Will current secondary pests become problems in the transgenic era?

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The introduction of Bt-transgenic cotton (Ingard® cotton) should lead to an overall reduction in insecticide use. Increased survival of predators should follow, which will help to reduce outbreaks of secondary pests, such as spider mites and aphids. Paradoxically, reduced pesticide use may increase problems with mirids and their control with broad-spectrum insecticides could reduce beneficial numbers and increase secondary pest outbreaks. Synthetic insecticides will remain a key component of cotton production for the foreseeable future and this also has implications for secondary pests in Bt-cotton. These and other possibilities for the transgenic era are discussed below.

What actually occurs will depend on many factors, such as the price of transgenic technology, cotton prices, rainfall, refuge requirements, insecticide resistance and so on. Crystal ball gazing is a risky business - in 10 years time my thoughts will appear either prophetic or pathetic. Nevertheless, I have tried to analyse the likely pest status of secondary pests in the transgenic era and to indicate some of the measures that could reduce or deal with potential problems now and in the future.

I have used the term "secondary pests" very broadly to cover all of the non-*Heliothis* pests, which is not strictly correct. I have assumed that Bt-cotton will control *Heliothis* spp., rough bollworm (*Earias huegeliana*), cotton looper (*Anomis flava*) and cotton leaf perforator (*Bucculatrix gossypii*) to sub-economic densities for most of the season (Fitt, pers. comm). Some lepidopterous (moth) pests have yet to be tested, including pink-spotted bollworm (*Pectinophora scutigera*), pink bollworm (*Pectinophora gossypiella*), tipworm (*Crocidosema plebeiana*), and cutworms (*Agrotis* spp.), although indications are that they will also be controlled.

What are the secondary pests?

The key secondary pests of cotton are mirids, mites, aphids, thrips and possibly the B-type whitefly in the future. The current pest status and important influencing factors for each of these pests are given below and their potential pest status in the future then discussed.

Thrips

Thrips (*Thrips tabaci* and *Frankliniella schultzei*) are seedling pests to some degree in most areas in most seasons. Abundance seems to be broadly correlated with availability of hosts through winter. Recent research has shown that thrips populations are rarely high enough to have an economically significantly effect on cotton yield or timing of maturity, even though plant growth (dry weight) can be severely reduced early in the season. Thrips are also important predators of mite eggs. Use of broad-spectrum organophosphate sprays to control thrips reduces beneficial numbers, allowing greater survival of mites and aphids and also possibly increasing survival of *Heliothis* eggs and larvae. Predation on thrips has received little attention. It is likely that thrips abundance on cotton is strongly linked to seasonal conditions and availability of protein sources, such as pollen or mite eggs, required for development and egg production.

Mirids

Green mirid (*Creontiades dilutus*) abundance fluctuates from season to season. When abundant they can cause significant damage to squares and to terminals. The ecology and biology of mirids is still poorly understood, though this is being addressed in a number of current projects (see paper by Simpson, Murray and Lloyd). Green mirids are also predators of *Heliothis* and mites under some circumstances. These comments can also be extended to the yellow mirid (*Campylomma* spp.). This species is probably even more significant as a predator of mite eggs and *Heliothis* by virtue of its often high abundance. Both types of mirids are currently controlled with broad-spectrum sprays which are highly toxic to beneficial insects. At present sprays applied for *Heliothis* control, such as endosulfan, are probably suppressing mirid populations to some extent through the early season. At present we are not aware of any significant predators or parasitoids of mirids in cotton.

Mites

Mites colonise seedling cotton in spring as they emigrate from senescent winter hosts. Potential mite outbreaks depend on the number of mites colonising the cotton crop and the survival of these colonisers. Mite survival is strongly influenced by predation, and use of broad-spectrum insecticides can reduce beneficial populations to the extent that severe, early mite outbreaks occur. Key predators of mites include ladybeetles, red & blue beetles, damsel bugs, big eyed bugs and thrips. In unsprayed cotton or cotton that is managed with non-disruptive pesticides, mites may be found but will rarely be a problem. 'Mite' years generally follow winters where there was enough rainfall to ensure abundant growth of winter hosts.

