

## Ingard® cotton — its role in cotton IPM

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### Abstract

The introduction of transgenic cotton, producing the Cry IAc protein from Bt (Ingard® cotton), offers the possibility to substantially reduce the number of insecticide applications for *Helicoverpa* control, thereby reducing the impact of insecticides on beneficial insects and facilitating development of IPM in cotton. Impediments to IPM in Ingard® crops include (a) insecticide drift from sprayed cotton refuge crops grown in close proximity to Ingard® crops for resistance management purposes (b) the lack of selective options to control *Helicoverpa* and other pests when necessary and (c) variable efficacy of Ingard® which necessitates supplementary use of insecticides for *Helicoverpa* control and impact on beneficial insect populations. Nevertheless with reductions in synthetic insecticides of 50-60 percent Ingard® cotton provides a platform on which to build IPM systems. New components to compliment Ingard® may include classical HPR, selective insecticides, Envirofeast (food spray) and lucerne trap/refuge crops. In the future even more efficacious transgenic varieties will be available and allow greater interaction of this technology with other IPM tools.

### Introduction

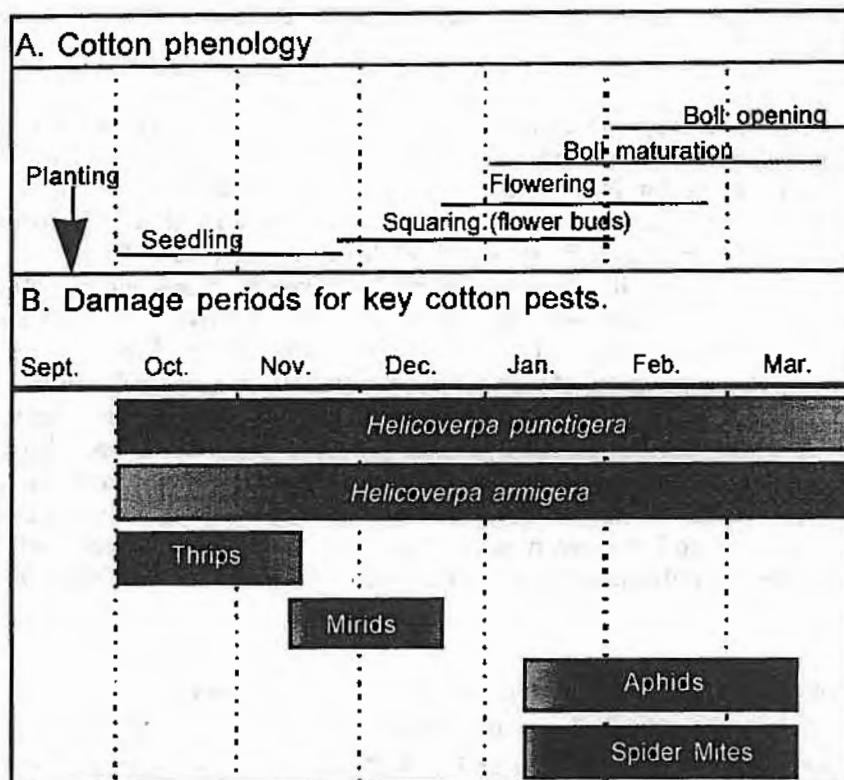
Cotton production in Australia is highly mechanised, with significant inputs of water, fertiliser and pesticides as well as agronomic expertise to grow crops with yields and fibre quality among the worlds highest (Hearn and Fitt 1991). Management of insect and mite pests relies mostly on use of synthetic insecticides and acaricides. This 'intervention' approach brings with it problems of cost, insecticide resistance, reductions in beneficial insect populations with associated secondary pest outbreaks (Wilson *et al.* 1996) and potential for environmental contamination. To reduce these problems pest management must become more environmentally responsible and sustainable, with decreased emphasis on insecticides as the primary means of management. The advent of Ingard® cotton offers the possibility to significantly reduce insecticide inputs for control of larvae of *Helicoverpa* spp., the primary pests of cotton in Australia (Fitt 1994). Here we review current efforts toward development of an integrated approach to pest management (IPM), the impediments to IPM, and the contribution that Ingard® technology can make to development of IPM.

