Cotton Pest Management Guide for suggested thresholds				
	Maximum 2 consecutive sprays of any one insecticide group, alone or in mixtures			
ENDOSULFAN see label for aerial application restrictions				
FOLIAR *Bacillus thuringiensis* (BT) - on conventional and Bollgard cotton, but EXCLUDING any refuges				
HELICOVERPA VIRUSES (Gemstar, Vivus) avoid season long use of low rates				
AMITRAZ - Max of 4				
PRODIGY#			**PRODIGY#**	
ABAMECTIN - for H. *punctigera*, max.2,including mite sprays				
AFFIRM				
	STEWARD * – Max of 3			
	INTREPID – Max. 1 at any rate including mite sprays			
		TRACER – Max of 3		**March 1**
		PYRETHROID & PYRETHROID MIXES - PBO, max of 2 -Talstar sprays, max of 2, including mite sprays		
		CHLORPYRIFOS (+ methyl) – Max of 3, including mixtures		
		PROFENOFOS & other OPs – Max of 3, including mixtures		
		METHOMYL		
		THIODICARB		

*** No use of Steward or Tracer on Chickpeas after October 15th**
# Maximum of 3 sprays over entire season

Figure 2. The Cotton Insecticide Resistance Management Strategy for Northern NSW and Southern QLD 2004/2005 season. For Registered trademarks see Table 1

Historically, new groups of insecticides and new technologies only became available for insect management in Australian cotton one at a time. This resulted in the sequential overuse of each technology upon release and strong selection for resistance. Once resistance to an insecticide group has been detected in Australia, we have attempted to manage it re-actively through the IRM strategies. This approach has successfully preserved older groups and has bought time for the development of new technologies and new approaches. However, once resistance problems to any insecticide group or technology are detectable in the field they are established and very difficult to slow down or reverse. The 'history' of resistance to older insecticides places increased selection pressure on each new insecticide or new technology (such as Bollgard®), as it becomes available. This emphasises the need for a pro-active approach to resistance management.

In the late 1990's a suite of new tools for the management of *Helicoverpa* spp. became registered in Australian cotton. None of these new technologies had an established resistance problem but none of them were 'resistance-proof'. Successful implementation of pro-active IRM alongside IPM will prevent selection from being channelled towards any single insecticide group. This should result not only in preservation of the new technologies, but also an easing in selection pressure and a benefit to the older insecticide groups. Future development of the IRM strategy will focus on pro-active resistance management (and restrictions) on the use of new tools, preservation of old tools and a continued positioning of broad-spectrum products later in the season. Complementary IRM and IPM management approaches aim to combine all the 'tools and tactics' available to growers and consultants to deal with multiple insect pests.

New more selective insecticides

Our progress in improving Integrated Pest Management in Australian cotton has been accelerated by the introduction of new technologies, both less disruptive chemistry and insect resistant transgenic plants (Table 1).

Table 1. New technologies for control of *Helicoverpa* spp. in Australian cotton. AIRAC is the Australian Insecticide Resistance Action Committee, a subgroup of the National Association for Crop Production and Animal Health (Avcare)

Active ingredient	**Trade name**	**Australian distributor**	**Mode of action**	**AIRAC grouping**	**Features**	**Registered**
Transgenic Cry1Ac	Ingard®	Monsanto	Mid-gut membrane disruption	11 C	Ingested, active on *H. armigera* and *H. punctigera*	1996
Spinosad	Tracer®	Dow Agrosciences	Acetylcholine receptor modulator	5 A	Ingested + contact, active on *H. armigera* and *H. punctigera*	1997
Chlorfenapyr	Intrepid®	BASF	Mitochondrial disruption	13 A	Ingested + contact, *H. armigera*, *H. punctigera* and mites	1999
Abamectin	Agrimec®	Syngenta	Chloride channel activator	6 A	Ingested, active on *H. punctigera* and mites	1999
Emamectin benzoate	Affirm®	Syngenta	Chloride channel activator	6 A	Ingested, active on *H. armigera*, *H. punctigera* and mites (supression)	2000
NPV	Gemstar®	Bayer Cropscience	Baculovirus	Not classified	Ingested, active on *H. armigera* and *H. Punctigera*	2000
Indoxacarb	Steward®	Dupont	Sodium channel blocker	22 A	Ingested, + contact, active on *H. armigera*, *H. punctigera* and mirids	2001
Methoxyfenozide	Prodigy®	Dow Agrosciences	Chitin biosynthesis inhibitor	17 A	Ingested, active on *H. armigera*, and *H. punctigera*	2001/2002
Transgenic Cry1Ac and Cry2Ab	Bollgard II®	Monsanto	Mid-gut membrane disruption	11 C	Ingested, active on *H. armigera*, and *H. punctigera*	2003/2004

Compared with older chemical groups, most of the new products have reduced negative effects on the abundance of beneficial insects and are in general more compatible with the development of IPM systems. These technologies have allowed management of pests while preserving and encouraging biodiversity – a range of 'beneficial' insects that can assist the control of pests.

