

The changing climate for entomology

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Introduction

In the four years since the release of Bollgard II® and the relaxation of the cap limiting the area of Bt cotton (Fitt & Wilson 2005) there have been significant changes to pest management in cotton. Widespread adoption of Bollgard II® (>85% of the area; Pyke in press) and improved efficacy compared to Ingard® have resulted in an 85% reduction in insecticide use. Bollgard II® crops currently receive less than one spray per hectare for *Helicoverpa* spp, compared with 7 -11 in conventional crops (Figure 1). Here we review the current trends in pests and pest management in the current cotton system, highlight challenges, report on new tools to help manage pests and finally discuss the implication of climate change for IPM in cotton.

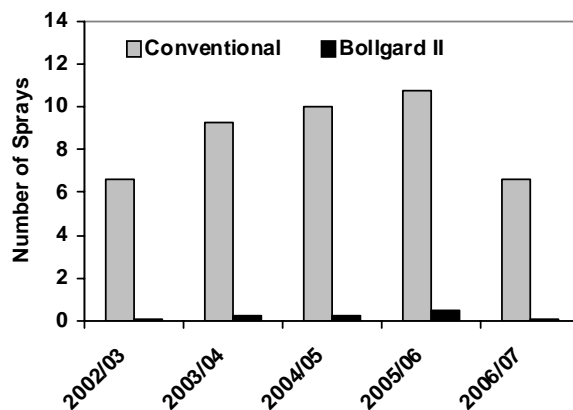


Figure 1. Number of sprays for *Helicoverpa* control on conventional or Bollgard II® cotton (contains the Cry1Ac and Cry 2Ab proteins). Source: Pyke (in press) and CCA Bollgard Comparison Report 2006/7.

Changes in pests and pesticide use

In conventional cotton sucking pests are coincidentally controlled by sprays applied against *Helicoverpa* spp. Reduced spraying against *Helicoverpa* spp in Bollgard II® allows sucking pests to survive and the number of sprays targeting sucking and other pests is higher in Bollgard II® (Figure 2). In conventional cotton *Helicoverpa* spp. account for over 90% of insecticide applications, whereas in Bollgard II® crops sucking pests are being targeted, especially green mirids (> 60%) and cotton aphids (>15%) (Figure 3, Pyke in press). The spectrum of insecticides is also different. In conventional cotton, insecticide use is biased toward *Helicoverpa* spp. control, (endosulfan, emamectin, amitraz, indoxacarb and pyrethroids; Figure 4). In Bollgard II® crops the bias is toward dimethoate and fipronil for mirid control (Figure 5).

The differences in insecticide choices lead to differences in secondary pest problems. In conventional crops endosulfan suppresses both aphids and mites (Wilson *et al.* 1998) and emamectin strongly suppresses mites. Hence, though conventional crops receive more insecticide applications, mites and aphids only occasionally require control. In Bollgard II® use of fipronil and dimethoate are detrimental to beneficial populations and increase the risk of mite outbreaks (Wilson *et al.* 2007). In response to this risk many Bollgard II® fields are prophylactically treated with abamectin (0.4 sprays per ha in Bollgard II® versus 0.1 sprays per ha in conventional).

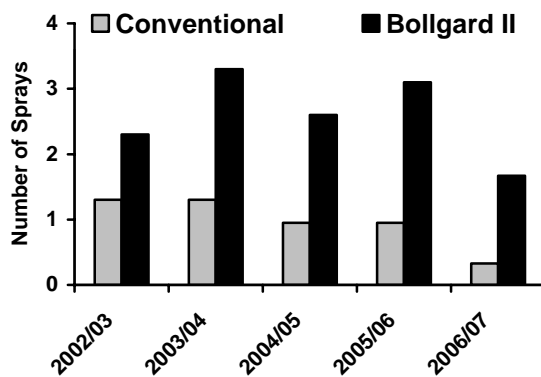


Figure 2. Number of sprays targeting sucking and other pests in conventional and Bollgard II® cotton. Source: Pyke in press and CCA Bollgard Comparison Report 2006/7.

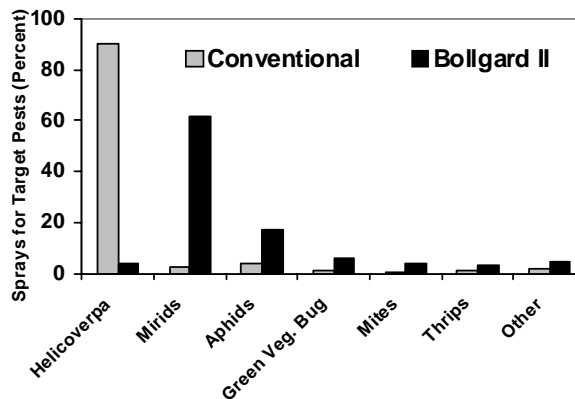


Figure 3. Percentage of total sprays applied for target pests in conventional and Bollgard II® cotton averaged for 2003/04 to 2005/06. Source: Pyke in press and CCA Bollgard Comparison Report 2006/7.