### Pests of cotton

Cotton in Australia is attacked by a wide range of herbivorous insects and mites, although only six groups are recognised as key pests (Fig. 1). Primary pests are the larvae of two noctuid moths, *Helicoverpa punctigera* Wallengren and *H. armigera* Hübner. Larvae damage the apical meristem of young cotton (tipping out), causing delayed growth, and later also feed on the flower buds (squares) and young fruit (bolls), potentially reducing yield depending upon severity and timing of damage (Sadras 1995; Sadras 1996). Mixed populations of these two species are found in cotton season long, but *H. punctigera* predominates in the early season, up to flowering, while *H. armigera* predominates mid to late season (Fitt 1989). *H. punctigera* remains susceptible to the main insecticide classes, while *H. armigera* has evolved high levels of resistance to several classes including to the pyrethroids, endosulfan,

carbamates and has incipient resistance to the organophosphates (Forrester *et al.* 1993 and pers. comm.).

**Figure 1.** Cotton phenology (A) and damage periods (B) for key pests of cotton for the major cotton regions of northern NSW and southern Qld



Other key pests include thrips, mirids, aphids and spider mites. Thrips (*Thrips tabaci* Lindeman and *Frankliniella schultzei* Trybom) attack seedling cotton, causing leaf distortion and tipping out which may lead to delayed maturity and/or yield loss (Wilson and Bauer 1993; Sadras and Wilson 1998). Thrips are control using prophylactic seed treatments or in-furrow insecticides, both of which are relatively selective (Wilson unpub. data), or by foliar applications of broad spectrum organophosphates. Mirids (*Creontiades dilutus* (Stål) and *Campylomma liebknechti* (Girault)) are a pest at the start of square (flower bud) production, and can cause tipping out and shedding of squares (Forrester and Wilson 1988). Aphids are a mid to late season pest, causing little direct damage to cotton but with the potential to contaminate the lint of open cotton bolls with honey-dew, making it sticky and less marketable (Pyke and Brown 1996). Spider mites are a mid to late season pest which feed on cotton leaves, reducing photosynthesis and causing substantial reductions in yield and fibre quality (Wilson 1993; Sadras and Wilson, 1997). Mite populations colonise cotton at seedling emergence and generally do not develop unless predators are reduced by insecticide sprays for other pests (Wilson *et al.* 1998).

### Current IPM in cotton

IPM involves integration of a range of techniques to manage pests, with the emphasis shifted from reliance on broad-spectrum insecticides to a range of techniques including conservation or augmentation of beneficial insect populations, host plant resistance (HPR), use of selective insecticides, incorporation of the compensatory capacity of the plant and cultural techniques. Current cotton production uses a number of these techniques. Almost all

cotton is managed by independent crop consultants or farm agronomists and well developed sampling strategies and economic thresholds are available for most pest species. Commercial cotton varieties with the deeply lobed okra leaf shape show partial resistance to both *Helicoverpa* spp. and spider mites, resulting in modest savings of about one insecticide application per season compared with normal or broad leaf varieties (Thomson 1995, Wilson 1994). Cultural techniques include cultivation of diapausing *H. armigera* pupae in the soil through winter which destroys them and reduces the carry-over of pupae which generally exhibit high levels of resistance to key insecticide groups (Fitt and Daly 1990).

Research has shown the value of predators in reducing secondary pest outbreaks (i.e. spider mites, Wilson *et al.* 1996) and in management of *Helicoverpa* spp. (Mensah and Harris 1995; Mensah 1997). Current efforts to integrate predation into the production system include use of lucerne strips in cotton to act as a nursery for predators, especially important during drought conditions when natural sources are scarce, and use of 'attractant' food sprays to draw predators from lucerne and into cotton (Mensah 1997). Lucerne is also more attractive to mirids than is cotton and so acts as trap crop for this pest if properly managed (Mensah and Khan 1997).

