Towards a Strategy for Using Bt toxins in New Zealand

A response to recommendation 7.1 of the Royal Commission on Genetic Modification

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1. The Royal Commission's Recommendation

The Royal Commission recommended:

that, prior to the release of any Bt-modified crops, the appropriate agencies develop a strategy for the use of the Bt toxin in sprays and genetically modified plants, taking into account:

- *the concept of refugia;*
- *limitations on total planted area;*
- *home gardener use.*

The Commission heard from growers and researchers about the use of the bacteria *Bacillus thuringiensis* (Bt) as an insecticidal treatment. These groups noted that the continual presence of Bt toxin in genetically modified plants could increase the risk of Bt resistance developing in local insect populations, which would reduce the value of Bt pesticides in conventionally and organically grown crops. It was noted that home gardeners also use Bt sprays.

The Commission agreed that Bt resistance should be avoided and considered that New Zealand needs to develop a strategy to manage the use of this insecticide, whether incorporated in genetically modified plants or used conventionally as a spray. The aim of such a strategy would be to delay the onset of insect resistance to Bt.

The Government accepted this recommendation and directed officials, led by the Ministry of Agriculture and Forestry, to investigate and report on the practicalities of strategies to help preserve the long-term effectiveness of Bt insecticide.

2. Background & History

BACILLUS THURINGIENSIS

Bacillus thuringiensis (Bt) is a rod shaped, aerobic, spore-forming bacterium. It is related to other *Bacillus* species such as *B. cereus*, the causative agent of some types of food poisoning, and *B. anthracis,* the causative agent of anthrax. During sporulation Bt produces protein crystals which are often toxic to invertebrates. The species comprises diverse strains with different toxin profiles, and the range of toxins can affect several different types of invertebrates.

Bt was first isolated in 1901 by a Japanese biologist, S. Ishiwata. Ishiwata identified the bacterium as the causal agent of a disease of silkworms. In 1938, commercial production of Bt as a spray for insect control began in France, and the first commercial Bt formulations were made available for field testing in the USA in 1958. Until the 1970s it was generally accepted that lepidopteran insects (moths and butterflies) were the only targets of Bt.

New markets were opened by the discovery in 1976 of the *israelensis* subspecies, which is toxic to larval mosquitoes and black flies (known as sand flies in New Zealand), and the discovery of the *tenebrionis* subspecies which is toxic to several beetle species.

In the 1980s, commercial interest in Bt grew as alternatives to synthetic pesticides were sought. The use of Bt toxin genes in genetically modified plants for pest control became an established field of research in the mid-1980s. From the mid-1990s, plants genetically modified to express the Bt toxin have become increasingly common, and are now grown widely in the USA and other countries, though their use remains controversial.

INSECTICIDE RESISTANCE & RESISTANCE MANAGEMENT

Until the 1950s, relatively few people considered resistance to pesticides to be a serious threat to pest management. Although some insects had evolved resistance to DDT, the prevailing feeling was that resistance could be overcome by using ever newer pesticides. However, in the 1970s, it became clear that at least some pests were evolving resistance faster than new and environmentally acceptable pesticides could be developed and brought to market. Indeed, two of the first three genetically modified Bt crops registered in the USA, cotton and potatoes, were targeted at markets essentially created by the recurrent evolution of resistance to insecticides in certain pests[1] (Roush, 1997).

The concept of resistance management began to evolve in the late 1950s. The aim of resistance management programmes is to "slow the evolution of resistance and thereby extend the useful life of valuable toxicants" (Roush, 1997). The historical lesson from insecticide resistance that is relevant to genetically modified crops is that resistance can most effectively be delayed by a combination of molecular biology, population genetics and careful management practices in the field.

Various Bt toxins (Cry proteins) can be inserted into target crops and this selection should minimise exposure of target pests to similar Cry proteins, for example by avoiding the use of the same Cry protein in sprays and genetically modified crops. Similarly, the use of the same Cry protein in multiple crops visited by the same pest species will favour the development of

[1] The pink bollworm (*Pectinophora gossypiella*), two cotton bollworms (*Heliothis virescens* and *Helicoverpa armigera*) and the Colorado potato beetle (*Leptinotarsa decemlineata*).

resistance and should also be avoided. Strategies for the application of these techniques in New Zealand have been proposed by Wigley *et al*. (1994) and Wearing and Hokkanen (1994), and are summarised by Madhusudhan *et al*. (2000).

