INTEGRATION OF *BT* COTTON IN IPM SYSTEMS: AN AUSTRALIAN PERSPECTIVE

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ABSTRACT

Insect pests may have a severe impact on cotton production in Australia. Key pests are *Helicoverpa* spp which are well adapted to exploit cropping systems and often evolve resistance to pesticides. Until recently adoption of IPM has been restricted by a lack of non-disruptive tools.

IPM must be founded on a thorough understanding of the ecology of pest and beneficial species, their interaction with the crop and surrounding non-crop environments. Insect resistant transgenic cottons have proved successful in providing a foundation for more sustainable, economically acceptable IPM with the integration of a range of other non-chemical tactics.

In Australia, *Bt* cottons (tradename INGARD®) expressing the CryIAc endotoxin from *Bacillus thuringiensis* subsp. *kurstaki*, were commercialised in 1996/97 and gradually increased in area under an industry agreed deployment strategy which limited use to 30% of the cotton area. Two gene (Cry IAc/Cry 2Ab) varieties (Bollgard II) have been commercialised from 2004/05 and have now completely replaced Ingard varieties. All *Bt* varieties are grown under a comprehensive management strategy designed to minimise the risk of resistance evolving in *Helicoverpa armigera*, the main target pest.

Commercial use of Ingard cotton varieties has reduced pesticide applications for *Helicoverpa spp* by 60%, providing major environmental benefits. Even greater pesticide reductions now occur with Bollgard II varieties. Pre-release environmental impact assessments demonstrated no significant effect of these *Bt* cottons on natural enemies. Commercial experience with *Bt* cotton crops has now shown a 3-4 fold increases in beneficial insect abundance compared to conventional crops. Co-incidentally several selective insecticides (indoxacarb, spinosad, and emamectin) became available for *Helicoverpa* control on conventional cotton, which further assisted in conserving beneficials. While resistance is the greatest risk for *Bt*

cottons their sustained value in IPM systems also requires focus on the management of secondary pests, which are suppressed in conventional cotton by *Helicoverpa* sprays. Enhanced levels of beneficial species help to partially suppress secondary pests.

Maintaining an appropriate balance and retaining the benefits of *Bt* cottons requires vigilant resistance management, sustained efforts to enhance beneficial species and non-disruptive, short residual pesticides for key sucking pests. Overall the stability of these systems will require mobilization of the whole farm environment and greater understanding of the flows of impacts and services between intensive cropping systems and the surrounding landscape.

INTRODUCTION

Insect pests represent a significant threat to Australian cotton production (Fitt 1994). Key pests include the noctuid moths *Helicoverpa armigera* and *H. punctigera*, spider mites (*Tetranychus urticae*), aphids (*Aphis gossypii*) and mirids (*Creontiades dilutus*), while insecticide resistance in several pests further complicates management.

Pest management using conventional pesticides can be effective but imposes significant economic and environmental costs including disruption of natural biological control agents. Integrated pest management has long been proposed as a more sustainable approach in many situations, however, the adoption of a truly integrated pest management approach has been extremely patchy.

Broadly IPM can be defined as "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms." (FAO 2002). In this paper we will illustrate how the adoption of *Bt* cotton varieties has assisted the implementation of IPM in the Australian cotton industry.

Many aspects of IPM have been applied in the Australian cotton industry since the late 1970s when the computer based decision support system, SIRATAC, was released to industry (Hearn and Bange 2002). The minimal IPM approach involved the use of sampling systems and thresholds to better time the use of pesticides. However, today IPM represents a more expansive approach which seeks to minimise pesticide use and include a broader range of tactics such as pest resistant varieties, conservation and augmentation of beneficial insect populations, use of selective and short residual insecticides, recognition of the compensatory capacity of the plant and various cultural control practices which have long been associated with the IPM concept.

These broad principles are captured in the "Integrated Pest Management Guidelines for Cotton Production Systems in Australia" produced for the Australian industry (Deutscher, Wilson, and Mensah, 2004 - http://cotton.crc.org.au/Assets/PDFFiles/IPMGL05/IPMGLFor.pdf). The Guidelines emphasise four principles:

1. conservation and utilization of beneficial insects;
2. preferential use of selective insecticides;
3. an emphasis on both profitability and sustainability, ensuring that both input costs and yield are considered, rather than the traditional emphasis on maximizing yield;
4. integration of all farm management activities, throughout the annual cycle of production, not just during the cotton season.

It is into this milieu that *Bt* cotton varieties contribute significantly by providing effective control of the key pests without disruption of the system so providing opportunities for the enhanced role of naturally occurring biocontrol agents to be recognised, manipulated and managed to achieve more sustainable systems.

