Changes in Production Due to Bollgard II and Roundup Ready Cotton

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Introduction

In 2005/06 the Australian cotton industry clocked up its 10th season of commercial insect tolerant Bt cotton production (i.e. INGARD® and/or Bollgard®II) and its 5th season of glyphosate herbicide tolerant cotton production (i.e. Roundup Ready®). When the industry entered the brave new world of applied biotechnology in 1996 there were expectations that it would bring about change and it certainly has. This paper looks at some of the changes and impacts experienced to date.

Impact of Bollgard II on insect pest management

Bollgard II provides near season long effective control of the two *Helicoverpa* spp. that attack cotton in Australia. As a consequence, under normal circumstances, very few sprays are now applied to Bollgard II to target these pests. In contrast, over 90% the insecticide applications made to conventional cotton are for the control of *Helicoverpa* spp. as the primary pests. In conventional cotton many sprays applied for *Helicoverpa* also provide control of other pests, but in Bollgard II crops, the practical elimination of *Helicoverpa* sprays has changed the status of some sucking pests. As a measure of these changes, Table 1 compares the percentage of insecticide sprays applied by pest based on fifty paired comparison crops of conventional and Bollgard II cotton during the 2004/05 season.

Table 1. Percentage of insecticides/miticides targeted by pest to conventional and Bollgard II crops in 2004/05 (source: Doyle *et al* 2005).

Pest	Helicoverpa	Mirids	Aphids	Green Veg. Bug	Mites	Thrips	Other
Conventional (%) *(total no. sprays = 11.4)*	93.0	0.9	4.2	0.9	0.2	1.2	0.4
Bollgard II (%) *(total no. sprays = 3.0)*	3.0	55.0	21.0	12.0	4.0	3.0	2.0

In summary, in Bollgard II:

- Mirids have become a primary pest. They are the most commonly sprayed pest and are usually the first pest to require spraying during the fruiting phase of the crop and, as a result, the choice of insecticide at this stage can have a critical impact on beneficials and subsequently other pests particularly mites, aphids and silver leaf whitefly.
- Green vegetable bugs (GVB) have become more common and require some treatment in their own right. Some sprays are now also being targeted at GVB on conventional

crops. This could possibly be due to the national crop now being 80% Bollgard II and acting as a source of GVB along with unsprayed cotton and pigeon pea refuges.

- Jassids and thrips have become more abundant late season, but their status as economic pests during this stage of the crop requires further clarification.
- Aphids continue to require a similar level of control, similar care with insecticide selection to manage resistance and similar careful monitoring particularly late season when honeydew is a potential risk.
- Mites are generally more common, but tend to be maintained at low levels by beneficials and in most instances not to require treatment unless a poor choice of early season control is made for mirids resulting in destruction of key mite predators.
- Silver leaf whitefly (SLW) is a key pest in central Queensland in both Bollgard II and conventional crops. It requires such careful management of other pests that it has become known as the "IPM enforcer" or if you have SLW as a pest you must practice IPM. SLW has started to become more prevalent on in southern Queensland areas and will need to be monitored carefully in those areas in the future if late season outbreaks are to be avoided.
- Beneficial species in general are much more abundant unless broad spectrum insecticides are used for other pests.

In dealing with mainly a complex of sucking pests in Bollgard II, there is a need to maintain a disciplined approach to IPM. This includes maintaining sound monitoring of all pests (including *Helicoverpa*), as well as always considering the softest effective option first. There is a risk that low cotton prices and cheaper broad spectrum sprays will lead to poorer pest management decisions.

Another major impact of Bollgard II is the reduction in spray applications both by air and ground. While this has reduced work for application contractors, it has been viewed as a significant positive benefit by many growers who apply insecticides with their own equipment. Benefits accrue not just from cost savings, but also from reduced exposure to pesticides during mixing and application and from a lifestyle point of view not having to spend hours on a spray rig.

