3.4 Objective 4 - Prevent the development of insecticide resistance

3.4.1 Introduction

Resistance occurs when application of insecticides removes susceptible insects from a population leaving those individuals that are resistant. Mating between these resistant individuals gradually increases the proportion of resistance in the pest population as a whole. Eventually this can render an insecticide ineffective, leading to field control failures. Resistance can be due to a trait that is already present in a small portion of the pest population or due to a mutation that provides resistance.

Management of resistance is essential to ensure that valuable insecticides remain effective. One of the objectives of IPM is to help manage insecticide resistance by reducing the overall use of insecticides, which reduces the number of selection events. However IPM programs rely on the availability of selective insecticides i.e. those that control only the target pest with little effect on beneficials as an important tool to manage pests. IPM and resistance management are therefore complimentary.

To help manage resistance the Australian cotton industry has developed the Insecticide Resistance Management Strategy (IRMS). This industry regulated strategy sets limits on which insecticides can be used, when they can be used and how many times they can be used. These limits are based on the outcomes of ongoing monitoring for resistance in *Helicoverpa* spp., mites, aphids and whiteflies, and are designed to prevent resistance developing or to manage resistance that has developed. The IRMS is usually devised for 2 or 4 major groups of regions, reflecting differences in pest pressure or timing of crop growth. For the success of the IRMS, it is important for every grower to follow their regional strategy. Most pests are not confined to a particular field or farm, so if one grower acts outside the strategy causing insecticide resistance on his / her farm, then it is possible for the resistant pest population to spread to neighbouring farms hindering the efforts of other growers who have been diligent in their pest management.

Resistance monitoring

Resistance monitoring for *Helicoverpa* spp., mites, aphids and whiteflies, is conducted each year and provides the foundation for annual review and updating of the strategy. The monitoring program is a coordinated effort between researchers, consultants, growers and extension staff. In addition to resistance monitoring, research is also carried out on the mechanisms of resistance. This is useful for devising strategies that avoid cross resistance and can also lead to field kits for identification of resistant insect populations before making spray decisions.

Testing for insecticide resistance in the laboratory.

The IRMS is designed to prevent resistance development, while managing existing resistance. Limiting the number of applications permitted for new insecticides is an example of pro-active management. The IRMS is responsive to changes between seasons as new information becomes available from resistance monitoring. However, every season is different and the weather and insect patterns of the previous season should not overly influence the long term aim of resistance management.

Resistance mechanisms

The main mechanisms of resistance are given below. However, resistance is complex and there can be number of mechanisms present in a single pest, to one or more insecticides:

- *Target site insensitivity:* changes to the target site proteins reduce binding of the chemical and hence reduce its toxicity.
- *Metabolic resistance:* chemicals are broken down to non-toxic substances by increased enzyme activity in the insect before they can act on the target site. (e.g. this is the most common mechanism in *H. armigera* for detoxifying organophosphates, pyrethroids & carbamates).
- *Penetration resistance:* changes in the insect's cuticle or gut lining (if ingested) can lead to slower uptake of chemicals. Normal detoxification enzymes can then act.
- *Altered behaviour:* the target insect's behaviour changes in a way that may allow them to avoid normally lethal spray deposits. E.g. they may move down the plant away from the spray or cease feeding on sprayed foliage.
- *Cross resistance:* the resistance situation is further complicated by resistance to one group of insecticides conferring resistance to another, referred to as cross resistance. An example of this is resistance in the cotton aphid to carbamates that also confers resistance to the organophosphates.

Resistance management tools

Resistance management relies on a number of core principles. The exact details may vary between pest species due to differences in life cycle, host range and ecology. Management of resistance to the Bt toxins (proteins produced in cotton by genes inserted from *Bacillus thuringiensis* var *kurstaki*) in Bollgard II® varieties and insecticides applied to the plant are essentially similar except that the options to rotate the toxin or restrict the number or timing of applications of the toxin are not possible with the transgenic plants. Some core principles used in the Australian IRMS include:

