Australian Government
Bureau of Rural Sciences

Genetically modified crops: tools for insect pest and weed control in cotton and canola

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ISBN 1 921192 19 4

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Preferred way to cite this report:

Holtzapffel R, Mewett O, Wesley V and Hattersley P 2008, *Genetically modified crops: tools for insect pest and weed control in cotton and canola*, Australian Government Bureau of Rural Sciences, Canberra.

Foreword

Agriculture has always been subject to the limitations imposed by insect pests and weeds. These stresses cause significant yield and quality losses to Australian crops and the cost of controlling them can be high. This report explores the role of genetically modified (GM) insect-resistant and herbicide-tolerant crops as tools for insect pest and weed control in Australia and overseas.

In the Australian cotton industry, which has been growing GM insect-resistant varieties for more than ten years, the agronomic and environmental benefits of this technology have been demonstrated. There have been reductions in insecticide use and pesticide residues in rivers. Together with the introduction of the Best Management Practices Program for cotton production, GM cotton has contributed to the increased sustainability of cotton farming. The majority of Australian growers have also reported economic benefits from growing GM cotton.

In a similar manner, the introduction of GM herbicide-tolerant canola varieties to Australia has the potential to increase yields, offer a greater choice of weed control options and reduce environmental impact by enabling farmers to use more environmentally-benign herbicides. This has been the experience in Canada.

There are also challenges associated with the adoption of GM crops. Managing the potential for insect pests to develop resistance to the active ingredient in GM insect-resistant crops is a major challenge. For herbicide-tolerant crops, the potential for weeds to become herbicide-resistant and, in the case of canola, the potential for transfer of herbicide tolerance genes to conventional canola plants or related weeds, are significant management challenges. Such challenges can be met through Integrated Pest Management and Integrated Weed Management systems, designed to maintain the sustainability of GM crops as new pest and weed control tools.

Future developments in GM insect-resistant and herbicide-tolerant crops are likely to provide further valuable tools for Australian agriculture.

K Schneider

Karen Schneider
Executive Director
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Executive Summary

Insect pests and weeds represent a high cost to Australian agriculture through reduced yield and the cost of control measures.

Insect pests and weeds cause significant yield losses in Australian crops and the cost of controlling them can be large. Insects are responsible for approximately 10–20 per cent yield losses in major crops worldwide, and far more in developing countries. For example, cotton bollworm (*Helicoverpa*) caterpillars have the potential to destroy an entire cotton crop if not controlled.

The total economic damage and control costs for *Helicoverpa* species in Australian agriculture were estimated in 1997 to be in the range of A$159 million to A$328 million annually, with the greatest proportion incurred by the cotton industry (A$102 million–162 million) before the introduction of GM insect-resistant crops in 1996.

Weeds are estimated to have caused an average loss of A$3.9 billion annually over the five year period 1997–98 to 2001–02. Australian farmers consider weed control to be one of their highest priority land management issues.

Insect-resistant and herbicide-tolerant crops assist with the control of insect pests and weeds in Australian agriculture.

Modern biotechnology has developed genetically modified (GM) herbicide-tolerant and insect-resistant crop plants as new tools to reduce the adverse impacts of insect pests and weeds on production. This report explores the significance of these crops for insect pest and weed control in Australia and overseas.

GM crops have become important components of Integrated Pest Management (IPM) and Integrated Weed Management (IWM) systems, which involve the use of a variety of methods to control insect pests and weeds in crops rather than reliance on a single type of control (e.g. chemical application). Such systems have been developed to improve the sustainability of control methods, particularly through decreasing the risk of the pests or weeds developing resistance to chemical controls.

Genetically modified insect-resistant and herbicide-tolerant cotton are grown extensively in Australia.

In Australia, GM insect-resistant and herbicide-tolerant cotton varieties are currently the only GM crops to have been grown extensively to date. They have made important contributions to the management of insect pests and weeds on Australian cotton farms since their introduction in 1996 and 2000 respectively. These new tools have also provided environmental benefits through reduced and/or altered use of some chemical inputs.

These contributions are discussed in this study and the effects of GM crops in selected overseas countries are reported for comparison. Some new developments are also outlined.

GM herbicide-tolerant canola was approved by the Gene Technology Regulator in 2003 for commercial release. It is being commercially grown in Australia for the first time in 2008.

Non-GM herbicide-tolerant canola varieties are widely grown in Australia, particularly in Western Australia. GM herbicide-tolerant canola was approved for commercial release by the Gene Technology Regulator in 2003 following assessment of human health and environmental risks. However, they were not permitted to be grown in major canola-growing states because canola-growing states imposed moratoria.

Following recent reviews of their moratoria, Victoria and New South Wales now allow commercial production of GM canola from 2008, thus giving their farmers access to the benefits of these GM canolas. Limited seed stocks, however, means there will be a small GM crop in 2008 in Australia.

This report considers Canada's experience with GM canola and explores its possible effects in Australia.

This report discusses the agronomic effects of non-GM herbicide-tolerant canola in Australia and reviews the agronomic, environmental and economic performances of both GM and non-GM herbicide-tolerant canola in Canada. The report concludes by exploring the effects of introducing GM herbicide-tolerant canola into Australia and by giving a brief description of new canola crops being developed.

Cotton

Insect-resistant GM cotton was first commercialised in Australia in 1996…

A GM cotton variety genetically modified to contain a protein toxic to *Helicoverpa* caterpillar pests, Monsanto Australia's Ingard® cotton, was commercialised in 1996. In 2003, Bollgard II® cotton was grown commercially for the first time, replacing Ingard® varieties by 2004–05. These varieties are often referred to as Bt cotton varieties because the toxic proteins they produce are the product of inserted genes which come from a bacterium called *Bacillus thuringiensis*. Bollgard II® cotton contains two Bt protein types, compared with one in Ingard® cotton. This not only increases efficacy but also lowers the risk that the target insect pests will become resistant to the toxins.

…and GM herbicide-tolerant cotton in 2000.

GM herbicide-tolerant cotton—tolerant to the herbicide glyphosate—was commercialised in Australia in 2000 (Monsanto Australia's Roundup Ready® cotton) and a second more effective version (Roundup Ready Flex®) in 2006. A different kind of GM herbicide-tolerant cotton (Bayer Cropscience's Liberty Link® cotton—tolerant to the herbicide glufosinate ammonium) became available in 2006.

GM insect-resistant cotton in Australia

GM insect-resistant cotton has contributed to decreased insecticide use…

In 2006–07, GM varieties accounted for approximately 90 per cent of production and 95 per cent of Australian cotton farmers now choose to grow GM cotton (but not necessarily exclusively). The number of insecticide sprays on Bollgard II® fields has been reduced by up to 75 per cent compared with conventional cotton, and the amount of insecticide active ingredient used has been reduced by up to 85 per cent. The types of chemicals being sprayed have also changed.

Insect control tends to be more specific, allowing beneficial (predatory) insects to remain in the crops. Yield comparisons between 1996–97 and 2004–05 have shown that Bt cotton varieties yield at similar levels to conventional cotton.

…and reduced environmental impacts.

Since the introduction of Bollgard II® and the Best Management Practices Program for the cotton industry, there have been reduced levels of pesticide residues detected in rivers. Changes in insecticide use have reduced the estimated environmental impact of the industry. A 2006 Australian study estimated that, between 1997 and 2004, the environmental impact of insect-resistant cotton in Australia was 64 per cent lower than the impact of non-GM conventional cotton.

In order to sustain these benefits, the risk of insects becoming resistant to Bt proteins needs to be managed. The cotton industry has developed and implements an Insect Resistant Management Strategy. Farmers are required to follow a Risk Management Plan when growing Bt cotton. Through these measures, the efficacy of Bt cotton varieties in Australia has been sustained to date.

GM herbicide-tolerant cotton in Australia

GM herbicide-tolerant cotton has contributed to reduced use of residual herbicides …

The use of glyphosate in fields sown to glyphosate-tolerant cotton is higher than in fields planted to conventional cotton. However, the increase in glyphosate use is associated with a decrease in the use of other (residual) herbicides in these fields. Compared with residual herbicides, glyphosate is a non-residual, non-mobile herbicide of lower environmental toxicity.

…and improved weed control.

Farmers growing glyphosate-tolerant cotton report better control of weeds that are particularly difficult to control in conventional cotton (e.g. nutgrasses and vines). Farmers have also decreased their reliance on hand hoeing, which is used extensively in conventional cotton.

There is a risk of weeds becoming resistant to glyphosate, but growers are required to take preventative measures.

Increased use of glyphosate could increase the likelihood of weeds becoming resistant to this valuable broad-spectrum herbicide. To minimise the risk, growers of GM herbicide-tolerant cotton must practise preventative resistance management strategies that have been endorsed by a Herbicide Tolerant Crop Technical Panel. The practices are detailed in an Integrated Weed Management Strategy included in an approved Crop Management Plan.

To date, glyphosate-resistant weeds have not been recorded in cotton fields in Australia, but farmers and others need to be vigilant to enable early control should resistance be detected.

Volunteer cotton in cotton fields has been a problem, but can be managed.

Control of volunteer (rattoon) cotton in a field, following a herbicide-tolerant cotton crop, has been a problem for farmers but has been manageable through a range of measures such as root-cutting or alternative herbicides. Introduction of glufosinate-ammonium-tolerant cotton (Liberty Link® GM cotton) in 2006 introduced a further control option.

Environmental impacts are estimated to be less than those of non-GM cotton.

A 2008 United Kingdom report estimates that for Australia in 2006, and based on the plantings of the different production systems, total herbicide active ingredient use was 2.7 per cent higher than the level expected if the whole crop had been planted to non-GM cotton varieties. However, the environmental impact was estimated to be 15.6 per cent lower, because residual herbicides were used less. Reduced residual herbicide use on GM herbicide-tolerant cotton has led to fewer incidents of residual herbicide detection in rivers.

GM cotton has economic and social value too.

The introduction of GM cotton varieties has also had economic and social benefits. For instance, the incidence of Occupational Health and Safety incidents has decreased as a result of reduced insecticide spraying and the reduced need for hand weeding in cotton fields. The altered use of chemicals by the industry has also improved community perceptions of the cotton industry. Spending on insecticides, herbicides and their application has decreased. Most Australian farmers find GM cotton to be more profitable and easier to grow than conventional cotton.

GM cotton overseas

The effects of GM cotton adoption overseas have also been examined.

The report also summarises the effects of GM cotton adoption in the United States of America, India and China. These countries were selected because they have all adopted GM cotton, and are all major producers and either major cotton exporters (the United States and India) or major cotton importers (China). They are thus either important competitors or markets for Australian cotton.

In the United States, although GM cotton is adopted at a lower level than Australia, it has also resulted in reductions in insecticide use, altered use of herbicides and increased profits.

Although Bt cotton, both single and double gene versions, were released in similar years in Australia and the United States, the level of adoption in the United States is much lower than in Australia. Only 57 per cent of cotton grown in the United States in 2006 contained a *Bt* gene(s) compared with about 90 per cent in Australia. This difference reflects the different insect pressures faced by farmers in the two countries.

Yield increases of around 10 per cent have been reported in the United States for Bollgard® (called Ingard® in Australia) and Bollgard II® cotton varieties in comparison with conventional varieties. Insecticide use in cotton crops in 2005 was approximately 60 per cent lower ten years after the introduction of Bollgard® cotton.

As in Australia, adoption of herbicide-tolerant cotton has increased glyphosate use on cotton in the United States while decreasing the use of other herbicides, with an overall decrease in estimated environmental impact. Varied estimates have also been made of the herbicides that would have been used, had GM herbicide-tolerant cotton not replaced conventional cotton. One report estimates the savings in 2005 at 7.8 million kilograms of herbicide active ingredient due to growing glyphosate-tolerant cotton, and 215 000 kilograms due to glufosinate-ammonium cotton.

In 2004, economic benefits for United States growers of insect-resistant cotton were reported to be an average increase in profit of US$100 per hectare.

In the two Indian states examined, insect-resistant cotton has increased yields, lowered insecticide use and increased profit.

The adoption of Bt cotton in India has been rapid, with an estimated 3.8 million farmers growing the crop in 2007 compared with 54 000 farmers growing in 2002. During this period, cotton yields are estimated to have increased from a low of 308 kilograms lint per hectare in 2001–2002 to 520 kilograms per hectare in 2006–2007, with up to 50 per cent of the yield increase attributable to Bt cotton.

Increased yields (ranging from 30 to 60 per cent) and increased profits (consistently reported by different studies) have been the main benefits from Bt cotton. A range of social benefits are also reported for India. For example, there has been an increased use of health services because more farmers can now afford them using the profits from growing Bt cotton.

GM insect-resistant cotton in China has decreased insecticide use and increased profits for cotton farmers.

Adoption of Bt cotton in China varies between provinces from 30–100 per cent. Reductions in pesticide use have been reported to vary between 60 per cent and 80 per cent. Net profit increases of up to 30 per cent are reported by Bt cotton growers while non-Bt cotton growers made losses. Bt cotton farmers reported fewer illnesses from spraying.

GM cotton developments in Australia

There are a number of developments occurring in Australia that may affect cotton pest and weed control in the future.

New insect-resistant cotton varieties are being developed and have the potential to continue to improve pest control in the Australian cotton industry. Developments include GM cotton varieties modified to produce Bt proteins with new modes of action and new insecticidal proteins isolated from plant rather than bacterial species. Increasing the number of insecticidal proteins available in GM cotton varieties is expected to decrease the risk of the primary insect pests developing resistance to GM insect-resistant cotton, allowing these crops to remain a cost-effective insect pest control method and to provide continued environmental benefits from the reduced pesticide use.

The Gene Technology Regulator has approved GM cotton for commercial release in northern Australia; previously it had been limited to regions south of latitude 22º South. GM cotton could provide a basis for successful establishment of a cotton industry in northern Australia, including northern Queensland, Western Australia and the Northern Territory. In the past, insect pressure contributed to crop failure in the Ord River Irrigation Area in northern Western Australia.

Canola

Non-GM herbicide-tolerant canola in Australia

Non-GM herbicide-tolerant canola is widely grown in Australia, …

Non-GM herbicide-tolerant canolas such as triazine-tolerant (TT) and imidazolinone-tolerant (IT) canola are widely grown in Australia. The introduction of TT canola to Australia in 1993 allowed rapid expansion of canola production areas, particularly in Western Australia, where TT canola can now account for more than 80 per cent of all canola grown. Although the mutation conferring herbicide tolerance in TT canola also affects the efficiency of photosynthesis, resulting in reduced yields, TT canola varieties perform better than conventional varieties in situations where weeds cannot be controlled by conventional means. IT canola has been adopted on a smaller scale, mainly where there is a prevalence of grass and broadleaf weeds.

…has improved weed control…

Herbicide-tolerant canola has provided more effective weed control, particularly for weeds that are closely related to canola, such as wild radish. Herbicide-tolerant crops can also be sown early into dry soil to take advantage of the first rainfall of the season. In conventional canola systems, sowing may need to be delayed until after the first rainfall to allow weeds to germinate prior to spraying so as to reduce competition with the young canola seedlings as they emerge.

…and contributed to the expansion of canola growing areas and adoption of no-till or conservation tillage.

Non-GM herbicide-tolerant canola has helped expand the areas that can be sown to canola because of better weed control but has not resulted in consistent increases in yield per hectare. TT and IT canola have also led to the shift to no-till or conservation tillage systems, with associated environmental benefits such as reduced soil erosion and increased soil water retention. However, more frequent use of a particular herbicide increases the risk of emergence of resistant weeds. In Western Australia, triazine resistant weeds were first reported in 2001.

GM herbicide-tolerant canola in Canada

Canada is an export competitor of Australia and grows a range of herbicide-tolerant varieties, both GM and non-GM.

Canada is the world's major exporter of canola and Australia's main export competitor. GM (glyphosate-, glufosinate ammonium- and bromoxynil-tolerant) and non-GM (imidazolinone-tolerant) herbicide-tolerant canolas were introduced into Canada within a relatively short period (between 1995 and 2000). TT canola was only ever a minor component of total canola production and is not now grown in Canada because it has been outperformed by other herbicide-tolerant canola varieties.

Of the approximately 5.9 million hectares of canola grown in Canada in 2007, about 87 per cent was sown to GM herbicide-tolerant varieties. Adoption rates of these canola varieties have steadily increased over the years since first introduced in Canada.

Canadian farmers report agronomic, environmental and economic benefits from growing GM herbicide-tolerant canola.

In a survey conducted in 2001, 20 per cent of Canadian farmers reported increases in acreage, 81 per cent reported more effective weed control, and 26 per cent had introduced conservation tillage as a result of growing GM herbicide-tolerant canola.

Canadian research has indicated that there are no marked changes in volunteer weed problems associated with herbicide-tolerant canola crops, except in no-till systems when glyphosate alone is used to control canola volunteers.

Canadian farmers have also reported decreased herbicide use, changes in the types of herbicides applied, and lower fuel use as a result of decreased tillage and numbers of herbicide applications. Lower fuel use results in lowered greenhouse gas emissions.

For 2006, the reduction in the amount of herbicide used was estimated to be 1.29 million kilograms, a reduction of 22.6 per cent. The estimated environmental impact of herbicides was also significantly lower by 32 per cent.

The 2001 Canadian survey reported an average 41 per cent increase in profits for GM herbicide-tolerant canola compared with conventional, non-herbicide-tolerant canola. Canadian canola farmers continue to opt to grow GM canola varieties.

Canada has found ready markets for its GM canola in Japan, China, Mexico, USA, the United Arab Emirates and Pakistan. Although it had lost market share in the European Union up to 2004, the EU has resumed some import of GM-derived canola oil for biodiesel production in recent years.

GM herbicide-tolerant canola in Australia

Australian farmers have only recently had access to GM herbicide-tolerant canola.

While Australian farmers have had access to two non-GM herbicide-tolerant varieties, TT and IT canola, since 1993 and 2000, they have only recently had access to GM herbicide-tolerant canola varieties—and at low levels of supply. Australian canola growers have not had access to the benefits Canadian farmers have gained from the use of GM herbicide-tolerant canola.

Benefits are expected, including increased yield, other agronomic benefits…

The primary economic benefit of the introduction of GM herbicide-tolerant canola varieties into the Australian cropping system is likely to be an increase in yield, as lower yielding TT canola varieties are replaced. In particular, InVigor® (glufosinate ammonium-tolerant) hybrid canola contains a genetic system that makes hybrid breeding easier and, as a consequence, is expected to provide a significant yield advantage.

Other agronomic benefits of GM herbicide-tolerant canola could include increased options for in-crop weed control, allowing rotations of herbicides with the potential to decrease the risk of resistant weeds developing, and increased yield in subsequent cereal crops, which currently can be adversely affected by triazine carry-over from TT canola crops.

…and decreased environmental impact.

In many Australian regions, the environmental impacts of the herbicide regimes suggested for Roundup Ready® (glyphosate-tolerant) and InVigor® (glufosinate ammonium-tolerant) hybrid canola varieties are estimated to be lower than for the current typical herbicide regimes for conventional or TT canola. However, farmers would also need to manage any increased risk of herbicide resistance that may result from adoption of these new herbicide-tolerant crops.

There is concern that growing GM canola will lead to herbicide-resistant weeds and gene transfer.

The main agronomic concerns with the introduction of GM herbicide-tolerant canola into Australia are the risk of emergence of herbicide resistance in weeds as a result of increased glyphosate use, and the risk of transfer of herbicide-tolerance genes to related weed species.

These concerns were considered by the Australian regulatory agencies prior to the approvals for commercial release of glyphosate-tolerant and glufosinate-ammonium tolerant canola in Australia.

Resistance to glyphosate is a major concern, but resistance management plans reduce the risk of herbicide resistance.

Glyphosate-resistant ryegrass is known from areas where glyphosate is used to kill pasture plants prior to sowing a crop, and in non-cropping situations, particularly where glyphosate is the only means of chemical weed control.

Resistance can be prevented by applying Integrated Weed Management practices, which aim to integrate as many different weed control options (chemical and cultural) as possible, through all phases of the crop rotation.

The Australian Glyphosate Sustainability Working Group has developed strategies for reducing the risk of glyphosate-resistant weeds. These strategies will be applied in crop rotations containing glyphosate-tolerant canola, and they include herbicide resistance management plans specifically prepared for the commercialisation of this canola crop.

The risk of gene flow to related weeds is low or negligible, but there will be gene flow between canola plants.

Risks to the environment, including the risks arising from gene flow to related weeds or conventional canola plants, have been evaluated by the Gene Technology Regulator and assessed to be very low or negligible.

Canola has a mixed mating system. It is predominantly self-fertile, but plant-to-plant out-crossing within canola has been found to vary from 12–47 per cent in Australian field experiments. Some long-distance pollen travel is also likely to occur, but at very low levels. Pollen movement has implications for the coexistence of GM canola and non-GM canola or related crops.

Gene flow to non-GM canola will be below agreed thresholds…

Australian and United Kingdom studies indicate that applying out-crossing rates to a whole field basis (GM field adjacent to non-GM field) translates to cross-pollination at the crop level of 0–0.07 per cent (Australian study) and 0.1 per cent (United Kingdom study). These rates are both below the industry approved threshold of 0.9 per cent for the adventitious presence of Gene Technology Regulator-approved GM canola grain in non-GM canola grain.

…and will be further managed through Crop Management Plans.

Gene flow from GM herbicide-tolerant crops to conventional crops will also be managed through Crop Management Plans and industry Stewardship Principles. Crop Management Plans include measures to maintain product integrity and enable GM and non-GM coexistence, such as crop separation distances and harvesting practices.

Volunteer canola in subsequent crops and gene stacking can be managed, as in Canada.

Volunteers, whether non herbicide-tolerant, single gene herbicide-tolerant or multiple herbicide-tolerant (GM and/or non-GM), can be controlled by the appropriate herbicides with alternative modes of action.

Unintentional stacking of multiple herbicide tolerance genes in volunteer canola plants or canola weed populations is potentially an issue. Stacking has been reported in Canada but few farmers target herbicide treatments or tillage operations specifically for volunteer canola; and a majority of farmers do not target volunteer canola more than they had in the past.

GM canola is unlikely to be disadvantaged in Australian and world markets.

The issue of whether or not Australian export markets will be affected adversely if Australia adopts GM food crops has been studied by the Australian Bureau of Agricultural and Resource Economics (ABARE). ABARE has found that marketers of GM canola and of products based on livestock fed on GM materials, including GM canola, are unlikely to be disadvantaged in the Australian and world markets—GM canola has found markets throughout the world at prices similar to those received for conventional canola.

The costs of identity preservation have been modelled by ABARE.

Identity preservation systems can be implemented if markets require segregated product (separated non-GM and GM canola grain). Segregation is already practised in Australia for commodities such as malting barley and durum wheat.

Systems to ensure that grain supplies meet particular standards for the adventitious (that is, unintended) presence of GM materials would be likely to incur associated costs. A price premium or production saving would be needed to offset such additional costs, and these would need to be larger than segregation costs.

The ABARE report concluded that co-mingling in the grain receival system, should identity preservation be implemented, is unlikely to introduce undesirable levels of adventitious presence of GM material in non-GM canola and other grains.

New traits for canola

Herbicide tolerance is important to canola growers and is being introduced into related Indian mustard.

Australian plant breeders are working to adapt varieties of Indian mustard (*Brassica juncea*) to Australian conditions. These Indian mustard plants produce an oil equivalent to that of conventional canola (*Brassica napus*) but have a higher tolerance to heat and drought conditions. Non-GM herbicide-tolerant varieties of

B. juncea are expected to be available in 2009 and trials with GM herbicide-tolerant varieties are also underway.

In the future, new traits in canola may be introduced in combination with herbicide tolerance.

There is a trend in canola breeding towards developing traits with consumer benefits. These include plants that produce healthier oils such as omega-3 oils. Varieties with some of these traits may be developed through conventional breeding, while others may require genetic modification. It is likely that at least some of the varieties released will also contain herbicide tolerance traits (either GM or non-GM).

Conclusion

Control of insect pests and weeds is a significant cost for Australian agriculture. GM insect-resistant and herbicide-tolerant crops are new tools for the farmer that can be used as part of Integrated Pest Management or Integrated Weed Management systems to maintain the sustainability of insect and weed control in Australia.

These GM crops provide improved insect pest and weed control, resulting in agronomic and economic benefits for growers. They also have benefits for the environment through altering the types and amounts of insecticides and herbicides applied to crops, reducing the impacts of pesticides, increasing the adoption of no-till farming, and decreasing fuel use.

The adoption of both GM insect-resistant cotton and the Best Practice Management Program by the Australian cotton industry have reduced insecticide use and the level of community concern about the use of chemicals within the cotton industry. The adoption of GM herbicide-tolerant cotton has improved weed control and reduced the level of residual herbicide use.

GM insect-resistant traits in cotton can provide a basis for extension of cotton-growing to more northern regions. GM insect-resistance technology continues to be developed and new insecticidal modes of action for GM cotton are being trialled in Australia.

If GM herbicide-tolerant canola varieties were widely introduced to Australia, the primary benefit is likely to be increased yield. Lower yielding triazine-tolerant varieties can be replaced by GM varieties. Other benefits are likely to be increased options for in-crop weed control, likely increased yield in subsequent crops (in cases where triazine carry-over from triazine-tolerant canola crops may have had an adverse impact previously) and reduced environmental impact from herbicides.

Contents

List of Abbreviations

a.i.	Active ingredient
AAS	Australian Academy of Science
ABARE	Australian Bureau of Agricultural and Resource Economics
ABC	Australian Broadcasting Corporation
ABS	Australian Bureau of Statistics
APVMA	Australian Pesticides and Veterinary Medicines Authority
BMP	Best Management Practices
Bt	*Bacillus thuringiensis*
CCA	Cotton Consultants Australia
CCC	Canola Council Canada
CFIA	Canadian Food Inspection Agency
CMP	Crop Management Plan
CRC	Cooperative Research Centre
CRDC	Cotton Research and Development Corporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry
EI	Environmental impact
EIQ	Environmental Impact Quotient
EPSP	5-enolpyruvylshikimate-3-phosphate
FSANZ	Food Standards Australia New Zealand
GM	Genetically modified
GMO	Genetically modified organism
GRDC	Grains Research and Development Corporation
ha	Hectare
HT	Herbicide-tolerant
IPM	Integrated Pest Management
IR	Insect-resistant
IRMS	Insecticide Resistance Management Strategy
IT	Imidazolinone-tolerant
IWM	Integrated Weed Management
kg	Kilogram(s)
NCCA	National Cotton Council of America
NSW	New South Wales
OGTR	Office of the Gene Technology Regulator
RMP	Resistance Management Plan

TGA	Therapeutic Goods Administration
TIMS	Transgenic and Insect Management Strategy
TT	Triazine-tolerant
USDA	United States Department of Agriculture
USDA-APHIS	USDA Animal and Plant Health Inspection Service
USDA-FAS	USDA Foreign Agricultural Service
USDA-NASS	USDA National Agricultural Statistics Service

Chapter 1 Introduction

This report is the result of a study funded by the Department of Agriculture, Fisheries and Forestry under the National Biotechnology Strategy. It investigates the agronomic, environmental and socio-economic effects of genetically modified (GM) crops used for insect pest and weed control in cotton and canola. The study includes GM crops currently commercialised in Australia, namely insect-resistant (IR) and herbicide-tolerant (HT) cotton, as well as GM crops with potential for release in Australia in the near future (five to ten years), particularly GM HT canola.

This report is structured as follows:

- Introduction and outline of the main issues (Chapter 1).
- Description of the agronomic and environmental effects resulting from the adoption of HT and IR cotton (Chapter 2) and HT canola (Chapter 3) in Australia.
- Chapters 2 and 3 also include descriptions of the effects of adopting these crops in overseas countries, as well as discussion of potential developments in this area that will be of relevance to Australian agriculture over the next 10–15 years. There is also some reference to economic and social effects of adopting HT and IR crops.

Definitions of the term GM vary. In this report the term refers to plants that have been modified through laboratory gene technology methods, as defined in the *Gene Technology Act 2000* (Cwlth), to exhibit new traits.

Section 1.1 Rationale behind the report

The impact of insect pests and weeds on Australian agriculture is enormous. For example, weeds are estimated to have caused a A$3.9 billion average loss of net benefits annually over the five year period 1997–98 to 2001–02 (Sinden et al. 2004). Australian farmers consider weed control to be one of their highest priority land degradation issues. Weeds also harm natural environments by competing with native species and reducing biodiversity.

It is estimated that insect herbivores are responsible for a 10–20 per cent loss of yield in major crops worldwide (Ferry et al. 2004) and far more in developing countries. For example, *Helicoverpa* caterpillars have the potential to completely destroy a cotton crop if not properly managed (CSIRO 2003). The total economic damage and control costs for *Helicoverpa* species in Australian agriculture was estimated in 1997 to be in the range of A$159 million to A$328 million annually (Adamson et al. 1997). Of this, the estimated range of total economic damage and control costs in cotton was A$102 million to A$162 million (Adamson et al. 1997); note these estimates were before GM insect-resistant cotton was introduced into Australia. Without control, *Helicoverpa* damage was estimated to cost up to A$818 million annually, with the proportion of costs incurred by each agricultural sector shown in Figure 1.1.