Aphids

Aphids enter cotton crops early in the season but outbreaks are generally not found until much later. Excessive use of broad-spectrum insecticides can induce aphid outbreaks via destruction of beneficial insects. However, this depends on the particular broad-spectrum insecticides used since some are also very effective aphicides (eg profenofos). Aphid control is still reliant on OP's and this is potentially disruptive of beneficial populations. In unsprayed cotton, beneficials, especially parasitoids, ladybeetles and syrphids can control aphid outbreaks but sometimes this takes too long and the aphids reach the point where insecticides are necessary. Beneficial insects attacking aphids include ladybeetles, syrphids (hover fly larvae), lacewings, some predatory bugs and parasitoids.

Whitefly

B-type *B. tabaci* (whitefly) may establish in cotton. Damage to cotton occurs through direct feeding, through geminivirus transmission and through fouling of plants with honeydew. B-type *B. tabaci* is resistant to a wide range of insecticides and develops resistance to new insecticides very quickly. Experience overseas suggests that this species needs an integrated approach to management (IPM), it develops resistance too easily and too quickly to be managed with insecticides alone. Predators of whitefly identified in Australia so far include ladybeetles, red & blue beetles, apple dimpling bugs and several parasitoids. CRDC and the CRC have recently funded a project by Dr Paul De Barro (CSIRO Entomology) to investigate the ecology, population dynamics and bio-control of whitefly. CRDC has also funded Dr Robin Gunning (NSW Agriculture) to investigate insecticide resistance and Bernie Franzman (DPIQ) to monitor population spread in Queensland.

Secondary pests in Bt-cotton?

Predation or parasitism is indicated as a key factor influencing population dynamics of key secondary pests such as mites, aphids and whitefly. Cotton hosts a wide range of beneficial insects - a comprehensive guide to key beneficial species can be found in "The cotton pest and beneficial guide" by Bruce Pyke and E. Brown. The role of beneficial insects in management of pests in cotton is discussed by David Murray and Robert Mensah elsewhere in this proceedings. Recent research by James Lytton-Hitchins (University of Sydney) has also shown the soil surface and litter also hosts a number of important predatory groups, including a diverse range of carabid beetles.

Most of the predatory groups are affected by synthetic insecticides to some extent, including soil surface predators, with the organophosphates, carbamates and pyrethroids probably the most detrimental. Bt-cotton will require 1 or 2 late season sprays specifically for *Heliothis* control, allowing much greater survival of beneficial populations for most of the growing season. If this were the *only* use of synthetic insecticides on Bt-cotton then mites, aphids and whitefly would often be kept at sub-economic levels by beneficials, although aphids may occasionally require spraying if they build up at boll opening. Predators could also eat *Heliothis* eggs and very small larvae in Bt-cotton crops, thereby helping to reduce selection for resistance. Bt-cotton offers the *potential* for reduced secondary pest problems and the development of a more IPM based production system for cotton. This should be even more so when Bt-cotton accounts for most of the cotton area and the reduction in spraying allows the wide-scale ecology of cotton regions to re-adjust.

A number of factors threaten the development of IPM in Bt-cotton, however, and could result in the *emergence or continuance* of the secondary pest problems we experience in conventional cotton at present. I am not trying to be a 'gloom merchant' but we should be aware of some of the potential changes to the cotton system and how we may react to them:

1. **The cost of Bt-cotton technology** will affect grower's and consultant's perceptions of risk. To some, Bt-cotton will represent protection from key pests and they will simply manage other pests as needed. Others may see the up-front cost of the technology as an investment that itself should be protected and may feel that any pest that reduces early season vigour or plant stand, or is perceived to do so, should be controlled, especially in the southern and cooler areas. Some such growers may use in-furrow insecticides to prevent seedling loss to wireworms (false and true) and damage from thrips. This will reduce early season predators of mites, aphids and other pests but may to some extent control these pests at the same time. As the efficacy of these products declines after about 4 to 6 weeks predators will begin to invade the crop and further help to control secondary pests and provide support for control of *Heliothis*. Other growers may use foliar OP sprays to control thrips, which would be very detrimental to beneficial populations. In both scenarios problems could arise if OP's or SP's are needed to control mirids. This would effectively eliminate predation for the entire early -mid season and ensure that secondary pest outbreaks remain a problem.