An important aspect of cotton management is the ability of the crop to compensate for a degree of early season damage by pests such as thrips (Sadras and Wilson 1998), *Helicoverpa* spp. or mirids, often without a penalty in yield or maturity (Brook *et al.* 1992). Control of thrips, for example, is only warranted in cooler production areas where the shorter growing season limits the ability of the crop to compensate (Wilson unpub. data.) or in years of extremely high abundance. Similarly thresholds for *Helicoverpa* spp. reflect both expected natural mortality and the compensatory capacity of the crop (Sadras 1995; Gibb, 1995). Sampling and threshold recommendations have been integrated into a decision support package, entomoLOGIC (Deutscher and Plummer 1998)

One of the greatest impediments to development of IPM in cotton has been the lack of tools to control target pests without also disrupting beneficial populations. Cotton is typically sprayed 8 - 14 times for insect or mite control through the growing season, with 6 - 10 of these applications targeted at *Helicoverpa* spp. Of the insecticides currently registered for control of pests in cotton most (organophosphates, carbamates, pyrethroids, endosulfan) are broad-spectrum and have a significant negative effect on one or more predator species (Wilson *et al.* 1998). Use of broad-spectrum insecticides substantially reduces beneficial populations, often leading to outbreaks of secondary pests such as spider mites (Wilson *et al.* 1996) or aphids and loss of predatory activity on the primary pests (Wilson unpub. data). Currently the only registered options for selective control of *Helicoverpa* spp. are the formulations based on the bacteria *Bacillus thuringiensis* var *kurstaki* Berliner (Bt). Unfortunately a combination of relatively high price and variable efficacy means that Bt sprays are not widely used.

A significant impediment to the development of IPM in cotton is the high value of the crop (\$3000 - \$4000 / ha gross value) and the relatively low cost of most insecticides (\$10 - 70/ha), which means that a yield loss of only 1 or 2 percent is worth more than an insecticide in the short term. Resistance in *H. armigera* is now reducing the efficacy of most insecticides, leading to a spiral of increasing costs and more frequent use of mixtures of insecticides. This spiral highlights the point that pest management based on insecticides alone is unlikely to be sustainable.

### **Ingard® and IPM**

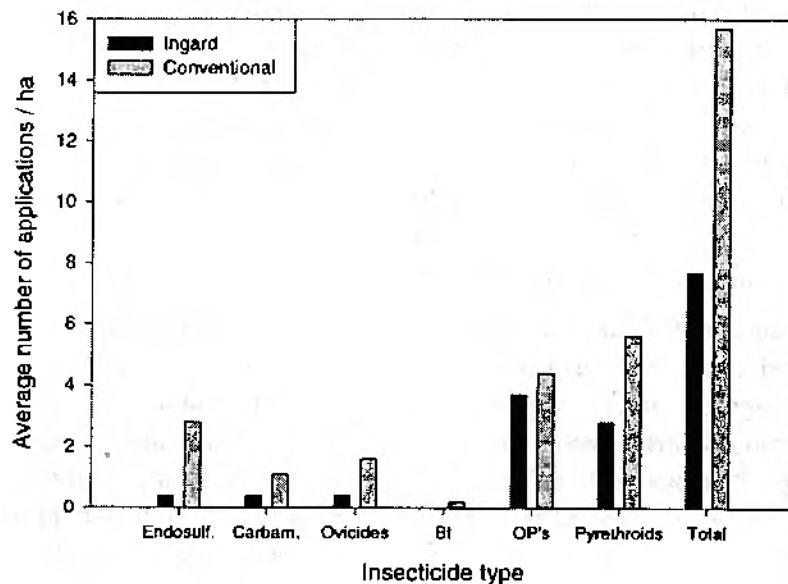
The introduction of transgenic cottons producing the Cry IAc protein from Bt (Ingard® cotton), offers the possibility to substantially reduce the number of insecticide applications for *Helicoverpa* control. Given that spider mites are an induced pest and that aphids may be selectively controlled with pirimicarb (see below) the need to use broad-spectrum insecticides should diminish significantly with this technology, with only mirids requiring foliar application of insecticides (Fig. 1). Research shows little effect of Ingard® cotton on non-target species, including non-lepidopterous pests, beneficial insects, and other canopy dwelling and soil dwelling species (Fitt *et al.* 1994; Wilson, Fitt and Forrester, unpublished data). Survival of beneficials should therefore be higher than in conventionally grown sprayed cotton, offering the possibility of developing true IPM in cotton.

