The introduction of transgenic cotton in 1996 has allowed the industry to totally revolutionise the way cotton is produced. Over 90 per cent of the cotton grown in Australia in 2012 utilised Bollgard II technology, making it arguably the most important technology the industry uses. Growers now have confidence in the technology to guard against Helicoverpa all season long. In combination with integrated pest management techniques, this confidence has seen pesticide use in the industry decline by more than 90 per cent. But, what calms the nerves of cotton growers and consultants, raises the heart rate of the cotton industry’s Helicoverpa ecology and resistance researchers. Constant expression of the Bt toxins means there is prolonged selection pressure each season, greatly increasing the risk that the industry’s pest nemesis, Helicoverpa armigera, will evolve to survive.

CSIRO’s resistance monitoring research has shown that in both of the target pests, H. armigera and H. punctigera, resistance genes to Cry2Ab are present, are higher than expected, and are probably increasing. This finding is especially surprising for H. punctigera which has never evolved significant resistance to conventional insecticide sprays. The different response to Bt and conventional insecticides could reflect an apparent lack of large spring migrations of moths from susceptible inland populations into cropping regions since Bollgard II cotton has been grown, resulting in less resistance dilution. There is also some evidence that H. punctigera is over-wintering in the proximity of crops which is again unusual for this species, and something that may have changed since Bollgard II was introduced.

The Bollgard II Resistance Management Plan (RMP) is the key to managing this resistance risk. Refuge crops are a mandatory component of the RMP and integral to the protection of the technology for future use.

**What is the purpose of refuges?**

The aim of a refuge crop is to generate significant numbers of susceptible moths that have not been exposed to the Bt proteins in Bollgard II. Moths produced in the refuge will disperse to form part of the local mating population where they may mate with any resistant moths emerging from Bollgard II crops, delaying the development of resistance. This strategy works because resistance to the Bt proteins has so far been found to be recessive, so if a resistant moth (rr) from the Bollgard II crop mates with a susceptible moth (ss) from the refuge, the offspring they produce (rs) are also killed by the Bt toxins.

**Refuge management**

The current RMP options for irrigated Bollgard II refuges are 100 per cent sprayed cotton, 10 per cent unsprayed cotton or five per cent pigeon pea (relative to the area of Bollgard II cotton grown) with almost 70 per cent of refuges grown being pigeon pea. These options were initially derived by models which showed that to delay Bt resistance in Helicoverpa it was necessary to ensure that 10 per cent of the Helicoverpa population were exposed to a non-Bt crop or, put in another way, that 10 per cent of all Helicoverpa eggs were laid on plants not containing Bt toxins. In the mid-1990s CSIRO research showed that on average pigeon pea produces twice as many susceptible moths as unsprayed cotton, so only half the area is needed to produce the same number of moths (five per cent pigeon pea refuge). Sorghum and corn used to be refuge options but were removed when resistance genes to Cry2Ab were shown to be increasing in H. punctigera which do not regularly use these plants as hosts.
Foliar applications of potassium are very important in cotton. Potassium is the key mineral required for fibre quality.

- Senescence of root systems post-flowering reduces capacity for potassium uptake
- Many soils are deficient in potassium
- Foliar applications of potassium are quickly absorbed and maximise fibre quality
- Apply potassium in combination with phosphorus or nitrogen to achieve maximum returns
- SLTEC has a foliar solution to suit your crop

SLTEC Fertilizers offers an extensive range of liquid fertilizer solutions tailored to deliver results.
No matter which refuge is grown, it is critical that they are managed to be most attractive to Helicoverpa moths when Bt cotton is also most attractive.

The productivity of refuges varies considerably in space and time, both between and within individual crops and also seasons. Not every dedicated refuge will produce large numbers of susceptible moths, but they need to have the capacity to potentially do so. By chance, some refuges may not be colonised by moths. Others may harbour abundant natural enemies of Helicoverpa (e.g. parasites and diseases). CSIRO research at St George has clearly shown that few refuges within a landscape (about 25 per cent) may produce most (over 50 per cent) of the refuge-derived moths. It is the collective performance of refuges within landscapes that is paramount to success.

