Implementation and Impact of Transgenic Bt Cottons in Australia

Gary P. Fitt, CSIRO Entomology and Australian Cotton Cooperative Research Centre
Narrabri, NSW, Australia

Cotton is a significant primary industry for Australia with some 500,000 ha grown, producing from 700,000 tons to 800,000 tons lint annually, although in the last few years drought has severely reduced area and production. Over 90% of production is exported as raw lint making cotton the third largest crop exported from Australia. Australia is the fourth largest player in the world export market. Yields and fiber quality are among the world's highest.

Australian cotton is attacked by a multitude of pests, with *Helicoverpa* spp. being easily the predominant problem (Fitt 1994, 2000). Historically pest management has relied largely on synthetic insecticides (Fitt 1994), although some biological approaches were also applied. The dependence on pesticide intervention brings with it several environmental and economic liabilities: development of insecticide resistance in key pests and secondary pests; reductions in beneficial insect populations with associated secondary pest outbreaks; potential for environmental contamination; and cost. Collectively these provide a strong rationale for the implementation of integrated pest management (IPM) systems, and Bt cottons as part of that.

There has been a long history of research into IPM approaches which might reduce pesticide dependence. Outcomes of this research coincided with the era of biotechnology and the introduction in 1996 of genetically engineered cottons expressing the delta-endotoxin genes from *Bacillus thuringiensis* subsp. *kurstaki* (Bt), which offered opportunities to drastically reduce pesticide requirements for the key Lepidopteran pests (*Helicoverpa armigera* and *H. punctigera*) and to implement sustainable and environmentally acceptable IPM systems. Both the Australian *Helicoverpa* spp. are naturally much more tolerant of Cry1A toxins than is *Heliothis virescens*, the main target for Bollgard cotton in the USA (Liao *et al.*, 2002). This difference introduces particular difficulties in achieving a high and consistent level of efficacy of Ingard® cotton varieties and certain challenges for robust resistant management strategies.

Bt cotton varieties have now been commercialized in nine countries: Argentina, Australia, China, Colombia, India, Indonesia, Mexico, South Africa and USA (James 2002). In Australia the Cry 1Ac gene from Monsanto is available in most commercial varieties (trade name Ingard®) from two seed companies, Cotton Seed Distributors and Deltapine. In this article, the introduction of Ingard® technology in Australia and the impacts this has had on producers, researchers, and the industry as a whole are discussed.

Ingard® Cotton – Phased Release

Table 1 summarizes the major field research and development stages for Ingard® Cotton leading to limited commercial release in 1996/97 and then phased introduction thereafter. Between 1992/93 and 1995/96, the field assessments involved pre-release regulatory research to establish performance and biosafety. Despite the potential benefits of Bt cotton technology and the demonstrated safety of Bt in conventional sprays, a number of potential environmental and ecological impacts required research prior to commercial release. These were addressed through a series of field and laboratory studies (Fitt *et al.*, 1994, Llewellyn and Fitt 1996, Brubaker *et al.*, 1999, Fitt and Wilson 2002), which in some cases are ongoing. Research continues on potential impacts of Bt cotton residues on soil microbes and potential weediness of Bt varieties in tropical environments of northern Australia (Eastick 2002).

The initial registration of Ingard cottons was conditional upon the development of an industry approved resistance management strategy. This process was overseen by the

Table 1: Scale of Field Assessment and Commercial Deployment for Ingard Cotton in Australia

Year	Area (Ha)	% of Cotton Area	Main Activity
1992/93	200 plants	-	Assessment of outcrossing risk and field efficacy.
1993/94	0	-	Field efficacy and assessment of outcrossing risk.
1994/95	10	-	Field efficacy and environmental impacts (non-targets, pest dynamics).
1995/96	40 (4 sites)	-	Environmental impacts and IPM performance.
1996/97	30,000	8.0	Five year registration granted and annual review. Limited commercial release by area and region.
1997/98	60,000	15.0	Limited commercial release by area and region.
1998/99	85,000	20.0	Limited commercial release by area and region.
1999/00	125,000	25.0	Limited commercial release by area and region.
2000/01	165,000	30.0	Limited commercial release by area and region.
2001/02	184,000	30.0	Capped at 30% until two gene Bt varieties become available (2003/2004).