Once genetically modified plants are deployed, there are a number of ways to slow selection in favour of resistance[2]. Expert opinion around the world has mainly supported the use of a **high dose / refuge approach** where the genetically modified plants produce as much toxin as possible and refuges are provided for insects with genes for susceptibility. This strategy is currently used in commercial production in several countries.

High dose/refuge approach

In the pest control context, the word "refuge" is used to mean an area of habitat where susceptible pests can survive. For example, if a cabbage-eating caterpillar is susceptible to chemical X, a refuge for that caterpillar could be an area of cabbages that was not sprayed with chemical X. The refuge must contain host plants that make it possible for the susceptible insects to breed without coming into contact with chemical X and being killed. The host plants do not necessarily need to be of the same species as the crop that is being protected.

Allowing susceptible insects to survive in a refuge reduces the rate at which the entire population is likely to develop resistance to the pesticide (see Figure 1).

Refuges are aimed at maintaining susceptible populations in numbers that will sufficiently dilute any resistance that arises in the target populations. The approach assumes that mating will be random between insects living in the refuges and those in the crop being sprayed or the genetically modified crop. Growers of genetically modified plants are usually required to provide their own share of refuges, both for equity reasons and to keep refuge sites close to the genetically modified plants.

The amount and size of refuges that are necessary will differ depending on the mobility and ecology of the insect, the type of crop and geographical area. The necessary size of the refuge can also vary depending on whether the refuge is sprayed with any chemical control, and on the biology of the pest and the crop. If unsprayed, higher numbers of susceptible pests could be expected to build up, meaning that the refuge area can be smaller. Inclusion of a refuge may reduce the proportion of marketable produce for some crops, which will affect growers' desire to use this strategy.

The ability of a pest species to move, its breeding biology, the crop biology and the pest's feeding habits will all have impacts on the size and type of refuges that are necessary to preserve the effectiveness of Bt. For example, if a pest species feeds on clover but also on broccoli, and a Bt broccoli crop is introduced, the refuge requirement may simply be to plant the broccoli in fields that are close enough to clover pasture to allow a population of non-resistant pests to be maintained. However, if a pest species is highly specific to one plant (crop) type, the refuge requirement may need to be for an unsprayed refuge of the same crop. The potential impacts of alternate hosts, adult and larval movement, and refuge position are currently being investigated in model systems using brassicas and potatoes (Cameron *et al*. 2002, Madhusudhan *et al*. 2000).

[2] For a list of various strategies that can be used to delay the onset of resistance, refer to Roush (1997).