For a refuge to be most effective, it must be planted close to its corresponding Bollgard II crop (within two km) to improve the chance that its moths will mate with potentially resistant moths from the Bollgard II. Helicoverpa are capable of migrating long distances, but during the cropping season a significant part of the population will remain localised on preferred hosts and move only a few kilometres.

The RMP requires growers to ensure that their refuge crops receive adequate nutrition, irrigation (for irrigated refuges), and weed and pest management (excluding Helicoverpa sprays) so that they remain attractive while Bollgard II is grown. A healthy and productive refuge is an asset for the future of the cotton industry, helping to ensure Bt technologies in their current and future forms continue to effectively control Helicoverpa.

Farm manager at Auscott Warren, Sinclair Steele, says that while it can be a challenge to manage pigeon pea, not having access to Bt technology due to resistance would be far worse.

“Establishing and managing a healthy refuge is an important part of our operations” says Sinclair. “Pigeon pea refuges are inoculated at planting, and we use residual herbicides to help make sure that refuge crops are healthy and weed free. The location of our refuges is also really important. We try to plant refuges upwind of the cotton in the prevailing wind direction to minimise potential Roundup Ready Herbicide drift onto pigeon pea, and also to make sure refuges aren’t impeding Roundup sprays on our cotton fields. Having healthy, attractive refuges means we are doing our bit for resistance management.”

Role of non-mandatory refuges

Helicoverpa are polyphagous which means that they feed on a wide range of host crops and vegetation, including cotton. Bt cotton dominates the total area of cotton grown in Australia but at a landscape scale it often forms part of a mosaic of other crops and vegetation.

Non-cotton crops and natural vegetation are known to be important for Bt resistance management by providing alternative sources of Bt susceptible moths apart from those produced by the mandatory refuges. But we cannot confidently rely on these unstructured refuges to produce moths because their effectiveness and distribution is highly variable.

An important characteristic of mandatory refuges is their synchronicity with the corresponding Bollgard II crop. The timing of refuge planting is dependent on the timing of Bollgard II cotton planting so that the refuge is flowering (both pigeon pea and cotton refuges) at the same time as the Bollgard II. Ideally, refuges should be as or more attractive to Helicoverpa than the corresponding Bollgard II crop to attract females to lay eggs in the refuge. So both structured and unstructured refuges play an important role in delaying resistance.

A valuable resource

With the industry currently looking at third generation Bt technology (Bollgard III), it is a crucial time for resistance management. CSIRO’s resistance monitoring data has detected resistance genes to both proteins in Bollgard II and a concerning increase in resistance to Cry2Ab. In addition, for the past three seasons CSIRO has performed screens against the new protein in Bollgard II (Vip3A) and found that in H. armigera the frequency of genes conferring resistance is around one in 20 moths. Not only is this higher than expected, it is much greater than the starting frequencies for Cry2Ab. Vip3A resistance genes have also been detected in H. punctigera at a frequency that is higher than expected, and higher than the starting frequencies for Cry2Ab.

Work is underway to characterise this Vip3A resistance. This information, along with data on the efficacy of Bollgard III against Helicoverpa (also underway), will be used with information on the frequencies of Cry1Ac, Cry2Ab and Vip3A to determine the RMP for Bollgard III. At this stage it is almost certain that we will not be developing a RMP with a clean resistance slate.

Mandatory refuges are a critical component of the current RMP, providing a reliable source of susceptible moths to dilute the population of resistant individuals. It costs money to establish and maintain a healthy and viable refuge but it is an investment to protect the future of Bt cotton in Australia, the value of which is the industry’s continued access to the technology. We cannot afford to not take refuges seriously, and all Bollgard II cotton growers have a responsibility to grow and manage their refuges well.