Transgenic and Insecticide Management Strategy Committee (TIMS), with a membership consisting of cotton growers, scientists, cotton consultants and chemical industry representatives. Since 2001, the legislated Office of the Gene Technology Regulator (OGTR) has assumed responsibility for the oversight of issues with GM crops in areas of human health and environmental safety.

Ingard® registration in 1996/97 allowed for 30,000 ha to be planted to transgenic Ingard® varieties representing about 8% of the total cotton area in that year. Thereafter the area of Ingard cotton increased in 5% increments up to 30% where it was capped by the industry in anticipation of future releases of more efficacious two gene (Cry1Ac/Cry2Ab) Bt varieties. Bollgard II cotton varieties have now been released in 2003/04.

Field Performance of Ingard® cottons

Pyke and Fitt (1998) provided a summary of the performance of Ingard® cotton varieties over the first two years of commercial use and the interaction of the industry with Monsanto. Prior to release and in the first year of commercial use there were a number of unrealistic expectations of Ingard® technology, which were reinforced by the initial license fee of A$245 per hectare. In the first year of field research in Australia, 1992/93, it was demonstrated that Bt transgenic cotton plants were very effective in controlling *Helicoverpa* larvae for much of the growing season, but did not provide season long control. There was evidence of a progressive decline in efficacy as plants matured and senesced (Fitt *et al*., 1994). This observation set the scene for much research which followed, seeking to quantify the seasonal changes in efficacy of Ingard varieties and the environmental/agronomic factors which may influence efficacy.

Subsequent experience in Australia has confirmed that efficacy of varieties expressing Cry1Ac is not consistent through the growing season and can be highly variable (Fitt *et al.*, 1994, Fitt *et al.*, 1998, Daly and Fitt 1998). Efficacy against *Helicoverpa* spp. typically declines through the boll maturation period, to the point where survival of larvae is little different to that in non-transgenic cotton (Fitt *et al*., 1994, Fitt *et al.*, 1998), although growth rates of survivors on the Ingard® crops are still dramatically reduced (Fitt unpublished). The decline in efficacy necessitates supplementary *Helicoverpa* control on Ingard® crops, particularly in the last third of the growing season.

Coupled with the variability of efficacy between crops, the consistent seasonal decline in efficacy has several implications. One relates to the uncertainty generated for crop managers and the confidence they may have in using thresholds for Bt cotton. Current thresholds are two small larvae/meter of row for two consecutive check dates (or one medium larva/meter on the first check). Some crops have suffered damage because consultants complied with the thresholds and left small larvae untreated; subsequent insecticide treatments failed to control larger larvae. An unfortunate consequence is that consultants may have adopted more conservative thresholds, thereby eroding the full IPM value of Ingard® cotton.