Modern biotechnology has developed new tools that aim to reduce the impact of insect pests and weeds on agricultural production and provide environmental benefits through reduced and/or altered use of some chemical inputs. These tools include GM HT and IR crop plants.

GM HT and IR crops plants are one part of an integrated approach that is needed to control and manage insect pests and weeds successfully. Integrated Pest Management (IPM) and Integrated Weed Management (IWM) systems have been developed to increase the effectiveness of pest and weed control by providing guidelines on how a range of methods can be utilised to achieve good control rather than relying on single methods.

GM crops provide new additional tools for integrated pest and weed management. Understanding the farm management issues associated with the deployment of these crops is important to the wider debate on the adoption of this technology.

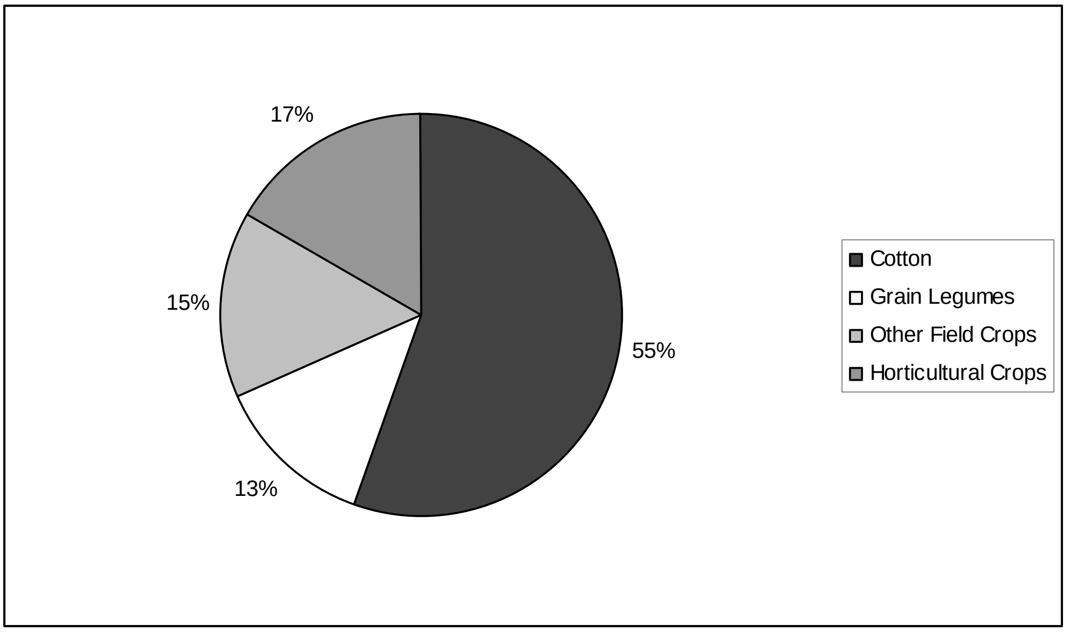

Figure 1.1 Relative distribution of costs of *Helicoverpa* for each agricultural sector (including cost of control and economic losses from 5 per cent residual pest damage)

Source: Data from Adamson et al. (1997)

The adoption of GM IR and HT crops also has implications for the environment. Insecticide and herbicide control regimes for such crops differ from those for conventional non-GM crops and non-GM HT crops. These differences are both quantitative (amount of active ingredient of pesticide applied) and qualitative (for example, the kind of pesticide environmental impact). Environmental impacts extend to ecological effects on river systems, changes in tillage systems and soil erosion and changes in the amount of fuel used to apply pesticides.

There are also socio-economic impacts on farmers, producers, agricultural suppliers, processors, wholesalers/retailers, the wider rural and regional communities and consumers. These effects result from changes in agricultural productivity, production methods and/or the size of the agricultural workforce. There can also be health benefits for farmers and regional communities, due to the altered use of insecticides and herbicides, and also lifestyle changes for farmers that result from the reduced time spent on chemical spraying.

This report aims to document the GM crops currently grown in Australia for insect pest and weed control and identify those GM crops under development or being grown overseas with the potential for commercial release in Australia in the near future. The report also provides a qualitative forecast of the contribution that these GM crops could make to weed and insect pest control in Australian agriculture in the future.

While this study considers such GM crops as tools for insect pest and weed control, it is worth highlighting that Australian biotechnology research also includes development of disease-resistant crop plants and other types of pest-resistant crop plants; for example:

- fungal-resistant cotton (OGTR 2006d)
- white clover resistant to the *Alfalfa Mosaic Virus* (OGTR 2004)
- barley resistant to the *Barley Yellow Dwarf Virus* (Wang et al. 2000)
- wheat resistant to the *Barley Yellow Dwarf Virus* [1]
- flax and wheat resistant to stem, leaf and stripe rust [2]
- wheat resistant to the *Fusarium* fungus [3]
- wheat resistant to cereal cyst nematodes [4].

Australia remains relatively free from many of the harmful diseases and pests that affect agricultural industries overseas, but potential incursions are a continual threat to the profitability and sustainability of Australia's agricultural industries. As medium- to long-term responses, GM crops offer significant options for control and management of new disease and pest incursions should they occur.

Section 1.2 Methodology

The study is a desktop review of existing information on IR and HT GM crops in Australia and overseas. The review was undertaken in consultation with an advisory group that included expert representatives from the Australian cotton industry, the Cooperative Research Centre (CRC) for Australian Weed Management, the Institute of Rural Futures at the University of New England, and the Grains Research and Development Corporation (GRDC). The role of the advisory group was to aid in the development of the project's methodology and content, facilitate access to information, identify appropriate contacts and review draft versions of this report.

Section 1.3 GM regulation—the state of play in Australia

In Australia, dealings with GM organisms (GMOs) are regulated under the *Gene Technology Act 2000* (Cwlth) by the Gene Technology Regulator (the Regulator) supported by the Office of the Gene Technology Regulator (OGTR). The aim of the regulatory framework is to protect human health and safety and the environment by identifying and managing potential risks posed by the use of this technology. The OGTR has developed a risk analysis framework describing the approach to risk assessment and risk management for genetically modified organisms. More information on the regulatory scheme is available at www.ogtr.gov.au.

The Regulator liaises with other regulatory agencies, including Food Standards Australia New Zealand (FSANZ), the Australian Pesticides and Veterinary Medicines Authority (APVMA) and the Therapeutic Goods Administration (TGA) to coordinate the regulation of GMOs for intentional release into the environment.

The regulatory role of the APVMA in regard to GM HT and IR crops includes consideration of the following:

- the risk to human safety via application of the relevant chemical or areas where the chemical has been applied
- the risk to human safety via exposure to food containing residues of the chemical

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[1] www.csiro.au/files/files/p2jg.pdf accessed 23 August 2007.

[2] www.csiro.au/files/files/pbb8.pdf accessed 23 August 2007

[3] www.csiro.au/files/files/pb2k.pdf accessed 23 August 2007

[4] www.csiro.au/science/psu5.html accessed 23 August 2007.

- the risk to the environment from exposure to the chemical
- the risk of prejudicing Australia's trade with other countries
- that the product will be efficacious according to the APVMA's requirements.

Aspects of consideration of the criteria may overlap with those of other agencies; however, APVMA consideration specifically relates to the chemical use associated with the GMO and/or any chemical resistance management issues that may occur through use of the GMO.

Food Standards Australia New Zealand (FSANZ) is an independent statutory agency established by the *Food Standards Australia New Zealand Act 1991* (Cwlth) to set food standards for Australia and New Zealand. The agency works within an integrated food regulatory system involving the governments of Australia and the New Zealand government.

As of July 2008, FSANZ had approved 35 foods produced using gene technology from seven GM crops: soybean, canola, corn, potato, sugarbeet, cotton and lucerne (FSANZ 2008). Most of the GM food products currently approved in Australia come from GM crops which have been grown and processed overseas. Labelling of these GM products is required to indicate that it contains GM ingredients unless the GM food or food ingredient is exempt from labelling in the FSANZ Standard 1.5.2 *Food Produced Using Gene Technology* (FSANZ 2003). The purpose of labelling is for consumer choice; not for food safety reasons. The following are not required to be labelled:

- highly refined foods where the effect of the refining process is to remove novel deoxyribonucleic acid (DNA) and/or novel protein
- processing aids or food additives where novel DNA and/or novel protein is not present in the final food
- flavourings which are present in the food in a concentration of no more than 1g/kg (0.1 per cent) in the final food as consumed
- foods or ingredients in which the genetically modified food is unintentionally present in a quantity of no more than 10g/kg (1 per cent) per ingredient. This tolerance level only applies where the manufacturer has sought to source non-genetically modified foods or ingredients
- food intended for immediate consumption that is prepared and sold from food premises and/or vending vehicles, including restaurants, take-away outlets, caterers or self-catering institutions where consumers can request information on the GM status of their foods from the vendor (FSANZ 2003).

Until recently, there has been only one broadacre GM crop grown commercially in Australia: cotton, which has been modified for insect resistance, herbicide tolerance or a combination of the two. HT canola was the next broadacre crop expected to be grown commercially in Australia with licences granted by the Regulator in 2003. The enactment of state and territory moratorium legislation, introduced in all major canola growing states in 2003, has prevented commercial plantings of GM canola varieties (Table 1.1) until recently. The legislation was introduced for marketing and trade reasons, not because of health and safety issues which, as outlined above, are assessed by Federal agencies under national agreements. In July 2007, four states (Victoria, South Australia, New South Wales and Tasmania) commenced reviews of their moratoria on GM crops. Following the reviews in Victoria, New South Wales and South Australia, GM canola has been approved for commercial production in Victoria and New South Wales from the 2008 season. Limited seed stocks means there will be a small GM crop in 2008. South Australia decided in February 2008 to maintain its moratorium.

Table 1.1 Gene technology moratorium legislation[5] (continued over page)

Jurisdiction	Legislation	Moratorium on GM canola/crops	Sunset/Expiry or Review Date
New South Wales	*Gene Technology (GM Crop Moratorium) Act 2003* (NSW)	The Act allows the Minister to make Orders prohibiting the growing of GM food crops. Until March 2008, Orders were in place prohibiting the cultivation of GM glyphosate- and glufosinate ammonium-tolerant canola varieties; however the Act was amended on 7 December 2007 to establish a Gene Technology Expert Committee to assess and advise the Minister on an industry's capacity to manage marketing and trade matters associated with a GM food crop.	Section 43 of the Act provides that the Act expires on 1 July 2011. After 7 December 2007, if the Minister is satisfied that appropriate criteria have been met, the Minister can approve commercial cultivation of a crop in New South Wales. Commercial cultivation of GM canola was approved in March 2008.
Victoria	*Control of Genetically Modified Crops Act 2004* (Vic)	The Act allows the Minister to make Orders prohibiting the growing of GM crops. An Order was in place prohibiting the cultivation of GM glyphosate- and glufosinate ammonium-tolerant canola varieties until February 2008.	No expiry or review provisions within the Act itself. Order was set to expire 29 February 2008 (s3 of order). The Victorian government decided in November 2007 to allow the GM canola Order to expire.
South Australia	*Genetically Modified Crops Management Act 2004* (SA)	The Act provides for a moratorium on the commercial cultivation of all GM food crops. The whole state is designated by Regulation as an area in which the cultivation of genetically modified food crops is prohibited. The Act allows for exemptions to be given for field trials under specific conditions.	Minister was required to conduct a review of the Act within four years (i.e. by 29 April 2008) of its commencement (s29). Under Schedule 1, s1(2) of the Act, the Regulation was to expire on 29 April 2008. A review announced in June 2007 recommended the Regulation be allowed to expire, but the Government decided in February 2008 to maintain its ban on GM canola.
Tasmania	*Genetically Modified Organisms Control Act 2004* (Tas)	The Act provides for a moratorium on the commercial cultivation of all GM crops (including GM canola) in designated areas. A Ministerial Order designated the entire state.	Section 36 provides that the Act expires on 16 November 2009. In August 2008, a Tasmanian Government Joint Select Committee report recommended that the prohibition on the release of GM food crops to the Tasmanian environment for commercial purposes should be extended and reviewed after five years (extending the moratorium until 2014).

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[5] Moratorium legislation has been introduced for marketing and trade reasons only. Issues relating to human health and safety and environment are assessed and managed by OGTR. Food safety is regulated by Food Standards Australia New Zealand.

Jurisdiction	**Legislation**	**Moratorium on GM canola/crops**	**Sunset/Expiry or Review Date**
Western Australia	*Genetically Modified Crop Free Areas Act 2003* (WA)	The Act provides for a moratorium on the commercial cultivation of all GM crops (including GM canola) in designated areas. Minister for Agriculture designated the whole state by Order on 22 March 2004.	Section 19 of the Act requires the Minister to carry out a review after the expiration of five years (i.e. after 24 Dec 2008). Report to be tabled in both houses of Parliament before 24 Dec 2009.
Australian Capital Territory	*Gene Technology (GM Crop Moratorium) Act 2004* (ACT)	The Act allows the Minister to make Orders prohibiting the growing of GM Crops. Orders have been given prohibiting the cultivation of GM glyphosate- and glufosinate ammonium-tolerant canola varieties. Section 39 enables the Minister to set an expiry date after 17 June 2006.	Section 39 provides that the Act expires on a date fixed by the Minister by written notice not earlier than 17 June 2006. The Act and moratorium remain in force.
Northern Territory	No legislation	None	N/A
Queensland	No legislation	None	N/A

Section 1.4 Integrated pest and weed management in Australia

1.4.1 Integrated Pest Management

Integrated Pest Management (IPM) strategies aim to manage pest populations using several means of control, with the benefits of avoiding development of pest resistance or the disruption of natural enemies of the pests (i.e. beneficial insects) which arise from reliance on and overuse of insecticides. The latter can in turn lead to outbreaks of secondary pests (Farrell and Johnson 2005). IPM seeks to maintain or increase profitability (i.e. yield and/or quality) while reducing synthetic pesticide use.

Resistance to insecticides is less likely to occur when a range of measures are used against a pest. Adopting an IPM strategy means managing pests throughout the whole year; not just during the growing season. Where possible, IPM encourages different pest control techniques to be used together, with the expectation that the combination of several complementary techniques will be more effective than their use in isolation (AAS 2001; Farrell and Johnson 2005).

The tools and strategies for managing pests using IPM techniques can be grouped under seven main objectives (Farrell and Johnson 2005):

- **Growing a healthy crop**—a healthy crop will have a high yield potential and capacity to compensate for pest damage.
- **Keeping track of insects and damage**—monitoring the crop to determine: the presence of pests; the level of infestation; the damage pests are causing; the level of beneficial insects; expected response to control options; environmental conditions; and the growth stage of the crop.
- **Preserving beneficial insects**—beneficial insects can help to control insect pests and reduce the need for chemical controls.
- **Preventing insecticide resistance**—rotating between chemical groups with different modes of action limits the time period during which an insecticide is used, thus restricting the number of generations of a pest that can be selected in or between seasons. Limiting the number of insecticide applications in a season restricts the number of selection events.
- **Managing crop and weed hosts**—weeds and volunteer crops provide over-winter hosts for pests, diseases and beneficial insects. The pest and disease problems that can be caused by weeds and volunteers will generally outweigh the value of weeds as refuges for beneficial insects. Some rotation crops can also act as hosts for insect pests and diseases or beneficial insects.
- **Using trap crops effectively**—trap crops can concentrate pests into a manageable area by providing them with an area of preferred host crop and they can be utilised at different times throughout the year to control a wide range of pests. Timely destruction of trap crops is expected to prevent their becoming nurseries for future pests. Trap crops can reduce the size of the pest population and thus reduce the amount of insecticide needed to control the pests and lower the risk of pests developing resistance to existing insecticides.
- **Communication and training**—good communication with neighbouring primary producers is essential to developing a successful IPM strategy.

1.4.2 Integrated Weed Management

By 2006, 33 different species of weeds in Australia were reported to have developed resistance to herbicides commonly used in Australian farming systems (CRC for Australian Weed Management 2006). In order to deal with the increasing problem of herbicide-resistant weeds, future weed control will have to rely more heavily on stopping weeds setting seed.

Integrated weed management (IWM) aims to increase the effectiveness of weed control. The main principle is to prevent weeds setting seed. Growers need to: be aware of the local weed spectrum and understand the interactions between weeds and their farming system; scout regularly to examine the weed problem and the success or failure of recent practices; evaluate the weed management system and develop economic and sustainable solutions; and, implement alternative management strategies to deal with any problems (Farrell and Johnson 2005).

Undertaking IWM is important for extending the life-span of current herbicides given that herbicides take a very long time to develop and discovery of new effective active ingredients cannot be guaranteed. By utilising a range of weed management systems in combination, IWM aims to ensure control of weeds by at least one component of the system, and advocates avoiding reliance solely on herbicides as a weed management option.

The use of IWM techniques throughout the entire cropping system, including rotation crops and fallows, should reduce: reliance on herbicides; the risk of selecting for herbicide-resistant weeds; the rate of shift in the weed spectrum towards herbicide-resistant weeds; the risk of herbicides accumulating in the soil and riverine systems; future weed control costs by reducing the number of weed seeds in the soil seed bank; and, weed competition with crop productivity (Farrell and Johnson 2005). A recently published IWM manual provides more details on IWM for Australian cropping systems (McGillion and Storrie 2006).

1.4.3 The relevance of new technologies to IPM and IWM in Australia

Integrated Pest Management

The traditional reliance on insecticides to control insect pests in cropping systems brings with it significant liabilities such as spray drift, chemical residues and the development of insect pest resistance. GM IR crop plants provide a foundation for more sustainable IPM practices, by integrating a range of non-chemical tactics and reducing the reliance on insecticides (Fitt 2000).

For example, the adoption of GM IR cotton varieties by the Australian cotton industry has resulted in a significant reduction in the application of broad spectrum insecticides used to control the cotton bollworm (*Helicoverpa* species) and other caterpillar pests (see Chapter 2 for more detail). This in turn has decreased adverse impacts on beneficial insect populations allowing these insects to survive and multiply (Fitt 2000).

The insecticidal toxins used in the currently available GM cotton varieties are highly specific to lepidopteran (butterfly and moth) species (e.g. bollworms) and have been shown to have little effect on non-target species including non-lepidopteran pests (e.g. mites, aphids) and beneficial insects (e.g. parasitic wasps) (Fitt 2000). The advantage of maintaining high populations of beneficial insects in cotton crops is that they provide a natural control for some secondary pests of cotton, particularly mites and aphids. The reduced use of broad spectrum insecticides allows increased emphasis on managing the populations of beneficial insects and Fitt (2000) suggests that management of beneficial insect populations should be an explicit consideration in future IPM decisions.

Combining the GM insecticidal traits with naturally occurring insect resistance traits in some cotton varieties could enhance the stability of IPM systems by providing simultaneous control of multiple insect pests. For example, transferring the insecticidal gene(s) present in the GM

IR cotton plants into okra-leaf varieties[6] of cotton will provide enhanced protection against both the bollworm and mites (Fitt 1994; 2000), further reducing the need to apply chemical pesticides for the control of these pests.

Integrated Weed Management

The adoption of IWM practices by Australian cotton farmers over the last ten years has resulted in an overall improvement in weed control according to surveys conducted by Charles et al. (2004). Charles et al. (2004) conducted surveys of irrigated cotton fields in the Gwydir and Macintyre valleys in 1992, 1996 and 2001. Over this period there was an average reduction in weed density from 1.84 weeds/m^2 to 0.51 weeds/m^2. Using the weed wild radish in southern New South Wales as a case study, modelling by Jones (2004) shows that adopting IWM control practices could result in substantial economic benefits as well as increasing the probability of there being a reduction in the weed seed banks.

HT crops represent a relatively new weed control technology that can be used as part of an IWM program. Both conventionally bred and GM HT crops are now available for farmers to use. Conventionally bred triazine-tolerant (TT) and imidazolinone-tolerant (IT) canola varieties have been used since 1997 and 2001 respectively (Chapter 3) and IT wheat has also been developed. GM glyphosate-tolerant cotton and canola and GM glufosinate ammonium-tolerant cotton and canola are grown commercially in a number of countries (see Chapters 2 and 3 for more details).

GM HT crops should not be considered a ‘silver bullet’, but rather one component of IWM. An over-reliance on non-selective[7] herbicides and GM HT crops to the exclusion of other weed management practices could lead to: the development of herbicide-resistant weeds; a shift in the weed spectrum to weed species that are more tolerant to a given herbicide; and, a shift to weed species that emerge after a post-emergence herbicide has been used (Knezevic 2002).

The adoption of GM glyphosate-tolerant cotton in Australia has led to a shift in the weed spectrum towards glyphosate-tolerant species (Charles et al. 2004). Shifts in the weed spectrum were also reported in experimental rotations with GM HT cotton varieties (bromoxynil-tolerant and glyphosate-tolerant) in the United States of America (USA) (Reddy 2004). Managing such shifts requires the adoption of an IWM system that focuses on using a number of different methods to reduce the weed seed bank. Reddy (2004) notes that rotation between bromoxynil and glyphosate-tolerant cotton varieties prevented the weed shift and resulted in better weed control. In addition to tolerating glyphosate, many of the weeds noted by Charles et al. (2004), which persisted in fields sown to glyphosate-tolerant crops, were also well adapted to minimum tillage as they have small seeds and biennial or perennial lifecycles. Although no case of glyphosate-resistant weeds has yet emerged in an Australian cotton field, Charles et al. (2004) believe that it is likely such resistance will eventually occur. Early detection, control and eradication would be important in this scenario.

Before the introduction of GM HT cotton in Australia, weed management practices were characterised by an integrated approach involving frequent use of herbicides that persist in the soil (residual herbicides), inter-row cultivation and hand-hoeing (Werth et al. 2006a). Since 2000, the extensive adoption of GM glyphosate-tolerant cotton varieties has resulted in an alteration in weed management practices towards heavy reliance on glyphosate. Werth et al. (2006a) argue that should growers choose to use glyphosate in place of, rather than in addition

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[6] Okra-leaf varieties of cotton have a different shaped leaf and greater resistance to mites.

[7] A selective herbicide will be effective against either grass weeds or broadleaf weeds while a non-selective herbicide will kill all plants. Non-selective herbicides cannot be used for in-crop weed control unless the crop is bred to be tolerant to that herbicide (e.g. glyphosate can be used for in-crop weed control on glyphosate-tolerant crops).

to, other weed management practices, the whole cotton industry could be at risk of the evolution of glyphosate-resistant weeds. These authors conclude that the best way to prevent glyphosate resistance from developing is to adopt an IWM strategy encompassing a variety of weed management options. This would include the availability of a range of HT varieties for a given crop, as well as non-chemical means of control.

The product ‘label’ accompanying herbicide products provides directions for use of herbicides and other information specified by the APVMA. Directions for use must be followed and are legally enforceable. The product label for the glyphosate herbicide registered by the APVMA for use on glyphosate-tolerant cotton (Monsanto Australia’s Roundup Ready® herbicide) stipulates that growers of glyphosate-tolerant cotton (Roundup Ready® and Roundup Ready Flex® cottons) must practise preventative weed resistance management strategies that have been endorsed by the Australian cotton industry’s Transgenic and Insect Management Strategy (TIMS) Herbicide-Tolerant Crop Technical Panel (APVMA 2006). Liberty Link® GM cotton (tolerant to the herbicide glufosinate ammonium) was released in 2006 and provides a new chemical rotation option for growers.

Using HT crops (GM or non-GM) as part of an IWM program can have a number of advantages including: a broader spectrum of weed control; reduced crop injury; less herbicide carryover; use of herbicides with reduced environmental impact; rotation with new herbicide modes of action for resistance management; and, crop management flexibility, particularly in no-till systems (Knezevic 2002). The ability to control weed species that are closely related to the crop is especially important (Section 3.2).

Section 1.5 No-till and conservation tilling practices

In the last 20 years, there has been increasing awareness and adoption of no-till and conservation tillage techniques that aim to reduce the negative effects of cultivation on soil erosion and moisture conservation (D'Emden et al. 2006). No-till and conservation tilling techniques can be facilitated by the adoption of HT crops that allow in-crop weed control using non-selective herbicides such as triazines, glyphosate or glufosinate ammonium (Crossan and Kennedy 2004; Tribe and Kalla 2005; Day 2006). Reduced soil cultivation can also assist in conserving soil structure and increasing the retention of carbon and nitrogen within the soil (thus reducing greenhouse gas emissions) (Crossan and Kennedy 2004; Lyon et al. 2004; Tribe and Kalla 2005). By decreasing tillage and increasing stubble retention, conservation tillage systems also lead to better timing of sowing, lower fuel costs and higher long-term productivity (D'Emden et al. 2006).

While HT crops support a conservation tillage system, weed pressures tend to increase when tillage is reduced, leading to a heavier reliance on herbicides. Furthermore, the increased use of a single herbicide will increase the likelihood of weeds developing resistance to that herbicide (D'Emden et al. 2006).

The land under no-till cultivation in Australia is expected to increase. Growers therefore need to be aware of herbicide resistance issues associated with this practice, including glyphosate resistance issues. Increased no-till adoption is predicted as a result of many factors. Based on a survey of 384 farmers from across Australia in 2003, the primary reasons are the benefits of soil conservation and better timing of sowing in relation to rainfall (D'Emden and Llewellyn 2004; D'Emden et al. 2006). The analysis also found that costs of herbicides (particularly glyphosate) in relation to diesel prices were also factors in determining adoption rates (D'Emden et al. 2006).

Section 1.6 Environmental Impact Quotient

As discussed above, an IPM strategy uses a combination of methods to manage pests without solely relying on chemical pesticides. However, it is important to consider not only the efficacy and cost of a pesticide, but also its potential environmental impact.

One method of estimating the environmental impact of different pesticide regimes in conventional and GM crop varieties is based on a measure known as the Environmental Impact Quotient (EIQ), developed by Kovach et al. (1992). The EIQ for individual agricultural pesticides is estimated using existing toxicological and environmental effects data. The EIQ is then used to assign a value (EI value per ha) that reflects the level of impact on the environment, determined by multiplying the EIQ by the amount (weight) of active ingredient of pesticide applied per ha.

EI values for the various pesticides used in a cropping strategy in a season can be summed, taking into account the number of applications of each pesticide in the regime and application rates. Thus, the environmental impact per ha for the pesticide regimes of different cropping strategies can be estimated and compared over a season by comparing the respective total seasonal EI values per ha of the total pesticides applied per season in each strategy (Kovach et al. 2004).

Individual EI values and total EI values are only indicators, and it is important to note that the EIQ does not take into account all environmental issues and/or effects (Brookes and Barfoot 2005; Knox et al. 2006). Any method of estimating or measuring environmental impact will inevitably have to be based on the data that exist or are obtainable and also on decisions about the relative importance and weightings given to various ‘environmental’ effects. The EIQ includes farmworker and consumer components as well as ecological components, and so human effects are given more weight than ecological effects in the EIQ in contrast to some other environmental impact indicators.

Other indicators give weight to different effects, for example an Australian measure developed by the Commonwealth Scientific and Industrial Research Organisation[8], the Pesticide Impact Rating Index, has a focus on aquatic toxicity effects and also on fauna relative to flora. We are aware only of data using the EIQ to compare broad environmental impacts of GM crops, as reported in this study.

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[8] http://www.clw.csiro.au/research/biogeochemistry/assessment/projects/piri.html

Chapter 2 Cotton

Section 2.1 GM Cotton in Australia

2.1.1 Introduction

Cottonseed was brought to Australia in 1788 by the First Fleet. Depending on water availability, the Australian cotton industry can generate about one billion dollars per year in export revenue, making it one of Australia's largest rural export earners and underpinning the viability of many rural communities (Cotton Australia 2006b; d).

On a global scale Australia is a relatively small cotton producer. For instance, in the 2004–05 growing season, Australia produced 2.2 million cotton bales in comparison to 28 million bales in China and 22 million bales in the USA (Cotton Australia 2006c)—a 'cotton bale' weighs 227 kg. Nevertheless, Australia is the third largest cotton exporter behind the USA and India (USDA-FAS 2006).

In the 2006–2007 season (a drought year), Australia grew about 100 000 ha of cotton, 90 per cent of which was GM. By comparison, in 2007, about 15 million ha worldwide were planted to cotton crops which have been genetically modified with *Bt* genes expressing toxins effective against lepidopteran pests (James 2007).

Two-thirds of Australian cotton is produced in New South Wales, with the rest produced in Queensland. The major production area in NSW is in the Gwydir River, Namoi River and Macquarie River valleys, although cotton is also grown near the Barwon and Darling Rivers in the west and the Lachlan and Murrumbidgee Rivers in the south of the state. In Queensland, most of the cotton is grown in the south of the state in the Darling Downs, St George, Dirranbandi and Macintyre valley regions. It is also grown near Emerald, Theodore and Biloela in central Queensland (Cotton Australia 2006c).