Changes in pesticide options for insect control (product use and associated costs)

Bollgard II has been associated with reduced use of the majority of insecticides used on cotton. In 2004/05, for example, out of 35 insecticides and miticides, usage was less for 29 of them in Bollgard II compared to conventional crops. Of the remainder, usage was similar for 1 insecticide and greater for 5 insecticides – all used for sucking pest control (Doyle *et al* 2005). In the first 3 seasons, Bollgard II crops have needed only 15% of the pesticide applied to conventional crops in terms of quantity per ha. In 2004/05 an estimated 2.8 times more chemical was applied to the 29 percent of the crop planted to conventional cotton than was applied to the 71 percent planted to Bollgard II (CCA 2005). Knox *et al* 2006 conducted an environmental impact assessment of Ingard and Bollgard II cotton in comparison to

conventional and concluded that there was a 64 percent reduction in environmental impact as a result of growing Bt cotton and that the inclusion of the Bt proteins produced by Bt crops only added 2 percent to their total impact.

Table 2 compares the six highest use insecticides or miticides, their primary target pests and relative use on Bollgard II (expressed as a percentage of the use on conventional). These data are derived from a series of 50 paired comparisons of Bollgard II and conventional crops selected from across all of the Australian cotton growing regions in 2004/05 and reported by Doyle *et al* 2005. This shows very clearly the significant differences in chemical use and target pests between conventional and Bollgard II crops. For the purposes of pest management they can almost be considered to be different crops. However, from an IPM perspective the principles that have been adopted in conventional cotton are identical in Bollgard II.

Table 2. The Six Most Commonly Used Insecticides or Miticides, Primary Target Pests and Relative Usage in Conventional and Bollgard II Cotton in 2004/05 (Doyle *et al* 2005)

Conventional	**Primary Pest Target** *(% use in Bollgard vs Conventional)*	**Bollgard II**	**Primary Pest Target** *(% use in Bollgard vs Conventional)*
Endosulfan	Helicoverpa *(11.5%)*	**Fipronil** (Regent®)	Mirids *(134%)*
Emamectin (Affirm®)	Helicoverpa *(0%)*	**Dimethoate**	Mirids, Aphids *(146%)*
Indoxacarb (Steward®)	Helicoverpa *(2.5%)*	**Acetamiprid** (Intruder®)	Aphids, Mirids *(53%)*
Amitraz	Helicoverpa *(2.5%)*	**Abamectin**	Mites *(25%)*
Fipronil (Regent®)	Mirids *(134%)*	**Endosulfan**	GVB, Aphids, Mirids *(11.5%)*
Spinosad (Tracer®)	Helicoverpa *(0%)*	**Deltamethrin**	Mirids *(28.6%)*

Planting both Ingard and Bollgard II has allowed growers to reduce input costs for pest management. However, overall performance has been quite variable in assessments made each season since 1996/97. Surveys conducted for CRDC by Cotton Consultants Australia have gathered data from numerous paired samples of conventional and Bt cotton to calculate pesticide costs (including Bt cotton licence fees) and yield to provide an estimate of overall economic performance. Figure 1 shows the economic performance of Bt cotton for each season as well as the cost of the licence fee charged by Monsanto. This is a measure of the average of the paired comparisons and shows that Ingard and Bollgard II have produced economic benefits, albeit some very small, in all seasons except 1996/97. Figure 2 provides an indication of variability of performance in terms of the percentage of comparisons returning an economic benefit, the percentage returning a benefit over $500 per ha and the percentage returning an economic loss of greater than $500 per ha.

Figure 1. Estimated economic outcome for Bt Cotton (Ingard 96/97 – 02/03 and Bollgard II 03/04 – 04/05) and Bt cotton licence fee ($/ha)*