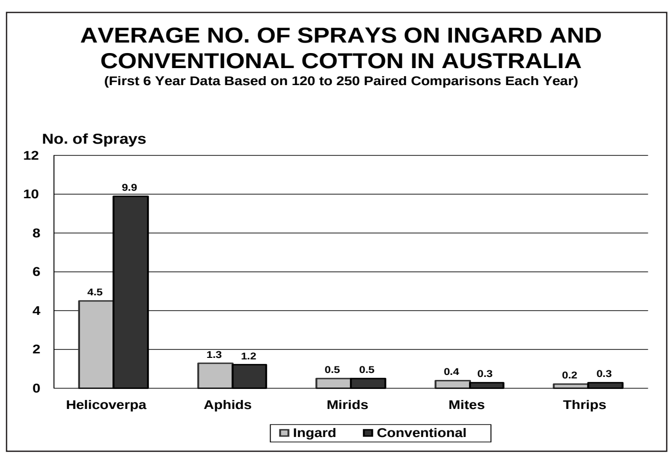
A second significant consequence of changing field efficacy is the added selection pressure that may apply on Bt resistance. The resistance management strategy in place for Bt cotton (Roush *et al*., 1998) relies on the use of refuges, but these work best when the plants are highly efficacious and have the capacity to kill a high proportion of heterozygous resistant individuals. Ingard cotton varieties expressing a single Cry1Ac gene clearly do not express a high dose and heterozygote mortality is unlikely to be high except perhaps when plants are quite young (up to squaring phase). A significant period of selective mortality is likely during the season. Given this, the other components of the resistance management strategy are even more crucial. It is for this reason that the use of Ingard cotton has been restricted by a cap on area in the first years of commercial use. This serves to magnify the size of the total refuge that includes the refuge crops grown specifically with Bt cotton, the area of conventional cotton (at least 70% of the total) and all other *Helicoverpa* susceptible crops grown in eastern Australia. This represents a huge refuge.

Impacts on Pesticide Use

Figure 1 summarizes the average spray numbers applied to Ingard® and conventional crops for a range of cotton pests. For *Helicoverpa,* there have been consistent reductions in the number of sprays applied to Ingard® crops compared to conventional ones, averaging 56% and ranging from 43% (1998/99) to 80% (2001/02). For the minor pest groups there has been no significant change in pesticide applications after 6 years.

In 1998/99 it is estimated that the reduction in spraying across 125,000 ha of Ingard® crops resulted in 1.75 million liters less pesticide entering the environment. Despite the variable performance, the average 56% reduction in pesticide applications for *Helicoverpa* represents a spectacular impact for an IPM product.

On average the greatest reduction in sprays has been during the squaring and flowering stages of crop development (50-



67%) whereas reductions during boll filling and opening have been more modest (20-35%). Consequently the most dramatic reductions in use have been among the early to midseason pesticide groups (endosulfan, carbamates and synthetic pyrethroids). In each case this reduction has major environmental benefits.

Impacts on Economic Returns

Comprehensive information on pesticide use, yields and returns to growers is provided in reports produced by the Cotton Research and Development Corporation of Australia. Table 2 summarizes the key points from these comparative analyses around the issues of yield, pesticide use, pest control costs and economic returns. With significant reductions in pesticide applications, Ingard® cotton could be expected to provide greater returns to growers. As yet there has been no comprehensive economic assessment of the value of Ingard technology in the Australian environment, in contrast to those in the USA (e.g. Falck-Zepeda *et al*., 2000), which show significant benefit accruing to growers.

In the 1997/98 season, Monsanto retained a license fee of A$245 per ha, but provided rebates totaling A$35 per ha for growers who complied with various components of the resistance management strategy. In subsequent years, the Ingard® license fee dropped to A$185/ha with an A$30 rebate for full compliance with the resistance management strategy, giving a net fee of A$155/ha which has remained largely unchanged since. During the first 4 years much of the economic benefit was subsumed by the technology license fee, with the result that net economic return was similar to conventional cotton (Table 2). There was however, huge variation in returns with some growers in each year achieving gains of A$1,000/ha while others recorded a net loss of A$1,000/ha.

In the last two years net economic returns from Ingard varieties have been considerably higher at over A$300/ha. This reflects the progressive improvement in varietal performance, increased experience of growers and consultants in managing Ingard cottons and the lighter pest pressure experienced in those years. Nonetheless, intangibles due to reduced environmental impact and enhanced sustainability have not been valued yet.

Over the six years of commercial use there have been changes in the license fee, area of Ingard® grown, range of varieties available and pest pressure, all of which complicate between year comparisons. In general, average yields of Ingard® have been comparable to or higher than conventional cottons, although in the 1998/99 season, yields of Ingard® varieties were markedly lower in one region (Gwydir). There were no significant differences in crop maturity (time from planting to harvest) between Ingard® and conventional varieties in any year.