GM IR cotton varieties were first commercially released in 1996. These IR cotton varieties contain one or two insecticidal gene(s) from the bacterium *Bacillus thuringiensis* subspecies *kurstaki* (*Btk*). *Bacillus thuringiensis* is a naturally occurring soil organism and its protein toxins are naturally present as crystalline inclusions in its spores. Hence, Bt toxins are also known as 'Cry' proteins. Bt toxin and spore formulations have been used in biological insecticide foliar sprays for over 50 years (Cotton Australia 2006c), including as crop production inputs by organic farmers (Biological Farmers of Australia 2006). These biological insecticides are approved by the APVMA.

The Bt protein(s) produced in GM Bt cotton are toxic to the caterpillars of *Helicoverpa* species, which are major cotton pests around the world. Ingestion of these proteins disrupts the caterpillar's digestive system, resulting in death. The toxins are specific to lepidopteran (butterfly and moth) insects and so highly targeted to the target pests compared with broad spectrum synthetic insecticides. Most non-target species, including all mammals, are not affected by the proteins.

Many different Bt toxins, effective against other insect groups, have also been identified (Ferry et al. 2004). For example, the Cry proteins produced by *B. thuringiensis* subspecies *israelensis* (*Bti*) have been used in conventional Bt spray products to control dipteran (fly) pests such as mosquitoes (Poncet et al. 1995).

The first Bt cotton commercially available in Australia, Ingard® cotton (expressing only the *cry1Ac* gene), was grown from 1996–97 to 2003–04. It was phased out of commercial production in 2004–05 and replaced with Bollgard II® cotton varieties expressing two *Bt* genes (*cry1Ac* and *cry2Ab*). The rationale for using two *Bt* genes is that target insects are much less likely to develop resistance to both proteins simultaneously than to develop resistance to one toxin protein. In the future, inserting a third *Bt* gene should further reduce the risk of insects developing resistance to the Bt proteins. Alternating different combinations of *Bt* genes each season could also decrease the risk of target insects developing resistance. In addition, other measures are put in place in IPM systems, such as providing 'refuges' or trap crops for target pests and mechanical destruction of the pupae which over-winter in the soil.

Weeds cause a range of problems for cotton farmers. They directly reduce yield by competing for sunlight, water and nutrients; reduce quality by way of contaminating the cotton lint (e.g. weed seeds getting caught in the lint); hamper water flow through irrigation channels, reducing water use efficiency and causing water-logging; or act as refuges for insect pests or disease-causing pathogens (Charles 1991).

As already indicated, in addition to insect pest resistance, cotton in Australia has also been genetically modified to be tolerant to herbicides. Herbicide tolerance traits are another tool in the weed management 'toolbox' for farmers. Australian cotton farmers currently have access to three different types of GM HT plants, tolerant to two different herbicides (glyphosate and glufosinate-ammonium). Varieties have also been bred to combine both the IR and HT traits (e.g. Bollgard II®/Roundup Ready® cotton).

Roundup Ready® and Roundup Ready Flex® cotton varieties are tolerant to the herbicide glyphosate by virtue of containing either one or two copies respectively of the *cp4 epsps* gene from the soil bacterium *Agrobacterium* sp. strain CP4. This gene encodes the enzyme CP4 5-enolpyruvylshikimate-3-phosphate (EPSP) Synthase. Plants contain a native[9] *epsps* gene that encodes an enzyme essential for amino acid synthesis (EPSPS) and is not present in animals. Glyphosate works as a herbicide by inhibiting the action of the native EPSPS enzyme resulting in the death of the plant. Both roots and shoots are killed because, after contact, glyphosate is translocated throughout the plant via the plant's vascular system.

The enzyme produced from the *cp4 epsps* gene in GM cotton is insensitive to the effect of glyphosate, so plants containing this version of the enzyme are still able to function and continue amino acid synthesis despite herbicide application. Therefore, glyphosate can be sprayed on GM HT varieties to control weeds that emerge, without killing the crop (OGTR 2003c).

Roundup Ready® varieties contain only one copy of the *cp4 epsps* gene and can tolerate glyphosate applications only up to the four-leaf stage (before reproductive tissues have formed), after which application can cause crop damage and yield loss. Roundup Ready Flex® varieties, which contain two copies of the gene, have increased and prolonged expression of the EPSPS enzyme and are tolerant to glyphosate during later stages of growth. This widening of the glyphosate application window gives growers increased flexibility in the timing of herbicide applications and assists them in adoption and development of IWM strategies (OGTR 2006b).

Bayer CropScience's Liberty Link® cotton varieties are tolerant to the herbicide glufosinate ammonium as a result of containing a copy of the *bar* gene, derived from the soil bacterium *Streptomyces hygroscopicus*. The *bar* gene encodes the enzyme phosphinothricin acetyltransferase (PAT), which acts to convert glufosinate ammonium into its inactive form, thus rendering the plant tolerant to the herbicide. The glufosinate ammonium herbicide is toxic to conventional cotton varieties. Liberty Link® cotton plants exhibit tolerance to application of glufosinate ammonium at all stages of their development cycle (OGTR 2006c).

Table 2.1 summarises the full range of GM cotton varieties currently available to Australian farmers. Until recently, GM cotton varieties were available for use only in the area of Australia south of Latitude 22° South. This was a precautionary measure until further research was undertaken to determine whether Bt cotton plants had a higher weediness potential in the

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[9] Here, the word 'native' refers to genes and regulatory sequences that are naturally present in the parent organism.

northern part of Australia. In 2006, the Gene Technology Regulator considered recently published data on the weediness potential of GM cotton in northern Australia and concluded that the risk of weediness was negligible. A licence to grow GM Bollgard II®, Roundup Ready Flex® and Roundup Ready Flex®/Bollgard II® cotton varieties in northern Australia was issued in 2006 (OGTR 2006f). The licence for Liberty Link® cotton also allows this variety to be grown in northern Australia (OGTR 2006c).

Since its introduction, uptake of GM cotton in Australia has been rapid, as indicated by Figure 2.1, which shows the estimated percentage of area planted to conventional and GM cotton since the GM varieties were introduced in 1996–97. These figures include Roundup Ready® cotton from 2000–01. When Ingard® cotton was first introduced, the APVMA placed a 30 per cent cap on the area permitted to be planted with Bt cotton in order to decrease the risk of the target insects developing resistance to the Cry1Ac protein. Following the replacement of Ingard® with Bollgard II® in the 2004–05 season, the cap was removed. However, all other resistance management procedures (see Section 2.1.3) must continue to be followed (Fitt et al. 2004).

In the 2006–2007 season, 92 per cent of Australia's cotton growers planted transgenic varieties (Monsanto Australia 2006).

Table 2.1 GM cotton varieties currently available to Australian farmers

Modified trait	**Trade name**	**Date approved for commercial release by the Gene Technology Regulator (application number)**
Insect resistance (*Bt*)	Bollgard II®	23 September 2002 and 26 October 2006 (DIR 012/2002 and DIR 066/2006)
Herbicide tolerance (glyphosate)	Roundup Ready®	14 September 2000 and 20 June 2003 (GR – 9* and DIR 023/2002)
Herbicide tolerance (glyphosate) and insect resistance (*Bt*)	Roundup Ready® / Bollgard II®	23 September 2002 (DIR 012/2002)
Prolonged herbicide tolerance (glyphosate)	Roundup Ready Flex®	16 February 2006 and 26 October 2006 (DIR 059/2005 and DIR 066/2006)
Prolonged herbicide tolerance (glyphosate) and insect resistance (*Bt*)	Roundup Ready Flex® / Bollgard II®	16 February 2006 and 26 October 2006 (DIR 059/2005 and DIR 066/2006)
Herbicide tolerance (glufosinate ammonium)	Liberty Link®	8 August 2006 (DIR 062/2005)

Notes: * GR–9 was approved by the Health Minister under the voluntary system that preceded the *Gene Technology Act 2000* (Cwlth).

Source: OGTR (2006a).

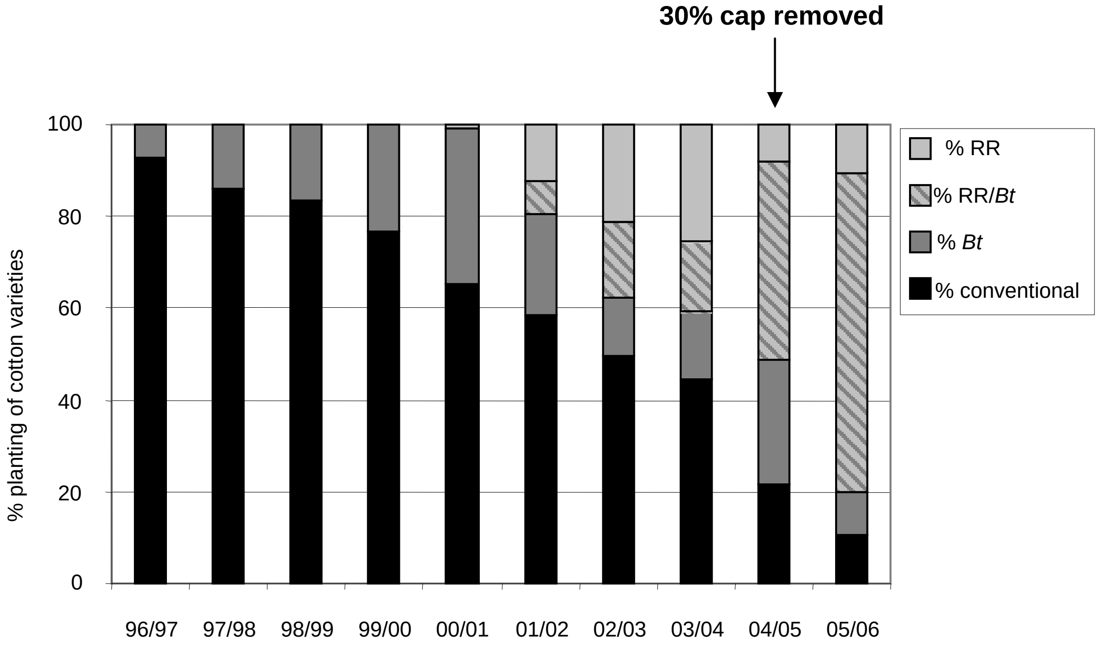

Figure 2.1 Per cent area of conventional and GM cotton grown in Australia since the 1996–97 growing season

Notes: RR, Roundup Ready® cotton varieties; Bt, Bt cotton varieties (Ingard® or Bollgard II®); RR/Bt, varieties with combined Roundup Ready® and Bt traits.

Source: Graphed from data supplied by the CRDC, based on Cotton Consultants Australia (CCA) market audits for 96–97 to 05–06.

2.1.2 Insect-resistant cotton

Agronomic Performance

Yield

Cotton is susceptible to damage by many insect pests which can cause serious crop losses. The main pests are caterpillar species of *Helicoverpa*, aphids, thrips, mirids and whitefly (Cotton Australia 2006a). In the 1960s, large areas of cotton were established in Western Australia's Ord River Irrigation Area (ORIA) but the industry there collapsed in the face of intense insect pressure and the development of resistance to insecticides (AAS 2001).

Insect resistance to major insecticides such as DDT, synthetic pyrethroids and organophosphates began to appear both in the ORIA and later in cotton growing regions in NSW and Queensland (Fitt 1994). In contrast, good yields are now achievable with minimal insecticide usage when genetically modified Bollgard II® varieties are used in combination with locally developed IPM (Yeates et al. 2006).

The introduction of GM cotton into Australia has had significant agronomic benefits for farmers. Decreases in insecticide use and changes in the quantity and type of herbicides applied (see Section 2.1.3) have together resulted in benefits in terms of better crop yields and lower input costs.

Australian cotton yield from the 1960–61 until the 2005–06 growing seasons is shown in Figure 2.2. This figure shows an overall increase in cotton yield from the 1960–61 growing season to the present day. An analysis of the rate of yield increase between the decades 1986–87 to 1995–96 and 1996–97 to 2005–06 in Australia reveals that in the last ten years yield has increased at a rate 3.6 times faster than the decade before it (USDA-FAS 2006). This rate of yield increase cannot be attributed solely to the adoption of GM cotton varieties as the last decade has also seen the development of improved breeding programs and the adoption of a Best Management Practices (BMP) Program by the Australian cotton industry. This program is a voluntary farm management system designed to ensure that cotton is produced with best practice across a range of focus areas: land and water use, chemical use and integrated pest management, soil health, biodiversity, climate change and energy, technology and human resources.

Nevertheless, GM varieties have been an important contributor to improved management practices and have allowed farmers to reduce the quantities of insecticides applied per hectare. Fitt (2000) regards transgenic IR cottons as perhaps the most significant step forward in cotton pest management.

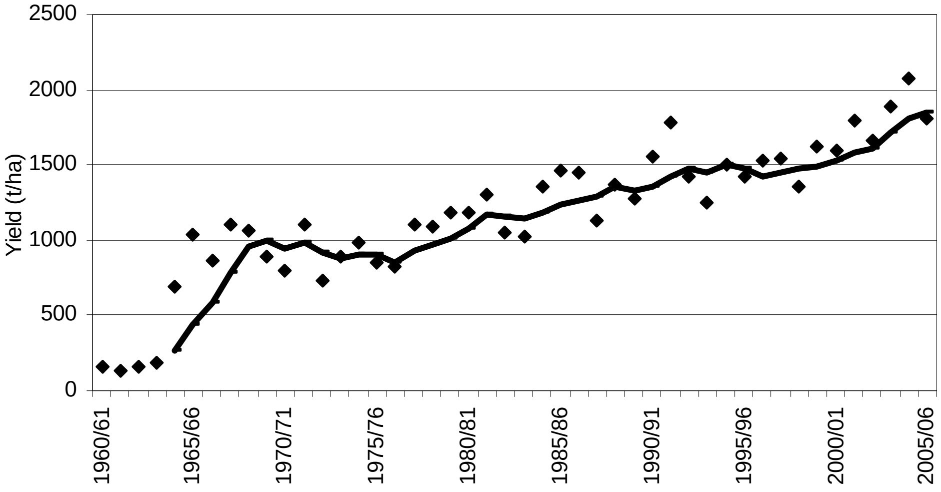

Figure 2.2 Australian cotton yield since 1960–61

Source: Graphed from data reported by USDA-FAS (2006). Data points indicate yields for individual years. The line represents the 5 year average yield for each of the previous 5 years commencing from the 1965–66 data point.

As shown in Figure 2.3, the comparative yields of Bt and non-Bt cotton varieties from 1996–97 to 2004–05 varies between seasons. For example, in 2004–05, the average yield was 10 bales of cotton per ha for both Bt and non-Bt cotton varieties, whereas in 2003–04 conventional cotton averaged 7.73 bales per ha while Bollgard II® averaged 8.27 bales per ha (Doyle et al. 2005). Variation in performance probably reflects changes in insect pressure each season and differences in the varieties planted by farmers.

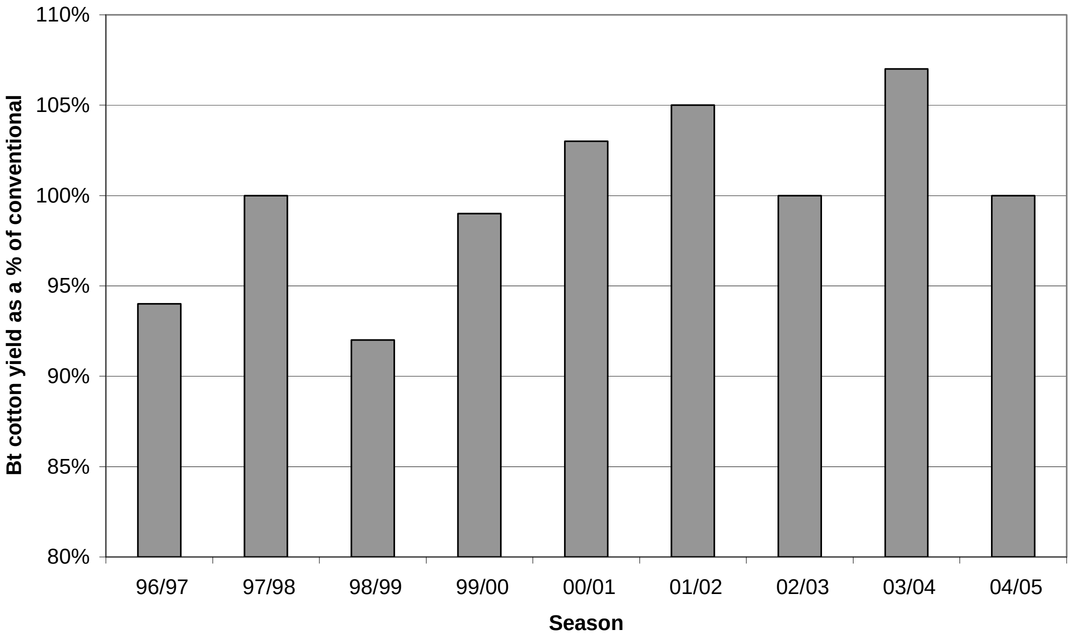

Figure 2.3 **GM Bt Ingard® and/or Bollgard II® cotton yield expressed as a percentage of conventional cotton yield**

Source: Browne et al. (2006) calculated from Cotton Consultants Australia data.

Improved weed control will also have contributed to yield increases in recent years, and in recent seasons most cotton grown is both IR and HT. It would be difficult to ascertain the relative contributions to yield of changed insect control, changed weed control, environmental factors (for example, insect pressure and temperatures) when comparing variety performance.

Unlike in other countries (see Section 2.2), yield and quality of Bt cotton varieties in Australia have not differed significantly from those of conventional cotton. However, insecticide use on Bollgard II® cotton in Australia is dramatically less compared with conventional cotton (see 'Environmental performance' below, and Table 2.2). The major agronomic impacts of growing IR cotton have been to improve pest management. *Helicoverpa* pests are no longer the primary pests of cotton, with Bollgard II® cotton now providing near season-long control.

Insecticide use

Table 2.2 compares the number of insecticide sprays applied to conventional and Bollgard II® cotton during the 2004–05 growing season and indicates the percentage of these sprays that targeted each of the pest groups that affect cotton (Doyle et al. 2005). In the 2004–05 season, Bollgard II® varieties received an average of three insecticidal sprays, in comparison to conventional cotton which required an average of 11.4 sprays (Table 2.2) (Doyle et al. 2005). This is a reduction of about 75 per cent in the number of sprays. Because Bollgard II® cotton provides excellent control of the two *Helicoverpa* species that attack Australian cotton, very few sprays are now used to control these pests. In contrast, over 90 per cent of the insecticide applications to conventional cotton are used to control these pests (Pyke and Doyle 2006).

However, in Bollgard II® crops, the elimination of sprays for *Helicoverpa* has elevated some sucking pests (normally controlled by sprays for *Helicoverpa*) from secondary to primary insect pest status.

Table 2.2 The percentage of insecticides/miticides by target pest in conventional and Bollgard II® crops in 2004–05

Pest	*Helicoverpa*	Mirids	Aphids	Green vegetable bug	Mites	Thrips	Other
Conventional (%) *(total no. sprays 11.4)*	93.0%	0.9%	4.2%	0.9%	0.2%	1.2%	0.4%
Bollgard II® (%) *(total no. sprays 3.0)*	3.0%	55.0%	21.0%	12.0%	4.0%	3.0%	2.0%

Source: Doyle et al. (2005).

Mirids can now be classed as a primary pest in Bollgard II® cotton as they are the most commonly sprayed pest and usually the first pest to require insecticide treatment during the fruiting phase of the crop. Thrips have become more abundant late in the growing season; aphids require a similar level of control as before; and although mites have become more common, they are maintained at low levels by other beneficial insects. Bollgard II® assists in maintaining a successful IPM strategy, as beneficial insects are generally much more abundant in Bollgard II® fields, provided that broad spectrum insecticides are not being used for the control of other pests (Pyke and Doyle 2006). The total amount of insecticide used is reduced.

A comparison has been made of the six most commonly used insecticides or miticides, their primary target pests and relative use on Bollgard II® (Pyke and Doyle 2006). These data, reproduced in Table 2.3, identify in more detail the differences in target pest and chemical use between Bollgard II® and conventional cotton.

Table 2.3 The six insecticides or miticides most commonly used on conventional and Bollgard II® cotton, their primary target pests and relative usage on conventional and Bollgard II® cotton in the 2004–05 growing season

Conventional	Primary pest target	Bollgard II®	Primary pest target
Endosulfan	*Helicoverpa* *(8.6-fold higher use on conventional cotton)*	**Fipronil** (Regent®)	Mirids *(1.3-fold higher use on Bollgard II® cotton)*
Emamectin (Affirm®)	*Helicoverpa* *(Not used on Bollgard II® cotton)*	**Dimethoate**	Mirids, aphids *(1.5-fold higher use on Bollgard II® cotton)*
Indoxacarb (Steward®)	*Helicoverpa* *(40-fold higher use on conventional cotton)*	**Acitamiprid** (Intruder®)	Aphids, mirids *(1.9-fold higher use on conventional cotton)*
Amitraz	*Helicoverpa* *(40-fold higher use on conventional cotton)*	**Abamectin**	Mites *(4-fold higher use on conventional cotton)*
Fipronil (Regent®)	Mirids *(1.3-fold higher use on Bollgard II® cotton)*	**Endosulfan**	Green veg bug, aphids, mirids *(8.6-fold higher use on conventional cotton, and different primary target)*
Spinosad (Tracer®)	*Helicoverpa* *(Not used on Bollgard II® cotton)*	**Deltamethrin**	Mirids *(3.5-fold higher use on conventional cotton)*

Source: Table adapted from Pyke and Doyle (2006).

Table 2.3 reinforces the data shown in Table 2.2 showing that *Helicoverpa* and mirids are the pests most requiring spraying in conventional and Bollgard II® cotton respectively. Pyke and Doyle (2006) comment that for pest management purposes they could almost be considered different crops. However, these authors believe that the IPM principles that have been adopted for conventional cotton will remain the same for Bollgard II®.

Monsanto Australia and the Cotton Catchment Communities Cooperative Research Centre in Narrabri, New South Wales, established a collaborative research program to determine the threshold level of insect pressure needed to warrant the use of insecticide sprays for *Helicoverpa* in Bollgard II® cotton (Australian Cotton Outlook 2006). The outcomes of this research program are used to assist Bt cotton growers to decide when it is cost-effective to apply insecticides targeting *Helicoverpa*.

Insect resistance to Bt toxin

The development of insect resistance to the insecticidal Bt toxins (Cry proteins) is the greatest potential limit to the continued efficacy of Bollgard II® cotton. Since future GM cotton varieties may also rely on the two *cry* genes used in Bollgard II®, protecting the efficacy of Bollgard II® also means protecting the future of this technology in Australian farming systems (Farrell and Johnson 2005).

There are two *Helicoverpa* species of concern to Australian cotton farmers: *H. armigera* and *H. punctigera*. Of these, *H. armigera* has consistently developed resistance to a number of insecticides while *H. punctigera* has not (Fitt 2003). The resistance profile of *H. armigera* is presented in Table 2.4. A gene present in the *H. armigera* population confers a high level of resistance to the Cry1Ac protein. It occurs at a frequency of less than one individual in a million and appears to have a high fitness cost (individuals with this gene are less fit than those without it). Another gene in *H. armigera* confers a high level of resistance to the Cry2Ab protein and occurs at a higher frequency (current estimates are that four in a thousand individuals carry the resistant version of the gene) (Farrell 2006).

Table 2.4 Resistance profile of *Helicoverpa armigera*

Widespread, high levels of resistance	Widespread, low/moderate levels of resistance	Occasional detection of low levels of resistance
Synthetic pyrethroids Methomyl (carbamate) Thiodicarb (carbamate)	Profenofos, chlorpyrifos, chlorpyrifos methyl (organophosphates) Endosulfan (organochloride) Chlorfenapyr	Indoxacarb Spinosad Emamectin

Source: Farrell (2006).

To prevent resistance developing to Bollgard II®, the Australian cotton industry's TIMS Committee has designed a pre-emptive management strategy that aims to prevent field-scale changes in resistance. The Insect Resistance Management Strategy (IRMS) is revised annually, taking into account factors such as the amount of Bt cotton grown, results of insect resistance monitoring in all growing areas in the previous season, insect pressures and insect control efficacy.

In addition, Monsanto Australia requires growers to be trained in and follow a Risk Management Plan (RMP). The RMP for Bollgard II® cotton requires growers to undertake various measures to ensure resistance to the Bt proteins is effectively managed. These measures include requiring the grower to plant refuge crops of minimum sizes, types and distances from the Bollgard II® crop, fixed planting windows, post-harvest crop destruction, control of volunteer and rattoon cotton, pupae destruction and trap cropping (APVMA 2003).

Planting windows are specified to reduce the length of the cotton season and thus reduce the length of time over which *Helicoverpa* are exposed to the Bt proteins. Pupae destruction involves cultivating the field following harvest to destroy *Helicoverpa* pupae that are over-wintering in the soil beneath the crop. Although this practice is incompatible with no-till farming, it is necessary to limit populations of moths that may be resistant to the Cry proteins emerging the following season (CRDC 2006).

A major element of the Bollgard II® RMP is the mandatory growing of refuge crops. As discussed in Section 2.1.4, this is also a significant economic consideration for cotton farmers. The use of refuge crops aims to provide locations where a significant number of susceptible insects that have not been exposed to the Bt protein can multiply. It is anticipated that these susceptible insects will breed with those from a nearby cotton crop that may be resistant to the toxins, thus reducing the chance that two resistant insects will meet and reproduce. Since resistant insects comprise only a minority of the overall breeding population, it is hypothesised that resistance genes will be constantly swamped by susceptible genes, maintaining the susceptibility of the insect population as a whole to Bt toxins.

The offspring from the mating of one resistant and one susceptible insect will each contain one susceptible and one resistant form of the gene (these offspring are called heterozygotes). The level of toxin expressed in Bollgard II® has been sufficient to kill heterozygotes in all the cases of resistance found to date (Farrell and Johnson 2005). In this way, the refuges manage the level of resistant insects within a population (Farrell and Johnson 2005).

Cotton growers can choose one of a number of refuge strategies, each based on their ability to support a large population of *Helicoverpa* moths. The size of the refuge depends on the choice of refuge strategy (Table 2.5). For instance, conventional cotton may be grown and sprayed with non-*Bt* insecticides, in which case the area of the refuge must equal the area of Bollgard II® cotton. Alternatively an area of conventional cotton 10 per cent of the size of the Bollgard II® area may be grown without spraying.

Table 2.5 Irrigated Bollgard II® cotton refuge options

Refuge strategy	Required refuge, as per cent of Bollgard II® area
Irrigated sprayed conventional cotton	100%
Irrigated, unsprayed conventional cotton	10%
Irrigated, unsprayed Pigeon pea	5%
Irrigated, unsprayed Sorghum	15%
Irrigated, unsprayed Maize	20%

Note: All the refuge crops (except unsprayed cotton) can be sprayed with non-*Bt* sprays.

Source: Pyke and Doyle (2006).

A Cotton Pest Management Guide, reporting the level of resistance to the Bt proteins in the *Helicoverpa* population is prepared annually (Farrell 2006). Bt resistance monitoring is continually reported for the regional cotton growing areas on the Cotton Catchment Communities Cooperative Research Centre website[10]. The most recent monitoring (end of season, February 2008) concludes that in all the sampled regions, the data do not indicate any major changes from previous seasons in survival rates to discriminating doses of Cry1Ac or Cry2Ab. To date, the cotton industry's IRMS and Monsanto Australia's RMP have maintained the efficacy of Bt cotton varieties.

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[10] www.cottoncrc.org.au/content/Industry/Publications/PestsandBeneficials/InsectResistanceManagement.aspx

Environmental Performance

In 1991, the cotton industry, through the Australian Cotton Foundation, commissioned an audit of the environmental impacts of cotton in Australia. At the time, the industry was a focus of public, media and environmentalist attention for its use of pesticides, including incidents where fish kills were attributed to pesticides in rivers (CRDC 2005). The auditors made 69 environmental and occupational health and safety recommendations. These were all implemented by the time of the second environmental audit in 2003 (GHD 2003).

Problems with insecticide residues persisted and cattle farmers reported endosulfan residues accumulating in beef which began to affect beef exports in the late 1990s (Gunningham n.d.). The introduction of the BMP Program, use of the GM cotton variety Ingard®, and improved IPM practices (see Section 1.4) were identified as important for improving the environmental performance of the cotton industry, particularly the decrease in detections of pesticide residues in drinking water (GHD 2003).

