Research update on IPM and secondary pests

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Summary

Bollgard II\textsuperscript{®} and selective insecticides have dramatically increased the opportunity for adopting integrated pest management (IPM) in the Australian cotton system. However, reduced or more selective spraying has allowed the emergence of some pests as potential problems, especially sucking pests such as mirids and green vegetable bug. Strategies to manage these pests and support IPM include;

- Sampling – regular sampling of pests, beneficials and plant growth and fruiting.
- Other crops – consider the abundance of pests and beneficials in other crops or vegetation on farm.
- Conserve beneficials as they will help manage other pests. Lower spray regimes mean that there are more beneficials and populations are more resilient.
- Track pest populations - using data to show trends in survival or growth of pest populations over time, especially for secondary pests.
- Insecticide choice – using the most selective insecticide option to conserve beneficials, helps to avoid future problems with secondary pests and contributes to reducing the survival of resistant \textit{Helicoverpa armigera} larvae in Bollgard II\textsuperscript{®} crops.

Introduction - What’s changed?

Changing one part of a system almost always has an effect somewhere else. With more selective insecticides available and the dramatic reduction in insecticide use due to Bollgard II\textsuperscript{®}, there is greater survival of insects generally. Some pests, especially mirids and green vegetable bug (GVB), which used to be co-incidentally controlled by sprays targeting \textit{Helicoverpa} spp., are emerging as more significant problems. Management of mirids and other sucking bugs is creating new challenges, as most of the effective control options are detrimental to beneficial populations, sampling is difficult and thresholds still being developed. In addition, a range of other issues are influencing attitudes and approaches to pest management in cotton. These include;

- Increased diversity of crops due to rainfall patterns, the low price of cotton and the necessity to maximize returns per megalitre. For instance, some growers are planting winter legumes when they are more profitable than traditional cereal alternatives and have the added advantage of increasing soil nitrogen levels. This means that the flow of pests and beneficials between crops is potentially more complex and needs to be understood for effective IPM to occur e.g. management of a more diverse range of crops requires a cropping system rather than a crop specific approach.
- Low prices are also driving some growers to target very high yields to maintain profitability. This is leading, in some cases, to high use of fertilizer especially nitrogen, reduced deficits for irrigation and often stringent pest control, with a ‘zero tolerance’ for some pests, especially mirids. These strategies contribute to increased costs and the latter in particular increases the risk of secondary pest outbreaks, such as the silver leaf whitefly, mites and aphids, especially if the older cheaper organophosphates (OP’s) and pyrethroids (SP’s) are used in an attempt to curb costs.
- There are also changes at the landscape level, due to the reductions in spray applications, though they are generally poorly documented. Crops have more insect life in them, including beneficials. The large areas of Bollgard II\textsuperscript{®} with often few sprays means that even if a field is sprayed, other nearby fields which are not sprayed are sources of beneficials for recolonisation. Our beneficial system has become more resilient as a result.
Resistance management is challenging as we aim to maintain susceptibility in *H. armigera* to conventional insecticides and to the Cry proteins in Bollgard II. Generally levels of resistance to conventional insecticides is declining in *H. armigera*, mites and aphids (Herron and Wilson 2006; Rossiter and Kauter 2006), possibly due to reduced spraying. This has allowed some relaxation of the insecticides resistance management strategy (IRM) (Rossiter and Kauter 2006), however, in the background concerns about resistance in *H. armigera* to the Cry proteins means that effective resistance management is crucial (Downes et al. 2006; Gunning et al. 2005).

In this paper we attempt to identify key emerging issues for IPM, driven by the factors above, and strategies, sampling methods and thresholds to deal with them.

1. **Emerging problems in cotton pest management**

Most of the changes developing in IPM are a result of a reduction in insecticide use due to Bollgard II® and increased use (generally) of more selective insecticides. Consequently, we have seen some pests emerge in higher numbers and causing problems. These emerging pests can be broadly grouped into five categories (i) sucking bugs (ii) late season leaf feeders (iii) secondary pests and (iv) soil pests and (v) *Helicoverpa armigera* survivors in Bollgard II crops.