The most consistent "winner" from Ingard® technology has been the environment, with reduced pesticide loads, while the cotton industry has gained long term sustainability through the progressive adoption of more integrated pest management approaches using Ingard® cotton as a foundation.

Despite the variability of economic return implicit in Table 2, and the additional management requirements imposed on growers by Ingard cotton, it is noteworthy that all the licensed area available each year has been sold. Clearly growers attribute value to the environmental benefits associated with Ingard® cotton. Indeed some 80-90% of growers have consistently identified their prime reason for growing Ingard® cotton as "protection of the environment". Since the 1999/2000 season, by which time expectations of Ingard® cotton were more realistic, over 70% of consultants and growers indicated they believe Ingard® cotton provided "even or better" value for money and some 80% of surveyed growers were "satisfied" with Ingard® performance.

Resistance Risk and Management Requirements

The major challenge to sustainable use of transgenic cottons is the risk that target pests may evolve resistance to the Cry1Ac protein. Resistance to conventional Bt sprays has evolved in field populations of *Plutella xylostella* (Tabashnik, 1994a,b) and the possibility of resistance is a real concern, particularly for *H. armigera* which has consistently developed resistance

Table 2: Yield and Economic Returns from Ingard and Conventional Cotton Across Australia

Year	Crop Type	Sample size *	License Fee/ha (A$)	Rebates (A$)	Net License Fee/ha (A$)	Yield/ha (Kg/ha)	No. of Sprays (Total)	Av. Cost/Spray** (A$)	Average Insect Costs/ha ** in A$ (Range)	Net Benefit in Insect Costs (A$)	Net Economic Benefit in A$ (Range)
1996/97	Ingard	210.0	245.0	'Value guarantee'	245.0	1,753 (1,660-2,025)	5.0	53.0	508 (410-622)	-41.0	-262 (-409 to +68)
	Conventional					1,873 (1,796-2,127)	10.3	45.0	467 (393-635)		
1997/98	Ingard	179.0	245.0	35.0	210.0	1,910 (1,726-2,082)	6.0	49.0	491 (434-515)	-35.0	22 (-111 to + 193)
	Conventional					1,901 (1,697-2,028)	10.2	45.0	456 (395-524)		
1998/99	Ingard	110.0	185.0	30.0	155.0	1,549 (1,452-1,876)	8.7	56.0	675 (418-853)	91.0	6 (-1,200 to +1,000)
	Conventional					1,676 (1,556-1,855)	14.0	52.0	766 (577-944)		
1999/00	Ingard	149.0	185.0	30.0	155.0	1,826 (1,526-2,019)	6.2	56.0	501 (414-656)	72.0	50 (-1,400 to +2,000)
	Conventional					1,810 (1,472-2,116)	10.3	56.0	573 (205-712)		
2000/01	Ingard	142.0	185.0	30.0	155.0	1,721 (1,683-1,989)	4.6	57.0	426 (279-545)	182.0	328 (-1,000 to +1,500)
	Conventional					1,665 (1,501-2,019)	9.9	61.0	608 (451-704)		
2001/02	Ingard	229.0	185.0	15.0	170.0	2,089 (1,574-2,216)	3.1	45.0	327 (260-433)	177.0	331 (-700 to +1,400)
	Conventional					1,989 (1,712-2,130)	8.6	53.0	504 (390-768)		

* Number of paired comparisons of Ingard and conventional cotton crops.
** Including net Ingard license fee.

to synthetic pesticides (Forrester *et al*., 1993, Fitt, 1989, 1994). For this reason a pre-emptive resistance management strategy was implemented with the commercial release of transgenic varieties. The strategy adopted in Australia is targeted at *H. armigera* and based on the use of refugia to maintain susceptible individuals in the population (Roush, 1996, 1997; Gould, 1994). This strategy seeks to take advantage of the polyphagy and mobility of *Helicoverpa* spp. to achieve resistance management by utilizing gene flow to counter selection in transgenic crops.