In addition to their effects on *Helicoverpa* larvae, several of the new products (Intrepid®, Agrimec® and Affirm®) control or suppress two-spotted mite populations. This can be a valuable feature of a product at times of the season when both *Helicoverpa* spp. And mite populations are increasing. In replicated trials, repeated applications of other new products are either neutral to mite populations, or may slightly accelerate their rate of increase (e.g. Tracer®), possibly due to disruption of thrips. What is required is a better understanding of the strengths and weaknesses of each new tool and adoption of all the available tactics to manage insects, not just reliance on substituting new chemicals for old (Holloway *et al.* 1999).

Incremental progress towards 'better IPM'

IPM in Australian cotton is reliant on voluntary compliance of growers and consultants, and a key to achieving this has been to move step by step towards 'better IPM'. In the past, cotton growers have rejected IPM after they have been told that their traditional approach was 'wrong' and the gulf between their practices and an IPM approach appeared to be insurmountable. A more constructive and effective approach in Australia has been to point out IPM practices that are already widespread at the grower level (such as scouting crops and spraying on thresholds) and then provide practical tools that allow growers and consultants to make the next step forward. The rapid adoption of the 'new' chemistry by growers and consultants is reflected in an increasing awareness of the value of beneficial insects. Researchers at the Australian Cotton Co-operative Research Centre have been carrying out field trials to evaluate some of the new insecticides for their efficacy against *Helicoverpa* spp. and their impacts on specific beneficial insect groups or species. This work contributes to independent evaluation of new technologies and a ranking for foliar insecticides according to their fit for Integrated Pest Management (figure 3).

Insecticide	Rate g. ai./ha	Overall Ranking					
Baculovirus		Very Low	Very Low	Very Low	Very Low	Very Low	Very Low
Spinosad	96	Low	Very Low	Moderate	Very Low	Moderate	Very Low
Emamectin benzoate	8.4	Moderate	Low	High	Low	Moderate	Moderate
Imidacloprid	50	Moderate	High	High	Low	Low	Moderate
Pyrethroids	19.5 - 24	Very High	Very High	Very High	Very High	Very High	Very High

http://www.cotton.pi.csiro.au

Figure 3. Excerpt from Integrated Pest Management guidelines for Australian cotton, supporting document number 1.

The transgenic cotton era

Genetically improved cotton varieties expressing the Cry1Ac delta endotoxin from *Bacillus thuringiensis* (Bt) became commercially available for use in Australia under the tradename (Ingard®) in 1996. The controlled deployment of this technology by Australian growers was capped at 30% of the total cotton acreage until 'Bollgard II®' expressing both Cry1Ac and Cry 2Ab became available in 2003/04. This season (04/05), Ingard® has been removed from the market and Bollgard II® is likely to be planted in excess of 70% of the total cotton area. Increasingly transgenic cotton is available to the grower in the form of 'stacked' varieties, expressing more than one Bt gene for control of *Helicoverpa* spp., as well as a gene for herbicide tolerance. This is important, because for the first time a grower's weed management decisions at the start of the growing season will have a major impact on his or her insect management decisions, and *visa versa* (figure 4).