**Sucking pests**

These are the pests such as mirids, green vegetable bug, green stink bug, red banded shield bug, and brown stink bug that feed on developing fruit.

Mirids are a problem in high numbers, especially through the boll filling period where they can detrimentally affect boll development. Mirid control is problematic because cheap options are broad-spectrum, while more selective options are more expensive (e.g. indoxacarb) or have limited use periods (i.e. endosulfan). Over reliance and possibly overuse of a limited range of control options, especially of fipronil (Regent) may increase the risk of resistance developing to this insecticide. A related issue is that damage is not obvious – black marks on the outside of bolls may or may not indicate damage to the seeds or staining of lint.

Green vegetable bug is also an emerging problem due to higher numbers, its capacity to cause considerable boll damage, the difficulties in sampling due to the patchy distribution. This distribution occurs because females lay eggs in rafts (clusters of 20-30) and the emerging nymphs only spread slowly. Achieving effective control with insecticides is also difficult as the bugs are often deep in the canopy where they are difficult to reach with insecticides. The other sucking bug species generally share similar problems, and they are all difficult to control later in the season when the canopy closes over the rows, restricting penetration of insecticides.

This situation is complicated by the increasing diversity of crops. For instance, soybeans are a good host for green vegetable bug and red banded shield bug and depending on the timing of growth compared with cotton, they could either be a trap crop (where they finish late) or a source of infestation (where they finish earlier than cotton). It is also worth noting that as the uptake of Bollgard II® increases, it is likely that less common sucking bug species will turn up in cotton in high numbers in some years, due to the reduced spray usage and influences by seasonal conditions and the abundance of alternative hosts. Good examples are the recent problems experienced with red banded shield bug (*Piezodorus hybneri*) in many regions and with the green stink bug (*Plautia affinis*) in cotton crops in the Gwydir Valley.

For all of these sucking bug pests a lack of understanding of ecology including alternative hosts, overwintering locations, and the effectiveness of predators or parasites as well as the limited availability of effective selective control options hinders the development of more refined IPM
strategies. Current studies of Whitehouse on the predators of mirids, Khan on thresholds for mirids, Herron on mirid resistance to insecticides, Mensah on biopesticides for mirid control and of De Barro and Hereward on the regional population structure of mirids will substantially advance knowledge in these areas.

Late in the cotton season a number of sucking pests have also sporadically emerged as problems, especially in fields with very low spray regimes. These include harlequin bugs, pale cotton stainers and cotton seed bugs. Normally, early sprays to target other pests coincidentally suppressed these late season pests. A lack of knowledge of ecology, sampling and thresholds for these pests could be an obstacle in the future.

Late season leaf feeders
In fields with low spray regimes there is a trend toward increasing populations of jassids and thrips late in the season. Jassids tend to damage older leaves first then progressively move to younger leaves through the season, often resulting in severe damage to leaves. Thrips damage is predominantly to the younger leaves which, late in the season are the most photosynthetically active and most exposed to sunlight. The thrips damage often appears as silvering along the leaf veins on the undersides of leaves but can include leaf distortion as well. Understanding of cotton compensation in response to early season damage is not very helpful here because the late timing of damage means plants do not have time to compensate as they do with early damage.

Secondary pests
Secondary pests are typically species that become problems as a result of a reduction in beneficial populations caused by use of broad-spectrum insecticides against other pests. Spider mite outbreaks following early season use of OP’s against thrips is a well known example, as thrips eat spider mite eggs. The most common secondary pests in cotton are spider mites, aphids and more recently the silver leaf whitefly (SLW- B-biotype *Bemisia tabaci*). The use of more selective insecticides in conventional cotton and reduced overall use of insecticides in Bollgard II® reduces the risk of secondary pest outbreaks. However, as with most complex systems the detail is important. For instance, in conventional cotton crops spinosad is a selective product to control aphids but also controls thrips and can therefore increase the risk of mite outbreaks. In Bollgard II® crops use of fipronil, pyrethroids or OP’s to control mirids increases the risk of spider mite and SLW outbreaks and selection for SP and OP resistance in aphid populations.