2. **Proximity to sprayed cotton** could strongly influence both pest and predator populations in transgenic cotton for two reasons. Firstly, secondary pests in sprayed cotton, induced by reductions in beneficials, could migrate into nearby Bt-cotton crops. Secondly, drift of broad-spectrum insecticides onto Bt-cotton crops could reduce beneficial numbers so that secondary pest outbreaks develop (pests tolerant insecticides better than predators do).

These scenarios are especially relevant when the area of Bt-cotton is small. The effect of insecticides applied to sprayed refuges and to conventionally managed cotton will have an over-riding effect on beneficial populations in cotton regions, for instance, beneficial populations generally crash each season when pyrethroids are used. Most growers and consultants favour the 'sprayed refuge' option, compared with the smaller but less profitable unsprayed refuge options. This perpetuates the status-quo - ensuring that beneficial populations are low and the likelihood of secondary pest outbreaks high.

However, patterns may change once Bt-cotton is more freely available. Experience with Bt-cotton may encourage growers to plant the maximum area possible, especially if they are getting higher yields, with a corresponding drop in the area of fully sprayed conventional cotton. The smaller unsprayed refuge option(s) (which can be sprayed to control pests other than *Heliothis* spp.) would then become economically attractive. This may allow 'area-wide' beneficial populations to survive better, with flow on effects in terms of secondary pests.

3. **Reduced spraying for *Heliothis* may allow greater survival of sucking pests**. Mirids are probably the key sucking bug pest. Their significance as a pest varies widely from season to season, possibly due seasonal conditions such as availability of hosts, though this is speculative. Reduced spraying will not make mirids a problem every year, but in years where they are abundant they will require specific control when previously *Heliothis* sprays would have partially suppressed their populations. Unfortunately, thresholds and sampling protocols for mirids are still unsatisfactory, so that most consultants will simply spray as soon as they find any mirids. Control of mirids requires use of broad spectrum chemicals such as OP's or pyrethroids, both of which are highly disruptive of beneficial population. Endosulfan is less disruptive of beneficials but most consultants have little confidence in the efficacy of endosulfan on mirids.

Other sucking bugs, rarely seen as pests in cotton could increase in pest status including a range of late season sucking bugs normally rarely seen in cotton, including cotton seed bugs, harlequin bugs, green vegetable bugs and cotton stainers. These pests can cause damage to bolls in the final stages of ripening, potentially reducing yield and fibre quality. Pyrethroids or OP's would be needed to control them and would be very disruptive of late season beneficial populations. The degree of problem would also be influenced by late season spraying for *Heliothis* on Bt-cotton. These sprays may also control the late season sucking pests - depending on their spectrum of activity.

4. **Whitefly could be a key pest mid- to late-season and destroy IPM** - given that this pest is difficult to control and develops resistance so quickly, it could destroy IPM, even in transgenic cotton. Beneficial insects will be crucial in controlling whitefly. Disruption of beneficials due to spraying or drift could lead to whitefly outbreaks, requiring control with broad-spectrum insecticides (if they can be controlled at all with available insecticides). If the whitefly were found to be vectoring a serious cotton disease, such as cotton leaf curl, the situation could be even worse as very low thresholds would probably be required to prevent disease infection. If this occurred early in the season, ie at flowering and followed earlier spraying for thrips, mirids etc then IPM would again be non-existent in Bt-cotton.

5. **Refuges could be hosts for whitefly and other pests or alternatively act as reservoirs for predators**. Refuge crops must be grown to produce susceptible *H. armigera*. The choice of refuge could be very important (see paper by Gary Fitt elsewhere in this proceedings). Refuges should be selected to ensure they do not generate problems such as mirids, mites, aphids or whitefly which may affect IPM in nearby transgenic cotton. Conversely, refuges may be helpful in providing a reservoir of predators and also as a trap crop for mirids (discussed below).

