GM crops: the first ten years - global socio-economic and environmental impacts

Graham Brookes & Peter Barfoot

PG Economics Ltd, UK

Dorchester, UK
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Executive summary and conclusions

This study presents the findings of research into the global socio-economic and environmental impact of GM crops in the ten years since they were first commercially planted on a significant area. It focuses on the farm level economic effects, the environmental impact resulting from changes in the use of insecticides and herbicides, and the contribution towards reducing greenhouse gas (GHG) emissions.

Background context

The analysis presented is largely based on the average performance and impact recorded in different crops. The economic performance and environmental impact of the technology at the farm level does, however vary widely, both between and within regions/countries. This means that the impact of this technology (and any new technology, GM or otherwise) is subject to variation at the local level. Also the performance and impact should be considered on a case by case basis in terms of crop and trait combinations.

Agricultural production systems (how farmers use different and new technologies and husbandry practices) are dynamic and vary with time. This analysis seeks to address this issue, wherever possible, by comparing GM production systems with the most likely conventional alternative, if GM technology had not been available. This is of particular relevance to the case of GM herbicide tolerant (GM HT) soybeans, where prior to the introduction of GM HT technology, production systems were already switching away from conventional to no/low tillage production (in which the latter systems make greater use of, and are more reliant on, herbicide-based weed control systems - the role of GM HT technology in facilitating this fundamental change in production systems is assessed below).

In addition, the market dynamic impact of GM crop adoption (on prices) has been incorporated into the analysis by use of current prices (for each year) for all crops.

Farm income effects[1]

The impact on farm incomes in the GM adopting countries has been very positive (Table 1). This derives from enhanced productivity and efficiency gains:

- In 2005, the direct farm income benefit was about \$5 billion. If the additional income arising from second crop soybeans in Argentina is also taken into consideration[2], this income gain rises to \$5.6 billion. This is equivalent to having added between 3.6% and 4.0% to the value of global production of the four main crops of soybeans, maize, canola and cotton;
- Since 1996, farm incomes have benefited by \$24.2 billion (\$27 billion inclusive of second crop soybean gains in Argentina);
- The largest gains in farm income have arisen in the soybean sector, where the additional income generated by GM HT soybeans in 2005 has been equivalent to adding 7.1% to value of the crop in the GM growing countries, or adding the equivalent of 6.05% to the value of the global soybean crop;
- Substantial gains have also arisen in the cotton sector (through a combination of higher yields and lower costs). In 2005, cotton farm income levels in the GM adopting countries

[1] See section 3 for details

[2] The availability of GM HT technology has played a major role in facilitating the expansion of second crop soybeans, usually following on from wheat (in the same season)

were higher by $1.9 billion and since 1996, the sector has benefited from an additional $8.44 billion. The 2005 income gains are equivalent to adding 13.3% to the value of the cotton crop in these countries, or 7.3% to the value of total global cotton production;

- Significant additions to farm incomes have also arisen in the maize and canola sectors. The combination of GM insect resistant (GM IR) and herbicide tolerant (GM HT) technology in maize has boosted farm incomes by over $3.1 billion since 1996. In the North American canola sector an additional $893 million has been generated.

Table 1: Global farm income benefits from growing GM crops 1996-2005: million US $

Trait	Increase in farm income 2005	Increase in farm income 1996-2005	Farm income benefit in 2005 as % of total value of production of these crops in GM adopting countries	Farm income benefit in 2005 as % of total value of global production of these crops
GM herbicide tolerant soybeans	2,281 (2,842)	11,686 (14,417)	5.72 (7.1)	4.86 (6.05)
GM herbicide tolerant maize	212	795	0.82	0.39
GM herbicide tolerant cotton	166	927	1.16	0.64
GM herbicide tolerant canola	195	893	9.45	1.86
GM insect resistant maize	416	2,367	1.57	0.77
GM insect resistant cotton	1,732	7,510	12.1	6.68
Others	25	66	N/a	N/a
Totals	**5,027 (5,588)**	**24,244 (26,975)**	**6.0 (6.7)**	**3.6 (4.0)**

Notes: Others = Virus resistant papaya and squash, rootworm resistant maize, Bracketed figures include second crop benefits in Argentina; Totals for the value shares exclude 'other crops' (ie, relate to the 4 main crops of soybeans, maize, canola and cotton)

Table 2 summarises this information for some of the main GM adopting countries. This highlights the important farm income benefit arising from GM HT soybeans in Argentina, GM IR cotton in China and a range of GM cultivars in the US. It also illustrates the growing level of farm income benefits being obtained in developing countries such as South Africa, Paraguay, India and Mexico.

Table 2: GM crop farm income benefits 1996-2005 selected countries: million US $

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton	Total
US	7,570	771	919	101	1,957	1,627	*12,945*
Argentina	5,197	0.2	4.0	N/a	159	29	*5,389.2*
Brazil	1,367	N/a	N/a	N/a	N/a	N/a	*1,367*
Paraguay	132	N/a	N/a	N/a	N/a	N/a	*132*
Canada	69	24	N/a	792	145	N/a	*1,031*
South Africa	2.2	0.3	0.2	N/a	59	14	*75.7*
China	N/a	N/a	N/a	N/a	N/a	5,168	*5,168*
India	N/a	N/a	N/a	N/a	N/a	463	*463*
Australia	N/a	N/a	4.1	N/a	N/a	150	*154.1*
Mexico	N/a	N/a	N/a	N/a	N/a	55	*55*
Philippines	N/a	N/a	N/a	N/a	8	N/a	*8*
Spain	N/a	N/a	N/a	N/a	28	N/a	*28*

Note: Argentine GM HT soybeans include second crop soybeans benefits. N/a = not applicable

In terms of the division of the economic benefits obtained by farmers in developing countries relative to farmers in developed countries, Table 3 shows that in 2005, the majority of the farm income benefits (55%) have been earned by developing country farmers. The vast majority of these income gains for developing country farmers have been from GM IR cotton and GM HT soybeans.