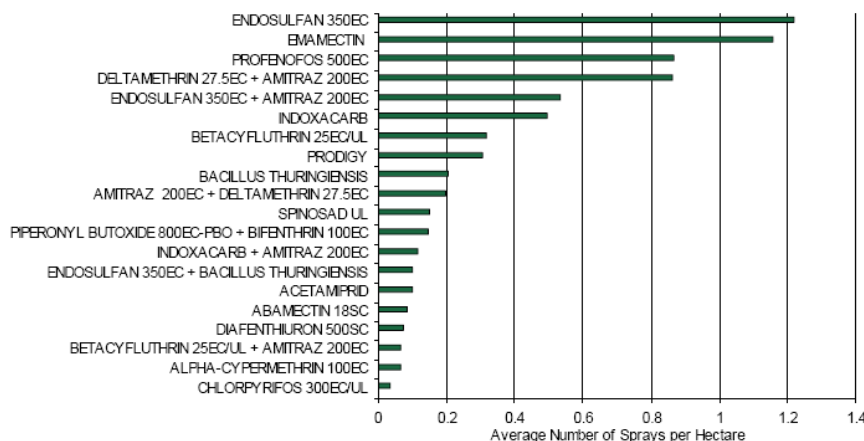


Figure 4. Insecticides and number of sprays used on conventional crops in 2006-07. Source: CCA Bollgard Comparison Report 2006/7.

Another change that has occurred since the advent of Bt cotton is a shift in the timing of *Helicoverpa armigera* populations (Figure 6). Long term sampling of *Helicoverpa* male moths using pheromone traps shows that since the introduction of Ingard® there has been a trend to much higher late season populations of *H. armigera*. In the last two seasons, however, this pattern has returned to low abundance late season, similar to the pre-Bt cotton era. We are uncertain about the

causes of this change (and there could be artifacts in the data, due to sampling methods), but it highlights that our system is in a very dynamic state.

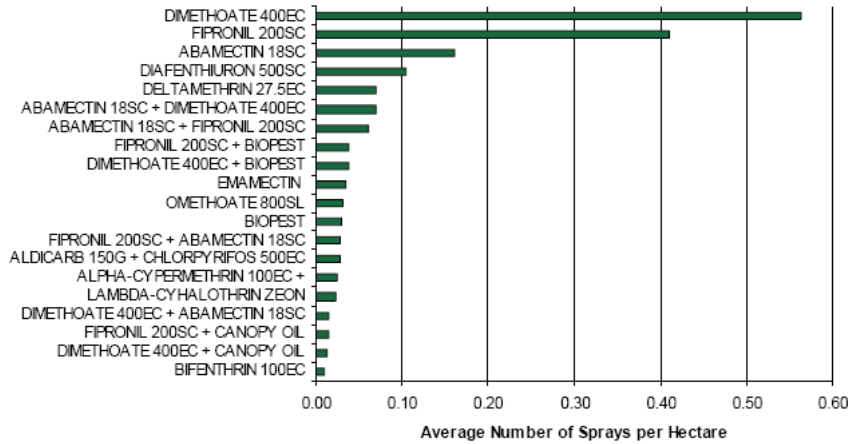


Figure 5. Insecticides and number of sprays used on Bollgard II® crops in 2006-07. Source: CCA Bollgard Comparison Report 2006/7.

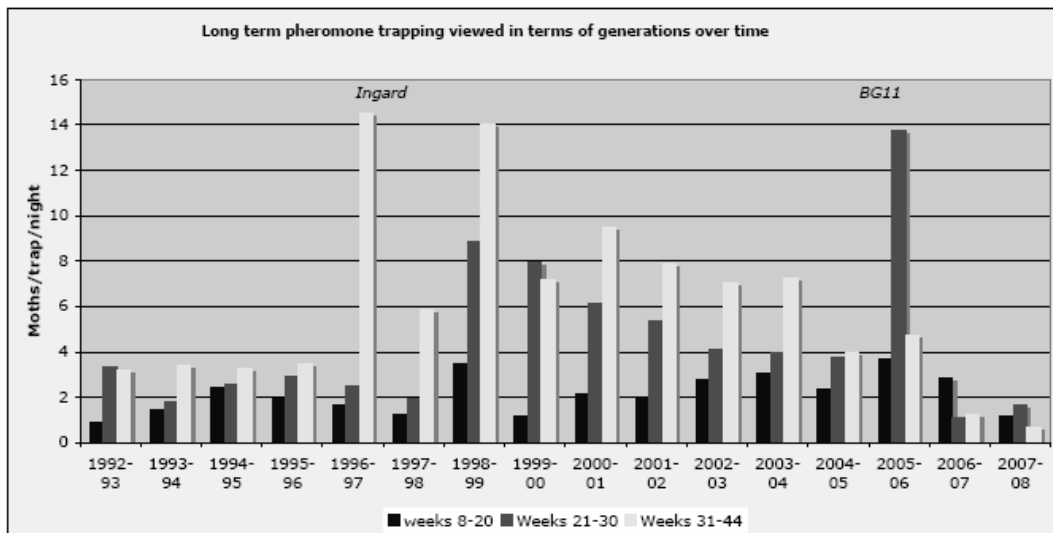


Figure 6. Abundance of *Helicoverpa armigera* in pheromone traps 1992 to 2008. Black bars represent early season, gray bars mid-season and white bars late season catches. Source: Colin Tann and Geoff Baker