Unfortunately the field performance of the initial releases of Ingard® cotton has not provided season long control of *Helicoverpa* (Fitt *et al.* 1998). Efficacy of Ingard® cotton crops against *Helicoverpa* 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). This decline in efficacy begins during flowering and supplementary *Helicoverpa* control has been necessary on Ingard® crops, particularly in the last third of the growing season. This continued requirement for some pesticide applications reduces the potential gains in conservation of beneficial insect populations.

A survey of 210 paired comparisons of Ingard® and conventionally managed cotton on commercial cotton farms in 1996-97 showed an overall reduction in insecticide applications for *Helicoverpa* of 52 percent on Ingard® cotton (9.7 on conventional cotton to 4.2 on Ingard® (Pyke and Slack-Smith 1997)). The insecticides applied to Ingard® crops were generally the more expensive and broad spectrum organophosphates, since they were applied during the later parts of the season, but also included carbamates and pyrethroids (Pyke and Slack-Smith 1997)  $\bar{N}$  all of which are destructive to beneficial populations (Fig. 2). The number of applications for other pests was not different. So while Ingard® cotton can be successfully grown with 50 - 60 percent less insecticide applications, the potential gains in conservation of beneficial insects has been largely restricted to the first half of the season.

The commercial release of transgenic cotton has required the development of strategies to delay the development of resistance in *Helicoverpa* to the Cry IAc protein (Forrester and Bird 1996). A key component of the strategy is the use of refuge crops to produce moths naive to the protein (Roush 1997). To be effective refuge crops must be within reasonably close proximity to Ingard® crops with a maximum separation of two km. Refuge options include unsprayed crops of cotton, corn or sorghum or conventionally sprayed cotton in differing proportions determined by their capacity to generate moths (Fitt and Tann 1996). To date sprayed cotton has proven to be by far the most popular refuge option. Drift of insecticides from sprayed cotton refuges to Ingard® crops, particularly following aerial application is likely to have a negative effect on survival of beneficial insects in the nearby Ingard® crops.

**Figure 2.** Number of applications per ha for each insecticide group to either Ingard® or conventional sprayed cotton across cotton regions in the 1996-97 cotton season. Data are a mean for 210 crops of either type, extracted from Pyke and Slack-Smith 1997.



In summary the key benefit for the development of IPM offered by Ingard® technology is a reduced need for season long control of a primary pest with broad spectrum insecticides. The main factors working against this benefit being realised are (1) the variable efficacy of Ingard® cotton and thus the need for supplementary insecticidal control of *Helicoverpa* spp. late and sometimes early in the season (2) the proximity of Ingard® crops to sprayed cotton and inherent risk of insecticide drift and (3) the lack of selective insecticides or non-chemical methods to control either *Helicoverpa* spp when necessary or other pests not controlled by Cry IAc.

#### Improving the contribution of transgenic technology to IPM

In its current form, the reduced pesticide requirement of Ingard® cotton through the early and mid season is valuable since this is the period when beneficial insects are naturally most abundant and will have their greatest impact against secondary pests such as spider mites and aphids.

One clear step toward improving the contribution of Ingard® to IPM is to have more efficacious varieties which could reduce or eliminate the need for supplementary *Helicoverpa* control. Varieties which express a second insecticidal protein (Cry IIA) are now well advanced. These genotypes have shown considerably enhanced efficacy and require much less supplementary insecticides in comparison with the current Ingard® varieties (Fitt unpub. data). In addition these 'stacked' varieties provide much greater stability of resistance management (Roush 1996). Other possibilities for insecticidal genes are also being researched (Llewellyn and Higgins 1998; Hanzlick and Gordon 1998).

