IPM and Resistance Management for the Future

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In the last 5 years there has been an dramatic and exciting shift in pest management approaches in Australian cotton, away from reliance on broad-spectrum insecticides as the main line of defence against pests, toward a more integrated pest management (IPM) based approach. This change has had a number of drivers, some positive, such as the advent of Ingard® varieties which have reduce insecticide inputs by 40-60% making IPM more achievable, some negative, such as increased costs of pest control ($400 to $1000/ha), increased insecticide resistance and environmental concerns due to off-target drift (Wilson, 2000).

IPM was born in the heady days following the development and release of the early synthetic insecticides in response to just these types of problems. Insecticides dramatically increased the productivity of many agricultural and horticultural crops. However, problems with insecticide resistance, primary pest resurgence and secondary pest outbreaks due to destruction of beneficial insects, human health and environmental pollution soon become apparent (Stern et al., 1959). The aim of IPM systems therefore is to minimize the use of synthetic insecticides, to reduce the problems above, yet maintain profitability.

Nevertheless, many IPM systems throughout the world still rely on insecticides to some degree, in particular more target-specific insecticides that help conserve beneficial populations. Management of insecticide resistance therefore remains a constant challenge. In this paper I review briefly what IPM is and what it has to offer in terms of reducing insecticide use, then discuss how IPM interacts with insecticide resistance management (IRM) and finally consider how both IPM and IRM might develop in the future and the interactions with new transgenic varieties.

IPM in Australian cotton

The uptake of IPM has been supported by the development and release in 1999 of the 'The Integrated Pest Management Guidelines of Australian Cotton' and associated supporting documents (Mensah and Wilson, 1999). These guidelines were derived from both research and on-farm experience of growers and consultants and described a workable IPM system for cotton. Maintaining profitability is stated up-front as a clear aim of the IPM approach. They emphasise a systems approach to IPM, especially focusing on 'off-season' activities that can influence the success of IPM through the growing season. The aim is to develop a year round system that supports IPM at each stage, not just from planting to harvest.

The guidelines emphasis many issues traditionally associated with IPM such as effective crop scouting, use of realistic pest thresholds, making use of the plants capacity to compensate for early damage, use of selective insecticides to conserve beneficial insects. Elements not normally associated with IPM are also emphasised, such as optimising fertilizer application and the timing of the last irrigation to avoid crop delay, which increases pest control costs, matching the cotton variety to the region, management of over winter-hosts of pests, the use of trap crops to attract Helicoverpa where they can be destroyed using viral insecticides (Gemstar) or mechanically by cultivation.

The initiation by growers and consultants of Area Wide Management Groups in particular has provided the peer support and communication necessary to give growers the confidence to set and achieve goals relating to IPM. For pests that are more mobile and particularly those with a broad host range such as *Helicoverpa armigera*, an area wide approach can help IPM by managing the pest abundance in a co-ordinated manner across an area (several farms, region, Figure 1). In this way growers and consultants can address the pest problem more effectively than if each grower did their own thing. Examples of AWM aims include delaying the use of 'hard' chemistry to conserve beneficial populations, the co-ordinated planting of trap crops and sharing of information through regular meetings. These groups have been well supported by extension and research staff keen to see progress continue. The pioneering work of the Area Wide Groups in the Darling Downs (Ferguson and Miles, 2002) is a good example of this participatory research approach outlined by (Dent, 1995).

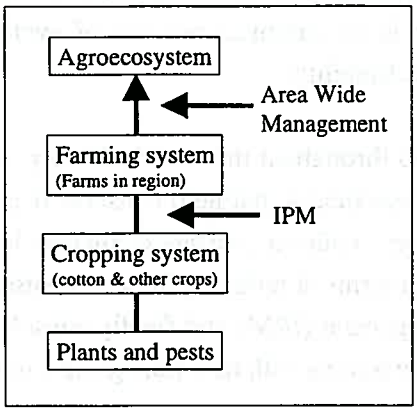

Figure 1. Conceptual link between IPM and AWM.