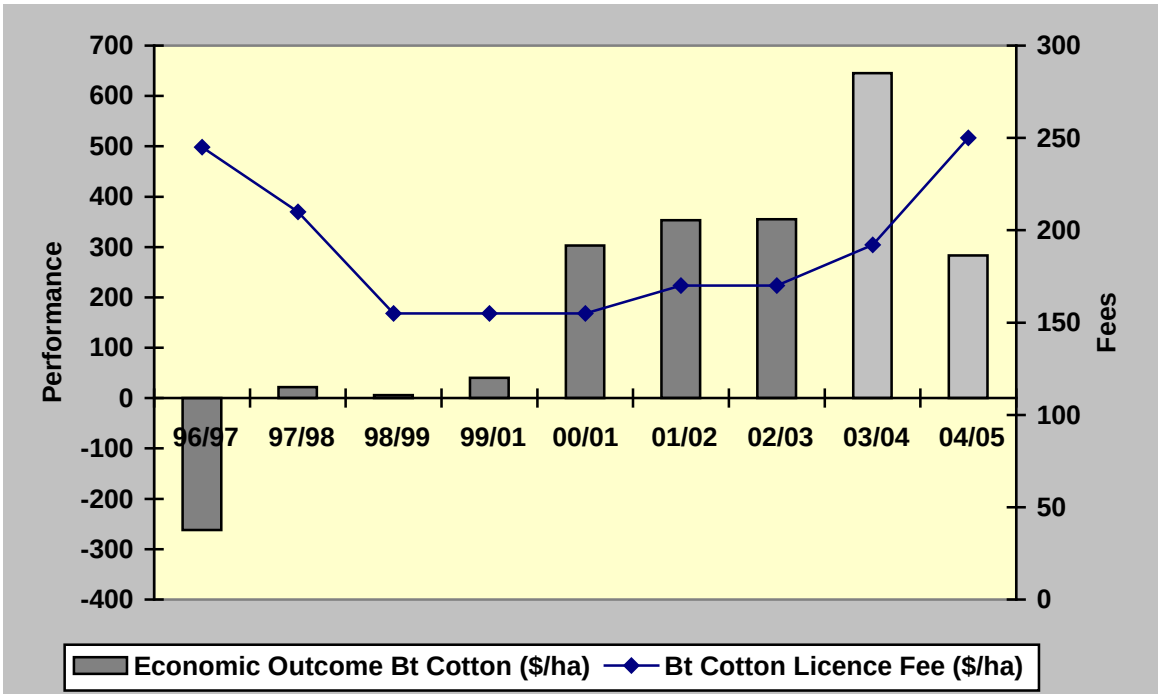
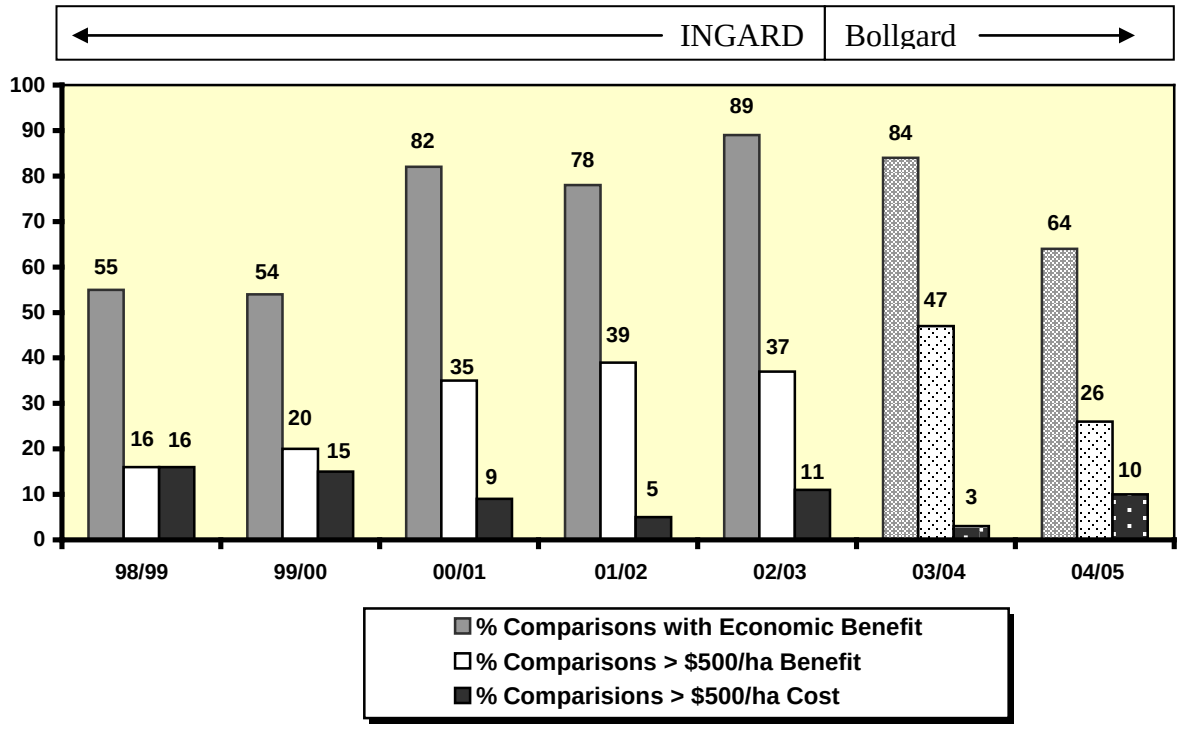