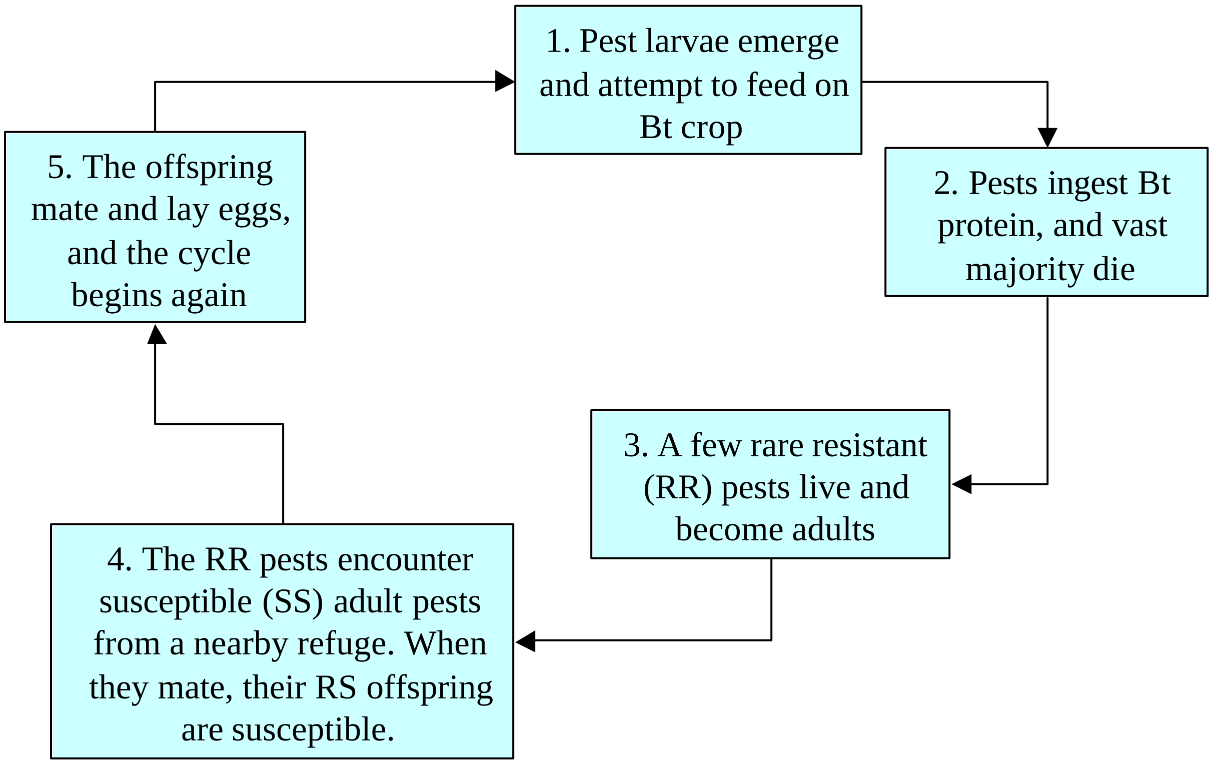

Figure 1: Basic theory of refuges and resistance for a genetically modified Bt crop

Where the damaging stage of a pest comprises only the larvae, and they do not move from plant to plant (e.g. some stem boring insects), then seeds for crops can be pre-mixed to contain both conventional seeds and genetically modified Bt seeds. This ensures that every crop effectively contains a refuge. Interplanting of susceptible and resistant plant lines is a variation on the same idea. Evidence that some insects move away from plants expressing pesticides to conventional plants may reduce the value of interplanting or seed mixtures. This suggestion requires further research.

The success of the high dose strategy depends on resistance being a rare and recessive trait. Insects with resistance genes may have varying degrees of resistance depending on whether they carry one (RS in Figure 1) or two copies of the gene for resistance (RR). Controlling the dose is important. The dose of toxin should be sufficient to kill all homozygous susceptible individuals (SS) and all heterozygotes with genes for both resistance and susceptibility (RS). It is generally not feasible to deliver a high enough dose of toxin to kill individuals homozygous for resistance (RR). If the dose is allowed to degrade, heterozygotes may survive and increase the frequency of the resistance gene.

CURRENT STATE OF KNOWLEDGE ABOUT BT RESISTANCE

The most compelling evidence that Bt resistance can evolve comes from field populations of the diamondback moth (*Plutella xylostella*) where resistance has developed after frequent exposure to Bt sprays. This moth is a major pest of vegetables around the world, and receives frequent exposure to pesticides. This exposure and the moth's biology have contributed to its extensive resistance to most insecticides in many growing areas. Laboratory selection in other species has shown that broad cross-resistance to many Bt toxins is possible. Four other lepidopterans in addition to diamondback moth have been suggested as showing resistance or potential for resistance to Bt under field selection (Glare and O'Callaghan, 2000).

Observations of diamondback moth have shown that resistance to Bt spray can evolve in the field in less than two years with sufficient selection pressure. The lack of field resistance to date in insects other than diamondback moth has been attributed to the relatively small amount of Bt currently applied in comparison to other pesticides.

With the increasing use of Bt genes in genetically modified plants, there is concern that resistance will develop more quickly and many strategies are under discussion to prevent this. After six years of commercialisation in the USA, no reported insect resistance has developed in response to the Bt toxins incorporated in Bt corn, Bt cotton, or Bt potato crops. A summary of research on the environmental impacts of Bt cotton in China claimed that insects would develop resistance to Bt cotton after 8-10 years of continuous planting (Xue 2002). However, one of the scientists whose work was quoted in the summary subsequently said that the research was incorrectly summarised and that no resistance was apparent after 4 years' study of field populations (Wu 2002).

Scientists believe that it is too soon to conclude whether current resistance management strategies for Bt crops have been successful in preventing resistance in the long term. More information is still required on mechanisms of resistance, inheritance, pest behaviour and other aspects before a complete management plan can be developed for pest insects (Glare and O'Callaghan, 2000).

3. Current Use of Bt Overseas

GENETICALLY MODIFIED BT CROPS

Countries that have had commercial releases of plants modified to produce Bt toxins include Australia, Canada, China, India, Mexico, South Africa, Spain, and the USA[3].