Table 3: GM crop farm income benefits 2005: developing versus developed countries: million US $

	Developed	Developing	% developed	% developing
GM HT soybeans	1,183	1,658	41.6	58.4
GM IR maize	364	53	86.5	13.5
GM HT maize	212	0.3	99.9	0.1
GM IR cotton	354	1,378	20.4	79.6
GM HT cotton	163	3	98.4	1.6
GM HT canola	195	0	100	0
GM VR papaya and squash	25	0	100	0
Total	**2,496**	**3,092**	**45**	**55**

Developing countries include all countries in South America

Cumulatively over the period 1996 to 2005, developing country farmers have acquired 47% of the total ($27 billion) farm income benefit.

Examination of the cost farmers pay for accessing GM technology relative to the total gains derived, Table 4 shows that across the four main GM crops, the total cost was equal to about 26% of the total farm income gains. For farmers in developing countries the total cost is equal to about 13% of total farm income gains, whilst for farmers in developed countries the cost is about 38% of the total farm income gain.

Table 4: Cost of accessing GM technology (in % terms) relative to the total farm income benefits 2005

	All farmers	Developed countries	Developing countries
GM HT soybeans	21	32	10
GM IR maize	44	43	48
GM HT maize	38	38	81
GM IR cotton	21	41	13
GM HT cotton	44	43	65
GM HT canola	47	47	N/a
Total	**26**	**38**	**13**

N/a = not applicable

As well as these quantifiable impacts on farm profitability, there have been other important, more intangible impacts (of an economic nature). Most of these have been important influences for adoption of the technology. These include:

Herbicide tolerant crops

- Increased management flexibility that comes from a combination of the ease of use associated with broad-spectrum, post-emergent herbicides like glyphosate and the increased/longer time window for spraying;

- Compared to conventional crops, where post-emergent herbicide application may result in 'knock-back' (some risk of crop damage from the herbicide), this problem is less likely to occur in GM HT crops;
- Facilitation of adoption of no/reduced tillage practices with resultant savings in time and equipment usage (see below for environmental benefits);
- Improved weed control has reduced harvesting costs – cleaner crops have resulted in reduced times for harvesting. It has also improved harvest quality and led to higher levels of quality price bonuses in some regions;
- Elimination of potential damage caused by soil-incorporated residual herbicides in follow-on crops.

Insect resistant crops

- Production risk management/insurance purposes – taking away the worry of significant pest damage occurring;
- A 'convenience' benefit (less time spent on crop walking and/or applying insecticides);
- Savings in energy use – mainly associated with less spraying;
- Savings in machinery use (for spraying and possibly reduced harvesting times);
- Improved quality (eg, lower levels of mycotoxins in GM IR maize);
- Improved health and safety for farmers and farm workers (from reduced handling and use of pesticides);
- Shorter growing season (eg, for some cotton growers in India) which allows some farmers to plant a second crop in the same season[3]. Also some Indian cotton growers have reported knock on benefits for bee keepers as fewer bees are now lost to insecticide spraying.

In relation to the nature and size of GM technology adopters, there is clear evidence that size of farm has not been a factor affecting use of the technology. Both large and small farmers have adopted GM crops. Size of operation has not been a barrier to adoption. In 2005, 8.5 million farmers were using the technology globally, 90% plus of which were resource-poor farmers in developing countries.

The significant productivity and farm income gains identified above have, in some countries (notably Argentina) also made important contributions to income and employment generation in the wider economy. For example, in Argentina, the economic gains resulting from the 140% increase in the soybean area since 1995 are estimated to have contributed towards the creation of 200,000 additional agricultural related jobs[4] and export-led economic growth.

Environmental impact from changes in insecticide and herbicide use[5]

To examine this impact, the study has analysed both active ingredient use and utilised the indicator known as the Environmental Impact Quotient (EIQ) to assess the broader impact on the environment (plus impact on animal and human health). The EIQ distils the various environmental and health impacts of individual pesticides in different GM and conventional production systems into a single 'field value per hectare' and draws on all of the key toxicity and environmental exposure data related to individual products. It therefore provides a consistent and fairly comprehensive measure to contrast and compare the impact of various pesticides on the environment and human health. Readers should however note that the EIQ is an indicator only and does not take into account all environmental issues and impacts. In the analysis of GM HT

[3] Notably maize in India
[4] Trigo et al (2002)
[5] See section 4.1

technology we have assumed that the conventional alternative delivers the same level of weed control as occurs in the GM HT production system.

Table 5 summarises the environmental impact over the last ten years and shows that there have been important environmental gains associated with adoption of GM technology. More specifically:

- There has been a 15.3% net reduction in the environmental impact[6] on the cropping area devoted to GM crops since 1996. The total volume of active ingredient (ai) applied to crops has also fallen by 7%;
- In absolute terms, since 1996, the largest environmental gains have arisen from the adoption of GM HT soybeans. This mainly reflects the (large) share of global GM crop plantings accounted for by GM HT soybeans. The volume of herbicide use is 4.1% lower and the environmental impact 20% lower than levels that would have probably arisen if all of this GM crop area had been planted to conventional cultivars. Readers should note that in some countries (notably in South America), the adoption of GM HT technology in soybeans has also coincided with increases in the volume of herbicides used and the environmental impact relative to historic levels. As indicated above, this largely reflects the facilitating role of the GM HT technology in accelerating and maintaining the switch away from conventional tillage to no/low tillage production systems with their inherent environmental benefits. This net increase in the environmental impact should, therefore be placed in the context of the reduced GHG emissions arising from this production system change (see below) and the general dynamics of agricultural production system changes (which the analysis presented above and in Table 5 takes account of);
- Major environmental gains have also been derived from the adoption of GM insect resistant (IR) cotton (the largest gains on a per hectare basis). Since 1996, there has been a 24% reduction in the environmental impact, and a 19% decrease in the volume of insecticides applied;
- Important environmental gains have also arisen in the maize and canola sectors. In the maize sector a 4.6% reduction in the environmental impact has occurred from reduced insecticide use and a switch to more environmentally benign herbicides has resulted in a further 4% reduction in the environmental impact of maize herbicides. In the canola sector, the environmental impact has fallen by 23% because of a switch to more environmentally benign herbicides.