With enhanced efficacy the prime value of Ingard® and future transgenics will be as the foundation for IPM and will be supported by other technologies. A new development in Australian cotton is the use of attractant food sprays and lucerne trap / nursery crop system (Mensah and Harris 1995; Mensah 1997) known as Envirofeast IPM technology. Initially developed as an IPM system for conventional cotton this system uses a predator to prey (pest) ratio as the basis for managing *Helicoverpa*, combined with strips of lucerne interplanted in cotton to serve as a trap crop for mirids, thus reducing the need for control.

The lucerne also serves as a nursery for beneficial insects (Mensah 1998). Because cotton fields are often large (50 - 150 ha) recolonisation of fields by beneficials may be slow after use of an insecticide if sources of predators are limited to farm perimeters (i.e. Duffield and Aebischer 1994). Use of nurseries may help recolonisation. A food attractant spray, with the trade name 'Envirofeast®' is used to attract predators from the lucerne nurseries into the cotton and retain them there, enabling a degree of manipulation of predator/prey ratios (Mensah 1997). Cotton treated with food spray is also less attractive for oviposition of *H. punctigera* than untreated cotton (Mensah 1996). Actively growing lucerne is substantially more attractive to mirids than cotton so the lucerne is partially cut on a regular cycle to ensure that some is always attractive (Mensah and Khan 1997).

Envirofeast technology and Ingard® are potentially complementary as the former reduces the need to control mirids and may also help to support the efficacy of Ingard® when this is declining, while Ingard® itself reduces disruption to predators by broad spectrum insecticides, particularly early season (Mensah *et al.* 1996). Predation may be of even greater significance in Ingard® crops as those larvae that do survive have markedly reduced growth rates (Fitt unpub. data) and are thus exposed to predation for a longer period at stages when they are smaller and less damaging. Furthermore, since many of the beneficial insects in cotton are generalists (Mensah and Harris 1994; Wilson *et al.* 1998), their increased abundance can minimise the risk of outbreaks of a range of secondary pests.

Another component for future IPM systems based on Ingard® cotton will be the range of new selective insecticides now becoming available. These include: fipronil, a phenyl-pyrazole being developed by Rhône-Poulenc for control of thrips and mirids (Hope 1995; Shaw *et al.* 1997); spinosad, a fermentation product of the actinomycete *Saccharopolyspora spinosa*, being developed for control of *Helicoverpa* by DowElanco (Murray and Lloyd 1997; Salgado *et al.* 1997); emamectin benzoate, a semi-synthetic avermectin insecticide derived from the fermentation product avermectin B<sub>1</sub> for control of *Helicoverpa* spp. and tetranychid mites being developed by Merck (Watkinson 1995; White *et al.* 1997). Selective control of mirids is important as they can only be controlled using broad-spectrum insecticides at present, which disrupt the beneficial complex early in the season (Fig. 1). Pirimicarb, a long established carbamate insecticide with selective activity against aphids has also recently (1997) been registered for aphid control in Australian cotton. This is not disruptive for a wide range of beneficial insects (British Crop Protection Council & the Royal Society of Chemistry 1994). Recent research on the non-target effects of these insecticides confirm that pirimicarb and spinosad are very selective, while fipronil and emamectin benzoate are more selective than a widely used standard, thiodicarb (Wilson, Lally and Holloway, unpublished data).

Highly selective insecticides based on Nuclear Polyhedrosis Virus (NPV) are also making a come-back in cotton. The recently developed 'Gemstar' formulation has performed reasonably well in recent evaluations in cotton (Teakle *et al.* 1996). Importantly, application of the Envirofeast food spray with Gemstar increases the reliability of infection of *Helicoverpa* with the virus (Mensah *et al.* 1996). Genetically modified viruses with enhanced speed of kill are also being developed (Richards and Christian 1998).

