Cotton Pest Control in Australia Before and After Bt cotton: Economic, Ecologic and Social Aspects

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Summary
The cotton industry in Australia has a history of management challenges presented by insect and mite pests. The sustainability of the industry was jeopardized by increasing insecticide resistance amongst major pests, and environmental and social issues associated with high reliance on insecticides. Transgenic Bt cotton has delivered huge benefits that now place the industry in a more secure position. Varieties containing the Cry 1Ac gene (Ingard®) were first grown commercially in 1996/97. These were totally replaced by varieties containing the Cry 1Ac and Cry 2Ab genes (Bollgard®II) in 2004/05. Compared to conventional cotton in 2003/04, Bollgard®II reduced chemical use by 90%. The adoption of Bt cotton has maintained profitability for cotton growers, reduced adverse environmental impacts of cotton production and delivered lifestyle benefits to rural communities in cotton producing areas.

The pre-Bt cotton era:
Modern intensive cotton production in Australia started in the early 1960s and has since progressed to an Industry valued at $AUD1.5 billion annually. Most cotton production in Australia is located in sub-coastal areas of eastern Australia, from central Queensland to central New South Wales, with potential for development across northern Australia (Figure 1). About 90% of Australian cotton is grown using irrigation. Production peaked in the 2000/01 season at 3.5M bales, from a total area of about 500,000 ha. Drought saw the 2002/03 season produce the smallest cotton crop in 15 years. The 2004/05 season has seen some recovery to about 2.6M bales, but water remains a limiting resource.

In the pre-Bt cotton era, *Helicoverpa* spp. were the key pests in all regions (Fitt 1994). Two species, the cotton bollworm, *H. armigera* (Hübner), and the native budworm, *H. punctigera* (Wallengren), were season-long pests demanding repeat insecticide applications during the growing season. On average, 8-12 sprays were targeted against *Helicoverpa* spp. during a season. These sprays coincidentally controlled other pests such as plant bugs (*Creontiades* spp.) and stink bugs (*Nezara viridula* (L.)), but problems were often encountered with secondary pests such as two-spotted mite, *Tetranychus urticae* Koch, and cotton aphid, *Aphis gossypii* Glover, whose natural enemies were decimated by broad spectrum insecticides.

Reliance on insecticides led to increasing problems with insecticide resistance in *H. armigera*, *T. urticae* and *A. gossypii*. More recently, silverleaf whitefly, *Bemisia tabaci* (Gennadius) B biotype, has been added to this list of insecticide-resistant pests following its discovery in Australia in 1994. Because of the seriousness of insecticide resistance in *H. armigera*, an Insecticide Resistance Management Strategy (IRMS) was implemented in 1983 in an effort to prolong the useful life of synthetic pyrethroids, and ultimately other insecticide groups (Forrester *et al.* 1993). This IRMS, though reviewed and

Figure 1. Australian cotton growing regions.

modified annually, remains in place to this day. An industry committee, Transgenic and Insecticide Management Strategy (TIMS) Committee, oversees the development and implementation of the IRMS.

Through the 1980s and 1990s there were warning signs that the cotton industry would struggle to remain viable given its dependence on insecticides. On the Darling Downs of Queensland, the cotton industry's problems peaked during the 1997/98 season. In most other regions, the 1998/99 season presented severe insect problems. The issues facing the industry were those of the triple bottom line – economic, environmental and social.

<u>Economic</u>: For some growers, high spray frequency under a constant barrage of pest activity led to spiraling costs; up to $AUD1,000/ha in the worst affected fields. This situation was exacerbated by declining performance of insecticides, in part resulting from mounting insecticide resistance in *H. armigera*. While some new insecticides e.g. spinosad, indoxacarb and emamectin, were becoming available, their high cost ($AUD60/ha) elevated overall costs of insect control programs. Depressed world cotton prices also impacted negatively on profitability.

<u>Environmental</u>: The high dependence on insecticides led to problems of contamination of non-target areas (pastures and waterways). In 1998, insecticide residues (endosulfan) were detected in beef destined for export markets, seriously jeopardizing international trade. In some cases insecticides were implicated in fish kills in rivers. The use of broad spectrum insecticides such as synthetic pyrethroids was blamed for decreased biodiversity in

agricultural areas. In particular, densities of natural enemies of pest species were severely disrupted, and secondary pest outbreaks were common.