6. **Control of minor pests could disrupt beneficial populations**. Minor pests such as cluster caterpillar (*Spodoptera litura*) and lesser armyworm (*Spodoptera exigua*) are not effectively controlled by the Cry IAc protein. *Spodoptera exigua* is an infrequent pest (about 2 years in 10) but can defoliate pre-squaring plants and require control disruptive insecticides. Another lepidoptera, the tobacco looper (*Chrysodiexis argentifera*) is not controlled by Cry IAc. This species has not been found on cotton, though it will grow well on cotton tissue in the laboratory, so it is probably a species that is worth watching out for. In recent years isolated outbreaks of the mealy bugs (*Maconellicoccus hirsutus*) have been found in cotton at Emerald and St. George. This pest causes gross distortion of the plants

and significantly reduces yield of affected plants. It tends to be found in patches in fields where it can reach quite high densities. Although not a serious problem yet, this pest could be important in Bt-cotton in central Queensland.

7. **Other species of lepidoptera could develop resistance to Bt-cotton**. Our resistance management plan for transgenic cotton really aims to prevent resistance developing in *H. armigera* (see paper by Neil Forrester elsewhere in this proceedings). However, rough bollworm, tip worm and pink-spotted bollworm all have relatively few hosts other than cotton. Dilution of resistance could be low and selection for resistance high, especially as the area of Bt-cotton increases. If these pests develop resistance to Bt-cotton then we may again need to resort to insecticide use for their control.

SECONDARY PESTS IN CONVENTIONAL COTTON?

Secondary pest problems in conventional cotton will probably increase in the short term. A number of factors are contributing to almost total reliance on insecticides for pest management, with IPM having little chance of adoption. These factors include:

1. **Increased resistance** to pyrethroids, endosulfan and more recently to carbamates and OP's is causing a lack of confidence in our ability to control *H. armigera.* This results in increased use of the products that do work such as thiodicarb, bifenthrin and profenofos and further reduces beneficial insect populations. Ironically, the broad-spectrum nature of some of these compounds, such as Talstar, will in some circumstances control secondary pest outbreaks (especially mites and aphids) by virtue of frequency of spraying for *Heliothis* (if you can still afford it). Lack of access to 'soft' options, especially Bt and Bt mixes means that there are no soft early season options for the sprayed refuge option. This may mean that secondary pest outbreaks may be more of a risk in these crops.

2. **The high price of cotton in recent years has 'hidden' the impact of resistance** and the increased cost of insect control - the relative cost of insecticides has been low compared to even tiny gains in yield (ie at $700 bale, a 0.05 of a bale/ha increase in yield is worth $35/ha). The push to produce early crops, which has been exacerbated by water shortages, lead many consultants/growers reduce their tolerance for pests early season, prevent any real attempt at preserving beneficials. The recent push by researchers for reduced spraying of thrips and adoption of an early season threshold of 2 larvae/m and the general acceptance of this strategy by consultants and growers is a positive sign and

indicates a recognition of the severity of the resistance problem.

3. **The efficacy of predators and natural mortality is difficult to predict,** making their integration into IPM difficult. Predators and natural mortality have an pivotal role in IPM for conventional cotton. Unfortunately we are still unable to make accurate forecasts of probable mortality from given predator densities. Sampling of predators is also problematic as it increases sampling time and requires a detailed knowledge of cotton insects and spiders. Soil surface predators such as carabids are also potentially important, but rarely likely to be found using any current checking systems.