Table 5: Impact of changes in the use of herbicides and insecticides from growing GM crops globally 1996-2005

Trait	Change in volume of active ingredient used (million kg)	Change in field EIQ impact (in terms of million field EIQ/ha units)	% change in ai use in GM growing countries	% change in environmental impact in GM growing countries
GM herbicide tolerant soybeans	-51.4	-4,865	-4.1	-20.0
GM herbicide tolerant maize	-36.5	-845	-3.4	-4.0
GM herbicide tolerant cotton	-28.6	-1,166	-15.1	-22.7

[6] The actual ai use and the EIQ impact or load in any year has been compared against the likely ai use and EIQ load that would have arisen if the whole crop in any year had been planted to non GM cultivars, using the same tillage system as used in the GM crop and, in the case of crops for which a comparison is made with GM herbicide tolerant crops, delivering the same level of weed control as delivered by the GM production system

GM herbicide tolerant canola	-6.3	-310	-11.1	-22.6
GM insect resistant maize	-7.0	-403	-4.1	-4.6
GM insect resistant cotton	-94.5	-4,670	-19.4	-24.3
Totals	**-224.3**	**-12,259**	**-6.9**	**-15.3**

The impact of changes in insecticide and herbicide use at the country level (for the main GM adopting countries) is summarised in Table 6.

Table 6: Reduction in environmental impact from changes in pesticide use associated with GM crop adoption by country 1996-2005 selected countries: % reduction in field EIQ values

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton
US	29	4	24	38	5	23
Argentina	21	NDA	NDA	N/a	0	4
Brazil	6	N/a	N/a	N/a	N/a	N/a
Paraguay	13	N/a	N/a	N/a	N/a	N/a
Canada	9	5	N/a	22	NDA	N/a
South Africa	7	0.44	6	N/a	2	NDA
China	N/a	N/a	N/a	N/a	N/a	28
India	N/a	N/a	N/a	N/a	N/a	3
Australia	N/a	N/a	4	N/a	N/a	22
Mexico	N/a	N/a	N/a	N/a	N/a	NDA
Spain	N/a	N/a	N/a	N/a	30	N/a

Note: N/a = not applicable, NDA = No data available. Zero impact for GM IR maize in Argentina is due to the negligible (historic) use of insecticides on the Argentine maize crop

In terms of the division of the environmental benefits associated with less insecticide and herbicide use for farmers in developing countries relative to farmers in developed countries, Table 7 shows that in 2005, the majority of the environmental benefits associated with lower insecticide and herbicide use have been for developing country farmers. The vast majority of these environmental gains have been from the use of GM IR cotton and GM HT soybeans

Table 7: GM crop environmental benefits from lower insecticide and herbicide use 2005: developing versus developed countries

	% of total reduction in environmental impact: developed countries	% of total reduction in environmental impact: developing countries
GM HT soybeans	53	47
GM IR maize	92	8
GM HT maize	99	1
GM IR cotton	15	85
GM HT cotton	99	1
GM HT canola	100	0
Total	**46**	**54**

Developing countries include all countries in South America

Cumulatively over the period 1996 to 2005, developing country farmers have acquired 48% of the total environmental benefits from lower insecticide and herbicide use.

Impact on greenhouse gas (GHG) emissions[7]

The scope for GM crops contributing to lower levels of GHG emissions comes from two principle sources:

- Reduced fuel use from less frequent herbicide or insecticide applications and a reduction in the energy use in soil cultivation. The fuel savings associated with making fewer spray runs (relative to conventional crops) and the switch to conservation, reduced and no-till farming systems, have resulted in permanent savings in carbon dioxide emissions. In 2005 this amounted to about 962 million kg (arising from reduced fuel use of 356 million litres). Over the period 1996 to 2005 the cumulative permanent reduction in fuel use is estimated at 4,613 million kg of carbon dioxide (arising from reduced fuel use of 1,679 million litres);
- the use of 'no-till' and 'reduced-till'[8] farming systems. These production systems have increased significantly with the adoption of GM HT crops because the GM HT technology has improved growers ability to control competing weeds, reducing the need to rely on soil cultivation and seed-bed preparation as means to getting good levels of weed control. As a result, tractor fuel use for tillage is reduced, soil quality is enhanced and levels of soil erosion cut. In turn more carbon remains in the soil and this leads to lower GHG emissions. Based on savings arising from the rapid adoption of no till/reduced tillage farming systems in North and South America, an extra 2,929 million kg, of soil carbon is estimated to have been sequestered in 2005 (equivalent to 8,053 million tonnes of carbon dioxide that has not been released into the global atmosphere). Cumulatively the amount of carbon sequestered may be higher due to year-on-year benefits to soil quality. However, with only an estimated 15%-25% of the crop area in continuous no-till systems it is currently not possible to estimate cumulative soil sequestration gains.

Placing these carbon sequestration benefits within the context of the carbon emissions from cars, Table 8, shows that:

- In 2005, the permanent carbon dioxide savings from reduced fuel use were the equivalent of removing nearly 0.43 million cars from the road;
- Cumulatively since 1996, the permanent carbon dioxide savings from reduced fuel consumption since the introduction of GM crops are equal to removing 2.05 million cars from the road for one year (8.5% of all registered cars in the UK);
- The additional probable soil carbon sequestration gains in 2005 were equivalent to removing nearly 3.6 million cars from the roads;
- It is not possible to estimate the probable soil carbon sequestration gains since 1996 (see above);
- In total, the combined GM crop-related carbon dioxide emission savings from reduced fuel use and additional soil carbon sequestration in 2005 were equal to the removal from the roads of nearly 4 million cars, equivalent to about 17% of all registered cars in the UK.