Social: Antagonism against the cotton industry mounted in some rural towns and in the capital cities. Although cotton production was a very profitable industry that brought wealth and flow-on benefits to inland towns, it was not always perceived as a 'clean and safe' industry. The high reliance on insecticides for pest management coupled with highly visible aerial application methods, and issues with health and the environment, served to reinforce the perception. Some rural communities strongly objected to the odours associated with some insecticides e.g. profenofos. There were some incidents where townsfolk were inadvertently targeted with insecticides, and local environmental groups opposing chemical use gained strength. In Emerald in Central Queensland, swarms of *B. tabaci* B biotype exacerbated the concerns. Cotton was blamed for the problems encountered by townsfolk as whitefly moved off cotton at the end of the season and infested home gardens and ornamental plants.

Introduction of Bt cotton

Transgenic Bt cotton containing the single gene expressing the Cry 1Ac toxin (Ingard® by Monsanto) was evaluated in field trials during the early 1990s. Ingard® was first released commercially in the 1996/97 season, when 30,000 ha (10% of the Australian cotton crop) was sown to Ingard® (Pyke 2003) (Table 1). The percentage of the crop sown to Ingard® increased annually in 5% increments, up to a capped area of 30%.

Two-gene Bt cotton containing genes expressing both Cry 1Ac and Cry 2Ab (Bollgard®II) was released commercially for the 2003/04 season, and in this season both Ingard® and Bollgard®II were grown (Table 1). The total Bt cotton area was capped at 40% of the cotton acreage, with no more than 25% to comprise Ingard®. Bollgard®II performed well and demonstrated its excellent caterpillar management properties. Ingard® was withdrawn from the market for the 2004/05 season, and coupled with this was the removal of the capped Bt-cotton acreage. Industry embraced this new technology, sowing about 70% of the national acreage to Bollgard®II.

Table 1. Bt cotton production in Australia – area and licence fees (after Pyke 2003)

Season	Area of Bt Cotton (as % of Total Cotton Area)	Area of Bt Cotton Planted (ha)	Bt Cotton Licence Cost (Net to Grower $AUD)
1996/97	10% Ingard®	30,000	245
1997/98	15% Ingard®	65,000	210
1998/99	20% Ingard®	85,000	155
1999/00	25% Ingard®	125,000	155
2000/01	30% Ingard®	180,000	155
2001/02	30% Ingard®	125,000	170
2002/03	30% Ingard®	66,000	167
2003/04	15% Ingard® 16% Bollgard®II	28,000 30,000	190 190
2004/05	70% Bollgard®II	218,000	250
2005/06	NA% Bollgard®II	NA	300

Pyke (2003) reviewed the performance of Ingard® during its first six seasons of commercial adoption. Ingard® performance was initially quite variable, but improved over time due to the introduction of improved Ingard® varieties, less severe insect infestations, wider adoption of integrated pest management (IPM) practices, introduction of newer, more IPM compatible insecticides (eg. spinosad, indoxacarb, emamectin), and overall improvements in the management of Ingard® crops.

An integral part of the adoption of Bt cotton was the implementation of a resistance management plan (RMP). Key elements of the RMP are

- Planting of effective refuges on each farm growing Bt cotton
- Defined planting window for Bt cotton
- Mandatory cultivation of Bt cotton crops and residues after harvest
- Removal of volunteer Bt cotton plants
- Monitoring of Bt resistance levels in field populations

The RMP assumed major importance while the industry was reliant on the single Bt toxin in Ingard®. It was essential that resistance to Cry 1Ac did not develop before the anticipated release of Bollgard®II. Despite some delays with the commercial release of Bollgard®II, no resistance to Cry 1Ac was evident (Mahon *et al.* 2003). Two gene Bt cotton provides much better efficacy, but more importantly, greater resilience against the risk of resistance.

What has Bt cotton delivered?

Economic: Reduced reliance on conventional insecticides has been the most outstanding contribution of Bt cotton. In its first six years of commercial use, Ingard® reduced total insecticide use by between 45 and 60% compared to conventional cotton (Pyke 2003). While Ingard® was not profitable compared to conventional in its early years, it became more profitable through time. In 2003/04, when Bollgard®II, Ingard® and conventional cotton were grown, Bollgard®II delivered a 90% reduction in chemical use compared with conventional cotton, while Ingard® reduced chemical use by 56% (Anon. 2004).

In 2004/05, growers in environmentally or socially sensitive areas were able to plant 100% Bollgard®II in conjunction with the appropriate refuge requirement.

Bt-cotton has also provided a platform on which to base IPM (Pyke 2003). Collins and Collins (2004) estimated the net industry benefit from adoption of IPM was valued at $AUD250M. Some of the changes influencing pest management approaches are outlined by Murray *et al.* (2005). Best Management Practices (BMP) are a cotton industry initiative to enhance environmental management of cotton farms. One of the modules of BMP contains the core principles of IPM, as outlined in the IPM guidelines (http://cotton.pi.csiro.au/Publicat/Pest/).