Key elements of the strategy are as follows:

- Effective refuges on each farm growing Ingard cotton
- Defined planting window for Ingard cotton to avoid late planted crops that may be exposed to abundant *H. armigera* late in the growing season
- Mandatory cultivation of Ingard crops to destroy most overwintering pupae of *H. armigera* and a requirement to remove any volunteer Bt plants in subsequent seasons
- Defined spray thresholds for *Helicoverpa* to ensure any survivors in the crops are controlled
- Monitoring of Bt resistance levels in field populations

All elements of the Ingard® management plan are included in a printed strategy provided to all cotton growers and available on the web (http://www.cotton.crc.org.au/Assets/PDFFiles/IMPInga.pdf). The plan stipulates planting times and areas for refuges, necessary distances of refuge from an Ingard® crop, and management requirements for refuges.

Refuge options have been defined on the basis of ongoing research which seeks to quantify the value of different options in generating moths (Fitt and Tann 1996) and ranks potential refuges in relation to unsprayed conventional cotton, regarded as the "control" refuge. Options are expressed as the number of hectares required for every 100 ha of Ingard® cotton. Current refuge options include:

10 ha of unsprayed conventional cotton
100 ha of sprayed conventional cotton
15 ha of unsprayed sorghum
20 ha of unsprayed corn
5 ha of unsprayed pigeon pea

Refuges are required to be in close proximity to the transgenic crops (within 2 km) to maximize the chances of random mating among sub-populations (Dillon *et al.*, 1998). At present the conventional sprayed cotton refuge option remains most popular, although an increasing proportion of growers are now using unsprayed non-cotton refuges (40% in 01/02). Unsprayed refuges will also be used for the future extensive deployment of Bollgard II™ cottons expressing both Cry1Ac and Cry2Ab proteins.

An additional element of the conservative Australian deployment of Bt cotton was the phased introduction of Ingard® varieties and imposition of the 30% cap of total cotton area. Bollgard II™ varieties have now been approved for commercial use and occupied about 5,000 ha in 2002/03. The two gene varieties provide much better efficacy and hence even greater reduction in pesticide requirement, but their main purpose is to provide much greater resilience against the risk of resistance (Roush 1998). The current season (2003/04) is a transition year with Bt varieties occupying 40% of total cotton area, made up of 25% Ingard varieties and 15% Bollgard II™ varieties. All Ingard varieties will be withdrawn after this season and the cap on area of transgenic will be withdrawn. This rapid transition to Bollgard II™ again reflects a commitment to resistance management in minimizing exposure of single gene Bt varieties.

All aspects of the Insect Management Plan for Ingard® and Bollgard II™ varieties are embodied in the label and are part of a single use contract growers must sign with Monsanto in order to purchase seed. Components of the resistance management plan are thus legally binding on the grower. To support this the contract and label also stipulate that each farm growing Bt varieties be audited three times each year to check on compliance with refuges, pesticide use and compulsory plowdown.

Transgenic Bt Cotton as a Foundation for IPM

Ingard and Bollgard II™ cotton varieties are not perceived as "magic bullets" for pest control in Australia. Instead they are viewed broadly as an opportunity to address environmental concerns about cotton production and more specifically as a foundation to build IPM systems which incorporate a broad range of biological and cultural tactics (Fitt 2000). Research has shown little effect of Bt cottons on non-target species, including non-lepidopterous pests, beneficial insects, and other canopy dwelling and soil dwelling species (Fitt *et al.*, 1994; Fitt and Wilson 2000; Fitt and Wilson 2002). Survival of beneficial is markedly higher than in conventional sprayed cotton, and they provide control for some secondary pests, particularly those which are induced pests in sprayed cotton (e.g. mites and aphids).

Reduced use of disruptive pesticides afforded by Bt varieties has allowed greater focus on the management and manipulation of beneficial species (Fitt 2000), through techniques for conservation and augmentation. A range of other IPM tactics can also be deployed. Indeed the last five years has seen a dramatic adoption of IPM systems (Wilson *et al*., 2003) with reductions in pesticide use in conventional cotton varieties as well as in Bt varieties. It could well be argued that Bt varieties have allowed growers to develop confidence in the capacity of beneficial insects to play a role in pest management and so have stimulated more widespread adoption of IPM than might otherwise have been possible.