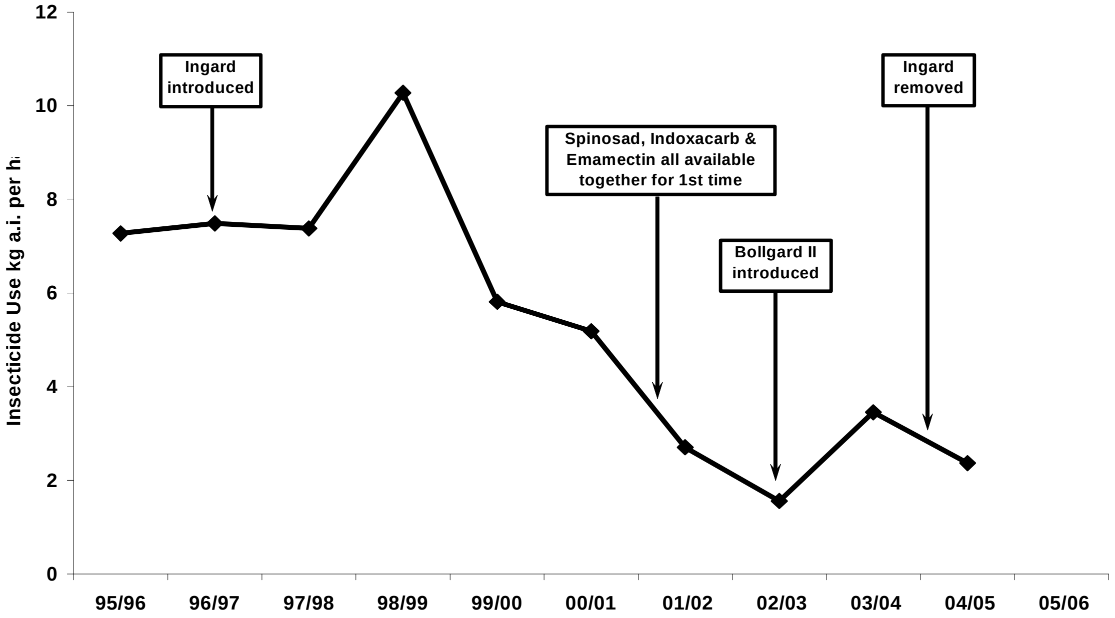

Figure 2.4 **Average quantities of insecticides used in Australian cotton crops from 1995–2005**

Notes: The introduction of Bollgard II® coincided with a drought year in which the area of cotton grown was also reduced.
The figure shows the trend in total quantities of insecticides and miticides applied per ha over a ten year period from 1995 to 2005. The reduction in insecticide use is due to improvement in IPM strategies including adoption of Bt cotton varieties and Best Management Practices by the cotton industry.
Source: Browne et al. (2006) calculated from CCA 2004 and 2005 market audits.

Over the last 10 years, adoption of Bt cotton varieties more compatible with the principles of IPM have allowed Australian cotton growers to reduce the amount of insecticide used per ha by 70–85 per cent compared to conventional cotton. The number of insecticide sprays used has been reduced by about 75 per cent (Browne et al. 2006) (Figure 2.4 and Table 2.2). Importantly, Bt cotton and the pursuit of IPM practices have also resulted in changes to the types of insecticides applied to cotton fields with an emphasis on ‘softer’ insecticides that allow beneficial insects to survive.

As Figure 2.4 shows, the amount of insecticide used on all types of cotton decreased between 1995–96 and 2004–05. The decrease was a result of introducing GM IR cotton varieties and the availability of new insecticide combinations (Spinosad, indoxacarb and emamectin, and a number of other ‘new’ insecticides), used in an IPM context. The use of Bt cottons and the new insecticides have together enabled pest control that is more target pest-specific. This is less disruptive to populations of beneficial insects than broad spectrum sprays such as the older organophosphate, carbamate and pyrethroid insecticides (Fitt et al. 2004).

Insecticides with good target species specificity are important tools for IPM. In addition, the new insecticides, coupled with the use of Bt cottons, have lower mammalian toxicity risks and are used at significantly lower rates of active ingredient per ha than the insecticides they replaced (e.g. endosulfan, synthetic pyrethroids and amitraz). Their availability has made a large contribution to the reduction in chemical load, including when used on conventional cotton varieties.

The introduction of the cotton BMP program in 1998 (Browne et al. 2006) improved the environmental performance of the whole cotton industry. In the early 1990s, pesticide contamination off-farm was a major issue for the industry. As a result of the adoption of GM IR cotton varieties in 1996–1997 and the BMP program in 1998–1999, there is now negligible detection of pesticides in rivers (Browne et al. 2006). Figure 2.5 illustrates the reduction in insecticide endosulfan contamination of four north-western NSW rivers between 1991 and 2005.

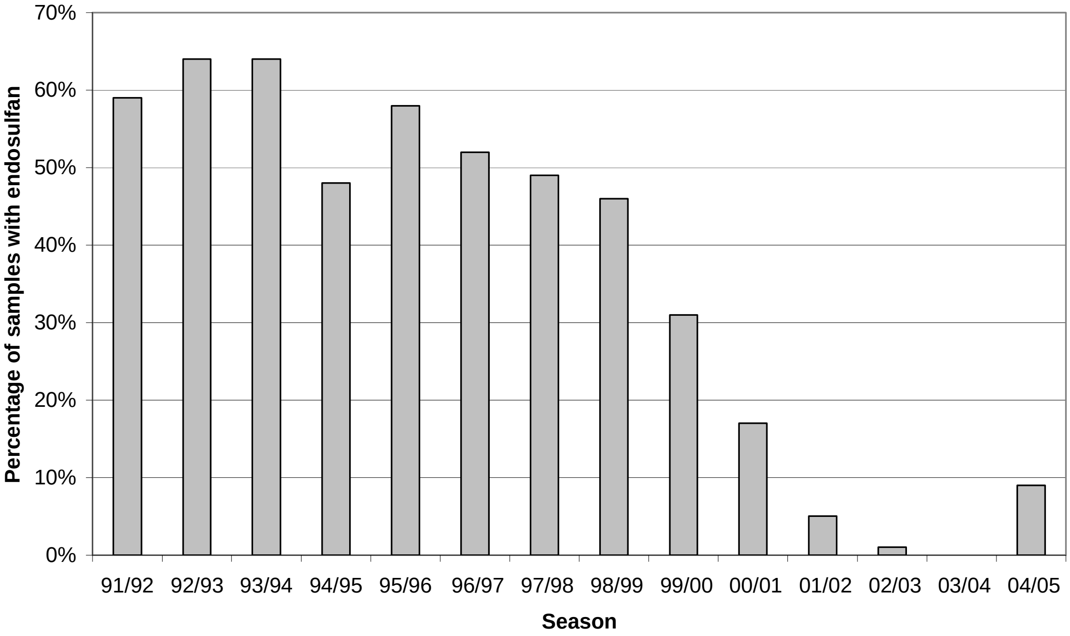

Figure 2.5 **Percentage of river water samples containing the insecticide endosulfan (four north-western NSW rivers combined)**

Source: Browne et al. (2006); NSW Department of Natural Resources.

Insecticides vary in their impact on the environment. Understanding the overall impact of adoption of Bt technology requires consideration of all the insecticides used in a season on the crop. Knox et al. (2006) assessed and compared the environmental impact of insecticides applied to Bt and conventional cotton varieties from 1997–98 to 2003–04 using the method of Kovach et al. (2004).

Table 2.6 compares mean seasonal EI values per ha for conventional, Ingard® and Bollgard II® cotton grown in Australia (see Section 1.6 for more detail on EI values). The Bt protein(s) expressed by Ingard® and Bollgard II® varieties were included in the analysis. To determine the EI of the insecticidal Bt protein(s) expressed in the Bt cotton varieties, Knox et al. (2006) used data for expression levels and toxicity from both overseas and Australian experiments. They acknowledge the difficulties posed in determining a level of exposure for a whole season when the expression of *Bt* genes and the Bt protein levels vary throughout the season, in different parts of the plant and between different fields and even within fields. To avoid underestimating the impact of the Cry protein(s) Knox et al. (2006) selected the highest expression level and used the end-of-season biomass to calculate the amount of Bt protein produced per ha in a given season. This inclusion increased the EI values for Bt cotton by only 2 per cent.

The variability of the total seasonal EI values presented in Table 2.6 demonstrates seasonal differences and changes in insect pressure, chemical usage and the level of IPM adoption. However, what is clearly demonstrated across all seasons is that the EI values for Bt cotton were lower than for conventional cotton. These data suggest a significantly reduced level of environmental impact from Bt cotton (both Ingard® and Bollgard II®) when compared with the chemical use required for conventional cotton. For example, the EI value for Bollgard II® cotton in 2003–04 was only 13 per cent and that of Ingard® only 48 per cent of the EI value for conventional non-GM cotton. As noted above, these comparisons include taking into account an estimate of the Bt levels in cotton plants (Knox et al. 2006).

Table 2.6 Comparison of mean seasonal EI values for the amount of insecticide used per ha of conventional, Ingard® and Bollgard II® cotton (EI value per ha)

	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04
Conventional	266.3	425.0	282.1	293.4	133.9	83.4	186.3
Ingard®	219.7	307.5	202.3	133.2	54.1	24.1	89.5
Bollgard II®						31.1	24.5

Source: Knox et al. (2006)

2.1.3 Herbicide-tolerant cotton

Agronomic performance

Herbicide use and improved weed control

Approximately 80 per cent (280 000 ha) of the 2005–06 Australian cotton crop was planted to glyphosate-tolerant varieties including Roundup Ready®/Bollgard II® varieties (Figure 2.1). Uptake varied considerably between cotton growing regions. Factors that influence weed management decisions in cotton include: different weed spectra; spray drift issues; weeds with existing tolerance to particular herbicides; cultivation practises (e.g. the use of reduced tillage or no-till); crop rotations; overall cost of weed control; the logistics of spraying versus cultivation; and crop seedling vigour (Doyle 2005).

A Roundup Ready® (RR) cotton-only approach is constrained by the short window of opportunity for applying glyphosate (Doyle 2005). Glyphosate must be applied before the RR cotton plants begin to develop reproductive tissue (after the first four true-leaves have appeared). This can cause problems when wet weather or windy conditions prevent spraying during the available window and also in fields where late germinating weeds require control (Charles and Taylor 2006). The majority of growers surveyed by Werth et al. (2006b) agreed that the window for over-the-top application of glyphosate on RR cotton was too narrow.

Werth et al. (2006b) also reported that 21 per cent fewer growers applied full pre-emergence residual herbicide programs in fields planted to glyphosate-tolerant cotton. These results confirmed the survey results reported earlier by Doyle (2005), that the adoption of these varieties resulted in growers using a reduced residual herbicide program. Both Werth et al. (2006b) and Doyle (2005) reported that when Roundup Ready® cotton was grown in weedy fields with no residual herbicide applications at all, weed control proved to be worse than for conventional herbicide application programs.

There are two broad classes of herbicides used by cotton farmers: residual and non-residual. Residual herbicides, such as some triazines, imidazolinones, bipyridiliums and sulfonylurea herbicides, are classed as ‘residual’ because of their longevity in soil and consequent longer-term action. Non-residual herbicides such as glyphosate and glufosinate ammonium are short-lived in the environment as they either degrade rapidly or are quickly inactivated by soil contact. Because residual herbicides are active over a longer period of time, they present a higher risk of damaging crops (particularly grain crops) in subsequent rotations, for example by reducing yield, and they can also impact on natural ecosystems (Crossan and Kennedy 2004).

Werth et al. (2006b) report from a cotton grower survey in four cotton growing regions in 2003 that glyphosate use alone was higher in glyphosate-tolerant cotton fields (2.3 to 3.2 kg a.i. per ha) than in fields planted with conventional cotton (0.5 to 0.8 kg a.i. per ha). However, there was a reduction in the use of residual herbicides (see Environmental Performance below; Table 2.7), with less applied pre-planting and at planting. The reduction in herbicides applied other than glyphosate was variable between regions, with a reduction in the average amount used across all regions from 3.38 kg a.i. per ha for conventional cotton to 2.55 kg a.i. per ha for glyphosate-tolerant cotton (Doyle 2005; Werth et al. 2006b). Overall herbicide use when growing GM glyphosate-tolerant HT cotton varieties was higher (Table 2.7) compared with conventional cotton. There remains a need to apply some residual herbicide in cotton crops because some weeds are naturally tolerant to the herbicide glyphosate, such as red pigweed and sow thistle.

The introduction of glyphosate-tolerant cotton has caused changes in the herbicides that are used and the weed management strategies adopted. Overall, farmers have benefited from improved control of weeds that are difficult to control in conventional cotton (e.g. the nutgrasses, *Cyperus rotundus* and *C. bifax*, and vines such as *Ipomoea lonchophylla* and *I. plebia*) and from some reductions in the use of pre-planting herbicides, inter-row cultivation and hand-hoeing (Charles and Taylor 2006; Werth et al. 2006b). Environmental performance is discussed below.

Subsequent to the experience with Roundup Ready® cotton (above), Roundup Ready Flex® cotton was approved for commercial release by the Gene Technology Regulator in 2006 (OGTR 2006b). Adoption of this variety from the 2006–07 growing season has helped to alleviate most of the issues with the Roundup Ready® varieties described above due to the longer spraying window permitted with this variety. Roundup Ready Flex® cotton has given farmers an increased opportunity to spray in optimal spraying conditions.

Herbicide resistance

Reliance on glyphosate could result in the emergence of glyphosate-resistant weeds, which would compete with crop plants, incur costs in their control, and could spread to other farms. The adoption of Roundup Ready Flex® with its increased application window potentially increases the threat of glyphosate-resistant weeds if not managed correctly, particularly where other weed control measures are reduced. These potential problems can be avoided through the use of IWM strategies which involve continuing the use of certain residual herbicides (Farrell and Johnson 2005). IWM involves growers recording their field histories and the dominant weeds species in a given field, and managing weeds and herbicide use accordingly.

Preston and Roush (1998) suggest that it is the application frequency, rather than the volume of active ingredient applied, which is likely to result in increased resistance. Although glyphosate use has increased with the adoption of glyphosate-tolerant cotton, it has added only two additional glyphosate applications per season with a marginal reduction in other non-herbicide weed management practices (Werth et al. 2006b).

The APVMA includes advisory resistance management statements on labels of Roundup Ready® herbicide for use on Roundup Ready® and Roundup Ready Flex® cotton products. An example advisory statement is as follows: “Growers of Roundup Ready Flex® Cotton must practise preventative resistance management strategies that have been endorsed by the TIMS Herbicide Tolerant Crop Technical Panel. Practices are detailed in the Roundup Ready Flex® Cotton Integrated Weed Management Strategy included in the relevant Monsanto Crop Management Plan approved for the area in which the Roundup Ready Flex® Cotton is being grown. Growers must follow the Crop Management Plan approved for their area." (Approval no. 54112) (APVMA 2006).

To date, glyphosate-resistant weeds have not been recorded in cotton fields in Australia (Preston 2007), but farmers and others need to be vigilant to enable early control should resistance be detected.

Volunteer HT cotton

A second issue reported with the use of glyphosate-tolerant varieties is the control of both volunteer and rattoon (regrowth) plants (Doyle 2005). Control options for volunteer and rattoon cotton in subsequent crops or fallow include cultivation and/or use of alternative herbicides such as bipyridiliums including in mixes or as a 'double-knock' (sequential applications of knockdown herbicides with different modes of action). Growers reported that such control can be expensive and difficult. The most effective means of controlling rattoon cotton is through effective root-cutting of cotton stalks, followed by mechanical cutting of the root stump to prevent regrowth from occurring (NSW Department of Primary Industries 2007).

The availability of glufosinate ammonium-tolerant cotton varieties for the 2006–07 growing season provided Australian cotton farmers with an alternative weed control method to glyphosate. The ability to rotate herbicide chemistry allows better weed management and the capacity to delay or manage, or possibly prevent, the development of herbicide-resistant weeds. It also provides an 'over the top' control option for glyphosate-tolerant rattoon and volunteer plants in a subsequent cotton crop.

Environmental performance

Glyphosate is inactivated once it has bound to soil particles and for this reason it is classed as a non-residual herbicide and is not used as a pre-emergence herbicide (APVMA 1997). Compared to other herbicides commonly used in cotton production, it has lower human and aquatic toxicity and soil mobility.

Quantitative data on herbicide use from the records of surveyed growers are summarised in Table 2.7 (Werth et al. 2006b). These data show that average use of glyphosate was higher (up to six-fold higher, but averaging 4.6-fold higher) in fields planted to glyphosate-tolerant cotton than in fields planted to conventional cotton varieties. However, in three of the four regions surveyed, there was a decrease in the amount of other, residual herbicides used in these fields. In the fourth region (Macintyre), there was an increase. The regional average reduction was from 3.38 to 2.55 kg a.i./ha. The higher reduction (more than 50 per cent) in the use of residual herbicides recorded in the Darling Downs was due to a number of growers using glyphosate as the only herbicide (Werth et al. 2006b); some of these growers said they would use some residual herbicides in the future.

Table 2.7 Herbicide use in cotton crops

Region	Glyphosate use in glyphosate-tolerant cotton [a, b] (kg a.i./ha)	Glyphosate use in conventional cotton (kg a.i./ha)	Herbicides other than glyphosate used in glyphosate-tolerant cotton (kg a.i./ha)	Herbicides other than glyphosate used in conventional cotton (kg a.i./ha)
Darling Downs	3.18	0.49	1.3 [c]	2.96
Gwydir	2.82	0.59	3.38	3.93
Lower Namoi	2.61	0.79	2.38	3.13
Macintyre	2.35	0.49	3.15	3.52
Average	**2.74**	**0.59**	**2.55**	**3.38**

a.i. – active ingredient

[a] Average use from one month before planting to picking (about 9 months)

[b] Statistically significant difference between glyphosate-tolerant and conventional cotton ($P = 0.05$)

[c] Statistically significant reduction in herbicides other than glyphosate used in glyphosate-tolerant cotton compared to conventional cotton on the Darling Downs ($P = 0.05$)

Source: Werth et al. (2006b)

Total average herbicide use (kg a.i./ha) was 33 per cent higher in glyphosate-tolerant cotton than in conventional cotton (Table 2.7). However, glyphosate use has replaced some residual herbicide use, with the expectation that environmental impacts from residual herbicides could be reduced. Since the introduction of glyphosate-tolerant cotton there have been fewer incidents of residual herbicide detection in Australia’s river systems in north-western New South Wales where cotton is grown (Pyke and Doyle 2006). Although this reduction is due to the increased planting of glyphosate-tolerant cotton in part, the adoption of BMP by the Australian cotton industry has also likely played a large role.

Brookes and Barfoot (2008b) compare herbicide use in various cotton systems in a different way, by estimating what herbicide use would have been if non-GM cotton had not been replaced by GM HT cotton. Using different data, they calculate that total herbicide active ingredient load on GM HT cotton in 2006 was 2.7 per cent higher than the level expected if the whole crop had been planted to non-GM cotton varieties. The total EI value per ha, however, was 15.6 per cent lower.

Having realised that HT crops are useful but do not provide a complete solution to the problem of weeds, Australian cotton farmers appear to be using herbicide tolerance as an additional tool in their weed management toolbox, rather than as a substitution for traditional IWM practices. By using the technology in this way, they are less likely to be increasing the risk of glyphosate resistance developing in weed populations (Werth et al. 2006b).

2.1.4 Some socio-economic effects of GM cotton adoption in Australia

Insect-resistant cotton

McGahan et al. (1991) estimated the average annual loss due to *Helicoverpa* species in Queensland cotton to be 7.7 per cent of profits, despite an expenditure of A$7.5 million on control measures. An extrapolation of these data over the entire Australian cotton crop by Fitt (1994) suggested losses at that time in the order of A$60–70 million in the 1990–91 growing season, despite the expenditure of almost A$90 million on controlling these pests.

Using data supplied to the Australian Bureau of Statistics for the five years from 1989–90 to 1993–94, Adamson et al. (1997) estimated that the average total economic damage and control cost for *Helicoverpa* in Australian cotton was in the range of A\$102 million to A\$161 million per annum; the range depending on the estimate of the residual pest damage after pest control measures. These authors estimated that without management measures, *Helicoverpa* could cause an average loss to Australian cotton growers of A\$112 million–373 million.

The introduction of IR Bollgard II® has resulted in a reduction in the number of aerial and ground spray applications. As well as decreasing the direct costs of insecticides, the cost of applying them (time, staff, machinery etc.) is also decreased as a result of fewer applications.

In Australia, the majority of cotton farmers have realised an economic advantage from growing GM cotton, although performance obviously varies due to environmental or climatic differences across locations and seasons. Comparing the economic return of Bollgard II® cotton with that of conventional cotton shows that in the 2004–05 growing season, 66 per cent of 50 paired comparisons showed a net profit. In the 2003–04 growing season, 84 per cent of paired comparisons showed a net profit (Doyle et al. 2005).

Brookes and Barfoot (2006; 2008b) reported that Australian growers, while not generally benefiting from higher yield gains from using the technology, derive farm income benefit from lower costs of production. Net income losses were reported in the first two years of adoption of the technology (Ingard®, single gene Bt cotton), mainly because of the relatively high price charged for the seed. However, after the price was lowered in 1998, the net income impact was positive, with estimated cost savings of between US\$54/ha and US\$90/ha, mostly derived from lower insecticide costs (including application) more than offsetting the cost of the technology. In the few years of availability of the more effective Bollgard II® cotton, Australian farmers continued to make significant net cost savings of US\$186/ha to US\$193/ha, despite the higher costs of the seed. In 2006, at the national level, Brookes and Barfoot (2008b) report net farm income gains of US\$22.5 million and cumulative gains since 1996 of US\$179 million.

Responses to a survey by Cotton Consultants Australia in 2005 indicated that many farmers and consultants regard the non-GM cotton refuges for insect-resistance management (see Section 2.1.2) as a cost burden or lost opportunity to use the refuge area more productively. The lack of financially attractive options was reported to be problematic to farmers and there were concerns in regard to the maintenance of a refuge crop throughout the growing season. In particular, some farmers reported that it was hard to justify putting valuable water resources into a crop that provides them with no commercial value (Doyle et al. 2005).

The cost of refuge management for Bollgard II® cotton is significant and cannot be overlooked in determining the direct costs of growing this variety of cotton. The NSW Department of Primary Industries gross margin data advised that the costs, for example, of an unsprayed conventional cotton refuge (10 per cent of the Bollgard II® area) should be factored in at approximately A\$24/ha of Bollgard II® (NSW Department of Primary Industries 2005). This cost would vary depending on the exact type of refuge chosen. Costs and inconveniences aside, refuge crops are considered essential for helping to prevent resistance development and ensuring the efficacy of the technology (Farrell and Johnson 2005).

Farmer benefits from reduced insecticide use are not only economic; there are also health benefits arising from reduced exposure to pesticides during mixing and application, and social benefits through, for example, farmers being able to use the time they would have spent on spray rigs for other activities, including social activities. However, the reduction in insecticide applications has resulted in less work not only for growers who apply insecticides with their own equipment, but also for spraying contractors for whom less work is a negative.

A survey of Australian cotton farmers (Doyle et al. 2005) reported that the following non-agronomic reasons were important when deciding to grow Bollgard II® varieties of cotton:

- improved risk management associated with operating the farm, particularly in regard to occupational health and safety and spray timing issues
- reducing the variability of cost and uncertainty associated with controlling insects
- environmental considerations for boundary areas, populated areas and other sensitive sections of the farm such as waterways and grazing paddocks
- lifestyle factors such as reducing "general hassles" associated with the crop and time commitments.

The survey responses illustrate the complex interdependence of choice of crop for agronomic and environmental performance with socio-economic factors and motivations.

Societal impacts extend beyond those felt by farmers and spraying contractors. For example, the improved water quality of rivers resulting from reduced spraying has indirect health benefits. A survey of community perceptions to the cotton industry showed that while concerns about pesticide use remain in cotton growing districts, they are less than when last measured in 1998 (Pyke and Doyle 2006).

Herbicide-tolerant cotton

Costs of weed control in cotton have been high. A 1989 survey of growers of irrigated cotton in NSW revealed that, on average, weed control cost Australian cotton growers A$187/ha annually; the major components being A$76/ha for herbicides and A$67/ha for hand-hoeing ('chipping') (Charles 1991). A more recent study (a survey of farmers performed in 2001) of weed control in dryland cotton indicated that the on-farm costs of weeds ranged from A$148 to A$224/ha depending on the rotation being used; equivalent to an annual economic cost to the industry of A$19.6 million (Walker et al. 2005).

The NSW Department of Primary Industries gross margin budgets for the 2005–06 growing season estimated herbicide and application costs at: A$198/ha for surface irrigated conventional cotton in the Northern Zone; A$165/ha for dryland conventional cotton in the North East; and A$247/ha for GM Bollgard II®/Roundup Ready® cotton in the Southern Zone (NSW Department of Primary Industries 2005). These figures indicate that the cost of weed control is quite variable between cropping regions, agronomic practices and cotton varieties.

In the 2005 Cotton Consultants Australia survey, farmers gave the highest economic performance rating for Roundup Ready® cotton varieties to fields where weed pressure was considered to be high (Doyle 2005). Over half the cotton growers surveyed by Werth et al. (2006b) considered that despite the licence fee to use Roundup Ready® cotton, it was still cost-effective.

In Roundup Ready® cotton fields, mechanical weed control options such as tillage and chipping are reported to have been marginally reduced, the main effect being the reduction in number of times the field requires cultivation (Werth et al. 2006b). In particular, the decreased need for chipping has been a significant cost saving for Roundup Ready® cotton (Pyke and Doyle 2006). The use of HT cotton simplifies on-farm logistics by reducing time spent organising cotton chippers and spray operations, and addressing associated occupational health and safety concerns (Doyle 2005; Pyke and Doyle 2006).

There are also economic benefits associated with the ability to grow HT crops in fields with heavy weed burdens, because a cotton crop can now be grown in such fields and/or yield is improved. Residual herbicides can sometimes have a negative effect on early cotton seedling vigour; this is important when cotton seeds are heavily watered and must compete with a concurrent flush of weed germination (Doyle 2005). Decreased use of residual herbicides results in early cotton seedling vigour and improved weed control, another economic advantage.

Community perception of the Australia cotton industry

Historically, the perception of the environmental stewardship performance of the Australian cotton industry has been poor. However, opinions changed in the six years between 1998–2004. This is demonstrated in the results of Ray Morgan Research surveys conducted for Cotton Australia and the Cotton Research and Development Corporation in 1998 and 2004. Some results from these surveys were reported by Browne et al. (2006).

People in towns and regions associated with the cotton industry were asked to name their major environmental concern for their area. The percentage of people mentioning chemical use as a major concern reduced substantially between the two surveys (Figure 2.6). The introduction of BMP by the industry and the increased uptake of GM IR and HT cotton varieties during this period are likely to have contributed to this decreased concern.

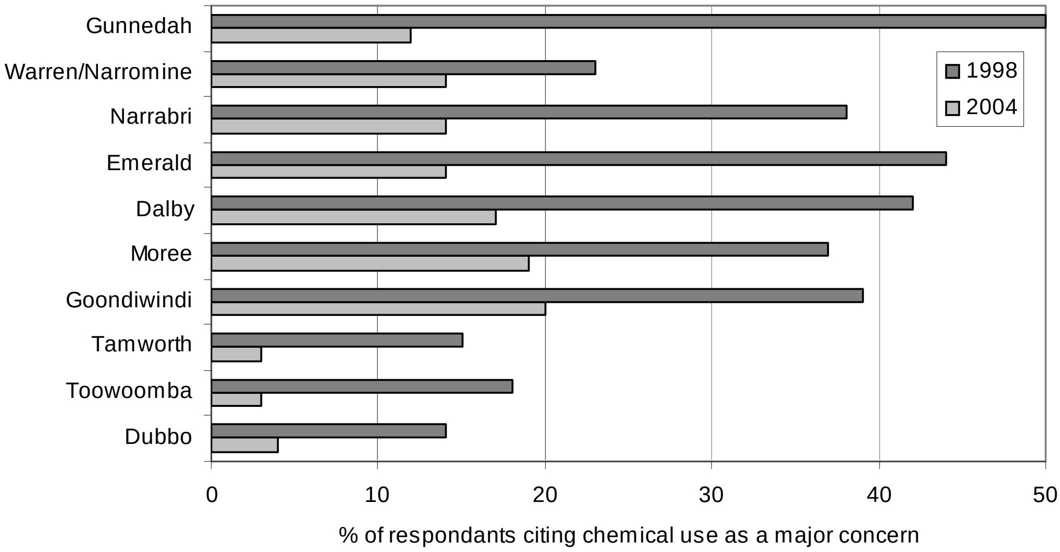

Figure 2.6 **Changing levels of community concern about chemical use in cotton growing regions between 1998 and 2004**

Notes: Question asked ‘What are the major environmental concerns for your area? Any others?’ (unprompted)

Source: Re-graphed from Browne et al. (2006)

Section 2.2 Impacts of GM cotton overseas

GM cotton is widely grown in seven countries—Argentina, Australia, Brazil, China, India, South Africa and the USA (James 2007). The level of adoption and reported agronomic, environmental and socio-economic effects vary between countries, depending in part upon insect pressures, technology costs and typical levels of inputs applied to cotton crops in each country. The literature focuses on different aspects in different countries. For example, reports on Bt cotton in developing countries focus mainly on yield changes and economic effects for small scale farmers, while reports for developed countries tend to focus more on environmental impacts such as changes in insecticide or herbicide use.