GENETICALLY MODIFIED COTTONS IN IPM

Bt cotton varieties expressing the Cry 1Ac protein from *Bacillus thuringiensis* subsp. *kurstaki* were first registered in Australia in1996 (INGARD®) and gradually increased in area under an industry agreed deployment strategy which limited use to 30% of the cotton area. Two gene (Cry IAc/Cry 2Ab) varieties (Bollgard II) have been commercialised from 2004/05 and have now completely replaced Ingard varieties. All *Bt* varieties are grown under a comprehensive management strategy designed to minimise the risk of resistance evolving in *Helicoverpa armigera*, the main target pest. Fitt (2003; 2004) provides an assessment of the impact of *Bt* cotton in Australia over the first six years of commercial use. While efficacy of INGARD cottons is not consistent through the growing season and can be highly variable (Fitt *et al.* 1994; Fitt *et al.* 1998), growers have learned to manage INGARD varieties and substantial reductions in pesticide use on *Bt* cotton have occurred.

Potential non-target impacts of *Bt* cotton were one of the environmental impacts which required pre-release assessment. Cry proteins from *Bacillus thuringiensis* (*Bt*) introduced have been deployed as safe and effective pest control agents in microbial *Bt* formulations for almost 40 years in many developed and developing countries (Glare and O'Callaghan 2000). Potential impacts of *Bt* cotton on non-target species may involve direct or indirect effects and a range of assessment protocols have been proposed. Schuler *et al.* (2001; 2004) and Poppy (2000) outline a comprehensive, hierarchical protocol for assessing non-target effects commencing with laboratory studies to assess direct or indirect impacts on non-targets or their predators and parasitoids – a worst case scenario, through a second tier of semi-field contained population experiments and finally a third tier of field experiments.

In the case of direct effects of Cry IAc and Cry 2Ab proteins on non-target species, the well established specificity of these proteins provides a clear safeguard that greatly reduces risks of direct effects on non-lepidopteran species. Non-targets such as predators which do not feed on the plant are not directly exposed and no evidence exists for a secondary impact through consumption of intoxicated prey. The reported effects of Cry IAb expressed in maize on the survival of lacewing larvae (Hilbeck *et al*. 1998a,b; 1999) were recently shown to be mediated by reduced prey-quality rather than any direct effect of the protein toxin (Romeis *et al*. 2004).

Research in Australia examined the diversity and species richness of invertebrate communities present in unsprayed *Bt* and conventional crops. Across a number of specific invertebrate categories, Fitt and Wilson (2002) found no significant impacts of *Bt* cotton. When analysed as a whole community (Whitehouse *et al.* in press) there were small differences between the communities in *Bt* cotton and conventional cotton, but these differences peaked at different times during the season, and the timing of differences was not consistent between years. Again for the majority of functional groups there was no impact of *Bt* cotton.

Indirect effects on non-target species may be mediated through changes in abundance and diversity of prey. The significance of a reduced density of Noctuid larvae and pupae as food sources for predators or as hosts for parasitoids depends on the importance of *Helicoverpa* life stages in cotton in maintaining local populations of these beneficials. Clearly within transgenic cotton fields, the abundance of some predators and parasitoids may be reduced, particularly those whose survival is closely tied to the abundance of *Helicoverpa,* but this is unlikely to threaten their regional persistence since in the cropping systems where cotton is usually grown a significant proportion of the *Helicoverpa* population is also present on other crops and uncultivated hosts (Fitt 1989; Hearn and Fitt 1992) where parasitoids are also active. None of the known predators that attack Lepidoptera in cotton are specialists; *Helicoverpa* may be only incidental prey items for some key predators whose within-field abundance is maintained by other prey. Other studies have sought further indirect effects of transgenic on parasitoids and non-target herbivores but have generally found no effect of the *Bt* plant itself (e.g., Schuler *et al*. 2001; 2004).

Within-field impacts on non-target insects, even if they do occur, are unlikely to be significant compared to the undoubted impacts from broad-spectrum pesticides. The appropriate control treatment for any experimental comparison of the impact of transgenic cotton must include not only unsprayed non-transgenic conventional cotton, but also conventional cotton with its required management which will usually involve synthetic pesticides (Fitt and Wilson 2002). A similar sentiment has been expressed by EU researchers (http://europa.eu.int/comm/research/fp5/pdf/eag-gmo.pdf). Observations over the past 6 years confirm that the abundance of beneficial invertebrates in commercial *Bt* cotton fields is markedly greater than in conventional fields.

An additional concern with *Bt* cottons is that secondary pests, once suppressed by insecticides applied for *Helicoverpa*, may become significant pests in their own right. The suite of sucking pests (mirids, aphids, stink bugs, cotton stainers etc.) are the group most likely to show such effects. While it is true that sucking pests have become a more significant part of the pest complex in *Bt* crops in some countries (Wilson *et al*. 2004; Wu *et al*. 2002) they have not required additional spraying at levels where the advantage of the *Bt* crop has been significantly eroded. In Australia, an average 60% reduction in sprays applied for *Helicoverpa* was accompanied by no change in sprays for mirids, aphids, mites and thrips (Fitt 2004). Likewise Wu and Guo (2003) report that *Bt* cotton in China help to prevent resurgence of aphid populations. By contrast in the south-eastern USA stink bugs have assumed significant pest status in *Bt* cotton crops (Greene *et al*. 2001).