MANAGING SECONDARY PESTS IN BT- AND CONVENTIONAL COTTON

From the points raised above it would seem that we are doomed to have secondary pest problems in transgenic cotton, despite the fact that we really shouldn't. However there are a number of tactics that we could use to improve the chances of successful IPM in transgenic cotton and conventional cotton;

1. **Mirids may be managed using trap crops.** Robert Mensah has shown that mirids are more attracted to lucerne than cotton (see paper by Dave Murray and Robert Mensah). He has shown that lucerne strips in cotton (constituting about 2% of the total area) should be sufficient to reduce mirid problems in adjacent cotton. The lucerne strips must be managed so that one half of each strip is mown to induce the fresh growth that is attractive to mirids while the other half is left to provide a habitat and so on. Lucerne strips could be used in Bt-cotton to reduce the potential for mirid outbreaks and the need to use broad spectrum insecticides. The same principle applies to conventional cotton and to sprayed refuges. If lucerne proves to be a good refuge crop for *H. armigera* then it may become an approved refuge in the IMP for Bt-cotton.

2. **Be pragmatic with Bt-cotton** - accept the philosophy that with Bt-cotton you already have guaranteed protection against the number one pest. Control of other pests should be on an 'as necessary' basis. Use of early season insecticides to maintain an insect free crop will lead to expensive secondary pest outbreaks and undermine the value of the Bt-cotton technology - both in terms of reduced insecticide load on the environment and in terms of straight profitability. Because *Heliothis* is not being sprayed, there will be a lot more insect life in Bt-cotton than most of us are used to - this was evident at the Ingard field days held last season. However it was also evident that most of the insects were either

benign to cotton or were predators, relatively few were pests.

Part of this approach could be to control thrips using seed treatments or *if necessary* using in furrow insecticides. Ideally the seed treatment is sufficient to allow plants to establish successfully, and little further control is warranted. If thrips do exceed thresholds (6 per plant) an OP could be used but only if absolutely necessary. In areas with recurrent thrips problems, such as the Darling Downs or where the local environment is likely to produce lots of thrips in spring, ie where cotton is surrounded by wheat, then an in-furrow insecticide is probably an economic choice and more compatible with IPM than repeated OP sprays.

Adhere to current thresholds for control of early season pests, especially mirids, rather than use insurance sprays. This will give predators a chance to be effective in Bt-cotton. Although mirids are difficult to sample reliably, monitoring of fruit retention will assist in evaluating if they are actually having and impact on cotton growth. In some instances, endosulfan, which is moderately toxic to beneficials may be sufficient to suppress mirid populations, rather than using OP's or pyrethroids which are highly hazardous to beneficials. Bifenthrin (Talstar) controls mirids and *Heliothis* and because it is acaricidal may also reduce mite survival, however, it is highly disruptive of beneficials and although it may be an effective solution, it is not compatible with IPM.

3. **Locate Bt-cotton crops to reduce potential drift** from sprayed cotton, especially while the area of Bt-cotton is small. Maintain this policy as far as possible even as the Bt-cotton area increases.

4. **Use a threshold of 2 very small or small larvae/m early season** for conventional cotton. This will reduce the number of sprays (except perhaps in heavy pressure years), reduce selection pressure on insecticides, make better use of non-chemical causes of mortality for *Heliothis* and make better use of predators to help with non-*Heliothis* pests, especially aphids, mites and potentially whitefly.

5. **Spray on larvae rather than eggs**, unless the egg lay is clearly going to result in more than 2 larvae/m, in conventional crops. This appears contrary to the recommendations we have been giving in the past to 'time sprays for egg hatch'. However, it allows a chance for predation and natural mortality on eggs and to some extent on very small larvae. The

Heliothis model available in entomoLOGIC estimates survival rates of eggs and larvae up to 3 days ahead (see paper by Lance McKewen and colleagues).

6. **Select the least disruptive option** when spraying is required. This is usually Bt or a Bt plus half rate endosulfan or Bt plus ovicide rate thiodicarb, although the latter two are more disruptive. At present the Bt sprays seem to have very poor credibility throughout the industry. Early in the season complete control of all larvae is not necessary provided the spray has reduced them to less than the threshold.

7. **Avoid growing winter crops in a way that will generate problems**. For instance safflower is a potential source of both mirids and mites for nearby cotton crops. Spraying the safflower with a pyrethroid to control mirids may eliminate predators and generate massive mite populations which can migrate to nearby cotton.