In the USA, the Environmental Protection Agency estimates that Bt field corn was grown on 0.4 million acres (1 percent) in 1996, 4.4 million acres (6 percent) in 1997, 14.5 million acres (18 percent) in 1998, 19.8 million acres (26 percent) in 1999 and 19.5 million acres (25 percent) in 2000. For Bt cotton, the total planted was 1.8 million acres in 1996, 2.6 million acres in 1997, 2.5 million acres in 1998, 3.6 million acres in 1999, and 4.4 million acres in 2000. For Bt potatoes, data indicate that 50,000 acres of Bt potatoes were planted in 1998 and 1999, and about 5000 acres were planted in 2000 (USEPA, 2001). In addition to commercial plantings, some 18 other Bt crop species including apples, broccoli, rice, tomato and walnut have been approved for field testing (Mellon and Rissler, 1998).

In Australia, it was estimated that around 30 percent of the cotton grown in the 1999-2000 season had been modified to express a Bt toxin[4]. In September 2002, a new variety of Bt cotton was approved for commercial release south of 22 degrees South. The new variety, called Bollgard II expresses two different Bt proteins and is therefore "expected to be less susceptible to insect predation and less likely to promote the development of resistance"[5].

NON-GENETICALLY MODIFIED BT SPRAYS

Pesticide sprays containing Bt are used worldwide, but only represent a small proportion of the overall global market for pesticides. There is evidence that resistance to Bt sprays can arise with overuse in the field and Bt sprays have recently been subject to resistance management programmes (e.g. Walker *et al*. 1999).

In the early 1990s, the global market for Bt-based bioinsecticide was estimated to be in the range of 100 million US dollars. In 2000, the global insecticide market was estimated at 8 billion US dollars and there was considered to be a strong indication that biological pesticides accounted for some 500 million US dollars (Joung and Côté, 2000). Again, market opportunities for Bt may be arising as consumers seek alternatives to products that have been sprayed with conventional chemical insecticides.

Bt-based sprays are used to control pests on a number of crops in the USA. The National Pesticide Use Database (1997) recorded that Bt-based sprays were used on 12 percent of apples grown, 56 percent of cabbage, 43 percent of lettuce, and 28 percent of strawberries. Bt-based sprays were used on less than 1 percent of cotton, corn and soybeans being grown[6].

[3] http://www.essentialbiosafety.info/dbase.php
[4] "Managing Bt resistance - http://genetech.csiro.au/research/cotton/fitt_bt_final1_long.htm
[5] "Gene technology regulator refuses commercial release of GM cotton in northern Australia, but gives approval elsewhere", Office of the Gene Technology Regulator, 24 September 2002, http://www.ogtr.gov.au/media/comcotton.pdf
[6] Refer to the National Pesticide Use Database, National Center for Food and Agricultural Policy, http://www.ncfap.org/database/default.htm

4. Current Use of Bt in New Zealand

Several pesticide (spray) products containing Bt are currently registered for use in New Zealand. These include Foray, Dipel, Delfin and Agree. Bt is one of the few pesticides available for insect control on organic crops. No genetically modified plants have been approved for release in New Zealand.

Bt products are used in the fruit industry to prevent leafroller establishment during the blossom period. In kiwifruit, around 40 percent of growers use Bt spray on their crops (Wigley & Chilcott, 1994)[7]. The kiwifruit industry is an example of one where the majority of production is through integrated pest management, and use of chemical sprays has been significantly reduced. Bt is similarly used in vegetable integrated pest management programmes in brassicas and tomatoes. However, the scale of the use of Bt by growers in New Zealand is still relatively small, hence the argument that large scale use in genetically modified crops is more likely to hasten the onset of resistance than continuing use as a spray.

Bt products have also been used by the New Zealand Government to respond to incursions of new pest organisms. The Bt-based spray Foray 48B has been used in the responses to white-spotted tussock moth and painted apple moth. A Bt-based product is also being used in the Ministry of Health's operation to contain and control the southern saltmarsh mosquito.

[7] Refer also to http://www.maf.govt.nz/mafnet/publications/pestrend/pestrends-07.htm

5. Resistance Management Strategies Overseas

In most areas where Bt crops are being grown overseas, resistance management is acknowledged as a priority for ensuring the long term viability of the crops. Case-studies in resistance management strategies from Australia and the USA are outlined below.

AUSTRALIA – INGARD® COTTON

The Australian cotton industry has developed a resistance management strategy in conjunction with the licensee of the technology (Monsanto), the Australian Cotton Cooperative Research Centre, and other bodies involved in the Australian cotton industry. The aim of the strategy is to help prolong the life and effectiveness of current and future technology to ensure the sustainability of the Australian cotton industry[8]. The main pest at which Bt is targeted in Australia is *Helicoverpa armigera*, a cotton bollworm.