A key example this season in the Darling Downs and in the past in the Emerald area has been the early use of OP’s for mirid control, reducing predators and parasites and allowing outbreaks of SLW to develop. This pest is particularly difficult to manage as numbers increase due to resistance to many compounds. Current control options are either costly (e.g. the selective insect growth regulators (IGR’s) or diafenthiuron), or have limited efficacy with potential negative effects on beneficial populations (e.g. neonicotinoids, OP’s and SP’s). Though we are most concerned about SLW as a pest due to honeydew contamination of lint, it is worth remembering that these pests are also effective vectors of exotic cotton diseases such as cotton leaf curl, caused by a begomovirus (a type of Gemini virus). SLW can spread this disease at numbers far below those that are a honeydew or damage risk, which would be a serious challenge to the sustainability of production. Due to the capacity of begomoviruses to recombine in unusual ways and move into new plant species, the risk to cotton is high, especially as tomato leaf curl is present in northern Australia and the tomato yellow leaf curl virus was recently found in the Lockyer Valley and Bundaberg regions.

Soil pests
False and true wireworms appear to be becoming a more significant pest problem. This may in part be due to the dramatic reduction in pesticide use. In the past the wireworms were generally only a problem in cotton planted into fallows (e.g. cotton, wheat, fallow, cotton). In these systems the lack of insecticide use during the wheat crop and fallow, and the additional organic matter added by the
wheat roots and stubble allowed wireworm numbers to build and potentially affect subsequent seedling cotton crops. In back to back cotton, insecticides from the prior cotton crop, coupled with the short interval and reduced organic matter limited the opportunity for wireworms to build up.

The trend toward more selective insecticide use in conventional cotton and the very low use of insecticides in Bollgard II® crops, the increased diversity of crops which receive few sprays and the contribution of organic matter to soils from these crops, and the increasing trend toward growing cotton after a fallow may all be contributing to an emerging wireworm problem. In addition it is possible that repeated reliance on a limited group of insecticides to control wireworm (predominantly carbamates and OP’s) means that there is a risk of developing resistance over time. Improved management of the wireworm complex is hampered by limited understanding of their population dynamics, effects of management practices and resistance to insecticides.

**Helicoverpa armigera survivors**

At times through the season *Helicoverpa* spp. egg or larval numbers in Bollgard II® crops may cause concern for growers and consultants. One theory is if very high egg numbers are found on a young Bollgard II® crop, they will hatch and feed before dying, but cause sufficient damage to squares that some are shed, leading to reduced retention. However, this theory has not been adequately tested. Later in the season, grubs may be found in Bollgard II® crops. Testing of these grubs has found resistance to the Cry 2Ab protein in a low proportion (2%) and no resistance to Cry 1Ac (Downes *et al.* 2006). However, the presence of these grubs, often in the plant terminal or in flowers and small bolls, may be a concern for yield.

### 2. Sampling methods for emerging pests

Effective sampling techniques provide the essential information for understanding population trends and determining if pests require control and sampling strategies for most pests are well established (see the Cotton Pest Management Guide or the Guidelines for Integrated Pest Management in Australian Cotton Production Systems). Sampling is even more critical for emerging pests where growers and consultants have less experience in dealing with them. Sampling should include (i) pests (ii) beneficials and (iii) plant development and/or fruiting dynamics. This is especially important for pests such as mirids where numbers of pests may not be a good indication of the amount of damage (see Fig 2b in Whitehouse 2006)). The critical factors are to match the sampling technique to the pest and to sample frequently enough with an appropriate sample size to monitor natural mortality and pest populations to allow effective control if necessary.