1. Limiting the time period during which an insecticide can be used. This restricts the number of generations that can be selected.
2. Limiting the number of applications, thereby restricting the number of selection events.
3. Rotation between chemical groups with different modes of action. Insecticides are grouped according to their mode of action (the way in which they kill the pest). There may be a range of insecticides in a particular group. Repeated use of insecticides from one chemical group can increase the selection pressure against that mode of action. If resistance develops it will usually affect all insecticides in the same group. Rotation between chemical groups reduces selection for a particular mechanism that is effective against a particular insecticide group. For fast breeding pests such as mites, aphids and whiteflies it is recommended that no insecticides / miticides from the same group are used consecutively. For *H. armigera*, up to two applications of the same group can be made, then rotation must occur.
4. Reducing overwinter survival of pests that have been selected for resistance. *H. armigera* can survive through winter as diapausing pupae in the soil. These pupae are in a state of arrested development through winter. When conditions warm up they will resume development. The trigger for pupae to go into diapause is reduced day length and temperature. Toward the end of the cotton season most pupae will go into diapause, and these will have been selected for resistance to insecticides, or to the Bt proteins in Bollgard II®. They can be controlled by cultivation thereby reducing the carryover of resistance from

Cultivating to control diapausing *H. armigera* pupae.

one season to the next. Mites, aphids and whiteflies all use weed or crop hosts during winter. Reducing the availability of these hosts will reduce the size of populations that infest cotton in the next season, and thereby reduce the number of insecticide applications and selection events.

5. Use of trap crops to concentrate a pest in a particular area where they can be controlled by other means i.e. destructive cultivation of the crop.

Several other strategies can also help in managing resistance. These include:

1. Selective insecticide use, consistent with the IRMS, helps conserve beneficial insects. Beneficials eat or parasitise resistant as well as susceptible pests. Beneficials can also lower overall populations of insect pests.
2. Using plant compensation allows for the plant's capacity to recover from a degree of damage without loss, thereby avoiding insecticide applications to prevent non-economic damage.
3. Avoid cross selection for resistance. Spraying for one pest can be simultaneously selecting resistance in another pest that is present, even though that pest is at sub-threshold levels.

3.4.2 Strategies for individual pests

Each pest has a different life cycle and ecology which means the strategy required to manage resistance may vary between species. Several examples for important pests are given below.

3.4.2.1 Helicoverpa

Large *Helicoverpa* larvae will move down to the soil to pupate.

Helicoverpa spp. have a relatively long life cycle (42 days or about 5 generations in a season) which makes this pest ideally suited to a resistance management strategy based on restricting chemical use to defined time periods corresponding to its generation time.

Of the two *Helicoverpa* species in cotton, *H. armigera* has developed the greatest resistance. This species is closely linked with cropping systems and is exposed to insecticides on many of these hosts. *H. punctigera* has the biological capacity to become resistant, and there are populations with low levels, but its ecology involves frequent migration to and from untreated hosts which dilutes any resistance.

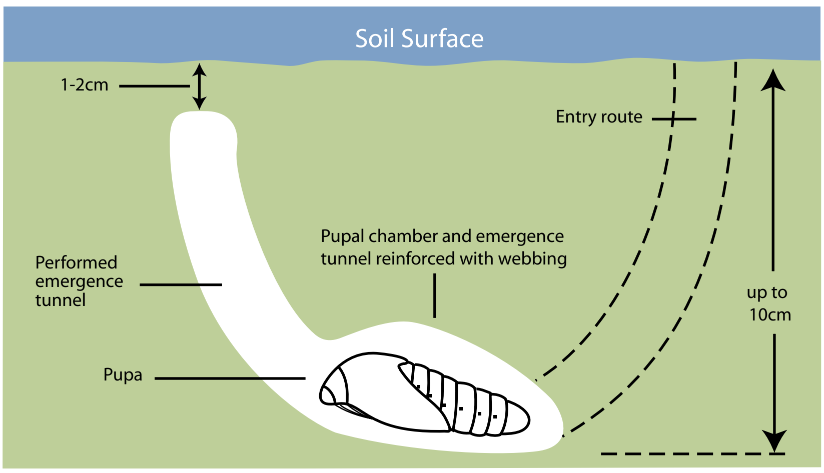
H. armigera are mobile pests which can move between cropping regions given favourable weather conditions. This makes it necessary to have an industry wide strategy that coordinates resistance management. The strategy also accounts for control of this pest in crops other than cotton, which is particularly important for insecticides used on more than one crop.

The pupal stage of the *Helicoverpa* life cycle normally lasts about two weeks. Older larvae leave the cotton plant and burrow into the soil. They form emergence tunnels, then turn into pupae. While in the pupal stage they undergo physiological changes into moths. The moth cannot dig so it uses the emergence tunnel to leave the soil (Figure 9).