The impact of drought

Bollgard II® became available during a period of drought and this has reduced the risk from secondary pests (e.g. mites, aphids, silver leaf whitefly, mirids) which require hosts through winter on which to feed and survive. Drought conditions limit the abundance and growth of these hosts, predominantly broad-leafed winter weeds which reduces the size of overwintering secondary pest populations which could move from the senescent weeds in spring onto seedling cotton crops. The propensity for outbreaks of mites in cotton is a function of the size of the overwintering population and hence the population on seedling cotton (Wilson 1994), and the effect of beneficials on these populations (Wilson *et al.* 1998). If there is a wet winter, populations moving to cotton will be higher and if beneficials are disrupted by insecticides there will be a high risk of outbreaks. Hence,

after a wet winter, sprays used on BGII may lead to significant problems with secondary pests, especially mites. This problem may be compounded if autumn and winter rains also generate high populations of *Helicoverpa* and other pests from inland regions (Fitt 1994).

Resistance in *Helicoverpa*, mites and aphids to insecticides

Since the advent of Bollgard II®, resistance to many insecticides has declined (see Figure 7 as an example). This is particularly significant for the more selective compounds used against *Helicoverpa* spp. such as spinosad, indoxacarb and emamectin which are very valuable in IPM. These products will be effective if they are required for occasional use. However, if Bollgard II® were to fail due to resistance, increased preferential use of these selective insecticides would quickly reselect for resistance. This threat would need to be managed through the Insecticide Resistance Management Strategy by restricting the window and number of applications and encouraging rotation with other insecticide groups such as the older SP, OP and carbamate groups. However the latter are disruptive to beneficials and increase the risk of secondary pest outbreaks.

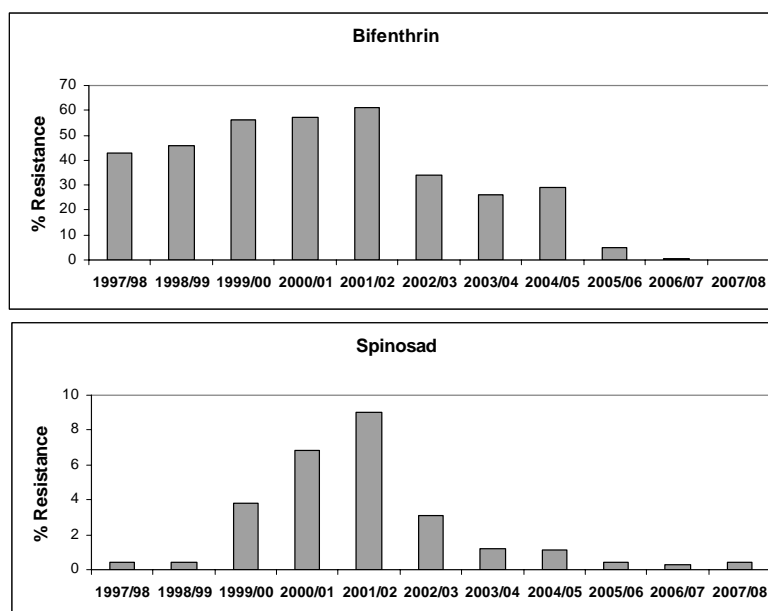


Figure 7. Changes in resistance levels of *Helicoverpa armigera* to bifenthrin and spinosad before and after the introduction and widespread uptake of Bollgard II® in 2003-04. Source: Louise Rossiter, NSW DPI.

Have we forgotten IPM?

The efficacy of Bollgard II® means that pest management in cotton is now far simpler. However, at the same time there is a risk that some of the hard won lessons from the past will be forgotten. This issue is highlighted by the management of mirids. Research has provided calibrations between sampling techniques (Threlfall *et al.* 2005), new thresholds (Khan *et al.* 2006a), and more selective control options (Khan *et al.* 2006b, Wilson *et al.* 2007). Unfortunately, recent surveys of growers and consultants by Dr Mary Whitehouse to define when mirids were sprayed, why and with what show that many insecticides are being applied at mirid densities well below the threshold and when crops have fruit retention levels well above the 60% retention threshold, below which mirid control would be considered necessary (Figure 8).

This is in part because the thresholds for beat sheet sampling are higher, as the beat sheet technique is more effective at sampling mirids (Threlfall *et al.* 2005; Wade *et al.* 2006), yet many growers and consultants are using the lower visual thresholds and hence spraying at low mirid densities. Spraying at below threshold levels increases costs, increases the risks of secondary pest outbreaks

but doesn't result in higher yields (Figure 9). These findings suggest we are in danger of getting on a mirid control treadmill, which will be disruptive to IPM in cotton.