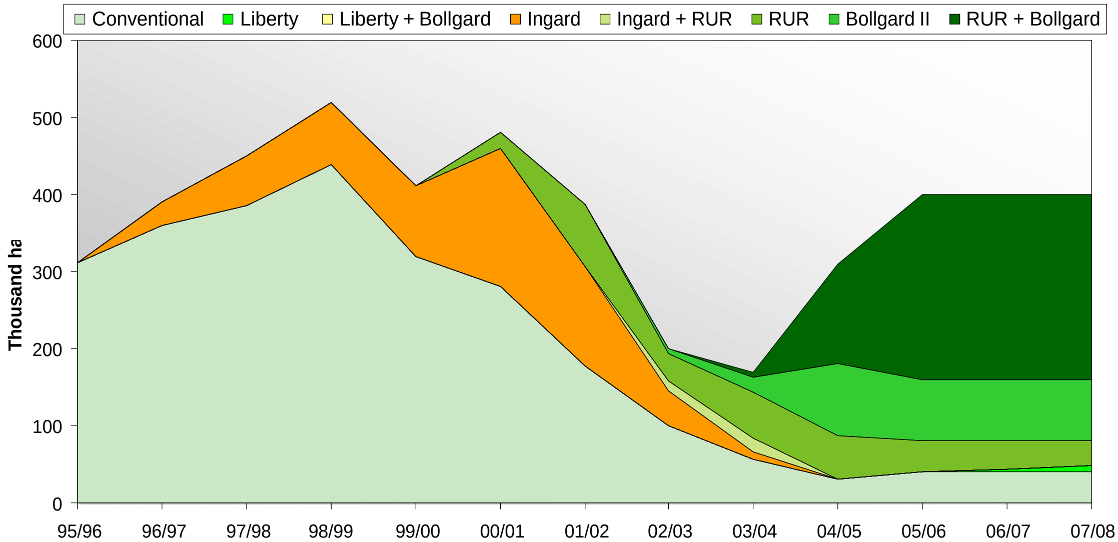


Figure 4. Uptake of transgenic cottons in Australia, including cotton expressing Bt toxins for protection from *Helicoverpa* spp. (Ingard® and Bollgard®), herbicide tolerance genes (Roundup Ready and Liberty), or both.

The implementation of transgenic crops has brought about significant changes in approaches to insect pest management, most notably a saving of foliar applied insecticides. These reductions in insecticide use have been most significant early and mid season in transgenic crops allowing growers to delay the use of broad-spectrum insecticides and to build up and conserve beneficial insects. Research has shown little effect of Ingard® and Bollgard II® on non-target species and densities of beneficial insects 2-3 times higher than in conventional crops (Wilson and Fitt unpublished).

Transgenic cottons are not, however, a 'silver bullet' for management of *Helicoverpa* spp. Experience with current varieties in Australia and the US has shown a decline in expression of Cry1Ac as the season progresses, so that after between 75 and 100 days after planting, the insecticidal efficacy of Ingard® plants becomes sublethal to major Lepidopteran pests. In Australia a high proportion of larvae surviving in Ingard® at this stage in the season are *H. armigera* with high frequencies of resistance to older conventional groups of insecticides. Varietal background appears to influence the rate of decline in expression of Cry1Ac (not all Ingard® varieties are equal), but variability in expression occurs within varieties and even within fields.

A major challenge to sustainable use of transgenic cottons is the potential of target pests to develop resistance to Cry proteins. The technology exposes 3-4 generations of *H. armigera* per year to continuous selection pressure at doses of Cry1Ac ranging from high at the beginning of the season, to moderate, low and finally sublethal doses in the last third of the life of the crop. In Bollgard II® crops, for the final 50 days of the season, the majority of control of *Helicoverpa* spp. Is provided by Cry2Ab only, placing strong selection pressure on this Bt protein. A pro-active, 'preventative' resistance management strategy was put into place in Australia prior to commercialisation of Ingard® and Bollgard II®. Each grower plants a mandatory 'refuge' *H. armigera* host crop on his or her farm, where no Bt products are used. These refugia aim to generate susceptible *H. armigera* to mix with, mate and dilute any resistant insects coming out of Bt crops.