Table 8: Context of carbon sequestration impact 2005: car equivalents

Crop/trait/country	Permanent carbon dioxide	Average family car equivalents	Potential additional soil	Average family car equivalents

[7] See section 4.2

[8] No-till farming means that the ground is not ploughed at all, while reduced tillage means that the ground is disturbed less than it would be with traditional tillage systems. For example, under a no-till farming system, soybean seeds are planted through the organic material that is left over from a previous crop such as corn, cotton or wheat

	savings arising from reduced fuel use (million kg of carbon dioxide)	removed from the road for a year from the permanent fuel savings	carbon sequestration savings (million kg of carbon dioxide)	removed from the road for a year from the potential additional soil carbon sequestration
US: GM HT soybeans	176	78,222	2,195	975,556
Argentina: GM HT soybeans	546	242,667	4,340	1,928,889
Other countries: GM HT soybeans	55	24,444	435	193,333
Canada: GM HT canola	117	52,000	1,083	481,520
Global GM IR cotton	68	30,222	0	0
Total	962	427,556	8,053	3,579,298

Notes: Assumption: an average family car produces 150 grams of carbon dioxide of km. A car does an average of 15,000 km/year and therefore produces 2,250 kg of carbon dioxide/year

Concluding comments

GM technology has, to date delivered several specific agronomic traits that have overcome a number of production constraints for many farmers. This has resulted in improved productivity and profitability for the 8.5 million adopting farmers who have applied the technology to over 87 million hectares in 2005.

During the last ten years, this technology has made important positive socio-economic and environmental contributions. These have arisen even though only a limited range of GM agronomic traits have so far been commercialised, in a small range of crops.

The GM technology has delivered economic and environmental gains through a combination of their inherent technical advances and the role of the technology in the facilitation and evolution of more cost effective and environmentally friendly farming practices. More specifically:

- the gains from the GM IR traits have mostly been delivered directly from the technology (yield improvements, reduced production risk and decreased the use of insecticides). Thus farmers (mostly in developing countries) have been able to both improve their productivity and economic returns whilst also practicing more environmentally friendly farming methods;
- the gains from GM HT traits have come from a combination of direct benefits (mostly cost reductions to the farmer) and the facilitation of changes in farming systems. Thus, GM HT technology (especially in soybeans) has played an important role in enabling farmers to capitalise on the availability of a low cost, broad-spectrum herbicide (glyphosate) and in turn, facilitated the move away from conventional to low/no tillage production systems in both North and South America. This change in production system has made additional positive economic contributions to farmers (and the wider economy) and delivered important environmental benefits, notably reduced levels of GHG emissions (from reduced tractor fuel use and additional soil carbon sequestration).

The impact of GM HT traits has, however contributed to increased reliance on a limited range of herbicides and this poses questions about the possible future increased development of weed resistance to these herbicides. Some degree of reduced effectiveness of glyphosate (and glufosinate) against certain weeds may take place. To the extent to which this may occur, this will increase the necessity to include low dose rates applications of other herbicides in weed control programmes (commonly used in conventional production systems) and hence may marginally reduce the level of net environmental and economic gains derived from the current use of the GM technology.

1 Introduction

2005 represents the tenth planting season since genetically modified (GM) crops were first grown in 1996. This milestone provides an opportunity to critically assess the impact this technology is having on global agriculture. This study[9] examines specific global socio-economics impacts on farm income and environmental impacts in respect of pesticide usage and greenhouse gas (GHG) emissions of the technology[10].

1.1 Objectives

The principal objective of the study was to identify the global socio-economic and environmental impact of GM crops over the first nine years of widespread commercial production. This was to cover not only the impacts for the latest available year but to quantify the cumulative impact over the nine year period.

More specifically, the report examines the following impacts:

Socio-economic impacts on:

- Cropping systems: risks of crop losses, use of inputs, crop yields and rotations;
- Farm profitability: costs of production, revenue and gross margin profitability;
- Trade flows: developments of imports and exports and prices;
- Drivers for adoption such as farm type and structure;

Environmental impacts on:

- Insecticide and herbicide use, including conversion to an environmental impact measure[11];
- Greenhouse gas (GHG) emissions.

1.2 Methodology

The report has been compiled based largely on desk research and analysis. A detailed literature review[12] has been undertaken to identify relevant data. Primary data for impacts of commercial cultivation were, of course, not available for every crop, in every year and for each country, but all representative, previous research has been utilised. The findings of this research have been used as the basis for the analysis presented[13], although where relevant, primary analysis has been undertaken from base data (eg, calculation of the environmental impacts). More specific information about assumptions used and their origins are provided in each of the sections of the report.

1.3 Structure of report

The report is structured as follows:

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[9] The authors acknowledge that funding towards the researching of this paper was provided by Monsanto. The material presented in this paper is, however the independent views of the authors – it is a standard condition for all work undertaken by PG Economics that all reports are independently and objectively compiled without influence from funding sponsors

[10] This study updates an earlier study produced in 2005, covering the first nine years of GM crop adoption globally. Readers should however note that some data presented in this report are not directly comparable with data presented in the 2005 paper because the current paper takes into account the availability of new data and analysis (including revisions to data applicable to earlier years)

[11] The Environmental Impact Quotient (EIQ), based on Kovach J et al (1992 & annually updated)

[12] See References

[13] Where several pieces of research of relevance to one subject (eg, the impact of using a GM trait on the yield of a crop) have been identified, the findings used have been largely based on the average

- Section one: introduction
- Section two: overview of GM crop plantings by trait and country
- Section three: farm level profitability impacts by trait and country, intangible benefits, structure and size, prices and trade flows;
- Section four: environmental impacts covering impact of changes in herbicide and insecticide use and contributions to reducing GHG emissions.

2 Global context of GM crops

This section provides a broad overview of the global development of GM crops over the last ten years.