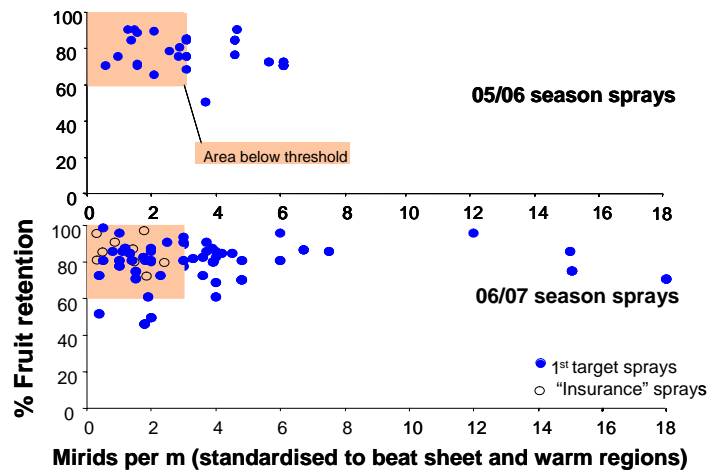


Figure 8. Application of insecticides for mirids in relation to the mirid density threshold (standardised to the beat sheet threshold for warmer regions) and fruit retention. The shaded area is the area where mirids are below threshold and retention is high and thus there should be few mirid sprays. Source: Mary Whitehouse.

Current management of mirids emphasises use of more selective insecticide options, such as reduced rates of insecticide combined with salt or a petroleum spray oil (Khan *et al.* 2006b, Wilson *et al.* 2007). However, it should be remembered that there are well researched alternatives to insecticides that can significantly help in management of mirids, but which have been adopted poorly. One of these is the use of lucerne strips to attract mirid populations. This occurs because mirids are more attracted to lucerne than cotton. The strips also harbour a range of other pests and plant feeding species that do not attack cotton (Mensah 2002b). Beneficial populations can build-up on these prey and move into and out of cotton, contributing to pest control (Mensah 2002a).

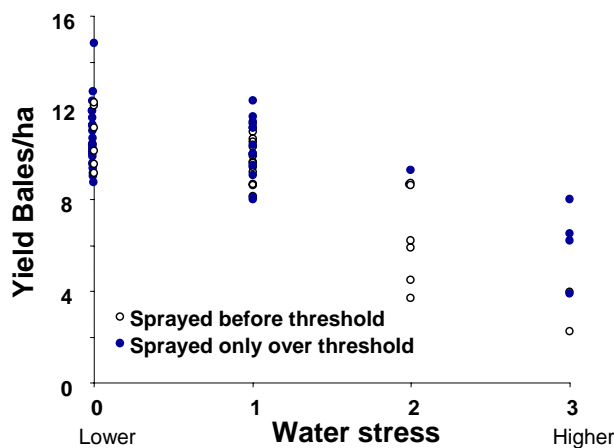


Figure 9. Yield of cotton in relation to water stress and whether the crop was sprayed when mirids were below or above threshold. This shows that spraying below threshold did not result in higher yield.

New tools for pest management

IPM is dynamic – unless new tools are developed to meet emerging challenges, the system will stagnate. The emerging challenges for which new tools are needed for cotton IPM include developing selective ways to control green mirids without flaring secondary pests such as mites,

and ways to manage emerging pests such as whiteflies and pests which occur only occasionally such as pale cotton stainers, which were abundant in some regions in the 2007/08 season.

New pesticides

The numbers of genuinely new active ingredients reaching the market have been declining for two or three decades. Increasing costs of researching new chemistry and meeting ever more demanding requirements for registration mean this trend will probably accelerate. Just as many observers believe we are near, or past, “peak oil”, we are probably past “peak chemistry”, too. Added to this is an unfortunate spin-off from the success of Bollgard II® - the Australian cotton market is now so small that many agrochemical companies do not regard it as a driver for R & D, or a prime target for new registrations. Nevertheless, there are a few potential new products which will become available over the next two seasons. They include:

- Rynaxypyr, to be marketed as Altacor® from Dupont, a chemical with a novel mode of action which produces quick paralysis of the insect mouthparts and is likely to be mostly used against lepidopteran pests such as *Helicoverpa* spp.
- Spirotetramat, to be marketed as Movento® from Bayer, a lipid biosynthesis inhibitor which is systemic and will be used against aphids and whiteflies.
- Flubendiamide and thiacloprid to be marketed as Lineout® also from Bayer, a mixture of two components, the first of which interferes with feeding by *Helicoverpa* using the same mode of action as rynaxypyr, while thiacloprid suppresses mirids and aphids.

Biopesticides

It is likely that fungal and viral biopesticides will become more important in cotton pest management in the future. This season has seen expanded use of *Helicoverpa* NPV (Virus®, Gemstar®), mainly on sorghum. The selectivity of these products means that we will see more of them in high pressure *Helicoverpa* seasons. While much of this may be in other crops in cotton farming systems, especially sorghum, the advent of ULV formulations may result in more use of NPV in cotton. We may also see the introduction of an NPV for *Spodoptera* spp. (armyworm), one of the few lepidopteran pests which is not well controlled by Bollgard II®. This virus is currently under development by Ag Biotech. Viruses are extremely selective, often infecting only one species. While this makes them the ultimate soft option, it also means they may be of limited value in multi-species infestations, and in some cases the size of the potential market may deter commercial interest. Fungi are also under development, in a project led by Robert Mensah with commercial partners Becker Underwood. Strains belonging to two genera, *Beauveria* and *Metarhizium*, are of particular interest. Fungi have the advantage of being able to infect through contact rather than requiring ingestion. The strains under investigation are targeted mainly at sucking pests especially mirids and aphids. They offer the potential for soft options for mirids, and are likely to become available in a few years.