A summary of some of the reported effects in the USA, India and China is presented here. These three countries were selected because they have all adopted GM cotton, are all major producers, and are either major cotton exporters (the USA and India) or major cotton importers (China). They are thus either important competitors or markets for Australia.

Comparisons of effects between countries are complicated by the use of different varieties of Bt cotton and even different genes: during genetic modification, the original insertion of a gene usually occurs in a cultivar that is easy to genetically modify. Breeding then occurs to transfer the gene to cultivars that are more suitable for growing in particular regions. Each country will have its own cultivars, which perform differently to those in other countries. China is using some Bt cotton varieties that express a different *Bt* gene to the Bt cotton varieties grown in Australia, the USA and India.

2.2.1 Insect-resistant cotton

United States of America

Insect-resistant cotton containing the *Bt* genes *cry1Ac* (Bollgard®, called Ingard® in Australia) and *cry1Ac/cry2Ab* (Bollgard II®) were commercially released in the USA in 1996 and 2003 respectively. The National Agricultural Statistics Service (NASS) of the USDA reported that 18 per cent of upland (*Gossypium hirsutum*) cotton grown in 2008 was IR (includes both Bollgard® and Bollgard II®) and 45 per cent contained both IR and HT traits (NASS 2008). This level of adoption is lower than in Australia and is thought to be due to different insect pressures between the two countries.

Bollgard II® varieties have not been adopted as widely in the USA as in Australia, with Bollgard® varieties continuing to be grown extensively. The continued use of Bollgard® in the USA, in contrast to Australia, may be because this variety is reported to have ten-fold higher efficacy against *H. virescens* (a major American bollworm species) than *H. armigera* (the major Australian bollworm species) (Fitt 2003). Bollgard® is also very effective against another major lepidopteran pest, the pink bollworm (*Pectinophora gossypiella*) (Sankula 2006). On the other hand, Bollgard II® provides greater protection against other lepidopteran species for which Bollgard® is less efficacious (cotton bollworm [*H. zea*], fall armyworm [*Spodoptera frugiperda*], beet armyworm [*S. exigua*] and soybean looper [*Pseudoplusia includens*]) (Sankula 2006).

Agronomic effects

Early evaluations showed that Bt cotton provided more effective control of the three major caterpillar pests of cotton in the USA and yield increased across the Cotton Belt (Edge et al. 2001). An average yield increase of 90 kg/ha (approximately 10 per cent) for Bollgard II® as compared to Bollgard® in the USA was reported by Mullins et al. (2005, cited in Sankula et al. 2005). Brookes and Barfoot (2008b) report average yield increases of 9 per cent for Bollgard® (1996–2002) and 11 per cent for Bollgard II® (2003–2006).

In an overview of the effects of introducing Bt cotton in the USA, Fernandez-Cornejo and Caswell (2006) summarise the results of six primary studies on the effects on yields. Five of those studies reported increases in yield and one reported no change.

Environmental effects

US NASS surveys of agricultural chemical use between 1993 and 2005 reported a high degree of variability for different insecticides, with the use of some insecticides increasing since the introduction of Bt cotton, while the use of others has decreased. Some states (particularly California and Texas) have not grown large areas of GM Bt cotton (usually less than 10 per cent of their cotton acreage) (NASS 2000; 2001; 2002; 2003; 2004; 2005; 2006) due to generally low bollworm pressure.

The use of insecticides varies seasonally with pest pressure. Nevertheless, whilst the annual average volume of insecticides used on the US cotton crop has fluctuated, Brookes and Barfoot (2008b) report that there has been an underlying decrease in usage. For example, during the period 1996–2006 the cumulative decrease in insecticide a.i. use is reported to be 21 per cent (15.3 million kg), and the cumulative reduction in the field EIQ load has been 19.5 per cent (Brookes and Barfoot 2008b).

Changes in insecticide use do not all relate directly to the introduction of Bt cotton. An example is malathion, which is used in cotton to control the cotton boll weevil in the USA (USDA-APHIS 2006). This insect pest, *Anthonomus grandis*, is a beetle (a coleopteran insect) and has been a sufficiently serious pest to be the target of specific eradication programs. This pest is not controlled, and was not expected to be controlled, by Bt cotton because the Bt toxin is specific to moths and butterflies (lepidopteran insects) and was introduced into cotton to target *Helicoverpa* (bollworm) insect pests.

The average amount of insecticides (a.i./ha) applied on cotton in the USA, decreased by 27 per cent in 1996, the year that Bt cotton was introduced (Figure 2.7)—the data shown are average application rates for both total GM and total non-GM cotton fields in the USA (NASS 2006). This reduction was sustained for the following two seasons before there was a 133 per cent increase in 1999. This sudden increase in insecticide use coincided with the initiation of eight new cotton boll weevil eradication programs (NCCA 2004), which resulted in a 358 per cent increase in the application of malathion to cotton fields.

During the first year of a boll weevil eradication program, spraying occurs on almost every cotton field, followed by decreasing applications in subsequent years (NCCA 2004). Malathion use has decreased since 1999 (Figure 2.7) and will generally continue to decrease unless further eradication programs are begun. As these applications of malathion are part of specific campaigns in specific areas and not routine control, insecticide application rate data *minus* malathion rates reflects more generally the insecticide use trend since 1995, the year before Bt cotton was introduced in the USA. Considering insecticide use minus malathion, Figure 2.7 shows that insecticide applications have generally declined since 1995; for example, the decrease between 1995–2005 was 55 per cent.

Excluding data for the three years when eradication programs peaked and malathion use was highest (1999 to 2001), the average total use of insecticide (a.i./ha) for the five years 1996–1998 plus 2003–2004 (1.38 a.i./ha) was 25 per cent lower than the total use of insecticide for the three years 1993–1995 (1.73 a.i./ha).

In an overview of the effects of introducing GM insect-resistant cotton in the USA, Fernandez-Cornejo and Caswell (2006) cite three primary studies which reported a decrease in pesticide use.

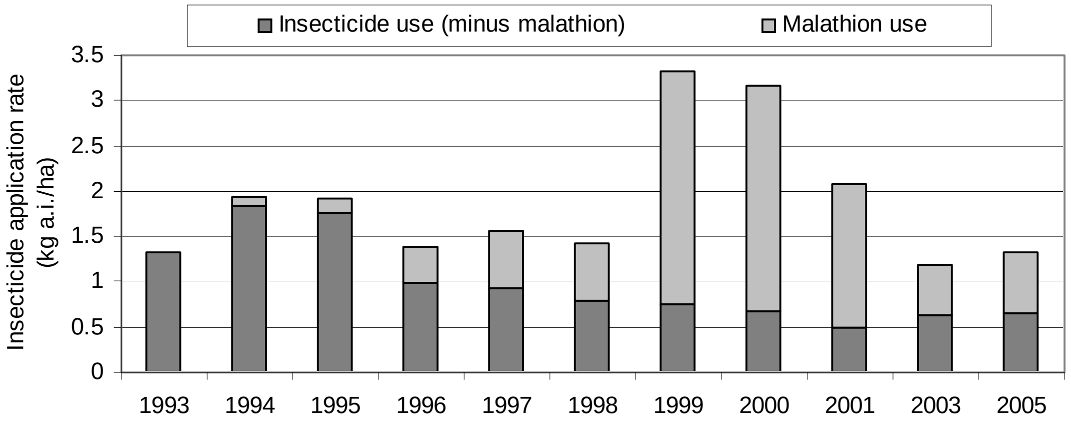

Figure 2.7 Amounts of insecticide applied to USA cotton (GM plus non-GM) fields (1993–2005)

Source: Graphed from data reported by the National Agricultural Statistics Service (2005).

Socio-economic effects

Expenditure on insect control was reported to be marginally reduced using Bollgard II® technology for the years 2003–2005, after subtracting the costs of the new technology from the insecticide cost savings; net cost savings were US$5.78/ha (Brookes and Barfoot 2005). Between 1996–2002, average profitability levels increased by US$53–115 per ha with Bollgard® cotton and by US$108–118 per ha between 2003–2006 with Bollgard II® cotton (Brookes and Barfoot 2008b).

Sankula (2006) reported the net economic advantage of Bollgard® compared to conventional cotton to be US$74.29/ha and for Bollgard II®, US$128.85/ha. These figures were calculated as the increase in production value plus the decrease in costs of insecticides and applications minus the costs of Bollgard®/Bollgard II® adoption.

Fernandez-Cornejo and Caswell (2006) cite six primary studies which reported an increase in returns for cotton farmers growing Bt cotton in the USA.

The reduction in the number of conventional broad-spectrum insecticide sprays when replaced by the in-plant protection offered by Bt cotton, reduces the levels of exposure and risk involved in purchasing, transporting, mixing and spraying insecticides for growers, their families and employees (Benedict and Altman 2001).

India

Bt cotton varieties expressing only the *cry1Ac* gene are officially recognised as having been grown in India since 2002, although some varieties were grown in the state of Gujarat in 2001 (Jayaraman 2001). By 2007, an estimated 3.8 million farmers were growing 6.2 million ha of Bt cotton compared with 300 000 farmers growing 500 000 ha in 2004 (James 2007).

There has been considerable debate in the literature about the net benefits of Bt cotton in India. In the two years following release (2002 and 2003) work was done to determine the economic impact of Bt cotton in the states of Gujarat and Maharashtra.

In Gujarat, Bennett et al. (2005) and Morse et al. (2005a) reported the results of a survey performed in the 2003–04 season. They analysed responses from 622 farmers who planted a total of 626 cotton plots, which were identified as non-Bt, 'official' Bt hybrids (bred by Monsanto Australia and its local partners) and first (F1) or second (F2) generation 'unofficial' Bt hybrids. 'Unofficial' seed may have been saved from Bt seed purchased the previous year (second generation hybrids) or bought from seed companies who have bred the *Bt* gene into their own hybrids (first or second generation hybrids). Yields were highly variable for all types of cotton; however, the authors report that the 'official' Bt varieties produced significantly higher yields than the non-Bt and ‘unofficial’ F2 hybrids (Table 2.8). After including the costs of insect control for all varieties, the profit was determined to be highest for the ‘official’ hybrids and lowest for the non-Bt varieties. However, due to variability in the results, not all differences were statistically significant (see footnote to Table 2.8).

Table 2.8 Results of survey of cotton farmers in Gujarat, India—yield, costs of sprays, and profit (Rp = Rupees)

		Yield (kg/acre)	Bollworm sprays (Rp/acre)	Sucking pest sprays (Rp/acre)	Other sprays (Rp/acre)	Profit (Rp/acre)
‘Official’ Bt hybrids	MECH12	832^{a}	971^{b}	1528^{b}	292^{a}	8 707^{a}
	MECH162	726^{ab}	477^{d}	1 472^{b}	188^{d}	6 512^{ab}
‘Unofficial’ Bt hybrids	F1	691^{b}	522^{d}	1 724^{a}	3^{b}	5 132^{bc}
	F2	601^{bc}	734^{c}	1 178^{c}	123^{c}	4 497^{bc}
Non-Bt hybrids		606^{c}	1 955^{a}	1 557^{b}	210^{b}	3 755^{c}

Notes:

Values are means reported in Table 1 of Bennett et al. (2005). Within a column (only), values with one, or at least one, superscript letter identical to that of any other value in the column, are not significantly different from that other value at $P \leq 0.05$. Evidence of statistical significance taken from graphs of the same data in Morse et al. (2005a).

Profit represents revenue minus total costs, where revenue equals yield multiplied by price received for the cotton, and total costs include seed costs, manure, inorganic fertiliser, insecticides, labour costs and irrigation.

In the state of Maharashtra, Morse et al. (2005b; 2006) report the results of surveys performed in 2002 and 2003. Sample sizes were 2 709 (in 2002) and 787 (in 2003) farmers, cultivating 7 751 and 1 580 plots respectively. Yields were significantly higher for Bt than non-Bt cotton (39 per cent higher in 2002; 63 per cent higher in 2003) with a significant reduction in expenditure on bollworm control in both years (72 per cent reduction in 2002; 83 per cent in 2003) leading to higher profits for Bt cotton (49 per cent higher in 2002; 74 per cent higher in 2003). Sprays for sucking pests were reduced in the first year but not in the second year (Table 2.9).

Table 2.9 Results of survey of cotton farmers in Maharashtra, India—yield, costs of sprays, and profit (Rp = Rupees)

		Yield (kg/acre)	Bollworm sprays (Rp/acre)	Sucking pest sprays (Rp/acre)	Profit (Rp/acre)
2002	Bt	850	280	568	15 700
	Non-Bt	611	984	634	10 524
2003	Bt	911	195	529	20 600
	Non-Bt	559	1 166	520	11 849

Notes:

Values are means reported in Table 1 of Bennett et al. (2005). For each year, values for Bt and non-Bt cotton in all pairs in a column are significantly different from one another at $P \leq 0.001$, with the exception of the 2003 values for the ‘Sucking pest sprays’ data pair for 2003. Statistical significance as reported in Table 1 of Bennett et al. (2006). There is no comparison between years. Conversions from quintals/acre to kg/acre for yield are based on figures for tonnes/ha reported in Table 1 of Morse et al. (2005b)

Profit represents revenue minus total costs where revenue equals yield multiplied by price received for the cotton and total costs include seed costs and insecticides.

During this period of adoption of Bt cotton in India, cotton yields increased from a low of 308 kg lint per ha in 2001–2002 to 520 kg/ha in 2006–2007, with up to 50 per cent of the yield increase attributable to Bt cotton (James 2007).

Increased yields (ranging from 30 to 60 per cent) and increased profits (consistently reported by different studies) are the main benefit from Bt cotton in India (James 2007). James (2007) also summarises a range of societal benefits reported for India, such as increased use of health services because farmers could now afford them using the profits from growing Bt cotton.

China

Bt cotton has been grown commercially in China since 1997, using varieties expressing the *cry1Ac* gene and later, varieties developed by Chinese researchers expressing the *CpTI* gene. Adoption rates, as estimated by Pray et al. (2002), vary for different provinces: by 2001, there was close to 100 per cent adoption in Hebei (the first province to adopt) and 80 per cent adoption in Shandong. Henan and Anhui had lower rates of adoption at about 30 per cent. Overall, approximately 31 per cent of cotton planted in China was Bt in 2001. An unreferenced estimate from Wang et al. (2006) suggests that this level may have increased to 65 per cent by 2004. By 2007, James (2007) estimates that 3.8 million ha were planted to GM Bt cotton. This is equivalent to approximately 69 per cent of the total area planted to cotton in China (using data on area harvested in 2005–06; USDA-FAS (2006)).

A number of farmer surveys have been performed from 1999 to 2001 to estimate the effects of Bt cotton adoption on small scale farmers in China (summarised in Pray et al. 2002). In provinces where both Bt and non-Bt cotton growers were surveyed, Bt cotton varieties yielded 5–6 per cent higher on average in 2001. James (2007) reports that, based on studies by the Centre for Chinese Agricultural Policy, Bt cotton in China increased yield by 9.6 per cent and reduced insecticide use by 60 per cent in 2007 compared with non-Bt cotton.

One of the main benefits for China is the decrease in the use of pesticides that has resulted from the introduction of Bt cotton. Since the early 1990s, cotton farmers in China have experienced serious problems with bollworm infestations resulting in very high levels of insecticide use (Huang et al. 2003; Wu and Guo 2005). The results of a survey of Chinese cotton farmers in 1999 indicated that pesticide spraying was an average of 6.6 applications in Bt cotton compared with an average of 19.8 applications per season in non-Bt cotton, with an accompanying 81 per cent decrease in the amount of pesticides applied (reduction from 60.7 kg/ha to 11.8 kg/ha), and a cost reduction of 82 per cent (Huang et al. 2002).

Subsequent surveys reported that pesticide applications on Bt cotton in comparison to non-Bt cotton decreased by 58 per cent in 2000 and 62 per cent in 2001. The reductions in insecticide application varied between provinces, with Jiangsu showing only a 14 per cent reduction in 2001, the first year that it was included in the survey. Bt cotton has not been widely adopted in this province as red spider mite is a more serious problem than bollworm (Pray et al. 2002).

Health benefits resulting from decreased spraying of cotton fields have also been reported. For example, Pray et al. (2002) asked farmers to report instances of illness following spraying. Their sample sizes are too small in some cases for statistical significance, however, the general trend suggests that farmers who grow Bt cotton are healthier than those who grown non-Bt cotton (Table 2.10).

Table 2.10 Percentage of farmers reporting illness after spraying cotton fields

Type of cotton grown	**% farmers reporting illness** (total number of farmers surveyed)		
	1999	2000	2001
Bt cotton only	5 (236)	7 (318)	8 (221)
Combination of Bt and non-Bt cotton	11 (37)	19 (58)	10 (96)
Non-Bt cotton only	22 (9)	29 (31)	12 (49)

Source: Pray et al. (2002).

On average, Bt cotton growers reported profits while non-Bt cotton growers reported losses (Table 2.11) (Pray et al. 2002). These higher net revenues occurred despite Bt cotton seed costing up to four times more than non-GM cotton seed in 2000 and 2001.

Table 2.11 Net revenue (US$) per hectare for Chinese farmers surveyed between 1999 and 2001

	1999	**2000**	**2001**
Bt cotton growers	351	367	277
Non-Bt cotton growers	-6	-183	-225

Source: Pray et al. (2002).

South Africa

Less extensive information on the effects of GM cotton is available for other countries. In South Africa, Purcell and Perlak (2004) report that, at the farm level in South Africa, improvements in insect control can impact the quality of life of farm families positively by reducing insecticide spraying, increasing incomes and offering savings in time. Time savings may be important for women in particular, as they often are heads of many of the households.

Global greenhouse gas savings resulting from GM insect-resistant cotton

A further environmental benefit from reduced insecticide use on GM IR cotton crops is the reduction in fuel use and consequent lowered greenhouse gas emissions. Brookes and Barfoot (2008a) estimate that the carbon dioxide savings from reduced fuel use between 1996–2006 in areas sown to GM IR cotton globally, were 98 million kg of carbon dioxide, equivalent to removing over 43 500 average family cars from the road for a year.

Assumptions were that an ‘average family car’ produces 150 grams of carbon dioxide per km. A car does an average of 15 000 km/year and therefore produces 2 250 kg of carbon dioxide per year (Brookes and Barfoot 2008a).

2.2.2 Herbicide-tolerant cotton

Changes in herbicide use in USA

There have been few studies published on the effects of herbicide-tolerant cotton other than in the USA and Australia. Results for Australia were presented in Section 2.1.3. There are two major sources of raw data on herbicide use on US cotton fields: the USDA national pesticide usage data (NASS 2000; 2001; 2002; 2003; 2004; 2005; 2006) and private farm level pesticide usage survey data from DMR Kynetec/Doane Agricultural Services Company[11] (Brookes and Barfoot 2008b). The NASS and DMR Kynetec/Doane data both show that, since the introduction of GM glyphosate-tolerant cotton in 1996, both the average herbicide application rate and the average field EIQ per ha for cotton fields in general in the USA have remained more or less steady (Table 40 in Brookes and Barfoot 2008b). For example, average herbicide application rates for all cotton fields was 2.25 kg a.i./ha in 1998 and 2.53 kg a.i./ha in 2006, with the field EIQ value per ha being 53.6 in 1998 and 47.5 in 2006 (using DMR Kynetec/Doane data).

In addition to glyphosate-tolerant cotton, two other GM HT cotton types have been planted in the USA. Bromoxynil-tolerant cotton (Group C herbicide[12]) was planted between 1995 and 2005 but was never widely used and glufosinate ammonium-tolerant cotton (Group N herbicide), which became available in 2004, is also not extensively planted. Herbicide application rates data on these other GM HT cottons are included in the averages data presented for GM HT cotton below, but these two types have made little impact on the overall change in use of herbicides on cotton over the years; overall herbicide use change patterns are mainly attributable to the introduction of GM glyphosate-tolerant cotton.

The DMR Kynetec/Doane dataset allows for a comparison of herbicide application rates between GM HT cotton (all GM types) and conventional cotton from 1997 to 2005. Average herbicide application rates (kg a.i./ha) are higher for GM HT cotton fields than for conventional cotton fields (Figure 2.8). The average herbicide application rate on GM HT cotton fields (for glyphosate-tolerant, bromoxynil-tolerant and glufosinate ammonium-tolerant cotton types) has been more or less steady at 2.5 kg a.i./ha between 2000 and 2003, increasing to 2.71 kg a.i./ha in 2004 and 2.79 kg a.i./ha in 2005 (Figure 2.8; Brookes and Barfoot 2008b). At the same time, application rates on non-GM conventional cotton has steadily decreased from 2.11 kg a.i./ha in 2000 to 1.6 kg a.i./ha in 2006 (Brookes and Barfoot 2008b).

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[11] http://www.dmrkynetic.com

[12] Appendix A lists the modes of action of the different herbicide groups, A to N, and gives selected examples of herbicides in each group.

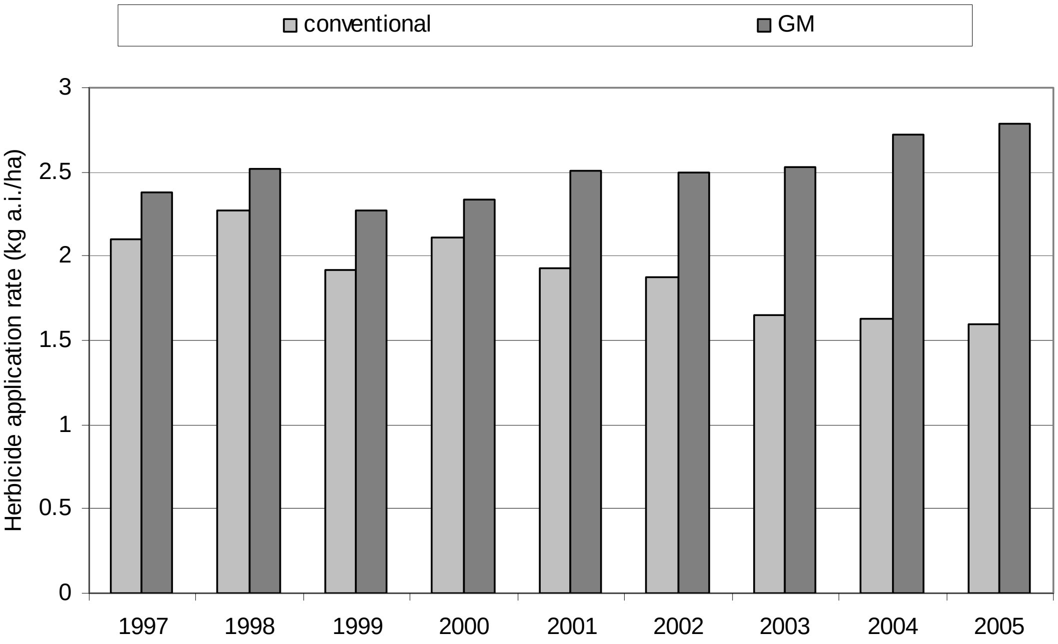

Figure 2.8 **Average herbicide applications rates for GM HT and conventional cotton fields in the United States (1997–2005)**

Source: Graphed from DMR Kynetec/Doane Agricultural Services Company data as presented in Brookes and Barfoot (2008b).

Brookes and Barfoot (2008b) explain that the first growers of GM HT cotton were probably those with the most significant weed problems and, as GM HT cotton was increasingly adopted, the remaining areas sown to conventional cotton were increasingly those which had the least need for weed control using herbicides and/or were in areas with a history of low level herbicide use. Average herbicide application rates to conventional cotton areas are expected, therefore, to be lower than would have been necessary to achieve a similar level of weed control in areas now sown to GM HT control had these areas been sown to conventional cotton.

In other words, for many areas, comparison of herbicide programs for conventional cotton that have been replaced by the new programs now used on GM HT cotton provides a more realistic basis for assessing the impacts of GM HT crops on herbicide use patterns. Such comparisons have been made in a series of National Center for Food and Agricultural Policy (NCFAP) reports, in which actual herbicide usages on areas planted to various cotton types have been compared with typical weed control programs needed for conventional cotton in these areas, as advised by university weed specialists (Sankula and Blumenthal 2004; Sankula et al. 2005; Sankula 2006). The areas analysed were from many different states in the USA, across the cotton belt.

Applying this approach to data for the 2004 and 2005 seasons, average total herbicide application rates were estimated by Sankula et al. (2005) and Sankula (2006) to be:

- 5.5 kg a.i./ha (2004) and 5.6 kg a.i./ha (2005) for conventional cotton
- 4.2 kg a.i./ha (data for 2004 only) for bromoxynil-tolerant cotton
- 3.7 kg a.i./ha (2004 and 2005) for Roundup Ready® (glyphosate-tolerant) cotton
- 3.3 kg a.i./ha (2004) and 3.4 kg a.i./ha (2005) for Liberty Link® (glufosinate ammonium-tolerant) cotton.

Based on these figures, Sankula et al. (2005) and Sankula (2006) estimate that in 2004 and 2005, for the whole USA cotton crop:

- Roundup Ready® cotton effectively reduced herbicide usage by approximately 6.3 million kg a.i. (2004) and 7.8 million kg a.i. (2005)
- Liberty Link® cotton effectively reduced herbicide usage by approximately 74 000 kg a.i. (2004) and 215 000 kg a.i. (2005)
- Bromoxynil-tolerant cotton effectively reduced herbicide usage by approximately 19 000 kg a.i. (data for 2004 only).

These NCFAP estimates are based on estimated herbicide application rates in the scenario where conventional cotton had been planted instead of the GM HT cotton variety, and a typical herbicide program had been applied to conventional cotton, as advised by university weed specialists (i.e. the conventional cotton average application rate used in the estimates was 5.5 kg a.i./ha for both 2004 and 2005). As expected, the latter is higher than the application rates measured in fields continued to be sown to conventional cotton.

The average application rates for GM HT cottons estimated by the NCFAP are also higher than those reported in Brookes and Barfoot (2008b) for GM HT cotton. This appears to be due to the different estimates of GM HT cotton adoption. The Agricultural Marketing Service data used by Sankula et al. (2005) for GM HT cotton variety adoption in 2004 (77.3 per cent for glyphosate-tolerant cotton; 1.1 per cent for glufosinate-ammonium cotton; and 0.2 per cent for bromoxynil-tolerant cotton—totalling 78.5 per cent GM HT adoptions) are higher than those reported by the NASS (60 per cent total GM HT crop adoption in 2004).

Brookes and Barfoot (2008b) have also estimated herbicide savings resulting from GM HT cotton adoption, but used in their calculations lower herbicide application rates for both conventional and GM HT cotton fields than did Sankula (2006). They did this to take into account actual recorded lower use rates data from DMR Kynetec/Doane, adjusting the NCFAP rates for 2005 and 2006 downwards. On this basis, they suggest the comparison rates of herbicide usage are, for example in 2006: an average herbicide application rate of 3.88 kg a.i./ha for conventional cotton and of 2.69 kg a.i./ha for GM HT cotton.

Using these figures, Brookes and Barfoot (2008b) estimate a national level saving of total herbicide use of 4.78 million kg a.i. in 2006 and a cumulative national level of herbicide use savings of 31.3 million kg a.i. between 1997 and 2006. These are lower values than the Sankula et al. (2005) and Sankula (2006) estimates, but still substantial.

It is not possible to verify these various estimated reductions/savings in herbicide use. As noted above, actual average total herbicide application rates for all cotton fields in the USA have been more or less steady and total herbicide use in cotton fields has increased (although total use varies from year to year depending on how much cotton is grown) since 1996, when GM HT cotton was introduced (Figure 2.9).

For all cotton fields of all types, both GM HT and conventional, the NASS dataset shows, as expected, that there has been a steady increase in the average amount of glyphosate applied per ha (kg a.i./ha) in USA cotton fields (Figure 2.9), as the percentage of area planted to Roundup Ready® cotton increased. By 2003, glyphosate accounted for at least 50 per cent of total average herbicide use in cotton fields (NASS 2000; 2001; 2002; 2003; 2004; 2005). This general shift to no-till management relies more on herbicide use to control weeds than on mechanical cultivation. Sankula (2006) reports that adoption of no-till agriculture in cotton has been extensive, with a 371 per cent increase in no-till area in 2004, the latest year for which the estimates are available, compared with 1996.