Key elements of the resistance management plan for Ingard cotton are:

- restricted planting times
- hectare restrictions
- refuge crops
- spray limitations
- pupae busting/trap crops
- control of volunteer plants

Adherence to the resistance management plan is required under the terms of the Ingard Grower Agreement and under the conditions of registration (Agricultural and Veterinary Chemicals Act 1994). Audits are carried out by Technology Service Providers (the resellers or distributors of the technology – i.e. the people who actually sell seed to growers and to whom Monsanto license or sell the technology) to ensure that growers have a known area of Ingard cotton and that the correct area of refuge is planted. Audits are also carried out by growers. Growers receive a rebate if a spraying record is supplied, and in New South Wales and South Queensland, growers receive a rebate if they fully comply with pupae-busting requirements. Random auditing is also undertaken by Monsanto to ensure good compliance. This includes screening cotton plants for the specific genes to see if the mapping of Ingard areas and refuges carried out by growers has been correct. Wilful non-compliance results in no rebate being paid and the denial of access to the technology for a period.

Restricted planting times

Ingard cotton must not be planted later than November 15. This avoids late maturing and therefore minimises the crop's exposure to high densities of *H. armigera* during late summer.

Hectare restrictions

Growers are restricted to a maximum of 400 ha or 30 percent of the total cotton grown per farm unit and in situations where the Ingard area is less than 400 ha but exceeds 30 percent of the total cotton grown there are additional refuge requirements.

Refuge crops

The aim of a refuge is to generate significant *Helicoverpa spp.* populations which have not been exposed to the Bt protein. Moths produced in the refuge crop disperse to form part of the local mating population where they may mate with moths emerging from the Ingard crops,

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[8] A Guide to the INGARD® Resistance Management Plan 2001/2002. Cotton CRC, Australia.
http://www.cotton.crc.org.au/Assets/PDFFiles/IRMS/IRMS0102/Ingard01.pdf
http://www.cotton.crc.org.au/Assets/PDFFiles/IRMS/IRMS0102/RMPIng12.pdf

reducing the chances that two resistant moths will meet and mate. Provided that susceptible moths from the refuges always predominate in the local area they can effectively dilute resistance and slow down the rate at which resistance increases.

For this to be successful, refuge areas must be close to the Ingard cotton crop and must provide sufficient moths. The relative number of adults that emerge per hectare from Ingard cotton and the associated refuge crops determines the required size of the refuge areas. There are different percentage requirements when using different refuge options. There are also different refuge requirements for irrigated and dryland Ingard cotton crops and for the differing growing conditions for cotton in different areas.

The different percentage requirements for the different refuge options are based on data collected from field experiments conducted by the Cotton Cooperative Research Centre over several seasons. The experiments measured the average productivity of several potential refuges. Only refuges assessed in this way are currently approved by the National Registration Authority for use with Ingard crops. Unsprayed conventional cotton and pigeon pea generally produce more moths and over a longer period than sorghum and corn which, while effective, are most attractive at flowering and produce moths over a shorter period.

The movement of *Helicoverpa spp.* moths during the summer cropping season depends on the mix of crops and their attractiveness at the time of moth emergence. The best location for a refuge crop is close to the Ingard crop and at least within 2km.

For irrigated cotton, the refuge crops must also be irrigated to ensure they maintain attractiveness relative to the cotton. For each 100 hectares of cotton in New South Wales and Queensland, a grower is required to plant a minimum of:

- an area of irrigated conventional cotton of 100 hectares which can be conventionally managed for *Helicoverpa spp.* and other pests (no Bt products may be used); or
- an area of irrigated conventional cotton of 10 hectares which will not be treated for any reason with products that control *Helicoverpa spp.*; or
- an area of:
  - unsprayed irrigated maize of 20 hectares which must be planted in three plantings to ensure attractiveness throughout the season; or
  - unsprayed irrigated sorghum of 15 hectares which must be planted in three plantings to ensure attractiveness throughout the season; or
  - unsprayed irrigated pigeon pea of 5 hectares, planted within two weeks of the Ingard cotton and managed to ensure several cycles of flowering throughout the cotton season.

Growers choosing sorghum or maize are audited during the growing season to ensure compliance and that sufficient, timely plantings have been made to ensure that the crop is attractive at the stipulated times.

For dryland cotton, the refuge options are restricted to sprayed or unsprayed cotton planted at the time of the Ingard crop. Other crops are not suitable due to the uncertainty of the water supply for dryland crops. Future research may identify other options for dryland refuges.

Where Ingard is more than 30 percent of total cotton, farmers are required to plant an additional amount of refuge.