Semiochemicals and plant extracts

Semiochemicals are chemicals which modify insect behaviour. They are usually of natural origin and include insect pheromones and plant volatiles. The moth attractant Magnet® has been under development by the Cotton CRC with commercial support from Ag Biotech for over a decade. It is likely to be registered and commercially available for the coming cotton season. Large scale trials in several cotton areas have confirmed the ability of this product to reduce moth populations on an area-wide basis. The ability of Magnet® to selectively reduce moth populations for some distance around the site of application offers several possibilities in area-wide management. These include:

- attract-and-kill in conventional cotton, where Magnet® reduces the egg pressure, allowing control tactics like natural enemies to work more effectively (Del Socorro & Gregg 2004).
- Moth busting, where Magnet® could be used to kill moths emerging from a Bollgard crop. This technique has been advocated as a replacement for pupae busting in certain regions eg central Queensland (Grundy *et al.* 2006)
- Selective attract-and-kill, where Magnet® might be applied to various parts of the landscape to kill more moths emerging from Bollgard II® cotton than from refuges, thus increasing the efficiency of refuges, or applied to Bollgard II® to relieve the pressure on nearby conventional cotton, as described by Mensah & Macpherson (2006)
- Attract-and-live, where Magnet® might be used without insecticide to concentrate egg laying on refuges, thereby increasing their efficiency, or on less vulnerable host crops.

Another semiochemical which may be of use in the future is the mirid pheromone recently identified by Lowor (2006). This pheromone, a sex attractant produced by females, is one of the very few pheromones from sucking pests which are known in the world. Unfortunately it is very volatile, which limits its use in the field. However, it is also cheap by the standards of pheromones. We have been investigating it as a monitoring tool for mirids this season. Results have been mixed – it predicts field populations well in some locations, but not in others. Further work is needed.

In the area of plant extracts we are likely to see a number of products become available in the next few years. One is from an African plant known as Plant X. Robert Mensah and his group, in collaboration with Growth Agriculture, are developing this as an oviposition deterrent and larvicide against *Helicoverpa* spp. (Singleton *et al.* 2004).

New transgenics

We will not deal with potential new transgenic technology in this paper, but we should note that Bollgard II® is not the end of the story. Monsanto has Bollgard III® in the pipeline, Syngenta has VIP-cot®, Bayer has Twinlink®, Dow has Widestrike®, and a local company, Hexima, has a proteinase inhibitor gene. However, it is unlikely that we will see commercial use of these products for some years, so the need to maintain susceptibility to Bollgard II® remains critical.

Bollgard II® and conventional - are we relying too much on GM?

We believe the time is right to initiate a discussion within the industry on whether we are relying too much on GM technology in the form of Bollgard II®. While the technology has undoubtedly brought many benefits to the industry, the question of sustainability remains. In the past, this has been largely addressed through discussions on the adequacy of various refuge options. There is however no clear boundary between what is and is not an adequate refuge. Put simply, the more refuge we have, the longer Bollgard II® will last. While it is entirely appropriate to set minimum standards in RMPs, we must remember that any refuge, structured or not, will add to the time it takes for resistance to appear. Figure 12 (Tabashnik *et al.* (2008) illustrates this dependence.

In the Ingard® era, when the proportion of Bt cotton was capped at 30% there was no issue with refuges. Growers almost exclusively used the sprayed conventional cotton option. The removal of the cap has allowed many growers to plant a high proportion of their farms to Bollgard II®, but also means they now require a specific refuge. This has sometimes resulted in poor quality refuges as many growers are reluctant to use limited water on economically unproductive refuges. Poor refuges are a problem as they may not produce enough moths to dilute any resistance that develops in Bollgard II® crops. Why not use a crop where the water used returns a profit, such as conventional cotton managed with IPM principles, including the new tools discussed above? This is one element in the case for a reduced reliance on Bollgard II®. In a mixed system (eg Barber 2008), Bollgard II® and conventional plantings are complementary as the reduced insecticide use

due to Bollgard II® helps to reduce selection pressure to insecticides used in conventional cotton, while conventional cotton provides a refuge to help reduce the risk of resistance in Bollgard II®. The availability of effective and selective chemistry to manage pests in conventional crops, and the development of semiochemicals such as Magnet® would assist this system. We have the capacity for ‘super IPM’ conventional cotton, to avoid a return to insecticide driven management of conventional cotton.

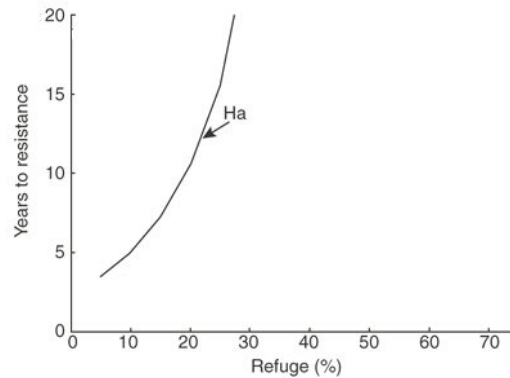


Figure 10. Years to the appearance of resistance in *H. armigera* plotted against the percentage of refuge, as modelled for a single resistance gene by Tabashnik *et al* 2008.