**Visual, beat sheet or sweep?**

The most common techniques are the visual sample and the beat sheet, with the sweep net just beginning to gain use. Each of these techniques has advantages and disadvantages. For pests or beneficials that do not move away quickly or that are poorly sampled in beat sheets or sweep nets, visual samples are best (e.g. *Helicoverpa*, mites, aphids, SLW, thrips), though some pests require specific visual techniques (e.g. mites and SLW). For pests or beneficials that are flighty, hard to see or deeper in the canopy the beat sheet tends to provide more consistent estimates of abundance, such as mirids or spiders. The sweep net is a compromise where the upper canopy is sampled well, and it is quick and easier to use than the beat sheet if the crop has been irrigated (Threllfall *et al.* 2005). There are calibrations available to relate the beat sheet and sweep net samples to visual samples, on which thresholds are based (see the Cotton Pest management Guide). Each of the techniques can be a check for the other, for instance if visual counts find few mirids, but fruit loss is high it would be worthwhile to do a beat sheet or sweep net sample to confirm that mirid densities are in fact low and they are not the cause of the damage.

**Emerging pests**

Mirids can be sampled using visual counts (though these tend to under estimate numbers), beat sheets (which tend to sample nymphs better), or sweep nets (which tend to sample adults
better)(Threllfall et al. 2005). The advantage of using the beat sheets in particular, is the good estimate it provides for beneficial numbers at the same time. Mirids tend to show a random or slightly more uniform distribution. Sample sizes for beat sheets and sweep nets are shown in Deutscher et. al.(2005)

The green vegetable bug in particular is very patchy in distribution as it lays its eggs in clusters. The nymphs tend to remain in the vicinity of the egg cluster, slowly spreading to nearby plants as they develop. They are also often lower in the canopy, though the adults may sometimes be seen in the upper canopy. Beat sheets are the best way to sample most stages of this pest, although sweep nets are good for detecting the presence of adult GVB.

Sampling has proven crucial to successful management of SLW, especially for timing the use of the insect growth regulators which provide effective control. Up until recently the sampling techniques used for this pest were adapted from those developed in Arizona. However, over the past several years Dr Richard Sequeira has noted that the distribution of SLW in Australian cotton field is different to that in Arizona and this has consequences for the timing of use of the insect growth regulator insecticide. A revised sampling technique has been developed and extension material describing it is being developed.

**Remember plant damage and beneficials.**

When considering sampling strategies we generally focus on pest abundance, but this is only part of the information that is needed. A recent survey suggests a high reliance on pest numbers when making decisions for mirid control, which is concerning given that mirid numbers do not always correlate well with damage (Whitehouse 2006). It is also important to measure plant damage to indicate how the plant is responding to the pest density, and to also monitor beneficial numbers as this will influence whether the pest requires control and, if so, the choice of insecticide. Early plant monitoring can include tracking node development by using the crop development tool on the CRC Website and monitoring fruit retention. After flowering, monitoring the fruiting factor is useful, and in the mid season bolls of susceptible ages should be sampled and scored for damage. This entails pulling the bolls apart and examining the lint and seeds for signs of damage. Sampling for beneficials can be by visual inspection of the crop, but recent research has highlighted the value of beat sheets for providing reliable and repeatable estimates of beneficial abundance (Wade et al. 2006). For some beneficials, such as *Trichogramma* spp, which attack eggs of *Helicoverpa*, it is impractical to estimate levels of parasitism in the field – in this case eggs must be collected and allowed to hatch so that the proportion parasitised can be estimated.

**Other crops**

With increasing diversity in our cropping system it is worthwhile to have an understanding of pest and beneficial abundance in other crops besides cotton. This is especially true for some of the emergent pests such as mirids and GVB which may move quickly between crops, and can move on mass from early maturing soybeans into cotton. Similarly, it is worthwhile to keep an eye on pest numbers on uncultivated vegetation near cotton fields as this may provide an indication of potential infestations.

**3. Confidence in traditional thresholds in a low spray environment**

The changed patterns of insecticide use mean that crops are growing in an environment where there will be more ‘insect life’ generally. Furthermore, as previously discussed unsprayed fields can be a source of beneficials to recolonise fields that have been sprayed. This means that pest management needs to take into account the likely higher contribution of beneficial insects to pest management. This has slightly different implications for pests that cause immediate damage, such as *Helicoverpa* and mirids, compared to those that cause more gradual damage such as most of the secondary pests (mites, aphids and whitefly).
For those pests that cause immediate damage, a good measure of potential mortality from predation and natural factors (high temperature and/or low humidity) is too look at survival over a series of checks. For instance, with Helicoverpa if very few eggs are making it through to larvae then mortality is high. Counts of beneficials and egg collections to assess parasitism will give greater understanding of the source of mortality and confidence that it will occur in subsequent checks. In addition, an assessment of plant performance, such as retention and node development will indicate if the crop is on track, and give greater confidence with pest management decisions. This can be supported by new tools such as the Crop Development Tool on the Cotton CRC website.