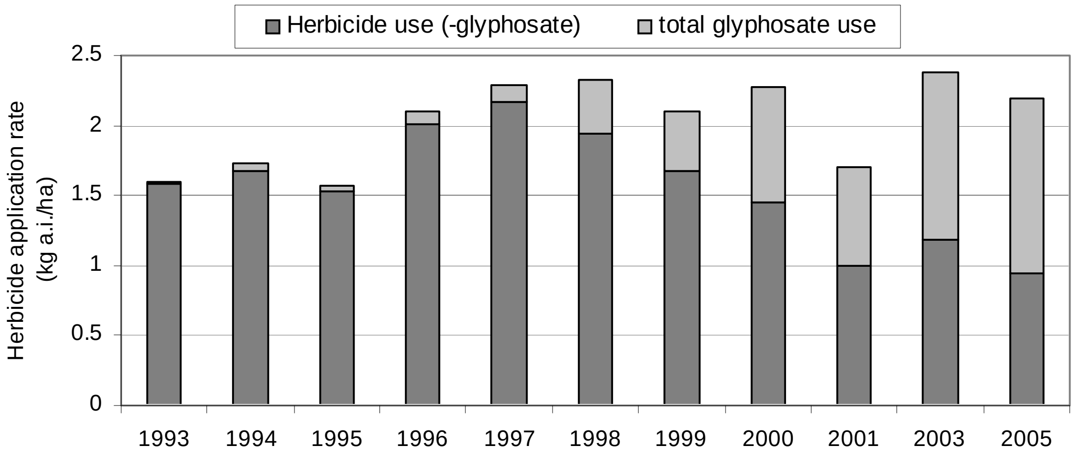

Figure 2.9 Herbicide application rates for US cotton fields (1993–2005)

Source: Graphed from data reported by the National Agricultural Statistics Service (2005).

Note: no data were reported for 2004. (-glyphosate) means all other herbicide use minus glyphosate.

Importantly, however, while the glyphosate usage rate has increased, the usage rate of other, residual herbicides has shown a corresponding decline between 1996 and 2005, with average herbicide application rates for all cotton types, as already mentioned, showing no overall increasing or decreasing trend (Figure 2.9) (Table 40 in Brookes and Barfoot 2008b).

As noted in Section 2.1.3 for Australian cotton, estimates and comparisons of environmental impacts of herbicide regimes need to take into account the different impacts of the various herbicides used in any herbicide program, not just the amounts of herbicide used. GM HT crops have enabled use of more environmentally benign herbicides, so that even though the average herbicide application rates on GM HT cotton in the USA has been consistently higher than on conventional (non-GM, non-HT) cotton, actual impacts may not have increased. The comparative ecotoxic effects and other potential effects of the herbicides being compared, and even indirect factors, should ideally also be taken into account.

Estimates of 'environmental impact values' per ha (not simple 'weight of active ingredient' measures), based on Environmental Impact Quotients and application rates (kg a.i./per ha) (see Section 1.6), indicate that total herbicide environmental impacts have declined in the USA since glyphosate-tolerant cotton was introduced, as in Australia (see Section 2.1.3).

Using the DMR Kynetec/Doane dataset of actual recorded herbicide usage, Brookes and Barfoot (2008b) estimate that the annual average EI values per ha for GM HT cotton were similar to those for conventional cotton up to 2002, but were higher for the years 2003–2005. It was suggested that this was attributed to remaining conventional cotton fields progressively being those in areas with the least weed infestation levels (hence GM HT cotton was not deployed in those areas). However, adjusting herbicide usage rates towards those estimated by NCFAP (above) for conventional cotton, estimates of environmental impact in 2006 were 70.43 per ha for conventional cotton and 48.6 per ha for GM HT cotton (Brookes and Barfoot 2008b). These findings are based on estimates of what herbicide use on conventional cotton would have been in cotton growing areas had GM HT cotton not been introduced.

If the environmental effects of adopting GM HT cotton were to be more fully analysed, the environmental benefits of no-till (including reduced cultivations, tractor use and fuel use, and reduced soil erosion) would also need to be taken into account.

Economic effects

Sankula (2006) estimates the economic impact of GM HT cotton on weed management cost changes in the USA to be a saving of US$39 million in 2005. This figure includes the costs of herbicides, application, adoption, tillage and hand weeding.

Section 2.3 Conclusions and future developments

It is clear from the above summaries that the effects of adopting GM cotton are often country-, region-, season- and probably cultivar- or variety-specific, suggesting that effects seen overseas may not be the same as for the Australian situation. This observation is important for the next chapter, which attempts to predict the impacts of GM HT canola in Australia, based in part on effects reported in Canada.

For cotton in Australia, the agronomic and environmental benefits are clear (Section 2.1). There have been reductions in insecticide and residual herbicide use leading to reduced incidents of river contamination by these chemicals. The majority of Australian cotton growers report economic benefits from growing GM cotton. Together with the introduction of the BMP program, GM cotton has contributed to the increased sustainability of cotton farming. The challenge will be to continue to develop varieties and farming methods that can maintain the usefulness of these technologies into the future.

Two new GM HT cotton varieties were introduced in the 2006–07 cotton growing season: Roundup Ready Flex® and Liberty Link®. The adoption of these varieties by growers is likely to result in a further reduction in the use of residual herbicides, inter-row cultivation and hand hoeing (Charles and Taylor 2006; Werth et al. 2006b). Although Charles and Taylor (2006) believe that a Roundup Ready Flex®-based system could help to optimise crop yields and be more environmentally friendly than a non-HT system, they also warn of the risk that weed species that are naturally tolerant to glyphosate could become more abundant and that glyphosate resistance may develop in other weed species. However, crop rotations and re-introduction of alternative weed control methods could be used to control glyphosate-resistant weeds if they emerged and a return to conventional weed management could be used if glyphosate-resistant weeds became a serious problem. Charles and Taylor (2006) reported that glyphosate damage to nearby crops has sometimes been a problem with Roundup Ready® cotton as the spraying window is very narrow, with some spraying done in less than ideal conditions. They predicted that the wider spraying window available with Roundup Ready Flex® cotton should lessen this problem by giving farmers more opportunities to spray their crops under calm conditions.

Charles and Taylor (2006) forecast that Liberty Link® cotton will have many of the same advantages and disadvantages of Roundup Ready Flex® cotton. However because glufosinate ammonium does not give good control of grassy weeds, a grass-specific herbicide is likely to be required in addition to glufosinate ammonium (Charles and Taylor 2006).

There are a number of alternative GM IR cotton varieties being developed in Australia. New varieties with novel modes of insecticidal action will be of benefit to the cotton industry as they will allow rotation of modes of action, which should decrease the pressure on insects to develop resistance.

Hexima Ltd (a Melbourne based biotechnology company) is developing GM cotton with novel insecticidal action based on plant genes encoding protease inhibitors (*NaPI* from tobacco and *PotI* from potato). Approved field trials have been conducted since 2004 under a licence from the Regulator (OGTR 2003e).

Dow AgroSciences Australia Pty Ltd has developed GM cotton expressing both the *cry1Ac* gene and another Bt toxin gene, *cry1Fa*. These varieties have been called Widestrike™ and were trialled between 2004 and 2006 under two separate licences from the Gene Technology Regulator (OGTR 2003d).

Deltapine Australia Pty Ltd has been developing GM cotton varieties that express the *vip3A* gene. This gene encodes another toxin gene from *B. thuringiensis* with a new mode of action. Following approval by the Gene Technology Regulator, a small scale field trial occurred in 2005–06 (OGTR 2005b). Earlier trials were also approved and conducted; these are detailed in the Risk Assessment and Risk Management Plan for the 2005–06 trial. More recently, the Regulator has also approved field trials of stacked varieties, expressing both the *vip3A* and modified *cry1Ab* genes (OGTR 2006e), and also the *cp4 epsps* gene (glyphosate tolerance) (OGTR 2007).

Novel first and second generation GM traits, such as water use-efficient cotton and cotton with healthier oil profiles, continue to be developed for Australian cotton. It is likely that these new traits will also be transferred to an IR and/or HT background, to facilitate insect pest and weed management in the new varieties.

Through the use of IR cotton, the cotton industry may be able to extend its growing regions to areas of north Queensland, the Northern Territory, and north Western Australia. Monsanto Australia and Bayer CropScience have been granted licences from the Gene Technology Regulator (DIR 066/2006, and DIR 062/2006) to proceed with the commercial release of GM IR and/or HT cotton varieties north of latitude 22° South (OGTR 2006f). Agronomic, plant breeding and seed production trials of GM cotton suitable for cultivation in northern Australia would need to be undertaken before release took place. Before commercial GM cotton production could begin in northern Australia, there are also a range of industry, infrastructure and community issues which would first need to be considered (OGTR 2006f), including an assessment of the commercial viability of IR and HT cotton cultivation in new areas such as the Burdekin region (north Queensland), the Ord River Irrigation Area and the Katherine region of the Northern Territory.

Chapter 3 Canola

Section 3.1 Introduction

Rapeseed (*Brassica napus* and *B. rapa*) was first grown commercially in Australia in 1969 by wheat farmers looking for alternative crops following the introduction of wheat delivery quotas (Reeves and Lumb 1974; Colton and Potter 1999). Initial varieties were imported from Canada and were not suitable for Australian conditions. The blackleg fungus disease quickly became a problem for growers, resulting in low yields, but Australian varieties with resistance to blackleg were subsequently developed in the 1970s.

The name 'canola' was introduced in Canada in 1979 for varieties with less erucic acid and glucosinolates than in rapeseed. These compounds reduce the nutritional value of the oil and meal (Colton and Potter 1999). Current canola standards require less than 2 per cent erucic acid and less than 30 micromoles of glucosinolates per gram of seed solids (CCC 2005a). The term 'canola' is used in Australia and Canada, but other countries continue to call the crop 'oilseed rape' or 'rapeseed'. The term canola will be used throughout this report but is intended to include rapeseed when referring to overseas data.

The first canola-quality varieties combined with blackleg resistance and high yield were released in Australia in 1987 (Colton and Potter 1999).

Canola is mainly grown in NSW, Victoria, South Australia and Western Australia, with small areas occasionally planted in Queensland and Tasmania. Canola is a valuable break crop for cereal rotations, reducing the incidence of cereal diseases in subsequent crops while providing a good economic return. Australian canola production quantities and sown areas for the major canola-growing states during the period 1998–2006, are shown in Figures 3.1 and 3.2 respectively. Seasonal variability of rainfall and temperature accounts for a lot of the variability in production that is seen in Figure 3.1 below, both between years and between states. For example, the drought in Eastern states is clearly reflected in the lower production quantities in 2006 in those states, compared with Western Australia.

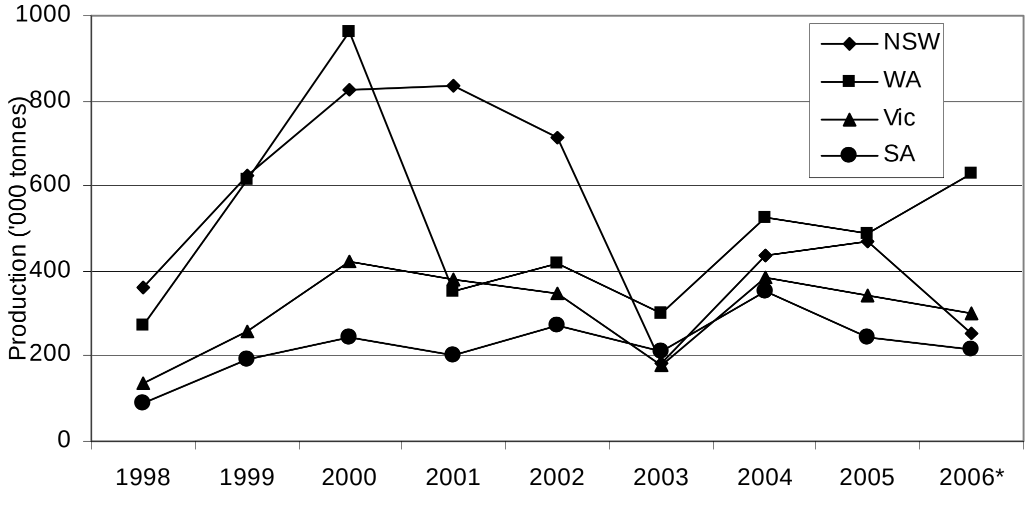

Figure 3.1 State production of canola (1998–2006)

* ABARE estimate (Duck et al. 2006)

Source: Australian Bureau of Statistics (1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006)

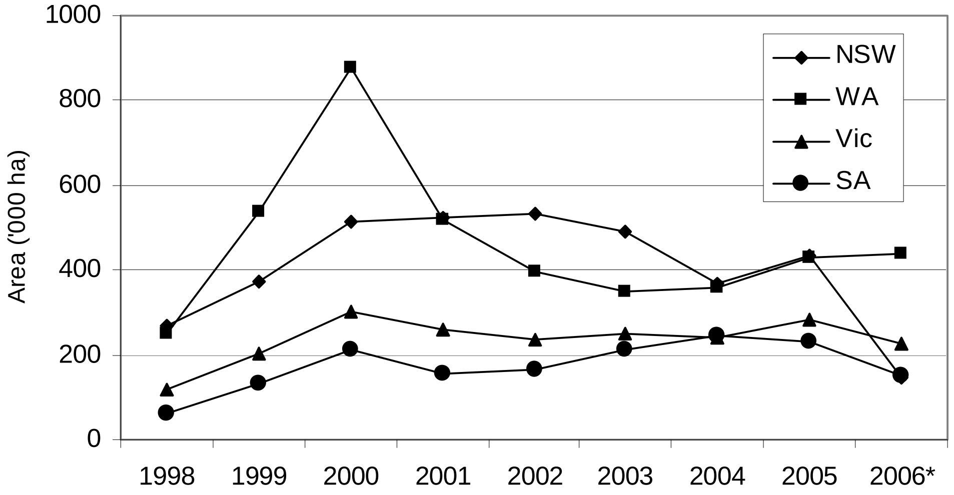

Figure 3.2 State canola area (1998–2006)

* ABARE estimate (Duck et al. 2006)

Source: Australian Bureau of Statistics (1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006)

The major world producers of canola are Canada, the European Union-27, the People's Republic of China and India. Australian production averaged approximately 3 per cent of world production over the period 2003–04 to 2005–06, but despite being a small producer, Australia supplies approximately 15 per cent of the world trade in canola. Canada is the major exporter (USDA-FAS 2006).

3.1.1 Weeds in canola crops

Weeds can have a number of negative effects on canola crops, as follows:

- Canola is a winter crop in Australia, with planting occurring from late April through to June. This can result in slow initial growth. Competition from weeds can lead to significant yield losses (Sutherland 1999; Blackshaw et al. 2002)
- Grass weeds can increase the incidence of root diseases such as 'take-all' fungus (*Gaeumannomyces graminis* var. *tritici*) in subsequent cereal crops (Sutherland 1999)
- Weed seeds from the *Brassicaceae* plant family (such as wild radish seeds) can contaminate canola harvests and increase the levels of erucic acid and glucosinolates in the grain, reducing grain quality (Sutherland 1999; Blackshaw et al. 2002).

Weed control costs for canola grown in Australia are high. A survey of weed costs in Australian winter crops during 1998–99, estimated that weed control costs (including herbicides and tillage) were A$147.2 million for canola crops, while weed losses (including residual weeds and discounting due to grain contamination) were A$58.6 million (Jones et al. 2005). Total weed costs were second only to those for wheat. Calculating the cost per ha, using figures for area of the different crops in 1998–99 from the Australian Bureau of Agricultural and Resource Economics (ABARE) (2003), indicates that weed control costs in canola were the most expensive at A$118/ha, compared with A$60/ha for wheat. Weed losses were A$47/ha for canola and A$22/ha for wheat.

Conventionally bred herbicide-tolerant canola varieties tolerant of triazine, a Group C herbicide, were introduced in 1993. These triazine-tolerant (TT) canola varieties have allowed production to expand into areas in which weed competition had previously restricted canola cropping (Colton and Potter 1999), resulting in an increase in the canola production area, particularly in Western Australia. Increases continued as early maturing canola varieties for low rainfall regions were introduced in 1997–98 (Figure 3.3).

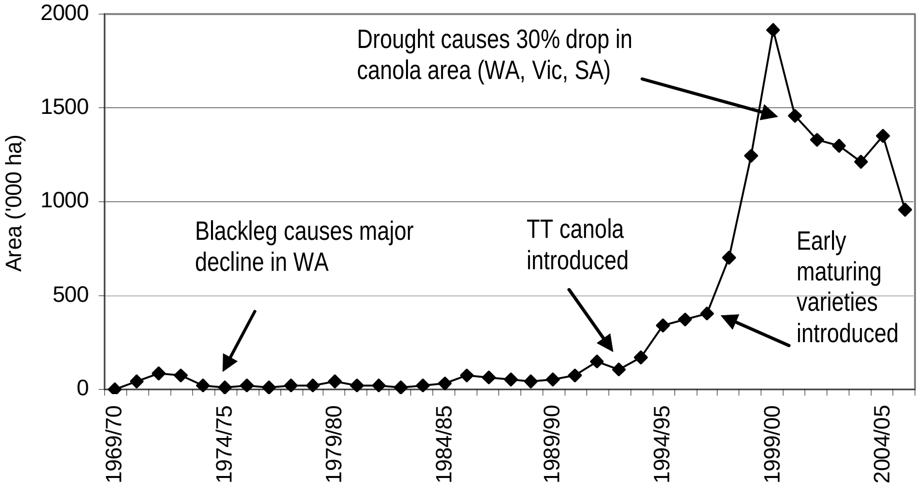

Figure 3.3 Production area of Australian canola (1969–2006)

Source: Graphed from data reported by USDA-FAS (2006), Colton and Potter (1999) and Australian Bureau of Statistics (2000; 2001).

A second non-GM HT canola variety was introduced into Australia in 2000. Imidazolinone-tolerant (IT) canola is tolerant of imidazolinone herbicides (Group B herbicides) but has not been as widely adopted as TT canola. This is mainly due the high level of resistance to Group B herbicides in weeds, particularly in Western Australia where TT canola is planted on an estimated 90 per cent of canola fields (Walsh et al. 2001; Norton 2003).

Two types of GM HT canola have been trialled in Australia. One type tolerates applications of glyphosate (Group M herbicide) and the other tolerates applications of glufosinate ammonium (Group N herbicide). Applications for the commercial releases of these varieties in Australia were approved by the Gene Technology Regulator, following assessments of the risks to human health and safety and the environment, in 2003 (OGTR 2003b; a).

Following these decisions there were concerns about potential risks to markets. Economic impacts are not assessed by the Regulator, as they are outside the scope of the *Gene Technology Act 2000* (Cwlth). A number of jurisdictions imposed moratoria preventing the commercial production of GM canola until at least 2008 (see Table 1.1). Moratoria were imposed under state laws, based on a 'Policy Principle' allowed under the *Gene Technology Act 2000* (Cwlth). The principle in question allows the designation, under state law, of areas for the purpose of preserving the identity of either GM crops, non-GM crops or both, for marketing purposes.

Section 3.2 summarises available data on the agronomic performance of non-GM HT canola in Australia as a basis for estimating the potential impacts of GM HT canola.

Section 3.2 Agronomic effects of non-GM HT canola

Prior to the introduction of TT varieties, the main weeds affecting canola production were wild radish, Indian hedge mustard, shepherd's purse, wild turnip, turnip weed, charlock, musk weed, Patterson's curse and *Vulpia* (Sutherland 1999). TT canola was rapidly adopted by farmers after its introduction in 1993 due to the relatively low-cost broadleaf weed control that can be achieved with triazine herbicides. This resulted in a rapid increase in area planted to canola with expansion across southern Australian and particularly in Western Australia (Norton et al. 1999; Sutherland 1999). An advantage of TT canola is that closely related weed species can be controlled in the crop, reducing contamination of the harvest. As previously mentioned, weeds closely related to canola (such as wild radish) can lower the quality of harvested grain by increasing levels of glucosinolates and erucic acid in the seeds.

Canola is usually sown in late autumn to early winter, with cool soils resulting in slow early growth, making the seedlings very susceptible to competition from weeds (Sutherland 1999). The ability to treat post-emergent weeds in HT canola crops with non-selective, in-crop herbicides allows crops to be sown dry to take earliest advantage of the first rainfall of the season. In conventional canola systems, sowing may need to be delayed until after the first rainfall to allow weeds to germinate and be sprayed to reduce competition with the young canola seedlings as they emerge later.

The introduction of HT canola has also assisted farmers to shift to no-till or conservation tillage systems (Norton 2003) with the associated environmental benefits described in Chapter 1. However, there has also been a concomitant increase in herbicide use as a result. For instance, the introduction of TT canola increased both the total volume of triazines used and their frequency of use (Hashem et al. 2001). Using the state canola areas data in Figure 3.2, the percentages of state canola crop areas sown to TT canola, and a maximum application rate of 2 kg/ha, it can be estimated that total triazines applied on TT canola in 2006 could have been up to 1 450 tonnes across Australia. Increased frequency in the use of herbicides can increase the risk of herbicide-resistant weed populations developing. Triazine resistant wild radish was first reported in Western Australia in 2001 (Hashem et al. 2001).

The introduction of TT canola in 1993 coincided with rapid increases in canola production area in that year. Yield varies significantly from year to year because of factors such as rainfall, but Figure 3.4 shows that there has been no trend of yield increase since TT canola introduction.

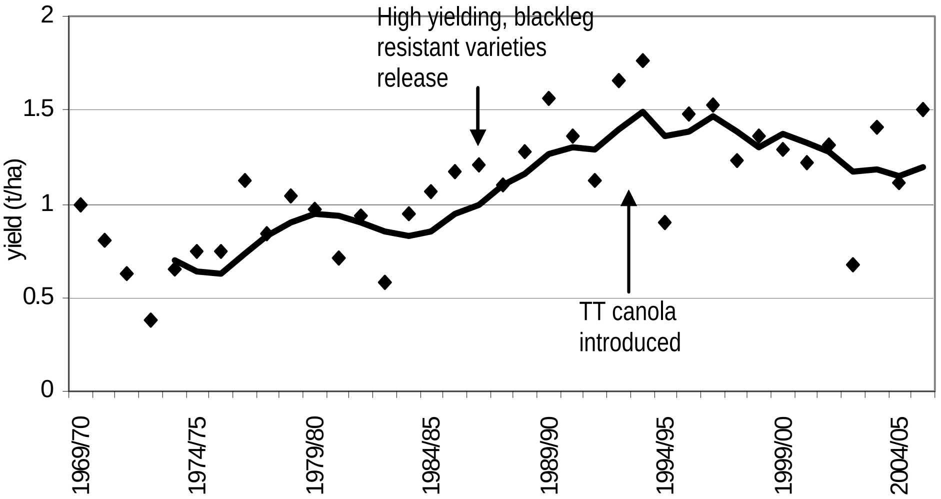

Figure 3.4 Canola yield in Australia (1969–2006)

Source: USDA-FAS (2006). Data points indicate yields for individual years while the line represents the preceding 5-years average.

In situations where weeds are absent or well controlled by herbicides other than triazine herbicides, TT canola varieties yield up to 20 per cent lower than conventional varieties and have a lower oil content. This is because the mutation that provides tolerance to triazine herbicides affects photosynthesis as well (Robertson et al. 2002). However, if TT canola is grown in situations where weeds cannot be adequately controlled without in-crop applications of triazine herbicides, TT canola is likely to provide a higher yield than conventional canola (Radcliffe 2002; McCaffery et al. 2006). This benefit partly explains the rapid expansion of canola growing areas following the introduction of TT varieties (Colton and Potter 1999; Sutherland 1999; Robertson et al. 2002). TT canola is most widely grown in Western Australia where it comprises approximately 80–90 per cent of the canola crop there. South Australia and Victoria plant respectively, about 65–75 per cent and 60–70 per cent of their canola crop to TT canola, while NSW plants 50–60 per cent (Canola Association of Australia, *pers. comm.*).

Section 3.3 GM HT canola in Canada

Three GM HT canola varieties were introduced into Canada over a period of six years from 1995. GM glufosinate ammonium-tolerant varieties (Group N herbicide) were introduced first, in 1995, followed by GM glyphosate-tolerant (Group M herbicide) and also conventional IT varieties (Group B herbicide) in 1996, then GM bromoxynil-tolerant varieties (Group C herbicide) in 2000 (Devine and Buth 2001).

Triazine-tolerant (TT) canola varieties had been made available to Canadian farmers in 1981, but a yield penalty combined with triazine's lack of broad spectrum weed control meant that TT varieties were cost-effective only in areas where competition was high from cruciferous weeds such as wild radish. Cultivation of TT varieties in Canada had decreased to less than 1 per cent of the total canola area by 1996 and has since been discontinued (Beckie et al. 2006), in sharp contrast to the current dominance of TT canola in the Australian crop.

Herbicide-tolerant canola is by far the most extensively grown GM crop in Canada; 5.1 million ha in 2007, which is 87 per cent of the total land area sown to canola (James 2007). Adoption rates of GM HT canola in Canada have steadily increased over the years since first introduced.

3.3.1 Agronomic performance

Canadian canola yields and production area have tended to increase since records began (Figures 3.5 and 3.6), and there has been less year-to year variation in yield compared with Australia (see Figure 3.4).

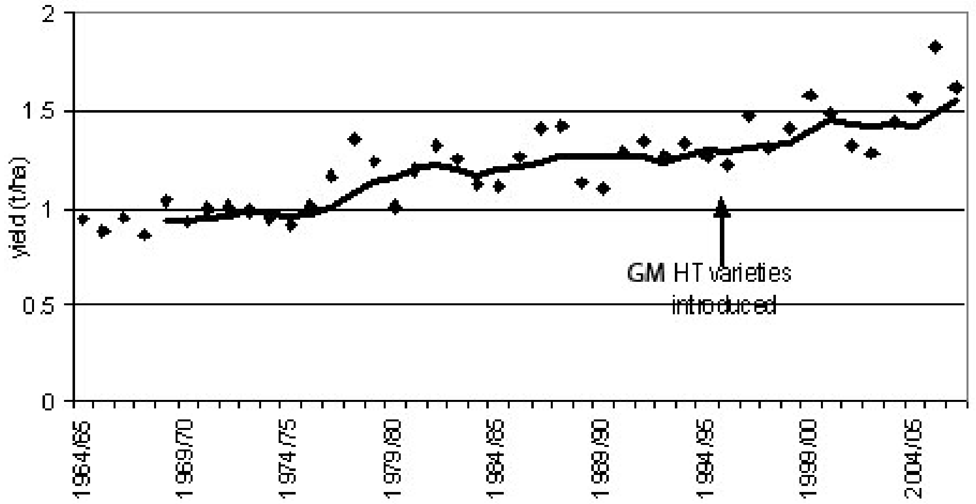

Figure 3.5 Canola yield in Canada (1964–2006)

Source: Graphed from data reported by USDA-FAS (2006). Data points indicate yields for individual years while the line represents the preceding 5-years average.

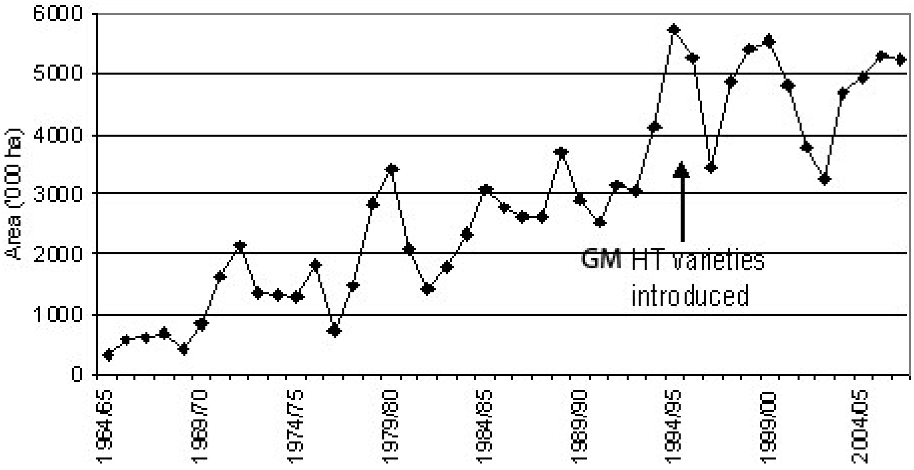

Figure 3.6 **Production area of Canadian canola (1964–2006)**

Source: Graphed from data reported by USDA-FAS (2006).

In 2001, a survey of Canadian farmers was conducted to determine their attitudes to GM canola and the agronomic performance of the varieties they grew (Serecon Management Consulting Inc and Koch Paul Associates 2001). The survey collected data from 650 Canadian farmers who grew at least 80 acres of non-GM, non-HT conventional canola or GM canola in the year 2000. Farmers were not questioned about non-GM HT varieties. Where farmers grew both GM and conventional varieties, they were asked to respond for the variety with the greatest area in the survey year. The numbers of farmers reporting for conventional and GM fields were evenly spread and the proportions within each of these groups growing different types (e.g. glyphosate-tolerant/glufosinate ammonium-tolerant or *B. napus*/*B. rapa*) were controlled to reflect actual proportions in the wider population.