Potential disadvantages might be that insecticide use would rise, with renewed selection pressure for resistance to them. There may also be consequences for the public perception of cotton. Growers would need to evaluate the lifestyle benefits of Bollgard II® cotton, and a serious question is whether the industry now has enough skilled personnel at all levels to manage pests in conventional cotton. In regard to economics, data from the CCA Bollgard Comparison Report 2006/7 show some interesting trends (Figure 11). It is clearly possible, at least in low pressure years such as 2006-07, to grow conventional cotton with yields as high as Bollgard II®, and spend less money on total pest management costs. On the other hand, it is possible to spend more on conventional cotton, and it is possible to spend too much for poor yielding crops of either type. We believe that the key to this trade off is the pest pressure. In seasons where there is high *Helicoverpa* pressure it is logical to grow mostly Bollgard II®, whereas in seasons with low *Helicoverpa* pressure growers could plant a higher proportion of conventional cotton. If growers

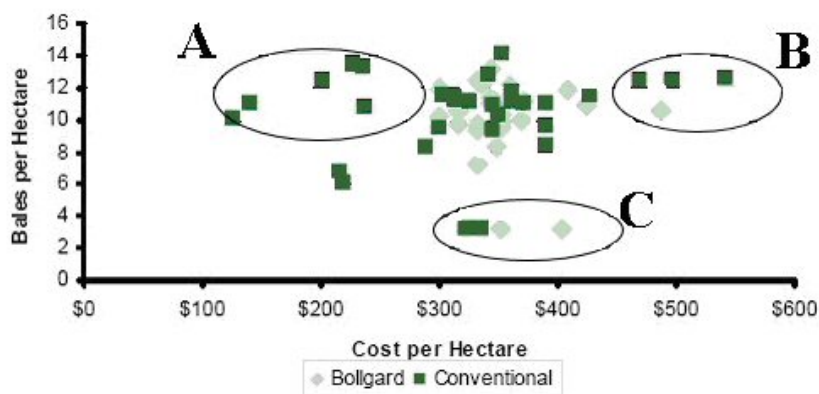


Figure 11. Yield and crop protection costs for Bollgard II® (including license costs) and conventional crops. Note that it is possible to grow high yielding conventional crops more economically than Bollgard II® (A), more expensively than Bollgard II® (B), and that it is possible to spend too much on pest control for a low yield in both types (C). Source: CCA Bollgard Comparison Report 2006/7.

knew in advance what type of season was coming up they could make informed decisions about the ratio of Bollgard II® to conventional cotton, saving money and reducing risk. Some capacity exists to forecast the abundance of *Helicoverpa* and other pests. A sophisticated system to forecast the

level of spring immigration from inland regions was developed over a decade ago (Hamilton *et al.* 1993), and shown by Gregg *et al.* (2001) to produce accurate forecasts for early spring. At a local scale, the HEAPS model for predicting *Helicoverpa* numbers and local movement (Dillon *et al.* 1996) could readily be adapted to make forecasts at a regional level.

Climate change – the wildcard

Temperature is a primary driver of insect life cycles. Higher temperatures mean shorter generation times and more rapid reproduction (shown for mirids in Figure 12). Some entomologists have jumped from this principle to the conclusion that insect pest problems will be worse with global warming. Certainly there is potential for more rapid population increases. There is also potential for pests to invade new areas, if winter temperatures rise enough to allow overwintering in previously marginal areas. However, it will not necessarily be all doom and gloom for pest management in cotton. First, heat can increase mortality in pest populations. Figure 12c shows that temperatures above about 35°C can be lethal for mirid eggs. Secondly, cotton growth is also temperature driven so the time when the crop is vulnerable to pests is reduced. Furthermore, the development of beneficial insects will also be faster – so they may keep up with pests. Similarly, rising CO₂ levels are associated with changes in the C:N ratio in plant tissue, and while pests may have to eat more to obtain their requirements of N, thus causing more damage, those same C:N changes may influence the survival of pests, either directly or indirectly. For example, in Texas aphids raised in elevated CO₂ were actually better food for a ladybeetle predator (Chen 2005).