Spray Limitations

To ensure that adults emerging from refuge crops have not already been selected for resistance to Bt protein, no Bt sprays are allowed on any refuge crops for the entire season. Any management action that negatively affects the population of *Helicoverpa spp.* is regarded as an 'insecticidal' action. Inter-row cultivation destroys pupae and is not allowed in refuge fields unless the same action is carried out in the associated Ingard fields. Food sprays[9] are not permitted in refuge crops. Food sprays will increase the levels of beneficial insects which will decrease the *Helicoverpa spp.* population, acting as a form of 'biological' insecticide.

Pupae-Busting

All Ingard cotton crops must be cultivated after harvest at a level adequate to stop regrowth and to destroy pupae in the soil. In some states, pupae remain dormant in the soil over the winter months. In Ingard cotton, the pupae may comprise a higher proportion of resistant individuals as they will have survived on Ingard and then pupated. By destroying these pupae it is possible to selectively remove the more resistant individuals and reduce the overall frequency of resistant *Helicoverpa spp.* in the area.

Trap Crops

In Central Queensland, *Helicoverpa spp.* pupae produced late in the season do not remain in the soil but emerge within 15 days of pupating. Trap crops can be employed to attract any adult *Helicoverpa* emerging after the cotton has been cut out. After the cotton is harvested the trap crops should be destroyed, removing the food for the larvae which will then die.

Control of Volunteers

The presence of Ingard cotton volunteers within a conventional cotton crop imposes further selection pressure for Bt resistance. Conventional cotton volunteers within an Ingard cotton crop are also of concern. Growers are required to remove volunteers as soon as possible from all fields planted with Ingard cotton following conventional cotton and from all fallowed and conventional fields following Ingard cotton.

USA – INSECT RESISTANCE MANAGEMENT (IRM) FOR BT CORN & COTTON

In the USA, the Environmental Protection Agency (EPA) has imposed insect resistance management (IRM) requirements on registered Bt plant-pesticides (USEPA, 2001). It considers that sound IRM will prolong the life of Bt pesticides and that this is in the interest of growers, producers, researchers, and the American public. The EPA's strategy is two-fold: mitigation of any significant potential for pest resistance development in the field by use of IRM plans; and developing better understanding of the mechanisms behind pest resistance.

The EPA identified seven elements that should be included in a resistance management strategy for genetically modified Bt plants:

- knowledge of pest biology and ecology;
- appropriate dose expression strategy;
- appropriate refuge;
- resistance monitoring and a remedial action plan should resistance occur;
- employment of integrated pest management;
- communication and education strategies on use of the product; and
- development of pesticides/constructs that have alternative modes of action.

[9] Food sprays are artificial food supplements containing whey, yeast or sugar. They can act as an attractant and feeding supplement for some beneficial insects. Registered products that may be used include: EnviroFeast®, Bug-Chow®, and Pred-Feed®.

A dose rate of 25 times the protein concentration necessary to kill susceptible larvae has been defined as the minimum. It is considered that this toxin level should kill the majority of insects that are heterozygous for resistance to Bt. Refuges have been designed to produce a ratio of 500:1 Bt-susceptible insects to Bt-resistant insects. The placement and size of refuges is based on the current understanding of pest biology and Bt technology.

The IRM programmes for Bt corn and Bt cotton include:
- requirements for a non-Bt refuge in conjunction with any acreage of Bt crop;
- anyone purchasing Bt seeds must sign a grower agreement which contractually binds the grower to comply with the IRM programme and that there will be a mechanism by the year 2003 by which every grower annually affirms their contractual obligations to comply with the IRM programme;
- an IRM education programme;
- an IRM compliance monitoring system including a third party compliance survey and mechanisms to address non-compliance;
- an insect resistance monitoring programme for each target pest;
- remedial action plans to be implemented if resistance does develop; and
- annual reporting of the IRM and other activities.

Compliance

Grower compliance with refuge and IRM requirements is a critical element for resistance management and significant non-compliance may increase the risk of resistance. However, it is not known what level of non-compliance would compromise the risk protection of current refuge requirements.

To minimise the effects of non-compliance, the EPA considers that it may be necessary to develop a broad compliance strategy as part of the IRM strategy. Ideally this programme would include four major objectives:
- an understanding of the effect of non-compliance on IRM;
- identification of compliance mechanisms to maximise adoption of IRM requirements;
- measurement of the level of compliance; and
- establishment of an enforcement structure to ensure compliance and penalise non-compliance.