IMPACTS OF *BT* COTTON IN IPM

Commercial use of Ingard cotton varieties in Australia generated an average reduction in pesticide applications for *Helicoverpa* of 56%, with no significant change in pesticide applications for minor pests (Fitt 2004). With Bollgard II varieties now commercialised in the last two years and completely replacing Ingard varieties in the current (2004/05) cotton season, significantly greater reductions compared to conventional cotton have been achieved. Indeed during the 2004/05 season many Bollgard II cotton crops were not sprayed for pests. Anecdotal evidence also shows that researchers now find difficulty in establishing pest populations in field plots for experimental purposes because of the widespread high abundance of predators and parasitoids. As discussed later there have also been simultaneous reductions in pesticide use on conventional cotton over the last 5-6 years, although to a lesser extent.

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; Wilson *et al.* 2004). The most consistent "winner" from INGARD® technology has been the environment, with reduced pesticide loads.

Coincident with the adoption of *Bt* cotton varieties has been widespread adoption of an IPM approach, supported by a strong extension campaign (Christiansen and Dalton 2002). This is revealed by a significant change in grower attitudes in addition to significant reductions in pesticide use (expressed as active ingredient) on both conventional and transgenic crops (Fig. 1), achieving environmental gains and enhancing future sustainability of the industry. 385

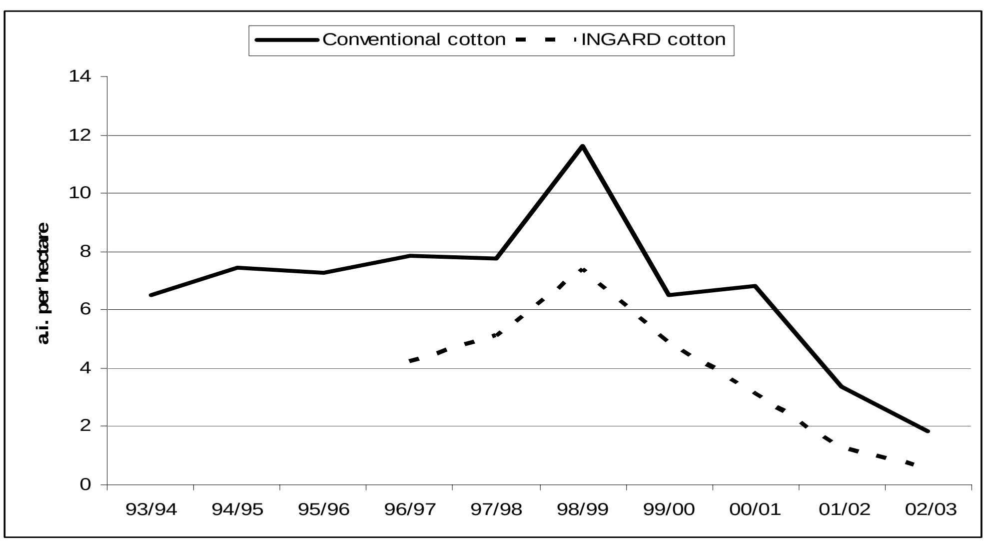

Figure 1. Change in Pesticide Use (active ingredient per hectare) on Australia cotton crops. Significant reductions have been achieved on both conventional and INGARD® cottons over the last 5 years. Source: Cotton Consultants Association Market Audit Survey 2003.

Care must be taken in interpretation of Figure 1 since insecticide use is linked to pest abundance and *Helicoverpa* spp. have been at relatively low densities during the prolonged drought in many cotton areas. Likewise several newer pesticides are active at much lower concentrations than the pesticides they replaced. It also seems unlikely that the reduction in pesticide use on conventional cotton results from the regional impact of *Bt* cotton on *Helicoverpa* abundance since over the period shown the area of *Bt* cotton was limited to a maximum of 30% of the cotton in a region. A number of factors are likely involved here, but one important possibility is that the coincident release of *Bt* cotton and the industry wide extension effort on IPM, allowed many growers to build confidence in the potential for IPM by managing their *Bt* cotton crops. They were able to become more comfortable with seeing a "living" crop, filled with numerous and mostly innocuous or beneficial insects, more attuned the critical importance of managing agronomic inputs, and more willing to work cooperatively with neighbours through the IPM and area wide groups. It will be instructive to view the ongoing management of conventional cotton and the performance and adoption of Bollgard II cotton varieties now that the 30% cap on *Bt* varieties has been lifted. In the 2004/05 season Bollgard II varieties accounted for 70% of the Australian cotton area.

CONCLUSIONS

IPM systems for future production of many broad acre and horticultural crops will, of necessity, be more complex than the pesticide based systems currently in place. In essence IPM reflects a sound interaction of science and pragmatism to achieve productive, viable and sustainable production systems.

As farming systems change the pest complex will also change. The fundamental role of IPM in reducing pest pressure and insecticide use means that it must continue to evolve. This is particularly so in high value, high input production systems such as cotton. For Australian cotton there seem little doubt that *Bt* cotton varieties have brought considerable gains in management of key pests but more importantly have facilitated a broader recognition and adoption of IPM principles, particularly the importance of natural biological control.

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