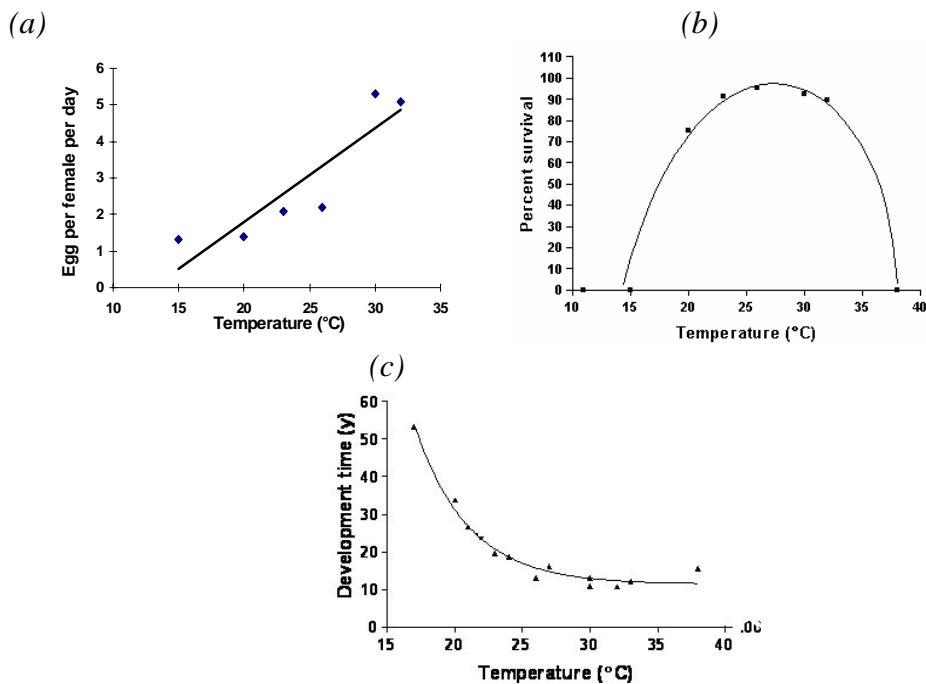


Figure 12. Effects of constant temperature on green mirids. (a) fecundity (eggs per female per day), (b) survival of eggs, (c) development time for nymphs. Data from Khan (1999).

Most of the gloomy predictions of increased pest abundance have been made for temperate and sub-arctic regions of the northern hemisphere, where temperature is limiting and rainfall is fairly predictable (eg Harrington *et al.* 2001). In the sub-tropical regions of the southern hemisphere where we grow cotton, the impacts of climate change might be very different. Temperatures in the cotton season are already close to optimum for development and survival of many pests, and further increases may push temperatures into the sub-optimum high range (e.g. Figure 12b). Further, most parts of Australia don't suffer the winter cold which limits the range of many northern hemisphere pests. The critical factor limiting populations of many insect pest populations

in Australia is not temperature but rain. Our rain is unpredictable in space and time, and so is the growth of many hosts (dryland crops, weeds and native plants). Native pests, like *Helicoverpa* and mirids, have evolved in this variable environment. How they are affected by climate change will depend on changes in the amount, distribution and intensity of rain, and presently these cannot be predicted accurately. For *H. punctigera*, for example, a temperature rise of say 2°C may not affect populations much, but changes in the autumn and winter rain in the inland may.

For some pests we can predict more confidently. Those with several generations within cotton crops are likely to become worse. Silverleaf whiteflies are an example. The tipping point for outbreaks seems to be about 8 generations in a season, which currently occurs in warm seasons in southern Queensland, but not further south. Climate change may push this zone into northern NSW and eventually even further south. However, getting more generations does not automatically mean higher pest numbers – it depends whether the population is increasing or decreasing during those generations. We need to remember that even pests like whiteflies, as well as aphids, mites and thrips, spend a number of generations on other hosts. Rainfall in autumn and winter will influence the abundance of hosts and the size of starting populations on cotton. Much depends on whether increasing temperatures are associated with more, or less, rain.

Of course climate change will affect much more than pests. We will see changes in farming systems. Growers may have more dryland crops and a wider variety of crops such as irrigated wheat, maize or soybeans. This could change the range of pre-season and within season hosts for both pest and beneficial insects. Farming systems of the future might make more use of minimum till methods and this could change the abundance of pests such as wireworms. The efficacy of beneficial insects may change if their life cycles become less well synchronised with those of their hosts or prey. There is, therefore, considerable uncertainty surrounding the way we will manage pests as the climate changes. These uncertainties add further weight to the need to develop forecasting systems for pests - if we can forecast what might happen in the short to medium term, we will be well on the way to predictions of what might happen further down the track.

Conclusion

Cotton pest management is probably as challenging now as it ever was. We have suggested that perhaps we are relying too much on Bollgard II® technology, and there is a case for more flexibility in the use of conventional cotton. Perhaps too we need to remind ourselves of the basic principles of IPM, especially in regard to the management of what we previously considered minor pests, such as mirids. The challenges of a new era in pest management, especially in a changing climatic environment, should not be underestimated. However, neither should the resourcefulness of the industry and those who practice and research its pest management. We have some potentially powerful new tools becoming available to us, including new pesticides, biotechnology, biopesticides, semiochemicals and forecasting techniques. If we continue to use Bt technology as a silver bullet, controlling mirids with sprays and not managing refuges adequately, we will have problems. The challenge is to forge a new IPM system for cotton. We have an array of tools, new and old, including lucerne strips, pupae busting, management of weeds and volunteers, new insecticides, new biopesticides, new semiochemicals and transgenics. We have the foundations of a strong IPM system that can ensure the longevity of transgenics and the viability of conventional cotton.