The benefits of AWM groups are increased if their approach has a significant effect on later pest problems in the group. Recent research looking at the movement of *H. armigera* between regions, using genetic markers known as micro-satellites, has begun to address this issue. Early analysis of results from the McIntyre, the Darling Downs and Emerald suggest that *H. armigera* may be more localised than previously thought (Graham, 2002). The approaches taken by growers in a region will therefore have a significant effect on local pest abundance and local resistance selection, helping IPM and IRM. A caution though is that this concept should not be taken too far, as the history of resistance development in *Helicoverpa armigera* indicates that there is some movement between regions, so there is still the threat of resistance genes coming in from other regions.

Despite the prospect for future sustainable pest management, the enthusiasm for IPM will be short-lived if the economics do not support this approach.(Hoque et al., 2000) addressed this issue by analysing the profitability of soft insecticide approaches, one of the key components of IPM, compared with traditional hard insecticide approaches for the Bates Scheme Area Wide Management Group, Boggabilla. They found a significant trend toward higher gross margins in those fields with managed with softer insecticides compared with harder insecticides for conventional and Ingard cotton (Figure 1). The cost differential has been attributed to the effect on pests of higher beneficial populations in fields with a lower BDI. Recent comparisons of beneficials numbers in fields managed with softer and harder approaches indeed shown that those with softer sprays have higher beneficial populations (Mansfield, 2002). Other studies by Chris Wicks (Wicks, this proceedings), and Australian Cotton CRC Industry Development Officers such as James Quinn in the Gwydir Valley and Mark Hickman in the Upper Namoi have confirmed these findings. IPM is clearly profitable, dispelling the old myths that IPM was risky and led to low yields.

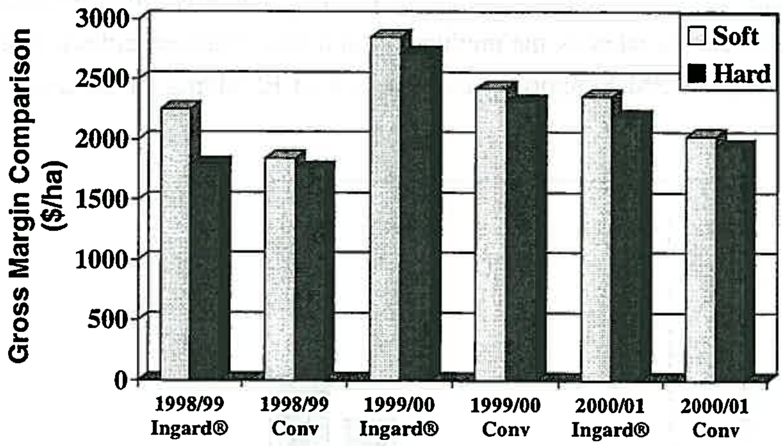

Figure 1. Gross margins for fields managed with soft insecticides verus hard insecticides for Ingard and conventional cotton varieties for the Bates Scheme Area Wide management Group, Boggabilla.

IRM and IPM

IPM seeks to reduce insecticide use, IRM seeks to manage resistance. The two are inextricably linked. The viability of IPM is linked to the maintenance of effective, selective options for insect control when needed. This is the aim of our IRM strategies, both for conventional insecticides and for transgenics. The viability of the IRM is linked to the effectiveness of our IPM strategies at reducing insecticide use and resistance selection. IPM systems allow for pest damage and density so that pests are only controlled when needed and with the most selective effective option thereby avoiding economic loss and conserving beneficials. These then eat eggs and young larvae, reducing the chances of needing to spray in the first place, thereby reducing selection for pest resistance.

The current IRM for insecticides and miticides uses a number of scientifically sound approaches to attempt to slow or reverse the development of resistance. This includes restrictions in time (windows), restrictions in selection events (number of sprays for most groups), rotation of insecticide groups (e.g. no more than two consecutive sprays from the same group), the use of synergists to overcome metabolic resistance to pyrethroids (e.g. PBO), the use of sampling and threshold to determine when pests require control, and the cultivation of overwintering *H. armigera* pupae. As new insecticide groups become available they are incorporated into the strategy, taking into account their likely use pattern. This process is adaptive in that the success of the strategy is measure by monitoring resistance each year. Changes in the use intensity or resistance status of insecticides are reviewed by a panel of technical experts, with input from commercial and industry groups, and changes made to mange resistance, usually pro-actively, but in some cases unfortunately re-actively.