Conclusions

Ingard® cotton, as the first commercial introduction of biotechnology to the Australian cotton industry, has shown the potential of transgenic pest tolerant crops to significantly reduce pesticide use, providing major environmental benefits. After an initial period of negligible economic benefits, Ingard varieties are now returning significant economic benefits. At this time it is not clear what the license fee for Bollgard II varieties may be. Despite this growers are likely to benefit in the long term through the clear contribution of Bt cottons to sustainability. Until now Ingard cotton has occupied only a restricted proportion of the Australian cotton area. With Bollgard II™ varieties the 30% cap will be removed and substantially larger areas are likely. That Ingard® cotton has not been a "magic bullet" is fortunate in demonstrating that pest tolerant transgenic cottons will need to be introduced as part of an IPM system that incorporates a range of tactics. The deployment of Bollgard II cotton and a range of herbicide tolerant cottons will see transgenic varieties become an important cornerstone of sustainable cotton production systems for Australia.

References

Brubaker, C.L., A.H.D. Brown, J.McD. Stewart, M.J. Kilby and J.P. Grace. 1999. Production of fertile hybrid germplasm with diploid Australian *Gossypium* species for cotton improvement. *Euphytica,* 108:199-213.

Daly, J.C. and G.P. Fitt. 1998. Efficacy of *Bt* cotton plants in Australia - What is going on? pp. 675-678 in *New Frontiers in Cotton Research* - Proceedings World Cotton Research Conference - 2; Athens, Sept. 6-12 1998; Editor: F. Gillham; Publishers: P. Petridis, Thessaloniki, Greece.

Dillon, M.L., G.P. Fitt and M.P. Zalucki. 1998. How should refugia be placed upon the landscape? A modelling study considering pest movement and behaviour. pp.179-189 In M.P. Zalucki, RAI Drew, GG White (eds). *Pest Management - Future Challenges.* Proceedings of the 6th Australasian Applied Entomology Conference, Vol. 1, Brisbane. University of Qld Press, Brisbane, Australia.

Eastick, R. 2002. Evaluation of the potential weediness of transgenic cotton in Northern Australia. http://www.cotton.crc.org.au/Assets/PDFFiles/TB3051.pdf

Falck-Zepeda, J.B., G. Traxler and R.G. Nelson. 2000. Surplus distribution from the introduction of a biotechnology innovation. *American Journal of Agricultural Economics*, 82: 360-369.

Fitt, G.P. 1989. The ecology of *Heliothis* species in relation to agroecosystems. *Annual Review of Entomology*, 34: 17-52.

Fitt, G. P. 1994. Cotton pest management: Part 3. An Australian perspective. *Annual Review of Entomology*, 39: 543-562.

Fitt, G.P. 2000. An Australian approach to IPM in cotton: integrating new technologies to minimise insecticide dependence. *Crop Protection*, 19: 793-800.

Fitt, G.P. and C. Tann. 1996. Quantifying the value of refuges for resistance management of transgenic Bt-cotton. In *Proceedings of the Eighth Australian Cotton Conference*, Broadbeach, August, 1996. pp. 77-83.

Fitt, G.P., J.C. Daly, C.L. Mares, C.L. and K. Olsen. 1998. Changing efficacy of transgenic Bt cotton - Patterns and consequences. Pp. 189-196 in M.P. Zalucki, RAI Drew, GG White (eds). *Pest Management - Future Challenges.* Proceedings 6th Australasian Applied Entomology Conference Vol. 1, Brisbane. University of Qld Press, Brisbane, Australia.

Fitt, G.P., C.L. Mares and D.J. Llewellyn. 1994. Field evaluation and potential impact of transgenic cottons (*Gossypium hirsutum*) in Australia. *Biocontrol Science and Technology*, 4: 535-548.