Although the results from the survey are not conclusive and may not always be statistically significant, they show that:

- 81 per cent of surveyed GM farmers reported more effective weed control through their use of GM varieties
- 59 per cent of surveyed GM farmers reported that weed control was easier
- 61 per cent of surveyed GM farmers reported that volunteer management following a GM crop was about the same as for volunteers from conventional crops
- 45 per cent of surveyed GM farmers said that GM varieties allowed them to plant earlier
- 20 per cent of surveyed GM farmers said that they had increased their acreage as a result of being able to grow GM canola. On average the increased area was 45 per cent
- 26 per cent of surveyed GM farmers had increased their use of conservation tillage as a result of growing GM varieties
- 48 per cent of those responding as conventional farmers also grew GM varieties, while 36 per cent of conventional respondents had never planted GM and 14 per cent had tried GM varieties but had not continued growing them.

Survey results reported 10 per cent higher average yields for GM HT varieties (1.65 tonnes/ha) than for conventional varieties (1.47 tonnes/ha); although the maximum reported yield was highest for a conventional variety (4.04 tonnes/ha), with the highest GM canola yield 24 per cent lower at 3.08 tonnes/ha. Many factors contribute to yield, but farmers concluded that the yield advantage for GM canola was due to varieties, with some impact also from slightly increased use of fertiliser.

Generally higher average yields for GM varieties were also reported in the Prairie Canola Variety Trials (PCVT) in 2004, 2005 and 2006 (Figure 3.7). These trials are conducted on sites kept weed-free through conventional herbicide application, meaning that HT varieties are not sprayed with their 'companion' herbicide. The trials compare the yields of a number of HT varieties to that of a conventional variety that was grown at each test site. Yields varied both between and within varieties. It is noteworthy that the seven highest-yielding varieties were all hybrids, indicating the value of hybrid vigour for yield (Figure 3.7). The hybrid nature of many of the GM varieties contributes significantly to their higher yields. Some non-GM HT varieties (IT varieties) are hybrid varieties, and yields are higher than their non-hybrid IT counterparts.

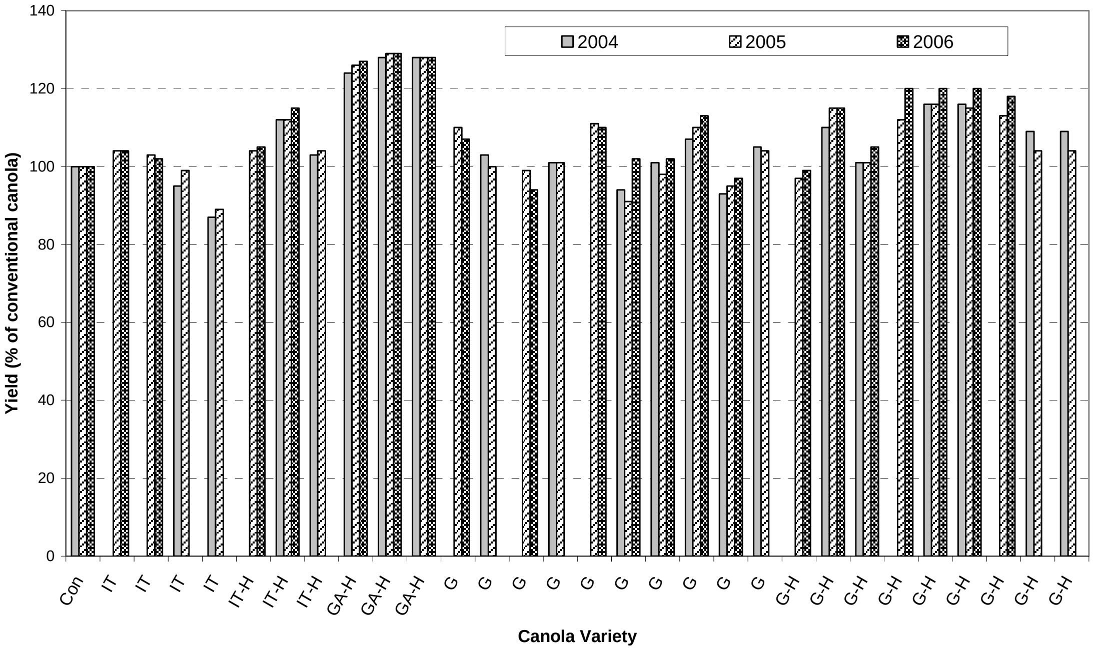

Figure 3.7 **Yield comparisons in the Prairie Canola Variety Trials (2004, 2005 and 2006)**

Notes: only varieties for which data exist for at least two of the three years are included. H, indicates that the variety is a hybrid; Con, conventional; IT, imidazolinone-tolerant; GA, glufosinate ammonium-tolerant; G, glyphosate-tolerant.

Source: Graphed from data reported by Canola Council of Canada (2008).

From the 2007 growing season onwards, the conventional canola comparison variety previously used for the PCVT was replaced by the average for two herbicide-tolerant hybrid varieties (one tolerant to glufosinate ammonium, the other tolerant to glyphosate). The reason for the change is that the new comparison varieties are more representative of the varieties being grown by Canadian farmers. Hence, from 2007, variety comparisons will be made to the average yield of the two new comparison lines. Since the new comparison lines are both higher yielding hybrid varieties, the comparative yield for the different canola varieties shown in Figure 3.8 below appears proportionately less, but this does not mean these varieties are lower-yielding than the year before.

The 2007 yield comparisons once again show that GM varieties are higher-yielding than conventional canola. However, so too are conventional non-GM IT varieties, provided they are hybrid. The latter can have yields equal to or higher than some GM varieties, with the exception of the glufosinate ammonium-tolerant hybrid varieties.

There have also been agronomic challenges in growing GM HT in Canada. These include: the effects of potential transgene transfer from GM canola to either non-GM canola or weedy relatives of canola; the control of GM canola volunteers on-farm; and, the potential for selection in weeds for resistance to the herbicide to which the crop was made tolerant. The Canadian experience is briefly referred to below, in a consideration of these issues for Australia (Section 3.4.1).

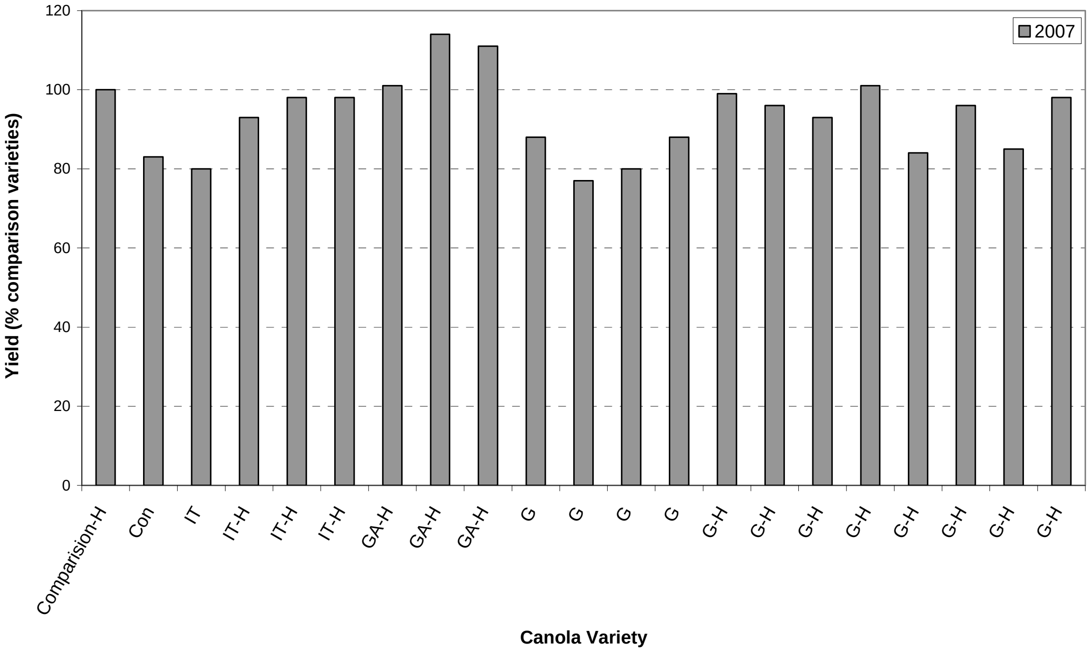

Figure 3.8 Yield comparisons in the Prairie Canola Variety Trials (2007)

Notes: H indicates that the variety is a hybrid; Con, conventional; IT, imidazolinone-tolerant; GA, glufosinate ammonium-tolerant; G, glyphosate-tolerant.

Source: Graphed from data reported by Canola Council of Canada (2008).

3.3.2 Environmental performance

The studies described below suggest that there are environmental benefits from GM and non-GM HT canola crops in Canada resulting from decreased herbicide applications and altered herbicide usage.

Between 1995 and 2000, the herbicide application rate (kg a.i./ha) on Canadian canola fields decreased by nearly 43 per cent as the proportion of HT canola, both GM and non-GM, rose from zero to 80 per cent (Brimner et al. 2005, based on the results of a Canadian farmers' herbicide use study). The types of herbicides applied also changed during this period, with about 60 per cent of the total area of canola grown, treated with either trifluralin or ethalfluralin (Group D herbicides) in 1995. However, by 2000 this had decreased to less than 12 per cent of the total canola area treated.

Glyphosate (Group M herbicide) was applied to approximately 5 per cent of fields in 1995 and 70 per cent in 2000. Glufosinate ammonium (Group N herbicide), imazethapyr (Group B herbicide) and imazamox (Group B herbicide) have also become more commonly used in canola (Brimner et al. 2005, based on the results of a Canadian farmers' herbicide use study). The study did not distinguish between GM and non-GM HT canola varieties.

Also investigated was the effect that these changes have had on the environmental impact of herbicides use, estimated as EI values per ha used in canola types for the years between 1995 and 2000. As explained in Section 1.6, the higher the EI value per ha, the greater the environmental impact. Although the average EI Quotient for the herbicides used on HT canola (averaged for herbicides used on both GM and non-GM HT canolas) was higher than for the herbicides used on conventional canola, the application rates were lower for many of the herbicides on the former, resulting in lower total EI/ha values and a lower overall environmental impact of herbicide use in HT canola. Total EI/ha averaged 22.56 and 8.03 for the years 1995–2000 for total conventional and total HT canola respectively (Brimner et al. 2005). The authors concluded that the decline in herbicide use and estimated environmental impact since the introduction of HT canola varieties was due to the use of herbicides at lower application rates, a reduced number of applications, and a decreased need for use of herbicides in combination.

Brookes and Barfoot (2005) used a similar method to estimate environmental impact of herbicides used on GM HT canola in Canada. They based their calculations on 'typical' herbicide regimes for the different canola varieties, considering five herbicides in their calculations. The authors estimated that there was a decrease in the total seasonal EI/ha values for each of the different types of GM canola in comparison with conventional canola for 2004, with the 'field EIQ load' for GM HT canola fields 32 per cent lower than if the entire canola crop had been planted to conventional non-HT canola varieties.

For 2006, the reduction in the amount of herbicide used was estimated to be 1.29 million kg, a reduction of 22.6% (Brookes and Barfoot 2008b). The 'field EIQ load' was estimated to be 36.4% lower in 2006 than it would have been if conventional canola had been planted.

A further environmental benefit from reduced herbicide use in Canada is the reduction in fuel use and consequent lowered greenhouse gas emissions. Brookes and Barfoot (2008a)estimate that the carbon dioxide savings from reduced fuel use between 1996–2006 in areas sown to GM HT canola in Canada, were 136 million kg of carbon dioxide, equivalent to removing over 60 500 average family cars from the road for year. They further estimated that potential additional soil carbon sequestration savings resulting from the change to no-till and reduced tillage systems for GM HT crop areas, were 1 680 million kg of carbon dioxide over the same period (equivalent to removing 745 300 average family car equivalents from the road for a year).

3.3.3 Economic performance

The survey described in Section 3.2.1 (Serecon Management Consulting Inc and Koch Paul Associates 2001) also reported on economic effects of growing GM canola varieties compared with non-GM canola. The survey found that Canadian farmers growing GM canola, compared with those growing non-GM canola, spent (expenditure per unit area):

- 39 per cent less on herbicides
- 17 per cent less on combined operations (herbicide and fertiliser applications, plus cultivation)
- 33 per cent more for seed and seed application
- 6.5 per cent more on chemical fertiliser inputs.

Ninety per cent of growers (both GM and non-GM) reported dockage (price decrease for contaminants in the harvested seed sold), but the degree of dockage was lower for GM canola compared to conventional canola growers (3.87 per cent and 5.14 per cent respectively). It should be noted, however, that non-GM HT canola had not been included in that survey.

As a result, the net return (after all input costs, including labour, were deducted) was reported to be an average of 41 per cent higher for GM crops than for non-GM crops, at C$5.80/acre (C$14.33/ha).

It has been speculated that increased canola production in recent years as a consequence of HT canola adoption, has led to decreased prices. An increase of production of any good might be expected to lead to a decline in price. An econometric analysis (Serecon Management

Consulting Inc and Koch Paul Associates 2001), however, did not find a causal relationship between the level of canola production and its price (1982 to 2000). There was a strong positive relationship between canola price and other commodity prices, particularly the price of soybeans which are produced in large volumes. Soybeans tend to set the price of oilseeds in general, in part due to the substitutability of many vegetable oils (Holtzapffel et al. 2007).

Canada has found ready markets for its GM canola in Japan, China, Mexico, USA, the United Arab Emirates and Pakistan, although it had lost market share in the European Union up to 2004 (Foster and French 2007). The EU has resumed some import of canola oil for biodiesel production in recent years.

Section 3.4 Possible effects of introducing GM HT canola into Australia

3.4.1 Agronomic effects

In Canada, several GM and non-GM HT canola varieties were introduced within a short space of time, with approvals for unconfined release granted between 1995 and 1996 (CFIA 2006)[13]. By contrast, Australia has had access to only two HT varieties, TT and IT canola (since 1993 and 2000 respectively) until recently. Australian canola growers have had access to some of the benefits associated with herbicide-tolerant canola, namely the ability to expand canola growing into more weedy areas, ability to plant earlier in the season by dry sowing, and introducing conservation tillage. However, Australian farmers have not had access to all the advantages Canadian farmers have gained through the introduction of GM HT canola, particularly the advantages of increased yield, improved weed control and increased options for control.

The primary benefit of the introduction of GM HT canola varieties into the Australian cropping system will be the replacement of lower-yielding TT canola varieties with higher-yielding GM HT varieties, which should result in increased yields per ha. In particular, InVigor® hybrid canola is expected to provide a significant yield advantage as a result of hybrid vigour. Farmers would have the option to buy hybrid varieties for their hybrid vigour but use a conventional herbicide regime on the crop, depending on their assessment of the weed status and weed spectrum in their fields.

Additional benefits may be:

- increased options for in-crop weed control, allowing rotations of herbicides with the potential to decrease the risk of resistant weeds developing
- increased yield in subsequent cereal crops, which can be adversely affected by triazine carry-over from TT canola crops. Triazine carry-over effects are of particular concern following dry seasons or in alkaline soil. Wheat is slightly more tolerant of triazine carry-over than barley or oats, although tolerance varies between different wheat varieties. However, crops can be damaged by relatively low rates of triazine and, if combined with root diseases, the crops may die (Stanley 2003).

In a recent study conducted by Charles Sturt University in Wagga Wagga, NSW, the yield and economic performance of a GM glyphosate-tolerant canola variety (Roundup Ready® canola) was compared with conventional canola varieties over a typical five-year crop rotation system (Stanton 2004). In this trial, the author reports that Roundup Ready® (glyphosate-tolerant) canola consistently delivered superior weed control, higher yields and oil quality, and better profits when compared to current common canola varieties grown under conventional weed management systems. The researchers also found that there was better weed control

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[13] The Canadian Food Inspection Agency (CFIA) is responsible for the regulation of the environmental release of plants with novel traits. This includes both GM and non-GM traits.

throughout the five-year crop rotation using Roundup Ready® canola in the first year of the rotation, and that any subsequent volunteer canola was also easily controlled (Stanton 2004).

Norton and Roush (2007) estimate the agronomic benefits of replacing half of Australia's TT canola and 40 per cent of conventional canola, with GM HT canola. In this scenario, across the whole Australian canola crop, they estimate: a 7 per cent increase in yield; a 200 000 ha increase in total area sown to the annual canola crop; a 23 per cent increase in canola production; and, an accompanying increase in wheat production of 80 000 tonnes.

Some agronomic concerns associated with growing GM canola in Australia have also been raised. These are primarily in regard to:

- the risk of development of herbicide-resistant weeds and consequent loss of efficacy of the herbicide, due to increased use of the herbicide
- the risk of transgene adventitious presence in non-GM canola, due to transgene flow from GM canola to non-GM canola
- the risk of development of herbicide-resistant weedy relatives, through transfer of transgenes to related weeds, and consequent loss of herbicide efficacy
- the difficulty of controlling GM canola volunteers in a subsequent crop.

These concerns are discussed below.

Increased risk of development of herbicide-resistant weeds due to herbicide use

The development of resistance to herbicides is not a risk that is limited to GM crops. As discussed in Section 3.2, the frequent use of triazine (Group C) herbicides has led to the development of triazine-resistant weeds in parts of Australia. Resistance to Group B herbicides is also common in Western Australia (see below).

The risk of resistance developing to a herbicide varies between herbicides due to the different biochemical modes of action. As shown in Table 3.1, herbicides in Group B (e.g. imidazolinones, used on IT canola) and in Group C (e.g. triazines, used on TT canola) have a high to medium resistance risk. Group L and N (paraquat and glyphosate) herbicides on the other hand are regarded having a low risk of resistance developing (McGillion and Storrie 2006).

Glyphosate has been widely and frequently used throughout the world for about 30 years. It is widely used in canola fields as a knockdown herbicide to reduce weed pressure before sowing. It is a valuable tool for many different cropping situations in Australia. As indicated in Table 3.1, the risk of development of herbicide resistance to glyphosate has been considered to be relatively low for biochemical reasons (Jasieniuk 1995). However, since the first glyphosate-resistant annual ryegrass (*Lolium rigidum*) population was identified in 1997 (Powles et al. 1998), an additional 63 populations have been reported (Preston 2005; Preston and Wakelin 2007). Resistance has also been reported in Australia in barnyard grass (*Echinochloa colona*), while in other parts of the world resistance is known in a further four grass species and also in eight broadleaf species (including fleabane, *Conyza bonariensis*) (Preston and Wakelin 2007).

Annual ryegrass appears to be particularly adept at developing resistance to many herbicides, with populations identified that are simultaneously resistant to Group A, B, C and D herbicides (Powles 1999).The populations tend to occur at sites where glyphosate has been used as the only weed control method for a significant period, no other effective herbicides are used and there is no tillage. Clearly these populations are not where Roundup Ready® (RR) canola has been grown, because commercial RR canola crops are being grown for the first time in 2008. An analysis in 2005 (Preston 2005) reported that a third of the populations were located in areas that had been subject to chemical fallow (the practice of killing pasture using herbicides, prior to sowing a crop) for many years, 20 per cent were in vineyards, 17 per cent occurred along fence lines and 11 per cent were in no-till fields. The remainder occurred in irrigation channels, orchards, a firebreak, an airstrip and along a railway line.

The development of glyphosate resistance in weeds is of wide concern within the agricultural community and among weed professionals, as there have been no new non-selective herbicides developed recently—glyphosate was released in the 1970s and paraquat (Group L herbicide), the main alternative, in the 1960s (Weersink et al. 2005). A major problem identified by Weersink et al. (2005) with managing the use of glyphosate, is that it provides relatively cheap, good weed control, making it tempting to use it widely and often.

Table 3.1 Herbicide resistance risks for a range of herbicide mode of action groups

Herbicide group	Herbicide resistance risk	Selected examples of herbicides
A	High	'Fops', 'Dims' and 'Dens'
B	High	Sulfonylureas, imidazolinones and sulfonamides
C	Medium	Triazines, ureas, amides and nitriles
D	Medium	Dinitroanilines and benzoic acids
E	Medium	Carbamates and phosphorodithioates
F	Medium	Nicotinanilides, pyridazinones, pyrazoles, isoxazoles and triazoles
G	Medium	Diphenylethers, oxadiazoles, triazolinones and pyrimidindiones
I	Low	'Phenoxys' and 'Pyridines'
J	Low	Chlorocarbonic acids
K	Low	Acetamides, benzamines, benzofurans and phthalamates
L	Low	Bipyridils (paraquat and diquat)
M	Low	Glycines (glyphosate)
N	Low	Phosphinic acids (glufosinate)

Source: McGillion and Storrie (2006).

The Australian Glyphosate Sustainability Working Group (AGSWG)[14] has developed strategies for reducing the risk of glyphosate-resistant weeds and these could be used in rotations containing glyphosate-tolerant canola. The AGSWG provides a list of a number of factors that contribute to the development of glyphosate resistance and factors that minimise the risk of resistance developing.

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[14] www.weeds.crc.org.au/glyphosate/index.html

Risk-contributing factors are:

- continuous reliance on glyphosate pre-seeding
- lack of tillage
- lack of effective in-crop weed control
- frequent glyphosate-based chemical fallow
- inter-row glyphosate use (unregistered)
- frequent crop topping with glyphosate
- high weed numbers.

Risk-minimising factors are:

- the ‘double knock’ technique (glyphosate followed by full cultivation or use of the herbicide 2,4-D [Group L])
- strategic use of alternative knockdown groups
- full-cut cultivation at sowing
- effective in-crop weed control
- use of alternative herbicide groups or tillage for inter-row and fallow weed control
- non-herbicide practices for weed seed kill
- crop topping with alternative herbicide groups
- farm hygiene to prevent resistant seed movement.

Increased frequency of glyphosate application could increase the likelihood of resistance emerging in exposed ryegrass populations, depending on the risk management put in place. The recommended weed control regime for glyphosate-tolerant canola indicates that there will be an increase in the applied amount—and often in the frequency—of glyphosate on glyphosate-tolerant canola crops in comparison to TT canola crops in Western Australia (Tables 3.2 and 3.3). However, TT canola is not as widely grown in NSW and Victoria and many of the weed control regimes suggested in NSW for conventional canola (NSW Department of Primary Industries 2005) use glyphosate at the same (or greater) frequency as that recommended for glyphosate-tolerant canola, albeit at lower rates. The increased risk of resistance developing should not be as great in these regions (Table 3.3), particularly when combined with the strategies of the AGSWG described above and Monsanto Australia’s resistance management plan (see below).

Neve et al. (2003) have modelled the rate of development of glyphosate resistance in ryegrass populations in a no-till system and where glyphosate is used annually for ryegrass control. The authors predict that the introduction of glyphosate-tolerant canola would result in a rapid evolution of resistance in weeds associated with canola cropping. They predicted that resistance would evolve in a small number of ryegrass populations after seven years and in almost 100 per cent of populations after 20 years. By comparison, glyphosate resistance in a similar cropping system without glyphosate-tolerant canola was predicted in only half of the ryegrass populations after 20 years (Neve et al. 2003). It is important to note that this model relied on a single gene conferring glyphosate resistance and a closed ryegrass population (meaning there is no gene flow into the population from surrounding ryegrass populations). Allowing for gene flow from outside ryegrass populations, or markedly increasing the number of individuals present in a closed ryegrass population, could lengthen the timeline of predicted evolution of resistance made by this model.

Table 3.2 Recommended herbicide applications for Roundup Ready® and InVigor® hybrid canola

Herbicide system	Suggested herbicide applications (total a.i. applied)
Roundup Ready® canola	2 applications of Roundup® at 0.9 kg product/ha (1.24 kg glyphosate/ha total)
InVigor® hybrid canola	2 applications of Liberty® at 1.5L product/ha (0.6 kg/ha glufosinate ammonium total) OR at 2 L/ha (0.8 kg/ha glufosinate ammonium total)

Sources: APVMA (2006). Total a.i. applied was calculated using the formula: Volume applied (L/ha) x Herbicide formulation (kg/L) = Total a.i. (kg/ha).

Table 3.3 Suggested glyphosate applications[15] for TT canola in Western Australia and conventional canola in New South Wales

WA Region (TT canola)	**Number of glyphosate applications** (total a.i. applied)	**Cropping system and NSW region (conventional canola)**	**Number of glyphosate applications** (total a.i. applied)
Northern Agricultural region, WA	2 applications glyphosate (0.9 kg/ha)	Conventional long fallow (dryland central east NSW)	3 applications glyphosate (1.62 kg/ha)
South eastern Wheatbelt, WA	1 application glyphosate (0.54 kg/ha)	Conventional long fallow (dryland south west NSW)	2 applications glyphosate (1.125 kg/ha)
Esperance, WA	2 applications glyphosate (0.675 kg/ha)	Conventional after pasture (dryland south east NSW)	2 applications glyphosate (0.99 kg/ha)
Eastern Wheatbelt, WA	1 application glyphosate (0.54 kg/ha)	Conventional no-till (dryland central east NSW	2 applications glyphosate (0.9 kg/ha)
South coast, WA	1 application glyphosate (0.54 kg/ha)	Conventional no-till (dryland central west NSW)	3 applications glyphosate (1.53 kg/ha)
Northam, WA	1application glyphosate (0.45 kg/ha)	Conventional no-till (dryland north east NSW)	2 applications glyphosate (1.26 kg/ha)
Narrogin, WA	1 application glyphosate (0.36 kg/ha)	Conventional no-till (dryland north west NSW)	2 applications glyphosate (0.765 kg/ha)
Great Southern WA	1 application glyphosate (0.27 kg/ha)	Conventional irrigated (central NSW)	1 application glyphosate (0.432 kg/ha)

Sources: APVMA (2006); Regional economists (2005); NSW Department of Primary Industries (2005). Total a.i. applied was calculated using the formula: Volume applied (L/ha) x Herbicide formulation (kg/L) = Total a.i. (kg/ha).

In response to the risk of glyphosate resistance, Monsanto Australia has developed a resistance management plan (RMP) for Roundup Ready® canola to maximise the long-term sustainable use of glyphosate in Australian farming systems. The resistance management plan is a component of a broader crop management plan (CMP) which also covers implementation of strategies to manage other production aspects, such as the control of RR canola volunteers and meeting regulatory requirements (Monsanto Australia 2008). Implementing the RMP and CMP are conditions of the licensing agreement with growers.

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[15] The suggested herbicides regimes include herbicides other than glyphosate. A table listing all the herbicides suggested for use in each region is included at Appendix B.

The main principles of the RMP are summarised here and are based on integrated weed management systems. Farmers should:

- aim to enter the Roundup Ready® canola phase of the rotation with a low weed burden
- integrate as many different weed control options (chemical and cultural) as possible, through all phases of the crop rotation
- use registered application rates and assess effectiveness
- rotate herbicides with different modes of action throughout the crop rotation
- rotate HT crops with tolerance to herbicides with different modes of action throughout the crop rotation (avoiding, where possible, use of glyphosate immediately after a Roundup Ready® canola crop)
- regularly monitor the effectiveness of resistance management practices
- test weed populations for herbicide resistance status as part of continuing IWM.

A key component of RMP is a ‘paddock (field) risk assessment’ tool that has been developed to determine systematically the risk profile of each paddock where Roundup Ready® canola could be planted. The recommended management practices using the tool, for an assessed level of risk, aim to decrease the risk of glyphosate-resistant weeds developing in that paddock (Monsanto Australia 2008).

The development of resistant weeds is not likely to be as significant a problem with InVigor® hybrid canola, as glufosinate ammonium is not registered for use on broadacre crops other than on Liberty Link® cotton and InVigor® hybrid canola (APVMA 2006).

Some plants are more likely than others to develop resistance to herbicide. Populations of multiple-herbicide-resistant ryegrass occur across the wheat belt (Powles 1999; Llewellyn and Powles 2001). It has also been estimated that 21 per cent of wild radish populations are resistant to Group B herbicides (Walsh et al. 2001). This is a major reason that IT canola is not widely grown in Western Australia. Wild radish populations have also been found that are resistant to up to four different modes of action (Walsh et al. 2004).

The ability to use different herbicide-tolerant crops as part of crop rotations, in conjunction with good IWM practices (including non-herbicide control options), should delay the development of more multiple herbicide-resistant weeds. This should also reduce the impact of any gene flow that occurs as resistant weeds will only have an advantage under selective pressure of the relevant herbicide(s).

Due to the above concerns about weed resistance, farmers who currently grow TT canola in Australia and who assess their paddocks as having a risk of developing glyphosate-resistant weeds may choose not to grow Roundup Ready® canola. However, the weed control spectrum for both glyphosate and glufosinate ammonium will be an important determinant of whether or not these crops will be useful in particular situations.