Various compliance mechanisms have been proposed, including techniques such as grower contracts, grower certification tests, fines and other penalties, community refuges, sales incentives, crop insurance of the refuge, deposit/refund for planting refuges, databases of non-compliant growers, county/area-wide compliance goals and sale restrictions, intensified grower education, and grower audits.

At present, the EPA's authority is over the registrants and not over individual growers. Registrants have been responsible for compliance through the use of grower contracts. However, it has been noted that the EPA's reliance on industry to monitor and enforce compliance is "seen as a major problem". It has been recommended that a third party compliance monitoring programme should be developed. This would be accompanied by an appropriate enforcement programme. Penalties for non-compliance might include: sales restrictions; sales prohibitions to specific growers; registrant fines and warnings; and increased refuges for specific non-compliant growers (through grower contracts).

Refuges for Bt Corn

The EPA put in place a consistent set of required refuge strategies for all Bt field corn products beginning with the 2000 growing season. Registrants are required to provide the EPA with data on how much Bt corn is sold, county-by-county, and have to provide educational material to growers in order to promote responsible product use.

The strategies require a 20 percent non-Bt refuge to be planted within ½ mile of the Bt crop. In certain southern counties and states where most Bt cotton is grown, the requirement is 50 percent non-Bt field corn refuge for Bt Cry1Ab field corn products to mitigate the development of resistance by corn earworm populations that feed on both corn and cotton.

Outside cotton growing areas, agreements specify that growers must adhere to refuge requirements as described in the grower guide/product use guide. The specific refuge requirements for Bt corn are:

- Growers must plant a refuge of at least 20 percent non-Bt corn that may be treated with insecticides as needed to control pests.
- Refuge planting options include separate fields, blocks within fields, or strips within fields.
- External refuges must be planted within ½ mile of the Bt crop (¼ mile or closer is preferred).
- When planting a refuge in strips across a field, strips must be 4 rows wide and preferably 6 rows.
- Insecticide treatments for control of pests may only be applied if economic thresholds are reached for one/more of the target pests. Instructions to growers specify that microbial Bt insecticides must not be applied to non-Bt corn refuges.

For Bt sweet corn, no specific refuge requirements are necessary because of harvesting times. However, the EPA has determined that crop residue should be destroyed within 30 days, which should kill any live larvae remaining in the corn stubble.

Refuges for Bt Cotton

The refuge options for Bt cotton crops are:

- A 5 percent external untreated non-Bt cotton refuge that must be 150 feet wide and preferably 300 feet wide. The refuge must not be treated with sterile insects, pheromones, or insecticides and must be within ½ mile of the Bt crop.
- A 20 percent external refuge within 1 mile (preferably ½ mile or closer) from Bt cotton fields that may be sprayed or treated with sterile insects, insecticides (excluding foliar Bt products), or pheromones. There are no guidelines concerning the insecticides to be used or a policy of rotation.
- A 5 percent embedded refuge that must be 150 feet wide and preferably 300 feet wide embedded as a contiguous block within the Bt cotton field (i.e. the block must be surrounded by Bt cotton). The refuge may be treated with sterile insects, insecticide or pheromones whenever the entire field is treated and must not be treated independently of the entire field at any other time.

The 5 percent external, untreated refuge option is due to expire in 2004 unless new information becomes available. During the next two years, the registrant of Bt cotton will be required to develop considerable new data on alternative host plants as possible effective refuges. The registrant will also be required to submit protocols to begin field tests on alternative hosts and chemical insecticide sprays on Bt cotton.

6. Resistance Management Strategies in New Zealand

Currently, there are no specific restrictions on the use of Bt sprays by home gardeners or farmers – conventional and organic. The environmental impact assessments for the eradication programmes for the painted apple moth and the white spotted tussock moth considered that the spray programmes were unlikely to create sufficient selection pressure for the moths to develop resistance.

There is no clear indication as to what genetically modified Bt crops (if any) might be released in New Zealand. However, Bt genes have been incorporated experimentally into plants such as white clover, potatoes and brassicas and there are a number of well-known and established pests that affect those crops, for example grass grub, porina moth, diamondback moth and potato tuber moth.

Knowledge of pest biology is critical for developing effective strategies to delay resistance. The body of reports and evidence from overseas experience with Bt crops is clearly relevant, but some of the pest-crop combinations are unique to New Zealand and will require specific consideration based on their ecological interactions (e.g. Wearing and Hokkanen 1994).