Fitt, G.P. and L.J. Wilson. 2000. Genetic Engineering in IPM: Bt cotton. pp. 108-125 In: Kennedy, G.G. and Sutton, T.B. (eds). *Emerging Technologies in Integrated Pest Management: Concepts, Research and Implementation.* APS Press, St. Paul.

Fitt, G.P. and L.J. Wilson 2002. Non-Target Effects of Bt-Cotton: A Case Study From Australia. In "Biotechnology of *Bacillus thuringiensis* and Its Environmental Impact: *Proceedings of the 4th Pacific Rim Conference*", Akhurst, R.J., Beard, C.E., Hughes, P.A. (eds). CSIRO, Canberra. Pp. 175-182.

Forrester, N.W., M. Cahill, L.J. Bird and J.K. Layland. 1993. Management of pyrethroid and endosulfan resistance in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Australia. *Bulletin of Entomological Research,* Supplement No.1.

Gould, F. 1994. Potential and problems with multi-gene, high dose strategies for managing resistance to Bt toxins. *Biocontrol Science and Technology*, 4: 451-462.

Hearn, A.B. and G.P. Fitt. 1992. Cotton cropping systems. In: Pearson C. (Editor), *Field Crop Ecosystems of the World.* Elsevier Press, Amsterdam, pp. 85-142.

Holt H.E. 1998. Season-long quantification of *Bacillus thuringiensis* insecticidal crystal protein in field-grown transgenic cotton. Pp 215-222 In M.P. Zalucki, RAI Drew, GG White (eds). *Pest Management - Future Challenges*. Proceedings 6th Australasian Applied Entomology Conference Vol. 1, Brisbane. University of Qld Press, Brisbane, Australia.

Holt H.E., C.L. Mares and R. Akhurst. 2002. Determination of the Cry protein content of Bt transgenic cotton – a technical manual for laboratory use. *CSIRO Entomology Technical Report*, No. 92. 13pp.

James, C. 2002. *Global Review of Commercialised Transgenic Crops: 2001 Feature: Bt cotton*. ISAAA Briefs No. 26. 184pp. ISAAA: Ithaca, NY, USA.

Liao, C., D.G. Heckel and R. Akhurst. 2002. Toxicity of *Bacillus thuringiensis* insecticidal proteins for *Helicoverpa armigera* and *Helicoverpa punctigera* (Lepidoptera: Noctuidae), major pests of cotton. J. Invertebr. *Pathol.*, 80:55-63.

Llewellyn D.L.and G.P. Fitt. 1996. Pollen dispersal from a field trial of transgenic cotton in the Namoi Valley, Australia. *Molecular Breeding 2*. 157-166.

Pyke, B. and G.P. Fitt. 1998. Field performance of INGARD® cotton - the first two years. pp.230-238 In M.P. Zalucki, RAI Drew, GG White (eds). *Pest Management - Future Challenges.* Proceedings 6th Australasian Applied Entomology Conference Vol. 1, Brisbane. University of Qld Press, Brisbane, Australia.

Roush, R.T. 1996. Can we slow adaptation by pests to insect-resistant transgenic crops? pp.242-263 In G. Persley (ed), *Biotechnology and Integrated Pest Management*, CAB International, London, UK.

Roush, R.T. 1997. Managing resistance to transgenic crops. pp271-294. In N Carozzi and M Koziel (eds). *Advances in insect control: The role of transgenic plants.* Taylor and Francis, London, UK.

Roush, R.T. 1998. Two toxin strategies for management of insecticidal transgenic crops: Can pyramiding succeed where pesticide mixtures have not? *Philosophical Transactions of the Royal Society of London* B. 353: 1777-1786.

Roush, R.T., G.P. Fitt, N.W. Forrester and J.C. Daly. 1998. Resistance Management for Insecticidal Transgenic Crops: Theory and Practice. pp.247-257. In M.P. Zalucki, RAI Drew, GG White (eds). *Pest Management - Future Challenges.* Proceedings 6th Australasian Applied Entomology Conference Vol. 1, Brisbane. University of Qld Press, Brisbane, Australia.