Figure 2. Measures of the economic performance of Ingard and Bollgard II cotton relative to conventional cotton over 7 seasons*



*Sources: *The Performance of Ingard Cotton in Australia* – Reports Pyke 1999, Kwint and Pyke 2000, Doyle *et* al 2002a and 200b and *The CCA Bollgard Report* Doyle 2005.

The 2003/04 season marked the end of the Ingard era and so 2004/05 was the first year that Bollgard II was the only form of Bt cotton planted. Figure 2 suggests that overall economic performance was poorer in 2004/05 than for the previous four seasons. In relation to this result, it should be noted that 2004/05 was a record season for cotton yields, both conventional and Bollgard II yield averages were the same in the comparisons reported in Figure 2 and the Bollgard II licence fee increased by over 20 percent.

One cost not included in the measure of economic performance of Bollgard II is that of the unsprayed cotton or pigeon pea that must be grown as part of the refuge once the percentage of Bollgard II planted exceeds the capacity of other refuge options to meet requirements. Grower views on refuges and their cost are discussed below.

Bollgard II refuges – short term pain for long term gain?

Refuges have been a cornerstone of the pre-emptive resistance management plan for Bt cotton since it was introduced in 1996. The purpose of a refuge is simply to generate *Helicoverpa* spp. moths that have not been exposed to selection pressure from Bt proteins in their larval stages. For the refuge strategy to work, it is important for the Bt susceptible moths to significantly outnumber any "Bt selected" moths which might emerge following survival on Bt cotton crops. If the frequency of any Bt resistance genes can be maintained at a low levels in *Helicoverpa* spp. populations then longevity of technology like Bollgard II is more assured.

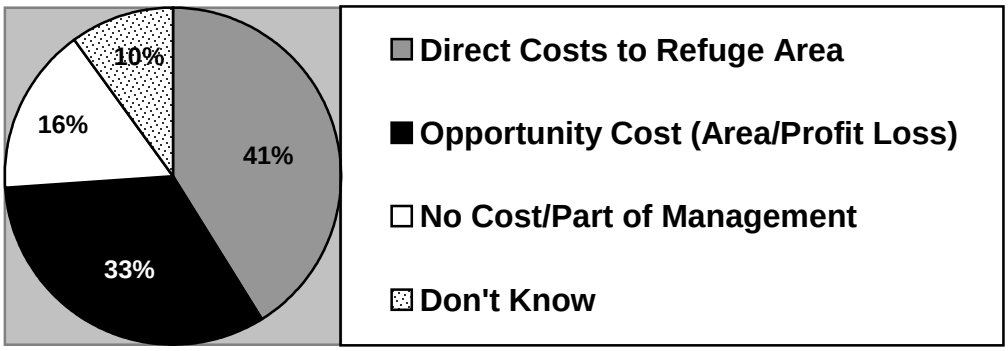
All refuge options are based on their equivalence to a 10 percent unsprayed conventional cotton refuge area. Therefore the size of the refuge area required for Bollgard II depends on the choice of refuge. For sprayed conventional cotton it must be at least 100 percent of the Bollgard II area; for unsprayed conventional cotton - 10 percent; for pigeon pea – 5 percent; for sorghum – 15 percent and for maize – 20 percent. While these refuge options were also available for Ingard cotton, because it contained just a single Bt gene, an additional precaution of a 30 percent cap on the total area planted was included until the two Bt gene Bollgard II technology became available. This strategy for Ingard was a success because the industry commenced production of Bollgard II with no evidence for any change in susceptibility in *Helicoverpa* spp. populations to the Cry1Ac Bt protein produced in Ingard. However, due to the 30 percent cap, the majority of growers chose to grow sprayed cotton as their Ingard refuge generally because it was considered to have no net cost to them.