Figure 9.

Position of the *Helicoverpa* pupa in the soil with entry and emergence tunnels.

Illustration: J. Beard



In autumn and winter, short day lengths and cool temperatures can trigger a proportion of pupae to go into diapause. This is a dormant phase that allows them to survive in a state of suspended development for several months. When soil temperatures increase in spring, normal development is resumed and moths emerge soon afterwards.

Diapause generally commences at the end of the cotton season, when the levels of insecticide resistance in *H. armigera* are at their highest. Moths that emerge in the following spring from diapausing pupae are likely to be highly resistant. In fact, these individuals are the major carriers of resistance from one season to the next. Cultivation to control insecticide resistant *H. armigera* pupae under cotton stubble (pupae busting) is a core non-chemical component of both IRMS and IPM.

Sample cotton stubble for pupae after harvest, using the guidelines published, in order to determine which fields require control and to prioritise those that do. Cultivate to control pupae as soon as possible after harvest and no later than August. Early cultivation will also kill any non-diapausing pupae remaining in the soil. Early cultivation also increases the chance of later rain events sealing up any remaining pupae emergence tunnels, preventing moths from emerging. Minimum tillage strategies for planting rotation crops may lead to poor pupae control. *MACHINEpak* and the *Cotton Insect Pest Management Guide* provide information on the effectiveness of different cultivation options for controlling pupae. Avoid cultivating under conditions that create other problems such as compaction, i.e. wet soil.

Helicoverpa pupae.

The stubble of other summer crops may also harbour *Helicoverpa* pupae. Sample to assess pupae densities under these crops as soon as possible after harvest and pupae bust if warranted. Grain crops not infested with *Helicoverpa* larvae by early March will not harbour diapausing pupae unless there has been re-growth.

To find out whether your pupae busting has been effective visit www.cotton.pi.csiro.au/Assets/PDFFiles/evalpup.pdf

Sampling for diapausing *Helicoverpa* pupae under crops in autumn or winter is critical for deciding which fields need to be cultivated to control pupae.

The proportion of pupae predicted to enter diapause on a given date for several cotton growing regions is given in Tables 11-15. These predictions are based on the model of diapause induction for *H. armigera* developed by Dr David Murray using field cages on the Darling Downs. The HEAPS (*Helicoverpa Armigera* and *Punctigera* Simulation) model has been used to estimate the time taken for eggs laid each week throughout February and March to develop to the pupal stage, and the proportion of insects that pupate on a given date that are likely to enter diapause. Pupae that do not enter diapause will continue their development, and their predicted emergence dates are also given.

Diapause induction is a complex process that is influenced by decreasing day length and daily temperature cycles. The model predictions given here should be considered as estimates only, because cotton fields in different locations within each region will experience different regimes of day length and temperature. There will also be seasonal variations. In cool seasons diapause induction may commence up to two weeks earlier, and in warm seasons diapause will occur later than average.

The stubble of other crops such as sunflowers may also harbour *H. armigera* pupae. Check to see if cultiation is required.

Contact your local industry development officer or district agronomist for the current induction data for your region.

The following tables are *H. armigera* autumn diapause induction and emergence dates of non-diapausing pupae for major regions (Central Qld and MacIntyre) based on long term average temperatures.

Table 11. Central Queensland *H. armigera* autumn diapause induction and emergence dates

Date of egg lay	Pupation	% Diapause	Non-diapause emergence
1 February	21 February	0.0	5 March
8 February	25 February	0.0	10 March
15 February	7 March	2.1	19 March
22 February	12 March	15.7	25 March
1 March	22 March	42.0	5 April
8 March	29 March	57.8	15 April
15 March	6 April	74.7	23 April
22 March	15 April	90.9	18 May

Table 12. Macintyre *H. armigera* autumn diapause induction and emergence dates

Date of egg lay	Pupation	% Diapause	Non-diapause emergence
1 February	25 February	0.0	11 March
8 February	3 March	0.0	18 March
15 February	11 March	11.4	28 March
22 February	19 March	29.1	6 April
1 March	27 March	46.8	17 April
8 March	5 April	64.4	30 April
15 March	14 April	78.6	20 May
22 March	25 April	92.4	12 June