Combination of Ingard® with other HPR characters through classical plant breeding may also enhance the stability of IPM systems. In Australia the okra leaf character, where the normally broad bladed leaf is replaced by a deeply lobed leaf shape, has been incorporated into commercial cotton and provides a degree of resistance to both *Helicoverpa* spp. and mites (Thompson 1995, Wilson 1994) and okra leaf Ingard® varieties have also been developed. A range of antibiotic factors are also found in *Gossypium hirsutum* including terpenoid aldehydes, volatile terpenes, sesquiterpenoid quinones and condensed tannins.

Recent research has indicated that increased levels of terpenoids such as gossypol or the related 'heliocides' caused reduced growth rate of *Helicoverpa* spp. (Fitt *et al.* 1995).

Sachs *et al.* 1996 showed that *Heliothis virescens* larval survival was reduced more on genotypes combining Cry IAb and high terpenoid levels, than on genotypes with either trait alone, indicating that combining these two traits should increase plant resistance to *H. virescens* and prolong the durability of the Cry IAb protein. Reduced growth rates and/or altered behaviour, where larvae on transgenic plants tend to move between feeding sites more frequently, may increase exposure of larvae to other sources of biotic or abiotic mortality (see for instance Johnson *et al.* 1997). Combinations of allelochemicals and insecticidal proteins may not always be positive however. Navon *et al.* (1993) reported that addition of condensed tannin to the diet of *H. virescens* in the laboratory reduced feeding and the mortality caused by the Cry IAc protein, suggesting that use of genotypes with high tannin may not be compatible with use of the Cry IAc protein in transgenic plants.

Any IPM system must be founded on rigorous sampling for pests and application of experimentally derived thresholds for control. Transfer of *Helicoverpa* sampling strategies from conventional cotton to transgenic cotton may be appropriate but could be influenced by the behaviour of *Helicoverpa* larvae on transgenic varieties. More extensive movement of larvae on transgenic varieties may necessitate some changes to sampling strategies and this is the subject of current investigation (Abbott and Fitt 1998).

Application of appropriate thresholds for Ingard® is important, serving to balance the competing aims of (a) reducing resistance selection by controlling *Helicoverpa* on Ingard® when necessary and also preventing economic loss against (b) use of synthetic insecticides and disruption of beneficial populations, the very things this technology was developed to reduce. Thresholds on Ingard® must allow time for larvae to feed sufficiently to ingest a lethal dose of Cry IAc, yet still allow intervention while larvae are of a size where they can be controlled effectively with insecticides (generally less than 6 mm) and before economic loss occurs. Cotton genotypes vary in their ability to compensate for pest damage (Brook *et al.* 1992; Sadras and Fitt 1997). Selection for genotypes with higher compensatory ability, for instance through faster recovery (Sadras and Fitt 1997) allow use of higher thresholds with less risk, therefore reducing the need to intervene and control *Helicoverpa* with disruptive insecticides.

On a larger scale, recent moves toward area wide management strategies to reduce *Helicoverpa* abundance may further assist the development of IPM, both in conventional and Ingard cotton. In central Queensland cotton growers have trialled the use of strips of pigeon peas, which are more attractive to *H. armigera* than cotton, as an in-season trap crop. Regular inter-row cultivation kills *Helicoverpa* pupae in the soil. The use of winter planted trap crops such as chick-peas, to concentrate *H. armigera* populations by providing an attractive host for at a time when few other hosts are available, is also being trialled. These crops can then be ploughed in to control pupae and larvae, thus reducing winter carry-over populations (Sequeira and McCosker pers. comm).

### Conclusions

The advent of Ingard® cotton provides an opportunity to enhance the development of IPM systems for cotton. While variable efficacy and the lack of selective options for *Helicoverpa* control impose difficulties for IPM, the significant reduction in synthetic insecticides provides a sound platform on which to build IPM systems. New components may include classical HPR, selective insecticides, Envirofeast and lucerne trap/nursery crops. In the future more efficacious transgenic varieties may allow more of the potential for this technology to

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