There is often a belief that sustained sub-threshold pest levels will cause economic damage if not controlled. Research by Dallas Gibb in the mid 1990’s using Helicoverpa thresholds of 1, 2 or 4 larvae per meter showed this to be false. In most experiments even 4 larvae per meter, used as a threshold did not cause yield loss. Similarly, Dr Tom Lei recently evaluated the effect of 8 larvae for one day versus 1 larva for eight days and found no effect of either damage level or yield. A key factor with sub-threshold populations is to allow beneficials to establish and contribute to pest management. In spite of this, some pest populations will increase and cause damage but provided this is below threshold, plants will compensate. Again, monitoring crop progress by one or more techniques provides useful corroboration that the crop is on track.

For pests that cause gradual damage it is more important to monitor population growth over time. For instance, with spider mites knowing the density at a given time is not very useful unless you know what density they were a week ago. This is because they can be thought of as ‘crop residents’. They can’t fly in or easily move away, so changes in population growth indicate effects of beneficial, miticides and the loss of mortality from beneficials if they are eliminated. In low spray Bollgard II® or conventional crops, mites colonise plants and begin to initiate hotspots. However, we suspect that the higher numbers of beneficials in these crops rapidly find these populations and control them. Some mites or aphids still manage to spread to nearby plants and begin to increase but are soon discovered by beneficials as well. So in low spray Bollgard II® crops we tend to see more even but lower populations, as every time the mites or aphids start to increase in local areas they are slowed down by beneficials. The rate of increase of mites or aphids in these crops tends to be low, often too low to result in economic loss. This can be in spite of populations exceeding the nominal threshold of 30% of plants infested. Similar principals apply to managing aphids and whitefly, although low populations of after boll opening need to be monitored closely to prevent honeydew contamination of cotton.

**Mirids and sucking bugs**
The effect of mirids on yield is complex because their damage to young bolls (8 – 20 days old) can range from almost no effect on boll weight through to damage to one or all locks. The impact of such damage is a product of timing of damage, which determines if squares or bolls shed and for retained bolls how many and how badly locks are damaged and the time the damage occurs in the fruiting cycle. Damage early in the fruit cycle allows for compensation as the plant can retain other fruit, damage in the middle of the fruit set period may affect yield because the time for compensation is reduced and the plant is approaching its carrying capacity, while damage late in the season may be less important as many bolls are or will shortly be beyond 20 days old and beyond being damaged. For mirids, thresholds are now available for the fruiting period, see article in this proceedings by (Khan et al. 2006a). Thresholds for other sucking bugs such as GVB and related species are provided in (Khan and Bauer 2002).

**Jassids**
The jassids or leaf hoppers have built up in some crops to such numbers that late in the season the upper surfaces of leaves appear almost white. Typically the damage begins in the lower canopy and progresses to the upper canopy as jassid numbers build. Preliminary research found that leaves at
mainstem node 10 below the terminal with about 80% of the upper leaf surface damaged had 3% less photosynthesis than undamaged leaves (Figure 1). However, damage to young upper leaves may be more important as preliminary research found that young leaves (mainstem node 3 below the terminal) with 80% of the upper leaf surface damaged had photosynthesis reduced by about 20% compared with undamaged leaves.