Table 13. Namoi *H. armigera* autumn diapause induction and emergence dates

Date of egg lay	Pupation	% Diapause	Non-diapause emergence
1 February	28 February	0.0	17 March
8 February	9 March	4.2	27 March
15 February	15 March	17.5	3 April
22 February	24 March	38.0	17 April
1 March	31 March	50.9	28 April
8 March	11 April	68.3	22 May
15 March	23 April	83.6	16 June
22 March	7 May	94.0	29 June

Table 14. Macquarie *H. armigera* autumn diapause induction and emergence dates

Date of egg lay	Pupation	% Diapause	Non-diapause emergence
1 February	23 February	0.0	13 March
8 February	3 March	0.0	25 March
15 February	14 March	17.6	6 April
22 February	21 March	31.9	13 April
1 March	2 April	51.0	7 May
8 March	11 April	68.8	25 May
15 March	1 May	79.5	23 June
22 March	12 May	91.1	4 July

Predicted emergence of H. armigera from diapause in spring

The proportion of diapausing pupae predicted to resume normal development and emerge as moths is given in Table 15 for each of the major cotton growing regions based on long term average temperatures. These predictions were made using the model of diapause termination for *H. armigera* developed by Dr David Murray. Diapause termination is influenced by soil temperatures. The model predictions should be considered as estimates only, because the interactions between soil temperature, moisture, and pupal depth will be strongly influenced by local conditions at the field level. In cool seasons these emergence periods may be delayed by up to two weeks, and in warm seasons emergence will occur earlier than average. Emergence from diapause is a long process that generally takes place over 6 to 8 weeks.

The following table shows the predicted spring emergence of *H. armigera* moths from winter diapause. Contact your local industry development officer or district agronomist for the current emergence data for your region.

Table 15. Spring emergence of *H. armigera* moths

Region	1% emergence	50% emergence	99% emergence
Central QLD	14 August	3 September	6 October
Macintyre	28 September	23 October	23 November
Gwydir	1 October	26 October	25 November
Namoi	4 October	29 October	28 November
Macquarie	21 October	13 November	12 December
MIA	27 October	17 November	9 December
D. Downs	1 November	12 November	20 December

3.4.2.2 Fast life cycle pests (mites, aphids, whiteflies)

The current strategy window system was originally developed for *Helicoverpa* spp. as the major pest. However with the introduction of Bt cotton and an industry wide acceptance of IPM for pest management, other secondary pests that once would have been controlled inadvertently through *Helicoverpa* spp. control are now increasing in importance. Therefore the strategy has now incorporated resistance management plans for secondary pests.

Cotton aphids reproduce parthenogenically, so young are clones of their mother. This reduces the chance for dilution of resistance.

Aphids, mites and whiteflies have very short life cycles, 5, 8 and 16 days respectively under summer conditions. This allows them to develop resistance to insecticides very quickly. It is important not to consecutively apply insecticides from the same group for control of these pests or when selecting chemistry for other pests. This strategy avoids selection of multiple generations with the same insecticide group. This applies even if short life cycle pests are below thresholds in pest checks.

Rotation between insecticide groups is especially critical with pests that reproduce by cloning such as cotton aphids (see the '*Cotton Pest and Beneficial Guide*', or the '*Managing Aphids Research Review*' available on the Australian Cotton CRC website). Any resistant survivors will pass their resistance trait directly to their offspring. In cotton aphid populations in Australian cotton regions there is no sexual reproduction and therefore no potential for dilution of resistance by mating with susceptible insects, as there is with most other pests.

Aphids, mites and whiteflies all use a wide range of hosts so management of these through winter to reduce the size of overwintering populations is critical in their management.

Aphid specific issues

For cotton aphids (*Aphis gossypii*) there is cross resistance between pirimicarb (carbamate), omethoate and dimethoate (organophosphates). Early season use of these chemicals risks re-selecting overwintering resistant aphids. The resistant strains are however susceptible to some of the other organophosphates and endosulfan, as well as neonicotinoids (imidacloprid (Confidor®), thiamethoxam (Actara®) and acetamiprid (Intruder®)), pymetrozine (Fulfil®) and diafenthiuron (Pegasus®).

Aphid parasitoid (*Lisiphlebus testaceipes*).