IPM in Australian cotton is likely to continue to depend to on the use of foliar applied insecticides to control pests. Emphasis in the selection of insecticides is increasingly toward those that are more 'target-specific' or selective. These have less disruptive effects on beneficial insects and so assist in conserving this natural source of mortality, not just for the target pest (e. g. *Helicoverpa*) but for other pests as well such as mites, aphids and more recently whitefly. Identification of more selective insecticides has been assisted by the publication of a table of insecticides and their effects on key beneficial groups (see IPM Supporting Document 1 in ENTOpak or on the Cotton CRC website).

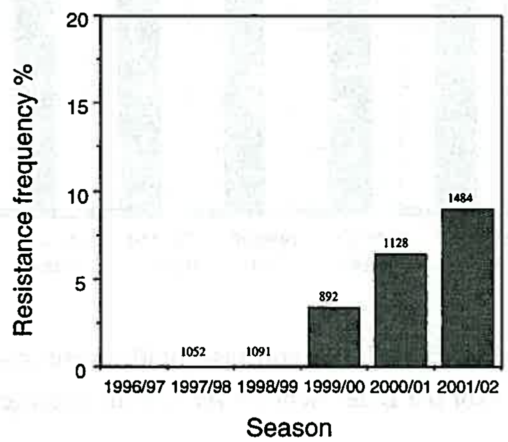

Figure 3. Resistance of Helicoverpa armigera to spinosad (Tracer).

Over the last few years we have seen the progressive introduction of a number of new insecticide groups with increase selectivity, offering greater flexibility in managing pests. However, the popularity of the more selective insecticides places them at risk in terms of resistance. Furthermore, the nature of insecticide discovery, development and registration has meant that new selective insecticides have become available sequentially. This has meant that some new insecticides have each had a period of 'newness' and have already been over-used to the point that resistance has already been detected. Rising resist to spinosad (Tracer) is an unfortunate example (Figure 3, see also (Gunning, 2002)).

The analyses of (Hoque et al., 2000) focused on the comparison of 'soft vs hard' approaches because the data was available for analysis. However, it would be wrong to assume that growers in the Bates Scheme have achieved their success simply by using soft sprays, they have embraced a wide range of IPM tactics such as tolerating early damage, using IPM thresholds, use of predator/pest rations, use of food-sprays, use of trap crops, extensive and frequent scouting and pupae busting which has lead to a robust system. The use of selective insecticides as a single IPM strategy is unlikely to lead to a sustainable IPM system because issues of resistance and environmental pollution are not dealt with effectively if selective sprays are simply used in place of broad-spectrum sprays.

The IRM has evolved over the years, and recently in particular a growing emphasis has been place on supporting IPM. In the past many supporters of IPM viewed the IRM as an impediment. This was because the emphasis in the strategy was focused on resistance management, with little emphasis on IPM. In the absence of a clearly defined IPM system, this mean that the use periods for insecticides in the IRM actually undermines IPM, for instance the availability of the pyrethroids and carbamates, both highly detrimental to beneficial insects, in stage 1. In recent years however the use periods for these less IPM compatible insecticides have been pushed later in the season, so that they will not be used early in the season and disrupt IPM.

As new insecticides become available it is essential that we have independent information on both their efficacy and non-target effects so that their positioning in the IRM can be matched with their IPM fit. The particular characteristics of insecticides are important, for instance spinosad (Tracer) has a low impact on predatory beetles and bugs, but is very disruptive of micro-hymenoptera (including Trichogramma), ants and thrips (which eat mite eggs).

Resistance and Ingard®

Many of the issue above apply equally to the transgenics (Ingard and Bollgard II). The transgenics are essentially a season long prophylactic toxin based approach. That is they rely on killing pests with a toxin that is (ideally) present at sufficient levels to control the pest season long. As such resistance is a major threat (Bird et al., 2003). However, the high target specificity of the Cry proteins in Ingard, and the low impact on non-target fauna mean that the transgenics have a very good fit in IPM systems (Fitt and Wilson, 2000).