2.1 Global plantings

Although the first commercial GM crops were planted in 1994 (tomatoes), 1996 was the first year in which a significant area (1.66 million hectares) of crops were planted containing GM traits. Since then there has been a dramatic increase in plantings and by 2005/06, the global planted area reached almost 87.2 million hectares. This is equal to five times the total agricultural area or nineteen times the total arable cropping area of the UK.

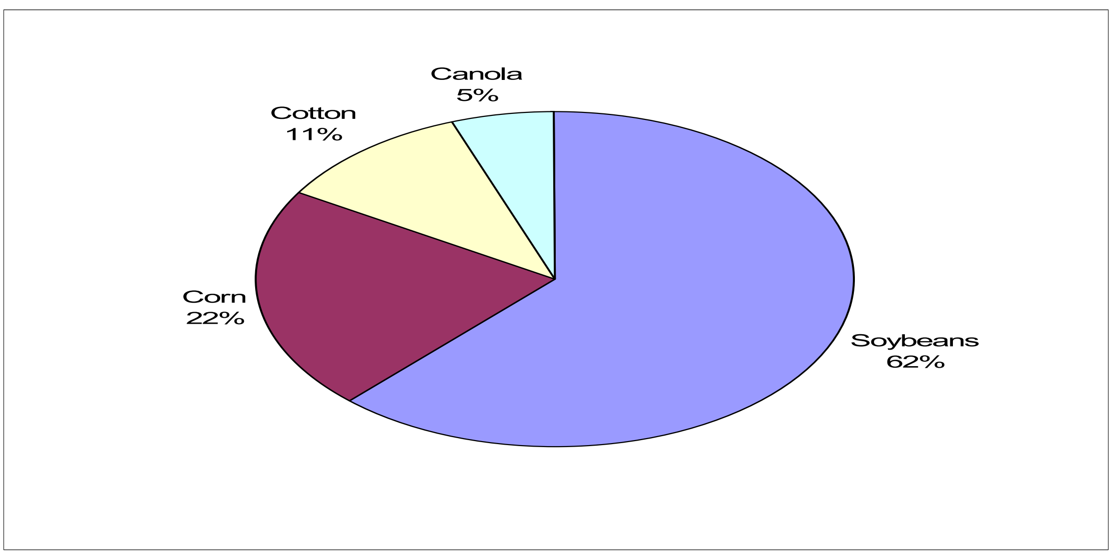
In terms of the share of the main crops in which GM traits have been commercialised (soybeans, corn, cotton and canola), GM traits accounted for 29% of the global plantings to these four crops in 2005.

2.2 Plantings by crop and trait

2.2.1 By crop

Almost all of the global GM crop area derives from soybeans, corn, cotton and canola (Figure 1)[14]. In 2005, GM soybeans accounted for the largest share (62%), followed by corn (22%), cotton (11%) and canola (5%). In terms of the share of total global plantings to these four crops, GM traits accounted for a majority of soybean plantings (59%) in 2005. For the other three main crops, the GM shares in 2005 were 13% for corn, 27% for cotton and 18% for canola (Figure 2).

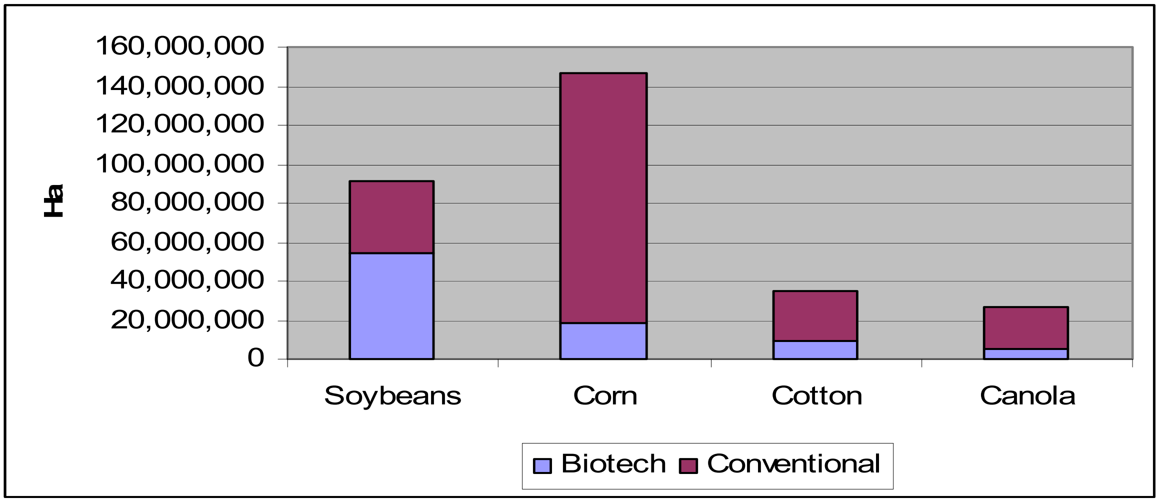
Figure 1: GM crop plantings 2005 by crop (base area: 87.2 million hectares)



Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

[14] In 2005 there were also additional GM crop plantings of papaya (530 hectares) and squash (2,400 hectares) in the USA