To complicate matters, use of pyrethroids against *Helicoverpa* can exacerbate resistance problems by selecting the pirimicarb / organophosphate resistant aphids to create pirimicarb / organophosphate / pyrethroid resistant clones that are highly resistant to virtually all organophosphates, carbamates and pyrethroids making them very difficult to control, especially toward the end of the season.

To avoid this problem, pirimicarb, omethoate and dimethoate need to be used less and more strategically. Pirimicarb's strategic use is with early season IPM as it is soft on many of the beneficial groups that control aphids. Omethoate and dimethoate's strategic use is at the end of the season where their negative impact on beneficials is less critical. This allows the softer chemistry to be used earlier, better utilising beneficial insects to reduce surviving pests.

If using a seed or in furrow treatment from the neonicotinoid group avoid using an insecticide from this group as your first foliar spray.

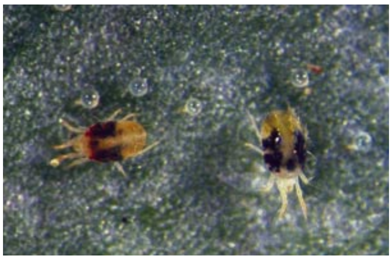
Mites use weed and crop hosts (like this marshmellow) to survive through winter. Good farm hygene can help reduce over-winter survival of mites, aphids and whiteflies.

Cotton aphids can overwinter on numerous crops, weed hosts and cotton re-growth or volunteer cotton. There is a risk of resistant clones persisting on-farm through winter. It is therefore important to reduce the availability of host plants over the winter period through the control of winter weeds and careful choice of winter crops. On farms where aphid resistance occurred in the last season, the grower should consider planting a winter cereal or a winter legume that is not a good aphid host, such as retch.

For more information on aphid management visit www.cotton.pi.csiro.au/Assets/PDFFiles/AphMang.pdf

Mite specific issues

Most miticides are also used against other pests. It is critical to be aware of this issue as use against another pest also selects for resistance in mites present in the field, even if they are at sub-threshold levels. Two-spotted spider mites (*Tetranychus urticae*) are widely resistant to organophosphate insecticides, to bifenthrin (Talstar®) and increasingly to chlorfenapyr (Intrepid®).



Mites have a relatively high reproductive potential of about 70 eggs per female.

Mites survive the winter in colonies on broadleaf weeds and crops such as safflower, faba bean and field pea. As these hosts senesce in spring, mites migrate to new hosts such as cotton seedlings. It is therefore important to practice good farm hygiene to control winter weeds and if you have experienced mite infestations in the past, carefully choose your rotation crop. Winter cereals and chickpeas are poor mite hosts.

Mite survival may also increase if the winter rotation crop is sprayed with a broad spectrum insecticide to control other pests, as this will reduce the population of mite predators.

In late maturing cotton crops, mites can enter diapause and move to the base of the plant into the cotton trash or crachs in the soil. Cultivation, for the purpose of pupae busting will help reduce the survival of these mites.

For more information on mite ecology visit www.cotton.pi.csiro.au/Assets/PDFFiles/miteeco.pdf.

Whitefly specific issues

The silverleaf whitefly (SLW), *Bemisia tabaci*, B-biotype is resistant to most insecticides used for control (including OPs, carbamates, pyrethroids, imidacloprid and insect growth regulators (IGRs)). Management of this pest hinges on an IPM strategy that incorporates biological, cultural & insecticidal management practices. This includes the avoidance of broad spectrum sprays and the strategic early use of IGRs to slow the growth of whitefly populations while allowing the buildup of beneficial insects to maintain whitefly at sub-economic levels. The IGR's are at risk due to resistance so use is limited to one application during a defined window within the season.

The silverleaf whitefly (SLW), *Bemisia tabaci*, B-biotype is resistant to most insecticides.

Although SLW has only been an issue in Central Queensland it has the potential given the right environmental and cropping conditions to be a problem elsewhere in the industry. Monitoring SLW populations is therefore conducted to provide an early warning of potential infestations.

The SLW does not have an overwintering diapause stage, and in warm areas can survive through the winter. A major factor to reduce the likelihood of a SLW outbreak is to discontinue the availability of host plants. This occurs in regions such as northern NSW and the Darling Downs where the predominant rotation is cotton / cereal or cotton / legume which are not particularly good hosts for the SLW. In regions such as the Emerald irrigation area, the continuous availability of suitable hosts such as horticultural vegetables, particularly cucurbits, encourages SLW outbreaks. Weed cucurbits or thistles should be controlled as they can also act as reservoirs for whitefly to survive through the winter months.