The value of the Bt derived Cry toxin in IPM and the cost of resistance in terms of cross resistance to foliar Bt sprays, and the damage to the future of transgenic in agriculture meant that pro-active resistance for Ingard was essential. The current resistance strategy relies on (1) a cap in the degree of expose of the technology to 30% of the planted area of cotton (2) the mandatory provision of refuges to provide moths not selected with Bt to dilute and resistance in Ingard crops (3) cultivation to destroy resistant pupae under transgenic crops and (4) crop hygiene to prevent carry over of stub or volunteer cotton form Ingard to conventional crops or vice-versa.

Ingard has allowed growers to reduce insecticide use by 40-60%, but the long-term viability of this technology is linked to IPM and IRM. Ingard makes an IPM more straightforward but is not a solution on its own, a point that has been made repeatedly (Fitt and Wilson, 2000). Due to diminishing efficacy after 75 – 100 days, Ingard crops often require supplemental control with insecticides an the later half of the season, thereby exposing insecticides to selection and hence the need for resistance management. IPM emphasises managing crop agronomy to avoid late maturing crops, reducing Helicoverpa abundance locally through use of trap crops and encouraging and conserve beneficials which will reduce the survival of eggs and larvae, thus reducing their exposure to selection by the Cry 1Ac protein. It is possible that the sub-lethal effects of Ingard later in the season may also be able to be capitalised on in IPM. Changes in the behaviour of larvae (feeding sites, movement) may make them more exposed to insecticides, and there is data suggesting that for some insecticides rates can be reduced and still provide effective control of larvae on Ingard, thereby also assisting in conservation of beneficials (Holloway, pers comm).

The future

These are truly exciting times to working in cotton research. The future hold the promise of further development of IPM systems, the new Bollgard II varieties and a range of tools for managing insects and mites including new selective insecticides and new bio-pesticides and crop spray oils. Below I review some of the opportunities and the challenges we will face in IPM and IRM.

Changes in the pest complex

Aphids, green mirids, green vegetable bugs and other stinkbugs are being seen more frequently and in higher numbers in IPM and transgenic crops with reduced spraying, or more selective spray selection. Previously broad-spectrum insecticides applied to control thrips or *Helicoverpa* also suppressed these pests. It is likely that this situation will continue to develop, especially if the current cap of 30% for Ingard is raised significantly for Bollgard II. In addition we have recently seen the first significant appearance of a new pest, *Bemisia tabaci* B-type (silver-leaf whitefly, SLW) and a potential pest, *Frankliniella occidentalis* (western flower thrips, WFT). This year for the first time we have also seen high abundances of leaf-hoppers (jassids).

These emerging pests pose a serious threat to our developing IPM and IRM systems. Aphids, SLW and WFT are resistant to many available control options and cotton aphids are also been identified as vectors of cotton bunchy top (CBT) ((Reddall et al., 2002), (Herron et al., 2002)). Currently registered options to control green mirids, GVB and other stinkbugs are limited to broader-spectrum insecticide groups, such as OP's. Endosulfan is registered and moderately selective, use is restricted to manage resistance and reduce environmental contamination.

Management of these pests requires detailed information of the damage they do and the plants capacity compensate for damage so that realistic thresholds can be derived. Research is underway for aphids (Wilson and Heimoana, unpublished), whitefly ((De Barro, 2002)), for mirids, GVB and stinkbugs ((Khan and R, 2002); (Lei et al., 2002)) and leaf-hoppers (Lei, Reddall and Wilson, unpublished). Significant research is also underway to understand the epidemiology of CBT and to breed resistant varieties ((Reddall et al., 2002)). Initial thresholds are beginning to emerge and be publicised (e.g. (Khan and R, 2002)) and should be refined over the next couple of seasons.

A greater understanding of the ecology of these pests is also required so tat bottlenecks in populations can be exploited to reduce abundance, for instance overwinter control of resistant aphid clones, and to understand the role of beneficials in managing these pests. Research is underway with aphids ((Franzmann et al., 2002)) and whitefly (De Barro, 2002), but the ecology of mirids, GVB and other stink bugs and the role of biocontrol agents still needs work, though recent research by Kahn is helping.