With Bollgard II, which contains two Bt genes and produces two different Bt proteins (Cry1Ac and Cry2Ab) with different modes of action, it is much more difficult for insects to develop resistance to it. Consequently, as soon as Ingard production ceased in 2004, the 30 percent cap was removed. This means that growers can elect to plant their cotton area to just Bollgard II provided they also plant the required area of unsprayed refuge. A consequence of this is that growers must plant unsprayed cotton or pigeon pea crops as refuges as the percentage of Bollgard II on farm increases towards the maximum area. Many growers see this as a direct cost or opportunity lost and, therefore, run the risk of losing sight of refuges being an essential

long term investment for maintaining the efficacy of Bollgard II. At present growers who effectively manage their unsprayed cotton or pigeon pea refuge crops receive no direct incentives and as a result there is an underlying danger that growers will seek to cut corners in the agronomic management of their refuges to save costs in the short term.

Figure 3 provides a summary of the views of 61 cotton growers who responded to a Cotton Consultants Australia survey in 2005 on the question of the cost to their business of growing a refuge for Bollgard II cotton. The majority of growers (74 percent) believed that the refuges they grew were either a direct cost across the refuge area and/or were a significant opportunity cost in terms of area, water and/or lost profits. A smaller percentage (16 percent) were either prepared to accept the cost of growing a refuge was a necessary part of growing Bollgard II or did not perceive any difference when they compared overall costs from their Bollgard II and conventional cotton. These results suggest that relatively few growers at present seem to regard the short term pain (cost) of growing a refuge is equal to the long term gain (maintaining efficacy).

Figure 3. Percentage of responses from cotton growers regarding the costs of growing refuges for Bollgard II cotton in the 2004/05 season (Doyle *et al* 2005).



The impact of Roundup Ready on cotton crop weed control

Since the introduction of Roundup Ready cotton there have been some broad changes in weed management in cotton. In summary there has been:

- An integration of Roundup Ready technology with the key practices on weed management in conventional cotton producing superior weed control in fields with heavy weed pressure.
- A reduction in the overall use of residual herbicides, particularly pre-planting and at planting. Post-planting usage of residuals has varied depending on seasonal conditions, but has tended to increase as these herbicides are used as lay-by applications.
- A lowering of detections of residual herbicides in our river systems. Although this is correlated with the increased planting of Roundup Ready cotton and the associated reduction in overall residual herbicide use, it does not prove cause and effect
- A reduction in the need for hand chipping. This is the main area where cost savings have been identified with Roundup Ready cotton to date.

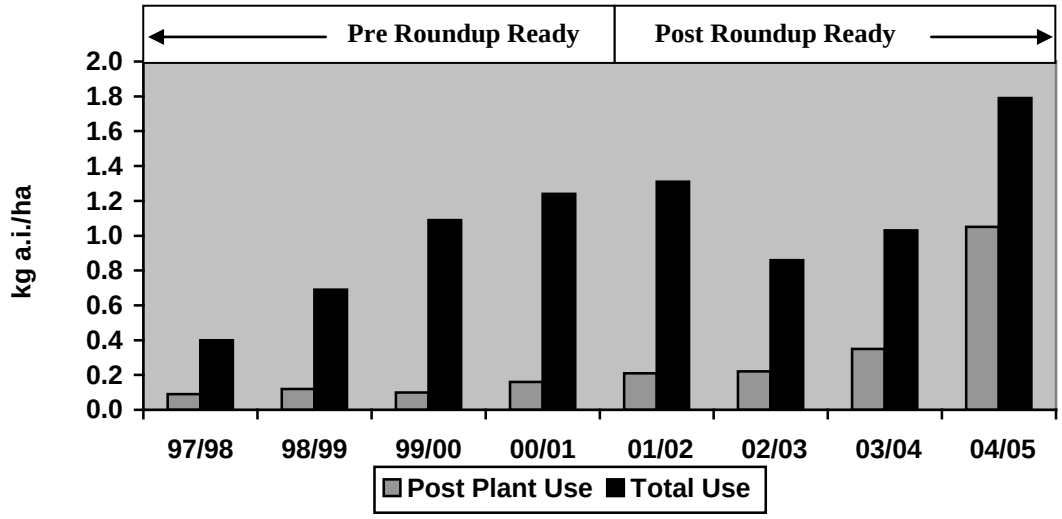
- A small but significant reduction in the need for cultivations that mainly target weed control.
- A change in the prevalence of some weeds in Roundup Ready cotton systems, eg. fleabane and Roundup Ready cotton itself. However, an improvement in the management of some key weeds eg. nut grass and post-emergence grasses.
- A need for additional care with over-the-top (OTT) sprays of glyphosate herbicide to minimise drift owing to the narrowness of the OTT window.
- No apparent impacts on yield.