The removal of broad spectrum sprays directed against *Helicoverpa* spp. has resulted in higher densities of plant bugs (*Creontiades* spp.) and stink bugs (*N. viridula*), and to a lesser extent leafhoppers (*Amrasca terraereginae* (Paoli)), present in Bt cotton. During the 2004/05 season, Bollgard®II crops were sprayed 1 to 3 times to control bug pests. While chemical options are available for these pests, they too are broad spectrum and not IPM-friendly. In order to address this situation, increased emphasis has been placed on research into pest status, thresholds and management of these pests.

As well as the cost of the Bt cotton licence fee (Table 1), additional costs are associated with mandatory refuge requirements. These costs vary with the choice of refuge type – conventional cotton, maize, sorghum, unsprayed cotton and pigeonpea. Under the licence conditions, growers of Bollgard®II are required to “pupae bust” their fields at the end of the season. This involves full surface cultivation to a depth of 10 cm to impose high mortality on any overwintering *H. armigera* pupae. Pupae busting is also recommended for conventional cotton fields as part of resistance management.

Despite the benefits of growing Bt cotton, many growers want to retain the skills and ability to grow profitable conventional cotton. This provides insurance against unforeseen problems with Bt cotton e.g. development of resistance to the toxins. Profitable production of conventional cotton also maintains competition for Bt cotton, and potentially helps place a ceiling on the cost of Bt transgenic technology.

The dramatic reduction in use of insecticides on Bt cotton has had some negative impacts. These include decreased business for aerial operators and groundrig spray contractors, reduced insecticide sales for chemical resellers and diminished market size for agrochemical companies. Some insecticide companies have responded to the challenge posed by Bt cotton by lowering prices for IPM-compatible insecticides, with the expectation that conventional cotton will be a valuable contributor to insecticide sales.

Ecologic: Recent water quality monitoring in central and north west NSW found that the number of times threshold values were exceeded for pesticide chemicals, such as endosulfan and chlorpyrifos, were fewer than for previous years (Collins and Collins 2004). For example, the percentage of detections of endolsulfan across sites in the Namoi, Gwydir and Macintyre valleys has decreased from around 45% in 1998/99 to less than 5% in 2001/02. These changes are believed to be correlated with low pest pressure as well as IPM, improved spray application, use of Ingard® cotton and implementation of BMP.

There have been no cases of beef contamination since the episode in 1998, with the significant reductions achieved in pesticide use across the cotton industry now recognised by the trading community. By applying BMP, improving IPM and spray application, the cotton industry has avoided inflicting any further damage on the beef industry.

The Second Australian Industry Environmental Audit (Anon. 2003) found that the industry has developed and implemented a wide range of improvements in its operations and environmental management practices since the 1991 audit. According to the audit, the use of transgenic cotton has been a major contributor to IPM adoption and the lower reliance on pesticides.

Social: Health surveys undertaken in Gunnedah in 1996 in response to community concern about pesticide use led to the conclusion that a number of health problems appeared to have been triggered or aggravated in susceptible people by exposure to pesticides and/or their odour (Collins and Collins 2004). The decrease in complaints in 2001/02 is attributed to lower pest pressure and/or adoption of IPM and BMP (Table 2). Such a decrease in complaints has been experienced broadly across the industry.

Table 2. Spray complaints (all crops) in north-west NSW (Gunnedah, Moree & Narrabri areas).

Season	Number of complaints
1998/1999	127
1999/2000	58
2000/2001	95
2001/2002	23
2002/2003	10

Source: Environmental Protection Agency data reported in 2003 Environmental Audit of cotton industry (cited in Collins and Collins 2004)

For cotton growers and their staff, Bollgard®II has delivered an improved quality of life. In particular, the reduction in insecticide sprays means growers are

- more relaxed, not constantly spraying at odd hours (often night time)
- less exposed to toxic substances
- able to focus on other issues e.g. land, water and nutrient management.

The Future

Bt transgenic cotton (Ingard® and Bollgard®II) has delivered huge benefits to the Australian Cotton Industry through reducing reliance on conventional insecticides. Further advancement is expected with new insect-active transgenics – WideStrike® by Dow AgroSciences and VipCot® by Syngenta – that are currently being evaluated in Australia. It remains to be seen how these will be integrated with existing transgenic technology. Without doubt, management aimed at delaying resistance to the toxins used in transgenic cotton should remain a high priority. While there is no evidence of field resistance to Cry 1Ac, a resistant laboratory culture has been developed (Mahon *et al.* 2003). Cry 2Ab resistance has been detected in field collections, and current information indicates that Cry 2Ab resistance may be unexpectedly common. There is no place for complacency.

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