There has been considerable work since 1996, funded by the Foundation for Research, Science & Technology, to develop resistance management strategies for specific crops in New Zealand, building on plans and case-studies in Wearing and Hokkanen (1994) and earlier work by Wigley. The potential impacts on Bt resistance of key factors including choice of Bt toxin (Wigley unpublished), alternate hosts (Cameron *et al.* 1997), adult and larval movement (Cameron *et al*. 2002a), and refuge position (Cameron *et al*. 2002b) are currently being investigated in model systems using brassicas and potatoes. Progress to date is summarised in (Madhusudhan *et al*. 2000).

7. Where to From Here?

There is no doubt that maintaining the efficacy of Bt products is in New Zealand's interests. The question is whether government regulation is required, and over which uses.

Home gardener use in New Zealand is probably not significant enough to be regulated as part of a resistance management strategy. No other garden insecticides are restricted in this way, and some other garden products are more widely used than Bt in commercial production. Restrictions on Bt may perversely create incentives for using more toxic alternatives and would also be extremely difficult to enforce. However, to properly assess whether it should be regulated, the amount of Bt used in home gardens in New Zealand needs to be estimated and compared against other uses.

Commercial farmers, particularly those using organic or integrated pest management methods use Bt sprays more extensively than home gardeners and could be subject to controls to manage resistance. These users have strong incentives to maintain the long-term effectiveness of Bt on a voluntary basis, though the only evidence of Bt resistance to date has arisen from over-use of Bt sprays. Proposals to limit the use of Bt sprays would need to consider the effect of disincentives to use Bt sprays compared to alternative sprays, and how the controls would be enforced.

If Bt crops were to be considered for field tests in New Zealand, appropriate choice of Bt transformations and the use of refuges could be required to manage pest resistance as part of the conditions of the field test. During the development and testing phase for any proposed Bt crop, effectiveness against specific pests should be assessed.

It is highly likely that approval to release Bt crops in New Zealand will only be granted if the applicant has satisfactorily addressed resistance management. This is because the continual presence of Bt toxins in genetically modified crops are thought to pose greater risk of accelerating resistance than the use of Bt sprays. While there is no ability at present to regulate the use of a genetically modified crop that has been approved for release, the government is considering the idea of conditional release. However, users of Bt crops will also have strong incentives to maintain the effectiveness of Bt over the long-term on a voluntary basis.

In summary, the government should consider the following questions/issues:

- The amount of Bt used by home gardeners and commercial farmers should be estimated and assessed for its potential to accelerate the development of resistance.
- Similarly, a decision to regulate Bt crops to delay resistance should be justified by assessing whether selection pressure applied to pests from the Bt crops is sufficiently different from other methods of controlling those pests, including the use of Bt sprays. The assessment should take account of the numbers of Bt plants being used, as well as their characteristics.
- If regulation is considered, the usual process of evaluating costs and benefits should be followed. In particular, monitoring and enforcement will be critical issues. For example, there may need to be some sort of third party audit system, and a way of collecting data about the amount and location of Bt crops being grown or Bt spray being used.
- The government should continue to consider the potential for resistance when using Bt sprays for biosecurity operations.

Potential applicants seeking to release genetically modified Bt crops in New Zealand should consider developing a resistance management strategy and should factor in the research required to generate sufficient information for the application. This research should include knowledge of the characteristics of the proposed crop and Bt construct to be released, together with an understanding of the biology and genetics of the targeted pests.

The most established methods of resistance management overseas involve using selected toxins and the refuge/high dose methods and these will potentially be of the most immediate use in New Zealand. The issues and requirements would depend case-by-case on the particular crop and its pests. When designing a resistance management system, the seven key elements identified by the USEPA should be considered:

- knowledge of pest biology and ecology;
- appropriate dose expression strategy;
- appropriate refuge;
- resistance monitoring and a remedial action plan should resistance occur;
- employment of integrated pest management;
- communication and education strategies on use of the product; and
- development of pesticides/constructs that have alternative modes of action.

In situations where agronomic knowledge is limited and likely to be case specific, offering registered products for sale and controlling their use is a challenge. Bt crops lend themselves well to being co-operatively managed, using both scientific knowledge (e.g. generalised as indicated in this paper, or more specific as available and needed) together with the specific local knowledge of the land manager (as alluded to in the case-studies). Plans reflecting the specific characteristics of the crop and the land can then be developed collaboratively and modified through time as understanding and knowledge increases. Such a programme will need to be scientifically developed in order to be effective. Its chances of success in implementing a resistance management programme will need to be assessed as part of the analysis. The criteria and the means by which success is measured will need to be established as part of the analysis.

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