![Figure 1. Effect of jassids on photosynthesis. Damaged leaves had approximately 80% of upper leaf surface damaged. Sampling was done when crops had approximately 20% open bolls.](image)

Current thresholds for jassids are not well defined. Field experiments where jassid numbers have been manipulated by insecticides show a very flat response between jassid damage and yield loss, reinforcing that high levels of damage are needed before yield is affected. Control of jassids is relatively cheap using OP’s, but this may not be justified economically and is disruptive of beneficial populations. As a flow on effect it is likely that jassids, because of their high abundance may be important prey for some key beneficials, hence reducing jassid numbers may also adversely affect beneficial numbers. We have little understanding of the population dynamics of jassids in cotton regions, including host preference, predators or parasites and overwintering.

**Thrips**

Similarly, thrips numbers are also often very high late in the season, causing damage to leaves which may be severe enough to result in leaf distortion and possibly reduce photosynthesis, which creates concerns about the effect of their feeding in flowers on boll setting. Again, little information is available, and the issue is complicated because the thrips are also very effective at suppressing mite populations. The species involved are tomato thrips (*Frankliniella schultzei*), which are not resistant to insecticides and western flower thrips (*F. occidentalis*), which are resistant to organophosphates, carbamates, neonicotinoids. Understanding of the population dynamics, host use and effectiveness of predators or parasites is limited. For western flower thrips this is an important priority as this species rapidly develops resistance to pesticides, a problem when some of the most effective options such as abamectin and spinosad are also used to control other pests, increasing the risk of coincidental selection of resistance.

**Silver leaf whitefly**

Until recently thresholds for SLW have been based on those developed by researchers in Arizona. However, recent research by Dr Richard Sequeira has developed modified thresholds more suited to the patterns of distribution, natural mortality and build-up of SLW in Australian cotton systems. These are in the process of being refined and will be extended to industry shortly.

**Helicoverpa in Bollgard II®**

Present thresholds for control of *Helicoverpa* in Bollgard II® are the same as those developed for Ingard®. A new student project will investigate this issue further to determine if heavy egg lays can
result in significant square loss, how susceptible grubs survive on Bollgard II®, define how much
damage they do, if predators or parasites affect this and to develop thresholds for control.

4. **New pest management strategies to deal with emerging pests**
The overall strategy for dealing with emergent pests is to apply the IPM strategies outlined in the
IPM Guidelines and bring in new information and tools to help deal with the emerging pests –
predominantly mirids. This involves:

**Sampling** – regular sampling of pests, beneficials and plant growth and fruiting. Select the
sampling technique appropriate to the pest, and if necessary use more than one to provide better
information. Use early retention, Fruiting Factor and the Crop Development Tool to help diagnose
if crops are on track.

**Other crops** – consider the other crops on your farm or nearby and sample them as well. This will
provide information on potential pest populations that could move into cotton crops and also
provide information on beneficial populations that could move as well.

**Conserve beneficials** as they will help mange other pests – the generally lower spray regimes
mean that there are more beneficails and populations are more resilient. Beneficials are important
for both conventional and Bollgard II® crops.

**Track populations** - use data to show trends. For *Helicoverpa* this can indicate survival between
checks, which can be due to Bollgard II®, natural mortality due to weather or beneficial predation.
Information on the impact of beneficials, especially for conventional crops, is useful in predicting if
*Helicoverpa* is likely to exceed threshold. For mirids keeping track of adult and nymph populations
gives information on population build-up, and potential for more damage nymphs develop. For
mites, aphids and SLW it is critical to track population development to determine the potential to
cause economic damage and for SLW is for the timing of use of the IGR’s.

**Selective insecticides** – using the most selective insecticides to manage mirids and other sucking
pests will help avoid future problems with secondary pests. Mixtures of reduced rates of some
insecticides with the addition of salt (Khan et al. 2006b) or spray oils may be more selective than
full rates of the insecticide. Early use of cheaper products such as OP’s or SP’s is an attractive
option, and due to more resilient beneficial populations may not be as disruptive as in the past, but
is still a risky strategy and also selects for resistance in aphids. Selection of insecticides is very
important for areas where SLW is a problem. Use of OP’s and SP’s in particular can be very
disruptive of beneficial populations, especially the parasitic wasp *Eretmocerus*. Additionally, the
recently introduced beneficial wasp parasite *Eretmocerus hayati* is spreading through the SLW
areas. This species is very effective at reducing SLW abundance both on uncultivated hosts and in
crops and may help reduce the need to control SLW (De Barro – personal communication).