In Canada, as part regulating herbicide-tolerant crops as ‘plants with novel traits’, the Canadian Food and Inspection Agency now requires proponents to develop a stewardship plan that details steps farmers can take to minimise the chances of weeds becoming herbicide-resistant (CFIA 2008).

Gene flow from GM canola to non-GM canola

Some gene flow from GM to non-GM canola and *vice versa* will occur, because of the out-crossing nature of canola. This issue has been reviewed in detail in previous studies (Glover 2002; Salisbury and Downey 2002). Out-crossing has implications for the coexistence of GM canola and non-GM canola or related crops.

Canola has a mixed mating system. It is predominantly self-fertile (self-pollinated), but plant-to-plant crossing rates average about 30 per cent (Salisbury and Downey 2002), varying from 12 per cent to 47 per cent in field experiments in Australia (Rieger et al. 1999). However, levels of inter-plant out-crossing in adjacent crops declines rapidly with distance, with most out-crossing occurring in the first few metres of the pollen source being tested in field experiments. Therefore, out-crossing rates need to be considered at whole crop or field levels to consider levels of potential adventitious presence of a trait or gene in an adjacent crop.

Out-crossing rates also vary depending on the local environmental conditions, local topography, insect populations, management practices and the particular varieties, as well as the distance from the source. Not surprisingly therefore, out-crossing rates reported from a range of studies in different countries show different ranges in six different large field trial studies (Salisbury and Downey 2002). For example, rates varied between 0.15 to 0.65 per cent at 40–60 metres in one study, to 0.14 per cent at 360–400 metres in another study. The highest rate in these studies was the 0.65 per cent value referred to above.

In Australian field-scale experiments in New South Wales, Victoria and South Australia (Rieger et al. 2002), the highest rate of out-crossing found was 0.197 per cent, although no out-crossing was detected at 69 per cent of sites. The general trend of lower out-crossing as distance increases (from source) was observed. Results indicated that gene flow in adjacent fields will be between 0–0.07 per cent in the great majority of cases. A later study (Ramsay et al. 2004) concluded that in the United Kingdom, as shown in the Australian study, pollination from one field to the next is likely to be less than 0.1 per cent averaged over the whole field.

Not only are these levels below the industry approved adventitious GM presence threshold in Australia (0.9 per cent), but gene flow from GM HT crops to conventional crops is further intended to be managed through industry Stewardship Principles and crop management plans (Monsanto Australia 2008), which include recommendations such as non-GM/GM crop separation distances and harvesting of adjacent non-GM canola borders for inclusion in the GM canola harvest, in order to achieve adventitious presence levels in grain below the 0.9 per cent threshold.

Some long-distance pollen travel occurs at very low levels, with levels of out-crossing beyond 400 metres irregular, and maximum distances being less than three kilometres in the Australian studies (Rieger et al. 2002). Using male-sterile plants as recipients, Ramsay et al. (2004) detected some gene flow over even larger distances (26 km in one case, from the nearest *known* source), discounting most other explanations for presence of the imidazolinone-tolerance gene in their experiment. They nevertheless concluded that “the management of cropping systems to ensure purity at pre-determined levels should be possible” even if both GM and non-GM crops were grown in the same region (Ramsay et al. 2004).

Development of herbicide-resistant weedy relatives through gene flow

Concerns regarding gene flow from HT canola crops also include the potential for gene flow to weedy relatives of canola, possibly leading to increased weed control problems. In a detailed assessment of this issue, Salisbury and Downey (2002) concluded that while herbicide tolerance gene flow from canola to weedy relatives is a remote possibility, it would not be expected to result in increased weediness or invasiveness of the species. *Brassica* hybrids and any weeds to which herbicide tolerance genes did successfully transfer would not have any competitive advantage except when challenged by the herbicide in question. Even in that scenario such plants could be controlled using other available herbicides or cultivation. Such controls would in any case likely occur in the course of rotational cropping over subsequent seasons.

While natural hybrids between canola (*Brassica napus*) and three weedy relatives (*Raphanus raphanistrum*—wild radish; *Hirschfeldia incana*—Buchan weed; and, *Sinapis arvensis*—charlock) have been reported, the frequencies are very low to extremely low. Importantly, gene flow is not known to have occurred from hybrids to any of these weedy relatives. There are significant barriers in all these species to successful gene transfer from *B. napus* (Salisbury and Downey 2002). While successful gene transfer at some time in the future cannot be ruled out completely, if it did occur for a herbicide-tolerant trait in one of these weed species the worst consequence would be losing the option to use that specific herbicide to control the weed species. Even this could be avoided once the gene transfer was known, through sound weed management practices and use of alternative herbicides.

The Gene Technology Regulator assessed the environmental risks arising from gene flow to related weeds and concluded that the risks were very low to negligible (OGTR 2003a).

Control of GM canola volunteers

Another potential issue is that glyphosate-tolerant volunteer canola plants in a subsequent crop could be difficult to control. Seed loss during harvest, approaching up to 10 per cent in some cropping, gives rise to 'volunteer' plants when they germinate in a subsequent crop. Volunteers from a previous crop can occur in more than one subsequent season, because canola seeds can remain dormant in soil for some years. Such volunteers may need to be controlled in the subsequent crop anyway, whether or not the canola crop had been herbicide-tolerant (either non-GM or GM).

While canola is not considered to be a serious weed in managed systems nor invasive of natural ecosystems in Australia, canola volunteers (both GM and non-GM) may require management in subsequent crops. This is particularly the case where the subsequent crop is a cereal crop; volunteers can significantly decrease cereal yield if not controlled early in the season, both in Australia and Canada (CCC 2005b).

Salisbury and Downey (2002) concluded for Australia, that enhanced management practices are required to ensure good control of volunteer canola, both in paddocks and in other disturbed areas. Monsanto Australia's CMP includes a range of strategies for the management of RR canola volunteers spatially and temporally (Monsanto Australia 2008). A range of on-farm management practices are recommended, both herbicidal and cultural, depending on the situation. Implementing the CMP is a condition of the licensing agreement with growers.

The size of the soil seedbank and longevity of canola seed in soil are also factors relevant to the incidence of volunteers in subsequent crops and seasons. Baker and Preston (*in press*) conducted a study on the persistence of the canola seedbank for up to three and a half years after the last canola crop was grown in farmer-managed fields (both no-till and tillage systems) in three geographical areas of the South Australian cropping region.

There has been speculation that no-till farming practices in southern Australia should reduce the potential for seed to persist in the field, because seed will not be buried but instead be exposed to seed predators and the long dry southern Australian summer season. However, despite some differences in seed germination in the initial time period for no-till system samples compared with tillage system samples, the seed persistence levels for both tillage systems converged rapidly and were not significantly different. Extrapolation of the seed bank data indicated the potential for a few seed to remain in the soil for extended periods of time, however the number of recovered seed that germinated was low overall and by 3.5 years there were no germinations recorded in either tillage system.

Baker and Preston (*in press*) concluded that neither time-since-harvest nor cultivation method was significant for the number of germinated canola seeds they found in soil samples from the farms. The canola seed bank and the number of volunteers declined rapidly in these managed cropping systems. The authors concluded that it is unlikely that herbicide-tolerant canola will become a major weed if volunteers are managed carefully.

Canadian research has indicated that there have been no marked changes in volunteer weed problems associated with HT canola crops compared with non-HT crops, except in no-till systems when glyphosate alone is used to control canola volunteers (Beckie et al. 2006). Canadian growers with experience with both conventional and HT canola systems have reported that volunteer canola management was the same for both types of systems or easier with HT varieties (CCC 2005c).

The Canola Council of Canada (2005b) lists a number of strategies to ensure good management of both GM and non-GM HT canola volunteers, including herbicide rotations and use of physical control. All volunteers, whether non-HT, single gene-HT, or multiple-gene HT, can be controlled by herbicides with alternative modes of action and/or cultivation.

Canola volunteers with multiple herbicide-tolerant traits have occurred in Canada where different HT crops have been grown in adjacent fields or together on a farm. The potential for stacking of resistance genes into canola volunteers or related weed species is not specific to GM HT crops, but the number of HT options made available with GM HT varieties has increased, with the potential to complicate the herbicide resistance management system that a farmer would need to adopt. Tracking the sowing history of specific paddocks is important, as is farmer education.

Few farmers in Canada target herbicide treatments or tillage operations specifically for volunteer canola, even though stacking has been reported; a majority of farmers were not targeting volunteer canola more than they had in the past (CCC 2005c).

3.4.2 Herbicide use environmental effects

Environmental risks of GM HT canola have been considered by the Gene Technology Regulator and assessed to be very low or negligible (OGTR 2003a; b). The environmental effects of the extension of use of herbicides on both non-GM and GM crops have been assessed by the APVMA.

Environmental risk assessment and regulatory conclusions are not the subject of this report, but in regard to herbicide environmental impacts, both glyphosate and glufosinate ammonium are regarded as having low ecotoxicity. Environmental Impact Quotients calculated for these two herbicides are lower than those for many of the common herbicides used on both conventional and TT canola paddocks. The total environmental impacts per season of each of the herbicide regimes suggested for a range of HT crops have been estimated (as EI values/ha) and compared with that for conventional canola in NSW. Values for GM Roundup Ready® canola, GM Invigor® hybrid canola, and non-GM TT canola in Western Australia are presented in Table 3.4. These values were calculated using the EIQ values published by Kovach et al. (2004) and the information on herbicide application rates for the various herbicide use regimes in Tables 3.2, 3.3 and Appendix B.

The comparison (Table 3.4) suggest that there could be significant environmental benefits as a result of changing from some of the current herbicide regimes to those recommended for GM Roundup Ready® and GM InVigor® hybrid canola. The estimated EI values per ha for the different herbicide regimes are: GM RR canola, 19; GM InVigor hybrid canola, 17–22.6; non-GM TT canola, 27.3–74.9; and, conventional canola, 16.8–50.2.

Table 3.4 Total environmental impact values per season calculated for a range of herbicide regimes (EI values per ha)

Canola system	Region	EI/ha
Roundup Ready®	Australia-wide	19
InVigor®	Australia-wide	17–22.6
Triazine-tolerant (TT)	Northern Ag region, WA	74.9
	SE Wheatbelt, WA	71
	Esperance, WA	40.3
	E Wheatbelt, WA	54.9
	South coast, WA	54.9
	Northam, WA	28.6
	Narrogin, WA	27.3
	Great Southern WA	49.9
Conventional long fallow	Dryland central east NSW	50.2
	Dryland south west NSW	36.2
Conventional after pasture	Dryland south east NSW	34.8
Conventional no-till	Dryland central east NSW	37.8
	Dryland central west	32.1
	Dryland north east NSW	19.3
	Dryland north west, NSW	16.8
Conventional irrigated	Central NSW	22.7

Source: Calculated using published EIQ values (Kovach et al. 2004) and herbicide regimes referenced in New South Wales Department of Primary Industries (2006), Regional economists (2005), and APVMA (2006). EI/ha was calculated using the formula: total a.i. applied (kg/ha) (see Appendix B) x EIQ = EI/ha.

An additional environmental impact not accounted for in Table 3.4 is the impact of cultivations on canola paddocks. The general environmental benefits of changing from a conventional tillage regime to a tillage regime for non-GM herbicide-tolerant canola have been described briefly elsewhere in this report (Section 1.5).

If TT canola is replaced with GM HT canola varieties, triazine use will decline and glyphosate and glufosinate ammonium use will increase. Norton and Roush (2007) estimate that triazine use would decline by 632 tonnes if half of Australia's TT canola and 40 per cent of conventional canola were replaced with GM HT canola, with significant benefits for the environment.

3.4.3 Economic effects

Marketing issues

The issue of whether or not Australian export markets will be affected adversely if Australia adopts GM food crops has been researched by ABARE. ABARE has found that marketers of GM canola and of products derived from livestock fed on GM materials, including GM canola, are unlikely to be disadvantaged in either Australian or world markets. GM canola seems to be finding ready markets throughout the world at prices very similar to those received for conventional canola (Foster and French 2007).

ABARE analyses since 2003 have cast doubt on the existence of economically significant price premiums for certified non-GM canola. According to ABARE, analysis of the import prices received for Australian and Canadian canola in the key canola importing countries suggests that GM canola is selling at virtually the same price as non-GM canola (Foster and French 2007). Moreover, it appears that there is only a niche market for certified non-GM grain. In early 2006, there were news reports that some canola growers on Kangaroo Island in South Australia had secured a contract to supply small quantities of non-GM canola to an importer in Japan (ABC National Rural News 2006). The value of this contract was not revealed. In mid-2008 there were similar reports of small sales of non-GM canola to Japan from Tasmania.

Costs of identity preservation

Identity preservation is the process by which a crop is grown, handled, delivered and processed under controlled conditions to assure the customer that the crop has maintained its unique identity from seed producer to end user. Identity preservation is carried out in the Australian grains industry with, for example, malting barley and durum wheat. If identity preservation systems are needed to ensure that grain supplies meet particular standards for the adventitious presence of GM materials, there will be associated costs.

Foster (2006) estimated the costs of segregating GM and non-GM grains in the central bulk handling and storage system or in a separate supply chain utilising shipping containers. Costs may arise both on the farm and at central bulk handling facilities. On-farm costs could include the cost of buying certified seed (to guarantee that adventitious GM materials do not exceed specified levels); crop management techniques such as appropriate separation distances between crops and control of GM volunteers; and cleaning of equipment after harvesting, handling, storing and transporting each type of GM grain. Costs in the central bulk handling system may be due to the need to test for GM materials and employ more labour during the receiving period. Delays during delivery of grain to the central bulk handling facilities may also increase on-farm costs as increased queuing times may delay harvests or require increased storage capacity on-farm.

The author concluded that the magnitude of any additional costs of grain segregation would vary according to factors such as the cost of certified seed, the queuing system for trucks at grain receival sites, and the range of grain being produced and needing segregation. Co-mingling in the grain receival system (when identity preservation is implemented) is unlikely to introduce undesirable levels of adventitious presence of GM material in non-GM canola and other grains, provided there is a reasonable level of cleaning between successive handling of different types of grain (Foster 2006). Revenue from a price premium and/or production cost savings would need to exceed or offset the additional costs of segregation.

Economic benefits

ABARE research shows that Australia stands to benefit from further GM crop adoption. Acworth et al. (2008) model the potential economic impacts of cultivating GM canola at the state level in Australia. They estimate the economic benefits (in 2006–07 dollars) of adopting GM canola over 10 years to 2017–18, from 2008–09, as: A$273 million for the 'Rest of New South Wales' region (New South Wales excluding the Murray Catchment Management Area);

A$165 million for Victoria; A$180 million for Western Australia; and A$115 million for South Australia. The potential economic impacts were measured by changes in gross regional products from the reference case, aggregated to 2017–18.

Norton and Roush (2007) estimate the economic benefits of replacing half of Australia's TT canola and 40 per cent of conventional canola, with GM HT canola. In this scenario, across the whole Australian canola crop, they estimate the benefits at A$157 million annually.

Wider economic and cost-benefit considerations and data are also discussed in ACIL Tasman (2007b). This report concludes that Australian and international (see Section 3.3.3 for Canada) evidence, including the increase in uptake of GM canola by growers, suggests that GM canola confers some cost, yield and gross margin advantages to growers.

A cost-benefit analysis of the economic impacts of the GM canola moratorium from 2004 to 2008 and of the impacts of future policy options, was commissioned by the Victorian Department of Primary Industries (ACIL Tasman 2007a). The cost of foregoing the herbicide management technology of the current GM HT crop varieties available was estimated to be substantial. For example, the direct cost (in net present terms) of extending the moratorium from 2008 to 2016 was estimated at approximately A$110 million–115 million. The analysis also concluded that continuing the moratorium would have denied Victorian farmers the potential use of a range of next generation GM canola traits such as improved oil qualities and other future developments (next section).

Section 3.5 Future developments

The use of non-GM HT canola varieties in Australia has provided agronomic benefits to Australian farmers by assisting them implement no-till systems and providing improved weed control for weed species that are closely related to canola. In Canada, GM HT canola varieties have provided additional agronomic, environmental and economic benefits to Canadian farmers. The introduction of these GM HT canola varieties to Australia are likely to offer a greater choice of weed control options and other agronomic, environmental and economic benefits in the future for the Australian canola industry, as described in Section 3.4. Because herbicide tolerance is such an important trait for canola growers, other novel or improved traits in canola breeding are likely to be incorporated along with herbicide tolerance (either GM or non-GM) in new varieties.

There is a trend in oilseeds crops breeding worldwide, towards developing crops with different oil composition to confer health benefits for consumers. Developments include plants producing high oleic acid (an unsaturated oil) and/or low linolenic or linoleic acid (polyunsaturated oils) content, to improve the relative levels of 'good cholesterol' oils in diets or to improve the stability of oils used in high-temperature cooking. Low cholesterol polyunsaturated oils (omega-3 and omega-6 type oils) are important for human health, and can be produced by introducing these novel traits into oilseed crops through genetic modification. The protein quality of canola meal could also be improved, for example by increasing the levels of certain amino acids such as lysine and methionine and decreasing levels of phytate (Holtzapffel et al. 2007).

No such new oilseed crops are yet grown in Australia, but some are already grown overseas, for example high oleic acid soybeans. Many of these traits have been developed through conventional breeding, but have been marketed in GM HT backgrounds. Other developments will involve genetic modification.

Canola-quality Indian mustard (*Brassica juncea*) varieties were first commercially grown in Australia in 2007. This species has a higher tolerance to heat and drought conditions than *B. napus* and a high level of blackleg resistance, so its use could increase profitability in marginal canola growing regions. However, the main barrier to rapid adoption of this species is reported to be the lack of HT traits, with IT and TT traits not expected to be available until 2009–10 (Nicol 2006). Bayer CropScience have field-tested GM *B. juncea* lines expressing the InVigor® hybrid trait and tolerance to an undisclosed herbicide (OGTR 2005a).

The future competitiveness of Australian canola exports may be compromised if new, higher quality oil or meal varieties are developed in GM herbicide-tolerant backgrounds or other GM canola varieties are grown by our competitors, yet state moratoria prevent Australian farmers from having the choice to grow them (Section 1.3).

Chapter 4 Conclusions

The impact of insect pests and weeds on Australian agriculture is significant. In Australia, the damage caused by insect pests and weeds, and the cost invested in controlling them, amounts to billions of dollars a year. Modern biotechnology has developed new tools that reduce the impact of insect pests and weeds on agricultural production and provide environmental benefits through reduced and/or altered use of some chemical inputs. Use of these tools has included the development of GM HT and IR crop plants.

Integrated Pest Management (IPM) and Integrated Weed Management (IWM) systems have been developed to increase the effectiveness of pest and weed control and to encourage the use of a wide variety of methods to achieve effective and sustainable control. Insect-resistant and herbicide-tolerant traits provide additional tools for integrated pest and weed management. This report has outlined the value of GM HT and IR crops for insect and weed control and noted additional agronomic, environmental and economic benefits arising from their use.

In Australia, GM IR cotton has been grown commercially since 1996 and GM HT cotton since 2000. Approximately 90 per cent of cotton grown in Australia is now GM. Over this period, the average number of insecticide applications to Bt cotton has decreased by up to 75 per cent in comparison to sprays on conventional cotton, while herbicide use has also changed. Less insecticide and less residual herbicide use have resulted in decreased pesticide detection in rivers close to cotton growing regions. GM HT cotton has also provided better control of weeds that had proven difficult to control in conventional cotton. As a result of both the adoption of GM cotton and the BMP Program by the Australian cotton industry, the level of community concern about the use of chemicals within the industry has fallen substantially.

Some of Australia's export competitors and a major cotton import market have also adopted GM cotton. Reported benefits in the three countries examined (USA, India and China) include increased profits, decreased chemical use and resulting health benefits, although the results for each country vary because many of the impacts are country-specific or region-specific. Also, cotton cultivars in which the traits are expressed vary from country to country and this also determines the performance of the GM cotton.

In Australia, GM insect-resistant traits in cotton can provide a basis for extension of cotton-growing to northern regions (north Queensland, the Katherine region in the Northern Territory, and the Ord River region in Western Australia). GM insect-resistance technology continues to be developed and new insecticidal modes of action for GM cotton are being trialled in Australia.

Non-GM HT canola varieties have been grown in Australia since 1993 and have contributed to the expansion of canola growing. They have provided better weed control and allowed earlier sowing, thus taking advantage of the first seasonal rainfall. GM HT canola has been approved for commercial production in Australia since 2003 but has not been grown commercially until 2008 as a result of state and territory moratoria. Victoria and New South Wales are the first states in Australia to grow GM HT canola, albeit on a limited scale, following the lifting of their moratoria on GM canola.

Canada, the major world exporter of canola, grows both GM and non-GM HT canola varieties. GM canola farmers report additional benefits of increased yields and wider options for weed control. Studies of the environmental performance of canola in Canada have indicated that the overall herbicide use in Canada has decreased since GM HT canola has been grown, with decreased use of some herbicides and increased use of the herbicides to which the crops are tolerant. The environmental impact of herbicide use was reported to be lower for GM HT canola compared with conventional canola. Farmers also reported an average increase in profits of 41 per cent.

If GM HT canola varieties were widely introduced to Australia, the primary benefit is likely to be increased yield. Lower yielding TT varieties can be replaced by GM varieties. Other benefits are increased options for in-crop weed control and likely increased yield in subsequent crops (in cases where triazine carry-over from TT canola crops may have had an adverse impact previously).

Agronomic concerns have been raised in relation to GM HT crops, such as an increased risk of developing herbicide-resistant weeds and greater difficulty in controlling volunteer canola. These types of risk are not specific to GM canola and any increased risk can be addressed through appropriate management techniques.

The herbicides (glyphosate and glufosinate ammonium) used with the GM HT canola varieties have low Environmental Impact Quotients and, in many cases, the environmental impact of the recommended herbicide regime per season may be lower than those currently applied in conventional or TT canola cropping.

There may also be issues in regard to non-GM/GM crop segregation and associated costs of identity preservation, should market demands warrant segregated supply chains. An ABARE report concluded that while there are likely to be additional costs associated with the segregation of GM canola, there do not appear to be sufficiently high price premiums in domestic and world markets for certified non-GM canola that would offset the additional costs of segregation. However, there may be very small niche markets that pay premium prices for non-GM product.

Estimates of overall economic impacts predict that Australian farmers will improve their returns from replacing TT canola with GM herbicide-tolerant canola varieties, through increased yields per hectare, increased canola production areas, and increases in wheat production.

Acknowledgements

This study was supported by the Australian Government Department of Agriculture, Fisheries and Forestry, Agricultural Productivity Division, under the National Biotechnology Strategy.

The authors wish to acknowledge the reviewers of this report: Chris Preston (University of Adelaide), Brendan Doyle (University of New England), Jeff Bidstrup (Bidstrup Farming Co), and David Cunningham, Julie Glover and Hilary Johnson (BRS, DAFF), Max Foster (ABARE, DAFF), and officers from the DAFF Agricultural Productivity Division, OGTR and APVMA, who provided valuable comment and feedback on the report.

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Ingard®, Bollgard®, Bollgard II®, Roundup®, Roundup Ready® and Roundup Ready Flex® are registered tradenames of Monsanto Technology LLC.

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Appendix A

Herbicide modes of action groups

Group	Mode of Action	Selected Examples of Herbicides
A	Inhibitors of acetyl CoA carboxylase (inhibitors of fat synthesis/ACCase inhibitors)	‘Fops’, ‘Dims’ and ‘Dens’
B	Inhibitors of acetolactate synthase (ALS inhibitors)	Sulfonylureas, imidazolinones and sulfonamides
C	Inhibitors of photosynthesis at photosystem II (PSII inhibitors)	Triazines, ureas, amides and nitriles
D	Inhibitors of microtubule assembly	Dinitroanilines and benzoic acids
E	Inhibitors of mitosis/microtubule organisation	Carbamates and phosphorodithioates
F	Bleaching: Inhibitors of carotenoid biosynthesis at the phytoene desaturase steps (PDS inhibitors)	Nicotinanilides, pyridazinones, pyrazoles, isoxazoles and triazoles
G	Inhibitors of protoporphyrinogen oxidase (PPOs)	Diphenylethers, oxadiazoles, triazolinones and pyrimidindiones
I	Disrupters of plant cell growth	‘Phenoxys’ and ‘Pyridines’
J	Inhibitors of fat synthesis (Not ACCase inhibitors)	Chlorocarbonic acids
K	Herbicides with unknown and probably diverse sites of action	Acetamides, benzamines, benzofurans and phthalamates
L	Inhibitors of photosynthesis at photosystem I (PSI inhibitors)	Bipyridils (paraquat and diquat)
M	Inhibitors of EPSP synthase	Glycines (glyphosate)
N	Inhibitors of glutamine synthetase	Phosphinic acids (glufosinate)

Appendix B

Suggested herbicide regimes for TT canola crops in Western Australia and conventional canola crops in New South Wales

WA Region (TT canola)	**Suggested herbicide applications** (total a.i. applied)	**Cropping system and NSW region (conventional canola)**	**Suggested herbicide applications** (total a.i. applied)
Northern Agricultural region, WA	2 applications glyphosate (0.9 kg/ha) 2 applications atrazine (2 kg/ha) 1 application trifluralin (0.816 kg/ha) 1 application haloxyfop-R* (0.039 kg/ha)	Conventional long fallow (dryland central east NSW)	3 applications glyphosate (1.62 kg/ha) 1 application 2,4-D amine (total 0.36 kg/ha) 1 application trifluralin (0.816 kg/ha) 1 application clopyralid (0.09 kg/ha) 1 application triclopyr (0.03 kg/ha)
South eastern Wheatbelt, WA	1 glyphosate (0.54 kg/ha) 2 applications of atrazine (2 kg/ha) 1 application trifluralin (0.816 kg/ha) 1 application of clethodim (0.06 kg/ha) 1 application of clopyralid (0.03 kg/ha)	Conventional no-till (dryland central west NSW)	3 applications glyphosate (1.53 kg/ha) 1 application 2,4-D amine (0.30 kg/ha) 1 application clopyralid (0.09 kg/ha) 1 application triclopyr (0.03 kg/ha) 1 application haloxyfop-R* (0.026 kg/ha)
Esperance, WA	2 applications glyphosate (0.675 kg/ha) 2 applications of 2,4-D ester (0.408 kg/ha) 2 applications atrazine (1 kg/ha) 1 application haloxyfop-R* (0.052 kg/ha)	Conventional long fallow (dryland south west NSW	2 applications glyphosate (1.125 kg/ha) 1 application trifluralin (1.008 kg/ha) 1 application haloxyfop-R* (0.0312 kg/ha)
Eastern Wheatbelt, WA	1 application of glyphosate (0.54 kg/ha) 2 applications of atrazine (2 kg/ha) 1 application of clethodim (0.048 kg/ha)	Conventional no-till (dryland central east NSW)	2 applications glyphosate (0.9 kg/ha) 1 application trifluralin (0.816 kg/ha) 1 application haloxyfop-R* (0.026 kg/ha) 1 application triclopyr (0.03 kg/ha) 1 application clopyralid (0.09 kg/ha) 1 application 2,4-D amine (0.3 kg/ha)
South coast, WA	1 application of glyphosate (0.54 kg/ha) 2 applications of atrazine (2 kg/ha) 1 application of clethodim (0.048 kg/ha)	Conventional after pasture (dryland south east NSW)	2 applications glyphosate (0.99 kg/ha) 1 application trifluralin (0.96 kg/ha) 1 application haloxyfop-R* (0.0312 kg/ha) 1 application clopyralid (0.09 kg/ha)
Northam, WA	1 application of glyphosate (0.45 kg/ha) 2 applications atrazine (0.95 kg/ha) 1 application haloxyfop-R* (0.052 kg/ha)	Conventional irrigated (central NSW)	1 application glyphosate (0.432 kg/ha) 1 application trifluralin (0.768 kg/ha) 1 application clopyralid (0.09 kg/ha) 1 application haloxyfop-R* (0.09 kg/ha)
Narrogin, WA	1 application of glyphosate (0.36 kg/ha) 2 applications atrazine (0.95 kg/ha) 1 application haloxyfop-R* (0.036 kg/ha)	Conventional no-till (dryland north east NSW)	2 applications glyphosate (1.26 kg/ha) 1 application haloxyfop-R (0.0312 kg/ha)
Great Southern WA	1 application of glyphosate (0.27 kg/ha) 2 applications of atrazine (2 kg/ha) 1 application haloxyfop-R* (0.052 kg/ha)	Conventional no-till (dryland north west NSW)	2 applications glyphosate (0.765 kg/ha) 1 application 2,4_D amine (0.225 kg/ha) 1 application haloxyfop-R* (0.0312 kg/ha)

* As there is no published EIQ value for haloxyfop-R, this was not included in the total EI/ha calculations shown in Table 3.4. If data were available, inclusion of this herbicide would increase the estimated EI/ha.