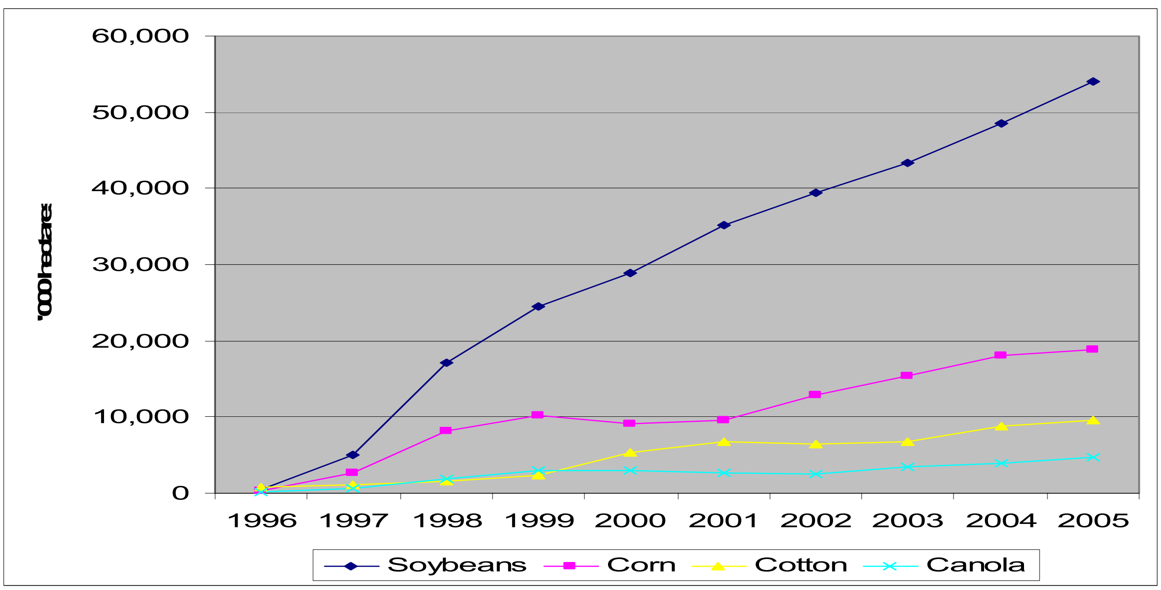
Figure 2: 2005's share of GM crops in global plantings of key crops (hectares)



Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

The trend in plantings to GM crops (by crop) since 1996 is shown in Figure 3.

Figure 3: Global GM crop plantings by crop 1996-2005



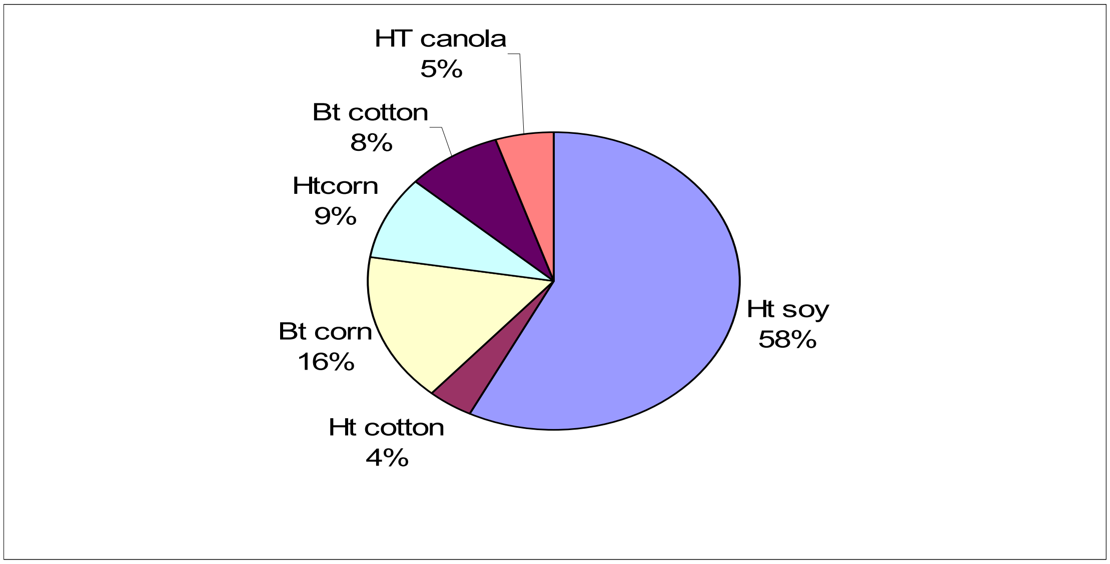
Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

2.2.2 By trait

Figure 4 summarises the breakdown of the main GM traits planted globally in 2005. GM herbicide tolerant soybeans dominate accounting for 58% of the total followed by insect resistant (largely Bt) corn and cotton with respective shares of 16% and 8%[15]. In total, herbicide tolerant crops account for 76%, and insect resistant crops account for 24% of global plantings.

[15] The reader should note that the total plantings by trait produces a higher global planted area (93.9 million ha) than the global area by crop (87.2 million ha) because of the planting of some crop containing the stacked traits of herbicide tolerance and insect resistance

Figure 4: Global GM crop plantings by main trait and crop: 2005

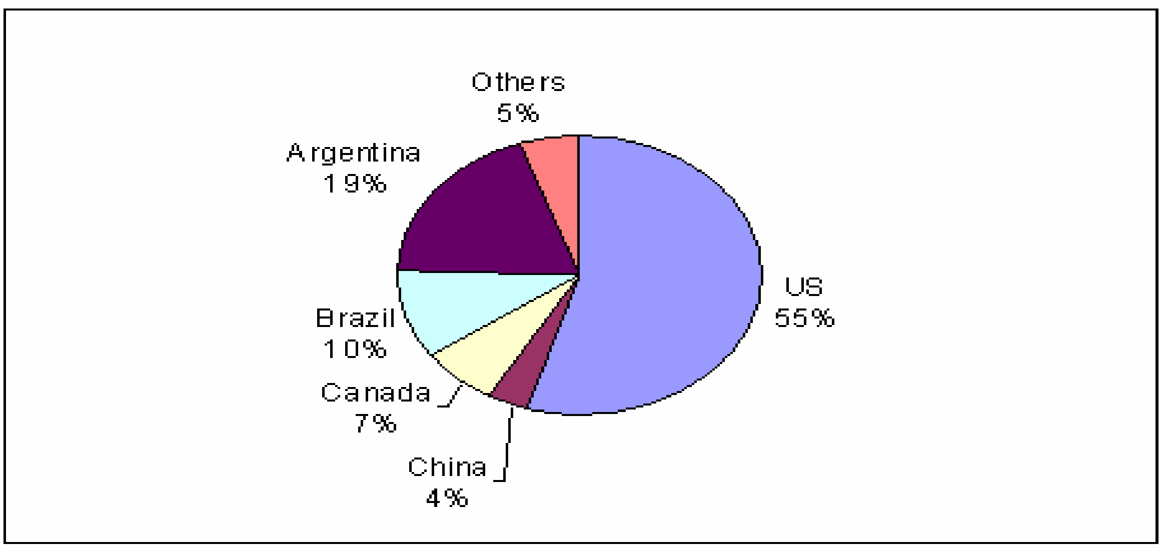


Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

2.2.3 By country

The US had the largest share of global GM crop plantings in 2005 (55%: 47.4 million ha), followed by Argentina (16.93 million ha: 19% of the global total). The other main countries planting GM crops in 2005 were Canada, Brazil and China (Figure 5).