Tabashnik, B.E. 1994a. Delaying insect adaptation to transgenic crops: seed mixtures and refugia reconsidered. *Proceedings Royal Society of London,* Series B. 255: 7-12.

Tabashnik BE. 1994b. Evolution of resistance to *Bacillus thuringiensis. Annual Review of Entomology,* 39: 47-79.

Wilson, L.J., R.K. Mensah and G.P. Fitt. 2003. Implementing IPM in Australian cotton. In, '*Novel Approaches to Insect Pest Management in Field and Protected Crops*'. (Eds, A. Rami Horowitz and Isaac Ishaaya). Springer-Verlag, Mühlhausen, Germany. In press.

Short Notes

• Varieties Planted in the USA-2003/04

The latest report from the Agricultural Marketing Service of the US Department of Agriculture shows that during 2003/04, about 140 varieties were planted on a commercial scale in the USA. The Cotton Program of the Agricultural Marketing Service of the USDA undertook informal surveys of cotton ginners, seed dealers, extension agents and other knowledgeable sources to estimate area planted to each variety and published a report in September 2003. According to the report *Cotton Varieties Planted 2003 Crop*, transgenic varieties were planted on 76% of the total area. This includes Bt varieties, herbicide resistant varieties and varieties with both types of genes. Varieties with only insect resistant genes accounted for only 1.4% of the total cotton area in the USA. Stacked gene varieties having insect resistant as well as herbicide resistant genes were planted on 47% of the total area. The herbicide resistant varieties, most of which are Roundup Ready, were planted on 28% of the total area. The percentage of area under transgenic varieties varied significantly among states from 100% in Florida to 42% in California. Transgenic varieties accounted for 56% of 2.3 million hectares planted to cotton in Texas in 2003/04. Deltapine brand varieties were the most popular in the USA during 2003/04, followed by Paymaster brands. Next table shows important company brands and area planted to their varieties.

Brands	% Area 2003/04	Main Varieties
Deltapine	33.0	DP 555 BG/RR, DP 451 B/RR & DP 458 B/RR
Paymaster	21.3	PM 1218 BG/RR, PM 2326 RR and HS 26
Fibermax	15.6	FM 958, FM 832 and FM 989BR
Stoneville	13.6	ST 489BR and ST 4793R
Suregrow	5.4	SG 215 BG/RR
All-Tex	3.1	Atlas and Atlas RR
Phytogen	2.1	PHY 72 (Pima)

In 2003/04, the most popular variety was DP 555 BG/RR, which is as tacked gene variety and was planted on 8.7% of the US cotton area, followed by ST 4892 BR planted on 7.9% of the total cotton area. No single variety accounted for more than 10% of the total cotton area in 2003/04.

Cotton breeding in the USA is in the private sector, and many seed companies are involved. Each seed company sells only its own brand name varieties, and seed companies are free to distribute any variety for general cultivation throughout the cotton belt. A system of self-accountability dominates the seed market, and companies are aware of tough competition among seed breeders. Healthy competition among seed companies ensures that only better performing varieties are promoted among farmers for general cultivation. There is no formal variety approval process, and if a variety has been released by a company, farmers are free to plant it on as much area as they want. However, extension agents and variety performance data suggest planting certain varieties in any given area.

• Top Ten Cotton Producing Countries

Ten countries planted 77% of the world's total area of cotton in 2003/04. The table (next page), shows that only six countries are among the 10 highest yielding countries in the world.

China (Mainland) is expected to produce one-fourth of world production in 2003/04, followed by the USA sharing almost 19% of world production. The top 10 countries are expected to produce 85% of world production; 50 other countries will produce only 15% of world production in 2003/04. Average yield have significantly improved in Brazil, China (Mainland) and Turkey in the last few years, while they have significantly fallen in Uzbekistan.