**Bringing it all together**
Table 1 shows a potential decision making process (taken from the IPM Guidelines) that brings
together the elements discussed above.

5. **Conclusions**
The advent of Bollgard II® along with the increase crop diversity and push for higher return per
hectare of land and megalitre of water is resulting in dramatic changes to the pest spectrum in
cotton. However, it is worth remembering that this technology strongly supports IPM by reducing
the need to control the primary pests (*Helicoverpa* spp.) and allowing much greater survival of
beneficial populations. Application of sensible pest management strategies will ensure we derive
the most benefit from this technology. Furthermore, application of IPM principals, especially
conservation of beneficial insects will have benefits in reducing the need to control secondary
The pests, and in reducing survival of resistant *Helicoverpa* in Bollgard II® crops, thereby reducing their chances of contributing to resistance development.

### Table 1. Potential decision making process for pests.

<table>
<thead>
<tr>
<th>SAMPLING</th>
<th>ASSESSMENT</th>
<th>DECISION</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monitor Plant Damage and Development</strong></td>
<td><strong>Apply CD Tool</strong></td>
<td><strong>Does crop need protection?</strong> (consider..... is it ahead of schedule and can tolerate some damage? Is poor retention due to pests or other factors?)</td>
<td><strong>Consider application issues...</strong></td>
</tr>
<tr>
<td>• Tip Damage</td>
<td><strong>Check damage thresholds</strong></td>
<td><strong>Are pests over, or close to the threshold? (consider ..... are pests increasing, static or decreasing? For pests such as mites, aphids and whitefly, static or decreasing population often indicate good predation levels).</strong></td>
<td><strong>Check IRMS regulations</strong></td>
</tr>
<tr>
<td>• Fruit Retention</td>
<td><strong>Check pest thresholds</strong></td>
<td><strong>Are predator numbers or parasitism rates too low to control pests?</strong> (consider….proximity to sources of beneficials, other pests present that beneficials may be controlling)</td>
<td><strong>Check Impact Table</strong></td>
</tr>
<tr>
<td>• Fruiting factor</td>
<td><strong>Track pest trends</strong></td>
<td></td>
<td><strong>Consider…</strong></td>
</tr>
<tr>
<td>• Boll damage</td>
<td><strong>Check Predator/Prey Ratio or Beneficial insect / prey ratio</strong></td>
<td></td>
<td><strong>Impact on beneficials</strong></td>
</tr>
<tr>
<td>• Crop development tool</td>
<td><strong>Check parasitism</strong></td>
<td></td>
<td><strong>Potential to flare pests</strong></td>
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<tr>
<td><strong>Monitor Pest Densities</strong></td>
<td></td>
<td><strong>NO… Come back and check again in two days</strong></td>
<td><strong>Using food sprays or biological insecticides or manipulating lucerne trap crops to restore the predator to prey ratio</strong></td>
</tr>
<tr>
<td>• Caterpillars</td>
<td></td>
<td><strong>YES… Choose an option</strong></td>
<td><strong>Monitor beneficials and calculate predator to prey or beneficial insect to prey ratios.</strong></td>
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<tr>
<td>• Mirids and GVB</td>
<td></td>
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<td><strong>What impact did the control have on beneficials – note for next time.</strong></td>
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<tr>
<td>• Mites</td>
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<td>• Aphids</td>
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<td>• Whitefly</td>
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<td><strong>Monitor Beneficials</strong></td>
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<td>• Predators</td>
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<td>• Parasites</td>
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**EVALUATION**

• Continue to monitor plant damage. Is the plant on track?  
• If not is it pest related or due to other factors.  
• Resample. Is the pest below threshold?  
• If not, why not – poor application, resistance, insufficient time (eg miticides, whitefly insect growth regulator)  
• Formulate new control options in relation to, efficacy, resistance and impact on beneficials.

• Monitor beneficials and calculate predator to prey or beneficial insect to prey ratios.  
• What impact did the control have on beneficials – note for next time.
Acknowledgements
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