Figure 5: Global GM crop plantings 2005 by country



Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

Table 9 shows the trends in GM crop plantings by country since 1996. This again highlights the importance of countries like the US, Canada, Brazil, China and Argentina both in current planting terms and as early adopters of the technology. More recently, significant and increasing areas have been planted to GM crops in newer adopting countries such as Paraguay, South Africa and India (and other countries such as Spain, Romania, the Philippines, Mexico and Uruguay).

Table 9: Global GM plantings by country 1996-2005 ('000 hectares)

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
USA	1,449	7,460	19,259	26,252	28,245	33,024	37,528	40,723	44,788	47,395
Canada	139	648	2,161	3,529	3,331	3,212	3,254	4,427	5,074	5,858
Argentina	37	1,756	4,818	6,844	9,605	11,775	13,587	14,895	15,883	16,930
Brazil	0	100	500	1,180	1,300	1,311	1,742	3,000	5,000	9,000
China	0	34	261	654	1,216	2,174	2,100	2,800	3,700	3,300
Paraguay	0	0	0	58	94	338	477	737	1,200	1,800
Australia	40	58	100	133	185	204	162	165	248	275
South Africa	0	0	0.08	0.75	93	150	214	301	528	595
India	0	0	0	0	0	0	44	100	500	1,300
Others	0.9	15	62	71	94	112	136	209	527	710
Total	**1,665**	**10,072**	**27,161**	**38,730**	**44,163**	**52,300**	**59,245**	**67,357**	**77,448**	**87,163**

Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

Within the leading countries, the breakdown of the GM crop plantings in 2005 was as follows:

- *The US*: the main GM crops were soybeans and corn which accounted for 57% and 33% respectively of total GM plantings. The balance came from cotton (9%) and canola (1%);
- *Canada*: canola dominated plantings with a 74% share. The balance was roughly equally split between corn (14%) and soybeans (12%);
- *Argentina*: soybeans accounted for the vast bulk of GM crop plantings (89%), followed by corn (10%) and cotton (1%);
- *In Brazil and Paraguay* all plantings were soybeans;
- *In China and Australia* all plantings were cotton.

In terms of the GM share of production in the main GM technology adopting countries, Table 10 shows that, in 2005, GM technology accounted for important shares of total production of the four main crops, in several countries. GM cultivars have been adopted at unprecedented rates by both small and large growers because the novel traits provide cost effective options for growers to exploit (eg, reducing expenditure on herbicides and insecticides).

Table 10: GM technology share of crop plantings in 2005 by country (% of total plantings)

	Soybeans	Maize	Cotton	Canola
USA	93	52	79	82
Canada	60	65	N/a	95
Argentina	99	62	50	N/a
South Africa	65	27	95	N/a
Australia	N/a	N/a	90	N/a
China	N/a	N/a	65	N/a
Paraguay	93	N/a	N/a	N/a
Brazil	40	N/a	N/a	N/a
Uruguay	100	N/a	N/a	N/a

Note: N/a = not applicable

3 The farm level economic impact of GM crops 1996-2005

This section examines the farm level economic impact of growing GM crops and covers the following main issues:

- Impact on crop yields;
- Effect on key costs of production, notably seed cost and crop protection expenditure;
- Impact on other costs such as fuel and labour;
- Effect on profitability;
- Other impacts such as crop quality, scope for planting a second crop in a season and impacts that are often referred to as intangible impacts such as convenience, risk management and husbandry flexibility.

As indicated in the introduction, the primary methodology has been to review existing literature and to use the findings as the basis for the impact estimates over the ten year period examined. Additional points to note include:

- All values shown are nominal (for the year shown);
- Actual average prices and yields are used for each year;
- The base currency used is the US dollar. All financial impacts identified in other currencies have been converted to US dollars at the prevailing annual average exchange rate for each year;
- Where yield impacts have been identified in studies for one or a limited number of years, these have been converted into a percentage change impact and applied to all other years on the basis of the prevailing average yield recorded. For example, if a study identified a yield gain of 5% on a base yield of 10 tonnes/ha in year one, this 5% yield increase was then applied to the average yield recorded in each other year[16].

The section is structured on a trait and country basis highlighting the key farm level impacts.

3.1 Herbicide tolerant soybeans

3.1.1 The US

In 2005, 93% of the total US soybean crop was planted to GM glyphosate tolerant cultivars (GM HT). The farm level impact of using this technology since 1996 is summarised in Table 11.

The key features are as follows:

- The primary impact has been to reduce the soybean cost of production. In the early years of adoption these savings were between $25/ha and $34/ha. In more recent years, estimates of the cost savings have risen to between $60/ha and $78/ha (based on a comparison of conventional herbicide regimes in the early 2000s that would be required to deliver a comparable level of weed control to the GM HT soybean system). The main

[16] The average base yield has been adjusted downwards (if necessary) to take account of any positive yield impact of the technology. In this way the impact on total production of any yield gains is not overstated

savings have come from lower herbicide costs[17] plus about $10/ha savings in labour and machinery costs;

- Against the background of underlying improvements in average yield levels over the 1996-2004 period (via improvements in plant breeding), the specific yield impact of the GM technology has been neutral[18];
- The annual total national farm income benefit from using the technology has risen from $5 million in 1996 to nearly $1.2 billion in 2005. The cumulative farm income benefit over the 1996-2005 period (in nominal terms) was nearly $7.6 billion;
- In added value terms, the increase in farm income in recent years has been equivalent to an annual increase in production of between +6.5% and +10%.