THE FUTURE

As the area of Bt-cotton increases, and the area of sprayed conventional cotton decreases, area wide reductions in *Heliothis* abundance and increases in predator abundance may occur due to the over-riding effect of Bt-cotton. Additionally or maybe alternatively the registration of some selective *Heliothis* controls, such as the spinosads or viruses (see below) may overcome the resistance problem for the short term and ensure that conventionally managed cotton provides a viable and competitive alternative to Bt-cotton. This would also open the door for more integrated pest management in conventional cotton - thus giving the prospect of reducing secondary pest outbreaks in conventional cotton. There are always new technologies or developments of existing technologies 'just around the corner'. Some possibilities for the future are given below:

1. **Environfeast technology** (foodsprays, lucerne strips and Bt sprays) may reduce oviposition by *Heliothis* spp. on conventional cotton, increase predation and possibly enhance the efficacy of Bt or virus sprays. This technology may also be applicable in the sprayed refuges although the Bt sprays are not available there. This is a new technology which, like Bt-cotton, growers and consultants will take time to get used to and accept. However, it offers great promise for increased IPM in cotton, especially early in the season. As part of this technology key beneficial groups are sampled and counts used in the decision making process. Although the population dynamics and prey consumption rates of most predators are poorly understood, this approach at least attempts to integrate predation explicitly into pest management.

Predator abundance fluctuates between seasons for reasons not understood. My data suggests that in years where early season predator abundance is lower the 'predator complex' is more easily disrupted by insecticides and chances of secondary pest outbreaks (mites) occurring higher. Work by Robert Mensah suggests that predator populations can probably also be manipulated to some extent by growing unsprayed 'refuge' crops which allow populations to be maintained. Senescence of these crops or use of food sprays could encourage predators to move from the refuge into cotton. This could help to overcome seasons where natural predator populations from other sources are low. Current research by Paul Walker (CSIRO Entomology) and Bernie Franzman (DPIQ) is investigating the predator and pest complexes in a number of crops and in native vegetation. Information from these projects may enable us to incorporate other crops as refuges in a smart fashion to maximise benefits from beneficial insects while minimising creation of pest problems.

2. **A range of more selective insecticides** (synthetic and biological) should become available over the next 3-5 years. These should enable better survival of beneficials with reduced likelihood of secondary pest outbreaks. On the conventional insecticide front a number of new insecticides are being tested. The fipronils (Rhone-Poulenc) are being developed for mirid control and should be more selective than current options. Pirimicarb (ICI), a selective aphicide, has proven very effective in the field and should become available soon. The spinosads (DowElanco), are currently being tested in cotton and appear to have high efficacy on *Heliothis* spp. and relative selectivity. Should whitefly become a major problem there are a range of potentially selective compounds that could be developed. Several new biological options are also being developed including improved strains of the NPV virus and in the future genetically engineered viruses with improved efficacy and photostability.

3. **Genetic engineering** may eventually provide a solution to the mirid problem. Recent discoveries by CSIRO have shown that it is possible to genetically alter a plant to produce a virus that is infective when eaten by an insect. If a virus of mirids were found it might be possible to produce plants that can produce the virus. This raises many other issues of course and is a long way off at present. Another approach is to alter plants to make their nutrients less available to mirids - thereby reducing growth rates and possibly fecundity (see poster display by Gillian Colebatch). Again these are ideas at present, and certainly well off in the distance, but, some may make the transition from laboratory to field. In the

meantime we must develop and use the considerable technologies we have available to us now.

CONCLUSION

I believe that Bt-cotton, in conjunction with Environfeast technology, offers perhaps the greatest opportunity for true IPM that we have ever had. However we have the capacity to miss this opportunity completely, it won't just happen and it certainly won't if we simply stick with a 'pesticide driven' mindset. In the end we must achieve a balance between obtaining the highest yield possible, at the expense of our environment and this new technology, and the development of a more broadly based system where a number of technologies support each other, creating a high yielding but sustainable industry. This will determine how much of the potential benefit from Bt-cotton we actually gain.

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