In the short term however a high priority, is the availability of selective options to control these pests so that IPM systems can be maintained. Significant research is being undertaken in this area both by Agrochemical industry and by public research, for instance detailed research on control options for aphids is being conducted at ACRI (Heimoana and Wilson, unpublished) and for the sucking bugs ((Khan et al., 2002)). The latter in particular have shown that rates of some insecticides can be halved by adding salt, providing good control with reduced impact on beneficials. Some of the newer compounds such as indoxacarb, diafenthiuron, fipronil and abamectin/emamectin are showing promise for more selective management of sucking bugs and may become available in future. Crop spray oils and biopesticides may also have a role in management of these pests (see papers by Hauxwell and Mensah in this proceedings).

Are these emerging pests going to negate the advantages of IPM or transgenic systems? These pests are definitely a serious threat, but research is underway and already beginning to identify potential ways to overcome them. Moreover as we learn more about these pest we will find better ways to managing them using better sampling, thresholds, conventional host plant resistance, trap crops (i.e. lucerne for mirids), natural enemies and selective insecticides and potentially biopesticides. An important issue though may be the need to consider resistance management for emerging pests. This would probably apply to green mirids in particular.

Opportunities to Improve IPM and IRM

There are many options to improve both the IPM and IRM systems. A particular challenge is to integrate these two systems more fully, so that there is the flexibility required in IPM to use the most appropriate insecticides for the particular pest / beneficial complex present in the crop. As a range of new insecticides become available, they will be screened for selectivity. This may make the task of providing effective selective control options for all pests at all stages of the season more practical. Some of the options in development include methoxyfenozide and novaluron, lufenuron for *Helicoverpa* control, novaluron, buprofezin and pyriproxifen for whitefly control and pymetrozine, acetamiprid, thiamethoxam, carbosulfan, novaluron for aphid control. At present the climbing resistance with spinosad is a warning however that valid resistance management must be maintained or the flexibility we desire for IPM will be repeatedly compromised by loss of new chemistry to resistance.

A major advance for IPM systems is a better understanding of how to get the best out of beneficial insects (Murray, 2002). This includes a better understanding of their impact on beneficials and who eats who so that the relative significance of different beneficials for different pests can be assessed and incorporated in decision-making tools, for instance a modified pest/predator ratio. There is also a need to better understand ways to augment natural enemies populations. Robert Mensah initiated this approach with his pioneering work using strips of lucerne. There is a strong need to continue this line of research to understand the interactions between beneficial populations and the diversity of crops and other hosts in the system (Murray, 2002).

A limitation with current IPM systems is the lack of capacity to predict the likely impact of natural mortality agents, such as viruses, parasitoids and predators. New research is seeking to understand better the value of beneficial in our IPM systems, including studies of *Trichogramma* egg parasites (Scholz et al., 2002), the value of predators of Helicoverpa (Mansfield, 2002). New diagnostic tools are also being developed based on molecular techniques by the Centre for Insect Diagnostics at the University of Queensland in conjunction with commercial partners (CGS). These include kits to assess if *Helicoverpa* larvae have been parasitised or infected with virus, and will enable better decisions on the need for control.

The opportunity to exploit the movement of both pests and beneficials also has potential for IPM systems. Initial research with food-sprays need to be extended to test if there are other opportunities to influence beneficial movement into crops. There is also the potential to manipulate *Helicoverpa* abundance in future, possibly through use of the attract and kill approach being developed using the Heliothis female moth attractant being developed by Alice Del Socorro and Peter Greg at UNE.

With reduced pesticide use in IPM crops and especially in Ingard there is increasing potential to re-evaluate the value of augmentive releases of beneficials. Recent research by Paul Grundy (QDPI) indicated that releases of nymphal stages of assassin bugs might have a role. The voracious appetite, wide prey range (including *Helicoverpa* and mirids), limited mobility and long life cycle may mean that this species is an ideal candidate. A range of other biocontrol insects, such as lacewings and Trichogramma are available commercially. The value and economics of releases of these into cotton needs careful research.

Another opportunity to improve IPM and IRM is 'site-specific' pest management. The current trend towards treating only those field that are over threshold and using selective chemistry means that the fields that are not sprayed serve as a refuge for beneficials and as a source of potential dilution of resistance for the sprayed fields. Drivers for this trend probably include factors such as the higher cost of newer insecticides. This type of approach has been dubbed 'site specific management' and in a broad sense is a type of precision agriculture. Recent research on the issue with Colorado potato beetle showed that site-specific management significantly decreased resistance selection and increased beneficial numbers (Midgarden et al., 1997).