For further information on managing SLW visit www.cotton.pi.csiro.au/Assets/PDFFiles/Wflymng.pdf

3.4.2.3 Other pests can develop resistance

The sucking pests (mirids and green vegetable bugs) previously controlled by broad spectrum sprays for *Helicoverpa* are becoming more common, particularly as greater areas of Bollgard II® cotton are planted with the associated reduction in spray numbers.

Although the resistance management strategy does not specifically mention these pests, they may develop resistance. It is important to consider this when controlling sucking pests as the over reliance on any one insecticide or insecticide group increases the risk of selecting for resistance.

Winter weeds and crops such as safflower are good winter hosts for mirids. It is therefore important to practice good farm hygiene to control winter weeds and choose your winter rotation crop carefully. For more information on weed and crop hosts refer to '*Cotton insect pests and their weed hosts'*, '*Cotton insect pests and their crop hosts'* and '*Managing and knowing your rotation crop'* in objective 5.

For more information on the life cycle and abundance of green mirids and green vegetable bugs visit the '*Cotton Pest and Beneficial Guide'* on the Australian Cotton CRC website.

It is important to consider resistance management when controlling pests such as the green mirid.

3.4.3 Using trap crops to prevent the development of resistance

Trap cropping is a technique used to concentrate a pest population into a small area of crop where they are easy to control. In cotton, trap crops can be used in spring and summer to concentrate and control populations of *Helicoverpa armigera*. This assists resistance management, as well as IPM, by reducing the size of the overall pest population which reduces the need to apply insecticides and reduces the selection pressure for the pest to develop resistance. Critical to the success of trap crops is controlling the concentrated population, preventing population increase and the flow of resistance genes. To be effective, trap crops must be considerably more attractive than the primary crop or other hosts available at the time or be the only suitable host available. If there are large areas of other attractive weeds or crop hosts, the trap crop is unlikely to be effective.

Spring trap cropping concentrates *H. armigera* moths emerging from diapause, usually between September and October. These moths will establish the first generation of larvae. The moths may originate within the cotton cropping system, i.e. they may have escaped control by pupae busting, and be carrying resistance genes from one season into the next. Alternatively, they may come from other nearby crops or weeds or be migrants from a long distance away. By concentrating and destroying this first generation it may be possible to reduce the size of future generations on cotton and other crops. Even in areas like Central Queensland, where levels of overwintering diapause is low, spring trap crops play an important role. They attract the eggs of the first and second generations of moths during a time when very few suitable hosts are available.

Pigeon pea (a last generation trap crop) growing along side cotton.

Summer trap cropping acts to draw *H. armigera* away from a susceptible crop like cotton, and can also produce large numbers of beneficial insects. Once the *H. armigera* are concentrated in the trap crop they can be controlled. In Central Queensland cotton growers use summer trap cropping as part of their insect resistance management strategy for Bollgard II® cotton (refer to '*Trap crops in Central Queensland'* in objective 6).

Last generation trap cropping has also been proposed as an option to help manage resistance, though the benefits are less clear. Last generation trap crops concentrate moths emerging late in the cotton season which are the non-diapausing pupae from the last generation in autumn. These pupae are likely to be more abundant under conventional cotton and will have had intense insecticide resistance selection, so by concentrating the eggs from these moths in the trap crop, the grower can control the resulting larvae and reduce the overall number of resistant *H. armigera*. The development of non-diapausing pupae is driven by temperature. Depending on when they pupated they could emerge in the autumn or early the following spring (before the diapausing pupae). The real question then is whether last generation or autumn trap crops are really necessary or effective. In most cotton regions a high percentage of pupae formed late in the season will enter diapause (see the diapause induction Tables 11 - 14). The small number which emerge during April, May, June are unlikely to successfully generate many larvae. The most effective method to control both non-diapausing and diapausing pupae is to pupae-bust as soon as practical after harvest.

For more information on trap cropping see objective 6 - '*Using trap crops effectively'*.

3.4.4 Controlling resistant pests

A ladybird larva feasting on a large aphid colony.

The best way to reduce the population of a resistant pest is through the encouragement and use of its natural enemies (usually in combination with the absence or minimal usage of broad spectrum insecticides).