Acknowledgments

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References

- Barber, J. (2008) Larval survival in Bollgard cotton. *Australian Cottongrower* 29(2): 10-13
- Chen, FG, & Parajulee MN. (2005) Impact of elevated CO₂ on tri-trophic interaction of *Gossypium hirsutum*, *Aphis gossypii* and *Leis axyridis*. *Environ. Entomol.* 34, 37-46.
- Del Socorro AP & Gregg PC (2004) Attract-and-kill for helioverpa moths: a new tool for area-wide management? *Proceedings of the 12th Australian Cotton Conference, Broadbeach, August 2006*. Australian Cotton Growers Research Association, Narrabri, New South Wales, Australia. pp. 721-728
- Dillon, ML, Fitt GP, Hamilton JG and Rochester WA. (1996). A simulation model of wind-driven dispersal of *Helicoverpa* moths. *Ecological Modelling* 86: 145-150.
- Fitt, G & Wilson, L. (2005). Integration of BT Cotton in IPM systems: An Australian Perspective In: *Second International Symposium on Biological Control of Arthropods* (ed M Hoddle) 382-389. USDA Forest Service Publication FHTET-2005-08, Davos, Switzerland - September 12-16, 2005.
- Fitt, GP. (1994) Cotton pest management : Part 3 - an Australian perspective. *Ann. Rev Entomol* 39, 543-562.
- Gregg, PC, Del Socorro AP & Rochester WA. (2001). Field test of a model of migration of moths (Lepidoptera: Noctuidae) in inland Australia. *Aust. J. Entomol.* 40: 249-256.
- Grundy, P, Short.S., Hawes, A, Zalucki, M. & Gregg P. (2006) Moth busting for Bt resistance management *Proceedings of the 13th Australian Cotton Conference*, Broadbeach, Queensland, Australia. pp. 525-531.
- Hamilton, JG, Rochester WA & Gregg. PC (1994). Predicting long-distance migration of insect pests in eastern Australia. San Diego, American Meteorological Society. Boston.
- Harrington R, Fleming RA & Woiwood IP (2001) Climate change impacts on insect management and conservation in temperate regions: can they be predicted? *Agric. For. Entomol.* 3, 233-240.
- Khan, M. (1999) *Aspects of the biology, ecology and management of the green mirid, Creontiades dilutus Stal, in Australia*. PhD thesis, University of New England, Armidale
- Khan, M, Quade, A & Murray, D. (2006a). Mirid damage assessment in Bollgard II - critical damage stage and action thresholds at different stages in irrigated and raingrown cotton. *Proceedings of the 13th Australian Cotton Conference*, Broadbeach, Queensland, Australia. pp. 537-542.
- Khan, M, Quade, A & Murray, D. (2006b). Mirid management - effect of salt rate when mixed with reduced rates of chemical. *Proceedings of the 13th Australian Cotton Conference, Broadbeach, August 2006*. Australian Cotton Growers Research Association, Narrabri, New South Wales, Australia. pp. 537-542.
- Mensah, RK. (2002a) Development of an integrated pest management programme for cotton. Part 1: Establishing and utilizing natural enemies. *Int. J. Pest Mgmt.* 48, 87-94.
- Mensah, RK. (2002b) Development of an integrated pest management programme for cotton. Part 2: Integration of a lucerne/cotton interplant system, food supplement sprays with biological and synthetic insecticides. *Int. J. Pest Mgmt.* 48, 95-105.
- Mensah RK & Macpherson I (2006) Attracting and killing moths on Bollgard II® cotton crops: a new strategy for managing *Helicoverpa* spp. on conventional cotton. *Proceedings of the 13th Australian Cotton Conference*, Broadbeach, Queensland, Australia. pp. 555-565.
- Lowor, S. (2006) *Isolation and identification of pheromones for some occasional pests of cotton in Australia*. PhD Thesis, University of New England.
- Pyke B (in press) The Impact of High Adoption of Bollgard®II cotton on pest management in Australia. *Proceedings of the Fourth World Cotton Research Conference. Lubbock, Texas. Sept 10-14 2007*.
- Singleton A, Wang E, Moore C & Mensah R. (2004) Managing *Helicoverpa* spp. on cotton with semiochemicals. *Proceedings of the 12th Australian Cotton Conference, Broadbeach, August 2006*. Australian Cotton Growers Research Association, Narrabri, New South Wales, Australia. pp. 711-719
- Tabashnik BE, Gassmann AJ, Crowder DW & Carriere, Y (2008) Insect resistance to Bt crops: evidence versus theory. *Nature Biotechnology* 26 199-203
- Threlfall, C, Deutscher, S, Wilson, L & Staines, T. (2005) Sweeping up mirids gives a net improvement. *Australian Cottongrower* 26, 55-57.
- Wade, M, Scholz, B, Lloyd, R, Cleary, A, Franzmann, B & Zalucki, M. (2006) Temporal variation in arthropod sampling effectiveness: the case for using the beat sheet method in cotton. *Ent. Exp. Appl.* 120, 139-153.
- Wilson, L, Mensah, R, Khan, M, Dillon, M, Wade, M, Scholz, B, Murray, D, Lloyd, R, Heimoana, V & Holloway, J. (2007). Impact of insecticides and miticides on beneficials in Australian cotton. In: *Cotton Pest Management Guide 2007-08* (ed T. Farrell). Cotton CRC and NSW DPI, Narrabri. pp 29-30.
- Wilson, LJ. (1994) Habitats of two-spotted spider mites (Acari: Tetranychidae) during winter and spring in a cotton-producing region of Australia. *Environ. Entomol.* 24, 332-340.
- Wilson, LJ, Bauer, LR & Lally, DA. (1998) Effect of early season insecticide use on predators and outbreaks of spider mites (Acari: Tetranychidae) in cotton. *Bull. Entomol. Res.* 88, 477-488.