Decision support tools can also contribute to more effective IPM and IRM in the future. The recent release of CottonLOGIC for the Palm Handheld Device offers the potential to simplify data collection and entry and to take the power of the Helicoverpa and mite models into the field. A recent meeting with grower and consultant identified a number of tools that may help IPM, especially tools to estimate sowing and flowering times for trap and refuge crops and to estimate the development of Helicoverpa populations and pupation time and duration to assist with control decisions (eg use Gemstar or cultivate). Similarly a diapause prediction tool could help identify when larvae are likely to develop into pupae that will go into diapause and, using winter weather when they are likely to emerge.

What about IPM, resistance and Bollgard II

Bollgard II is looming with the promise of enhanced efficacy against Helicoverpa spp. This offers the potential for even further reductions in insecticide use for Helicoverpa and other lepidopterous pests. If the efficacy of Bollgard II is going to be very good is it worthwhile pursuing IPM. I believe the answer is a resounding Yes. For three main reasons, continuing production of conventional cotton, management of other pests and resistance management for the transgenics.

With the two-gene approach it is believe that the risk of resistance is less and this should see an increase in the cap for Bollgard II. Resistance will however remain a major concern and comprehensive resistance management will remain a focus. Greater emphasis is likely to be placed on unsprayed refuges and it will be critical that these are productive in terms of producing Bt naïve moths to dilute and resistant survivors from Bollgard II crops. This should support the development of effect IPM approaches even further. Higher fruit retention levels are likely to occur and will require some fine-tuning of our agronomic and nutritional management. Sucking pests are likely to continue to rise in significance, requiring new approaches to management.

IPM may also help to delay the development of resistance of Helicoverpa to the Cry proteins. Firstly, conservation of beneficial can reducing egg survival in the first place, reducing the number of *Helicoverpa* exposed to resistance selection. Secondly, resistant *H. armigera* developed from cotton strains in Australia still have slow growth rates and reduced fitness when feeding on transgenic cultivars (Bird et al., 2003). Furthermore, as we move to the Bollgard II varieties we move more toward the high dose strategy discussed by (Roush, 1996). Under these circumstances survival of susceptible larvae is likely to be very low, so those surviving on Bollgard II are more likely to be tolerant or carry a resistance gene. In this case predation, by generalist predators, will decrease the numbers of survivors and may thereby contribute to slowing the rate of resistance development. This decrease in abundance also has the effect of making Ingard/Bollgard II refuges more effective by increasing the effective dilution rate – provided of course that the refuges remain productive (i.e. beneficials do not also reduce the productivity of the refuge).

(Fitt and Wilson, 2000) has suggested that insecticide resistant transgenic plants, such as Ingard, can form a good base for IPM. They do this by reducing the need to control *Helicoverpa* spp, the primary pest of cotton, thereby reducing helping to realise many of the benefits of an IPM system more easily. The development of new technology is often slow, and for this reason, if no other, a broad based, ecologically sound IPM system will continue to be crucial to maintaining the viability of our cotton production systems.

Conclusion

There is a strong and ongoing need for IPM in Australian cotton to support the aims of reducing insecticide use, resistance selection and environmental pollution. We are only just starting to see the benefits in terms of reduced insecticide use, reduced pest pressure and increased profitability. In the future a range of new technologies are likely to help with IPM systems including software tools to better forecast the dynamics of trap and refuge crops and the Helicoverpa population on them, which will help make better use of these crops, new diagnostic tools for detecting virus infection or parasitism of eggs or larvae, petroleum spray oils, offering selective management of some pests, new biopesticides and synthetic insecticides, conventional host plant resistance traits and new transgenes, too name a few. A historical focus on yield as the benchmark of a 'good' grower has hindered the development of IPM in this country. This has been compounded by striving for earliness at the expense of excessive insecticide use rather than sensible variety selection and management (see article by Milroy, Bange and Roberts in this proceedings). However, it looks like we have begun to make the change to discussing a good grower in terms of profitability and sustainability, rather than yield and earliness, which augers well for the future of IPM in cotton.

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