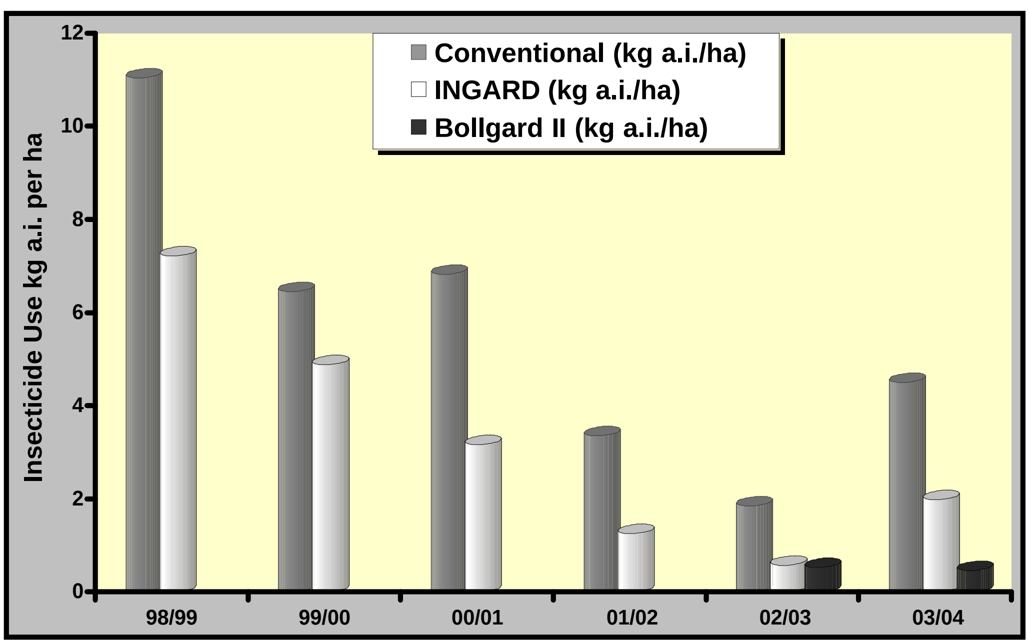
Our approaches to supplemental control of lepidopteran pests in transgenic crops may evolve to be very different from our approach in conventional cotton. Sub-lethal effects of either Cry1Ac or Cry2Ab may alter the feeding, movement or distribution of *Helicoverpa* larvae within the crop in a way that changes their exposure, uptake and susceptibility to foliar applied insecticides. We should not assume that the efficacy of insecticides against *Helicoverpa* spp. is always equal in transgenic and conventional cotton. The sublethal effects of Bt may provide a platform for more reliable performance of some foliar applied insecticides, the opportunities to register lower rates than those required for conventional cotton, and may facilitate a renaissance of some of the more IPM compatible, older insecticide groups such as endosulfan.

Changes in pest spectrum

Changes in pest spectrum, including an increase in the importance of sucking pests has been a major concern for cotton growers in Australia and the US. Pests which were widely considered to be of secondary importance such as aphids, mites, green vegetable bug (whitefly are not yet an established problem in Australian cotton) are becoming more common. The increased importance of *Aphis gossypii* has been driven by their recent development of resistance to organophosphates and carbamates, but other factors are also involved. Traditionally, these pests were controlled or suppressed coincidentally, by products applied to control *Helicoverpa* spp. New, more selective technologies now provide control of *Helicoverpa* spp. without effects on secondary pests. Another important driver of increasing sucking pest problems has been due to restrictions in the use of endosulfan, brought about by off-farm contamination of cattle in the 1998/99 season. Agronomists and consultants need to be aware that if endosulfan is not used, secondary pests that were previously controlled or suppressed by this compound (such as aphids) will become increasingly important. Progress in implementing successful IPM programs may be hindered by emerging pests (such as green vegetable bugs and mirids) for which only broad-spectrum chemicals are currently registered.

Optimisation and reduction of insecticide use

A combination of the successful implementation of resistance management, integrated pest management, the availability of technologies such as selective chemistry with low application rates of active ingredient per hectare and transgenic cottons, have enabled growers to improve yields and profitability with reduced inputs of pesticides. Over the last 6 growing seasons we have seen a trend of optimisation and reduction of insecticides in both conventional and transgenic cotton, with an overall reduction in insecticide use by 44% in the first generation transgenic crops compared with conventional cotton (Pyke 2004 & figure 5).



Source: Pyke 2004

Figure 5. Insecticide plus miticide use on conventional, Ingard® and Bollgard II® cotton expressed in kg active ingredient per ha

Conclusions

Preservation of as many useful tools for insect management as possible will be a key to IPM systems of the future. As fewer insect control decisions are made during each season, and new insecticide technologies become increasingly selective, then having exactly the right management tool for the job will become more and more important. The preservation of old and new technologies will be brought about by implementation of IRM strategies, which will have to become more IPM-compatible, positioning broader spectrum compounds later in the growing season.

IPM systems in the future will, of necessity, be more complex than the traditional insecticide dependent systems currently in place. This will require more understanding and more time in the crop on the part of the crop managers, consultants, agronomists and growers.

Transgenic cottons expressing insecticidal proteins with activity against one or more major pest will reduce the need for foliar applied insecticides, particularly early/mid season. This will facilitate uptake of a wide range of IPM tactics and may provide the added benefit of rejuvenating the performance and extending the useful life of some of the older insecticides. The challenge for the Australian cotton industry is to accumulate an understanding of a suite of new approaches that can equal the reliability of traditional approaches while continuing to improve yield and profitability. The costs and hazards associated with that traditional approach have proven to be a powerful driver for 'better IPM'. Considering the range of insect management tools now available, and our improving understanding of each of them, this ongoing challenge should not be impossible.

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