For example, a hungry ladybird can eat 50 aphids a day. Assassin bug nymphs have large appetites and can consume up to 160 small to medium sized *Helicoverpa* larvae over a 9–12 week period.

For more information on conserving beneficial insects refer to the section '*Guidelines for use of food sprays and the predator to pest ratio'* in objective 3.

3.4.5 Insecticide application failures

The presence of live pests following an insecticide application is not necessarily an insecticide failure. Some stomach poisons take 5-7 days after application before they give maximum control. Often while these insecticides are taking effect, the pest will cease feeding causing little if any economic damage to the crop.

If you suspect a spray failure:

1. Examine all the conditions that may have caused poor control.
2. Do not use rates above those recommended on the label or two insecticides of the same group. This does not improve the level of control.
3. Choose mixtures carefully on the basis of the pest spectrum.
4. If you suspect insecticide resistance, do not follow up with an application of the same insecticide group alone or in a mixture.
5. Do not expect satisfactory control of medium and large *Helicoverpa* larvae. Target *Helicoverpa* sprays against eggs and very small larvae.
6. Do not try and achieve 100% control. Aim to reduce the infestation below threshold.

For more information refer to the '*Cotton Pest Management Guide'*.

3.4.6 Resistance management for Bollgard II® crops

In Bollgard II® crops the two proteins (Cry1Ac, Cry 2Ab) that kill *Helicoverpa* and many other lepidopteran pests are present for the whole season. This prolonged exposure to the pest population of these proteins means there is very high selection for resistance.

A resistance management plan has been developed for Bollgard II® to preserve the effective life of this product. The strategy primarily makes use of the presence of two proteins as a pest would have to develop resistance to both proteins to survive (this is in theory, but in practice the two proteins are expressed at different levels and have different toxicities). The resistance strategy for Bollgard II® relies on growing refuge crops capable of producing sufficient susceptible *Helicoverpa* moths to dominate the mating with any survivors from the Bollgard II® crops as shown in Figure 10. The strategy also includes restrictions on the planting window to shorten the period of exposure to the proteins; guidelines on the management of volunteer or ratoon cotton; the destruction of pupae and control of above threshold pest levels with insecticides. In Central Queensland the destruction of pupae is ineffective as temperatures are too warm for pupae to go into diapause. Instead, trap crops are used to concentrate moths where their resulting larvae can be controlled by insecticides or pupae by cultivation.

Adherence to the resistance management plan is required under the terms of the Bollgard II® technology user agreement. For further information regarding the resistance management plan contact your Monsanto business manager or your local seed company, CSD or Deltapine.

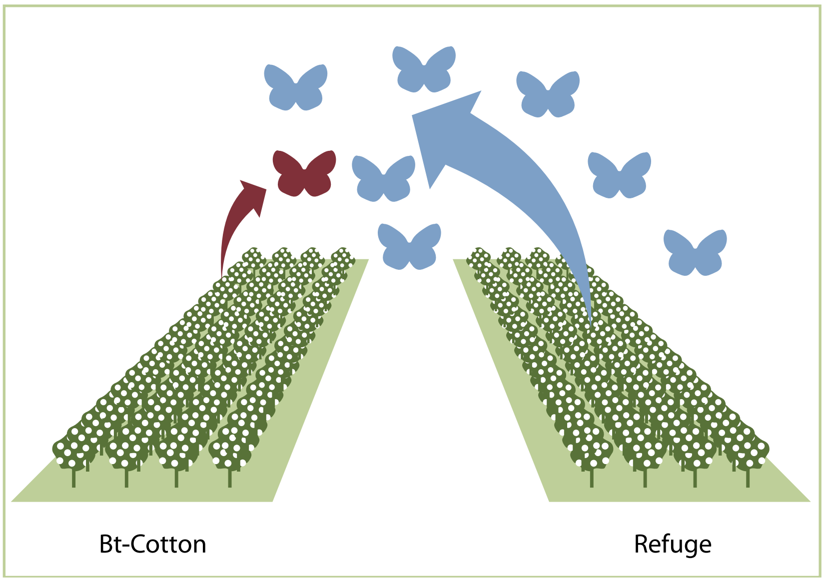


Figure 10.

Refuges produce large populations of susceptible moths (blue) to dilute any resistant moths (red) that have survived in Bollgard II® crops.

Source: Dr Gary Fitt (CSIRO)