The overall impact of Roundup Ready technology in its first five years can be considered positive and the perhaps the best measure of this is the adoption rate: 2001/02 - 19%; 2002/03 - 37%; 2003/04 - 40%; 2004/05 - 50%; 2005/06 - 74%.

Reflect on the cotton industry's use of glyphosate – is there evidence for over reliance?

Figure 4 presents a comparison of the total and post-planting usage pattern of glyphosate in the four seasons prior to the introduction of Roundup Ready cotton with the four seasons following the introduction. There is an upward trend in glyphosate use prior to the introduction of Roundup Ready cotton, but the drought affected seasons of 2001/02 and 2002/03 may have confounded this trend following its introduction. Post-plant usage of glyphosate relative to the total crop usage does show a consistent increase following the introduction of roundup Ready cotton.

Figure 4. A comparison of total crop and post-plant use of glyphosate on cotton in the four seasons prior and post release of Roundup Ready cotton *(Source: CCA Market Audit 2005)*



Droughts notwithstanding, there has been a trend over the last decade for increasing use of glyphosate during the cotton growing season. However, whether this usage pattern represents "over-reliance" is open to debate. A far more important consideration when considering the risks

associated with reliance on a single herbicide would be to examine glyphosate usage on all crops grown in the cotton farming system as well as in broadacre dryland cropping systems in general.

Conclusions

Change has been a hallmark of the modern Australian cotton industry since its foundation in the 1960s as production practices are constantly being refined and improved. However, it would not be an overstatement to suggest that in the last ten years biotechnology, in the form of Ingard, Bollgard II and Roundup Ready cotton, has contributed to the most dramatic changes in production practices ever seen in our industry. In the main these changes and their impact, particularly on reducing reliance on conventional agricultural chemicals, have been very positive. A clear measure of this is the adoption of Bollgard II and Roundup Ready technology – 90 percent of the 2005/06 crop.

References

CCA (2005). The 2004 Market Audit. A survey of crop management products used in the Australian cotton crop for the 2004/05 season. *Commercial, limited distribution report of Cotton Consultants Australia Inc.*

Doyle, B., Reeve, I. and Coleman, M. (2005). The Cotton Consultants Australia 2005 Bollgard Comparison Report. A Survey of Cotton Growers' and Consultants' Experience with Bollgard in the 2004-2005 Season. *A report prepared for the Cotton Research and Development Corporation and the Cotton CRC.* 136pp.

Doyle, B., Reeve, I. and Barclay, E. (2002a). The performance of INGARD cotton in Australia in the 2000/2001 season. *A Report Prepared for the Cotton Research and Development Corporation on behalf of Cotton Consultants Australia Inc.* 50pp.

Doyle, B., Reeve, I. and Bock, K. (2002b). The performance of INGARD cotton in Australia in the 2001/2002 season. *A Report Prepared for the Cotton Research and Development Corporation on behalf of Cotton Consultants Australia Inc.* 72pp.

Knox, O., Constable, G., Pyke, B. and Gupta, V. (2006). Environmental impact of conventional and Bt insecticidal cotton expressing one and two Cry genes in Australia. *Aust. J. Ag. Res.* 57: 501-509.

Kwint, P. and Pyke, B. (2000). The performance of INGARD cotton in Australia in the 1999/2000 season. *Cotton R&D Corporation Occasional Paper*. 46pp.

Pyke, B. (1999). The performance of INGARD cotton in Australia in the 1998/99 season. *Cotton R&D Corporation Occasional Paper*. 46pp.