Table 11: Farm level income impact of using GM HT soybeans in the US 1996-2005

Year	Cost savings ($/ha)	Net cost saving/increase in gross margins, inclusive of cost of technology ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1996	25.2	10.39	5.0	0.03
1997	25.2	10.39	33.2	0.19
1998	33.9	19.03	224.1	1.62
1999	33.9	19.03	311.9	2.5
2000	33.9	19.03	346.6	2.69
2001	73.4	58.56	1,298.5	10.11
2002	73.4	58.56	1,421.7	9.53
2003	78.5	61.19	1,574.9	9.17
2004	63.3	43.54	1,184.1	4.94
2005	63.3	43.54	1,170.0	6.36

Sources and notes:

1. Impact data 1996-1997 based on Marra et al, 1998-2000 based on Gianessi & Carpenter and 2001 onwards based on NCFAP (2003 & 2005)
2. Cost of technology: $14.82/ha 1996-2002, $17.3/ha 2003, $19.77/ha 2004 onwards
3. The higher values for the cost savings in 2001 onwards reflect the methodology used by NCFAP which was to examine the conventional herbicide regime that would be required to deliver the same level of weed control in a low/reduced till system to that delivered from the GM HT no/reduced till soybean system. This is a more robust methodology than some of the more simplistic alternatives (eg, Benbrook, 2003) used elsewhere. In earlier years the cost savings were based on comparisons between GM HT soy growers and/or conventional herbicide regimes that were commonplace prior to commercialisation in the mid 1990s when conventional tillage systems were more important

3.1.2 Argentina

As in the US, GM HT soybeans were first planted commercially in 1996. Since then use of the technology has increased rapidly, so that by the early 2000s, almost all soybeans grown in Argentina were GM HT (99%). Not surprisingly the impact on farm income has been substantial, with farmers deriving important cost saving and farm income benefits both similar and additional to those obtained in the US (Table 12). More specifically:

[17] Whilst there were initial cost savings in herbicide expenditure, these increased when glyphosate came off-patent in 2000. Gorwers of GM HT soybeans initially applied Monsanto's Roundup herbicide but over time, and with the availability of low cost genric glyphosate alternatives, many growers (estimated at 30% by 2005) switched to using these generic alternatives (the price of Roundup also fell significantly post 2000)

[18] Some early studies of the impact of GM HT soybeans in the US, suggested that GM HT soybeans produced lower yields than conventional soybean varieties. Where this occurred it applied only in early years of adoption when the technology was not present in all leading varieties suitable for all of the main growing regions of the USA. By 1998/99 the technology was available in leading varieties and no statistically significant average yield differences have been found between GM and conventional soybean varieties

- The impact on yield has been neutral (ie, no positive or negative yield impact);
- The cost of the technology to Argentine farmers has been substantially lower than in the US (about \$3-\$4/hectare compared to \$15-\$17/ha in the US) mainly because the technology provider (Monsanto) was not able to obtain patent protection for the technology in Argentina. As such, Argentine farmers have also been free to save and use GM seed without paying any technology fees or royalties (on farm-saved seed) and estimates of the proportion of total soybean seed used that derives from saved seed in 2004 were up to 80%;
- The savings from reduced expenditure on herbicides, fewer spray runs and machinery use have been in the range of \$24-\$30/ha, resulting in a net income gain of \$21-\$27/ha[19];
- The price received by farmers for soybeans was on average marginally higher than for conventionally produced soybeans because of lower levels of weed material and impurities in the crop. This quality premia was equivalent to about 0.5% of the baseline price for soybeans;
- The net income gain from use of the GM HT technology at a national level was about \$0.9 million in 1996 rising to \$480 million in 2005. Since 1996, the cumulative benefit (in nominal terms) has been \$2.47 billion;
- An additional farm income benefit that many Argentine soybean growers have derived comes from the additional scope for second cropping of soybeans. This has arisen because of the simplicity, ease and weed management flexibility provided by the (GM) technology which has been an important factor facilitating the use of no and reduced tillage production systems. In turn the adoption of low/no tillage production systems has reduced the time required for harvesting and drilling subsequent crops and hence has enabled many Argentine farmers to cultivate two crops (wheat followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no or low tillage methods has increased from 34% in 1996 to 90% in 2005 and about 15% of the total Argentine soybean crop was second crop in 2005[20], compared to 8% in 1996. Based on the additional gross margin income derived from second crop soybeans (see Appendix 1), this has contributed a further boost to national soybean farm income of \$527 million in 2005 and \$2.5 billion cumulatively since 1996;
- The total farm income benefit inclusive of the second cropping was \$1 billion in 2005 and \$5.2 billion cumulatively between 1996 and 2005;
- In added value terms, the increase in farm income from the direct use of the GM HT technology (ie, excluding the second crop benefits) in last three years has been equivalent to an annual increase in production of between +4% and +6%. The additional production from second soybean cropping facilitated by the technology in 2005 was equal to 15% of total output.

[19] This income gain also includes the benefits accruing from the fall in real price of glyphosate, which fell by about a third between 1996 and 2000

[20] The second crop share was 21% in 2004 (3 million ha). In 2005, this area fell to 2.3 million ha reflecting the decrease in the area planted to wheat in Argentina

Table 12: Farm level income impact of using GM HT soybeans in Argentina 1996-2005

Year	Cost savings ($/ha)	Net saving on costs (inclusive of cost of technology ($/ha)	Increase in farm income at a national level ($ millions)	Increase in farm income from facilitating additional second cropping ($ millions)
1996	26.10	22.49	0.9	0
1997	25.32	21.71	42	25
1998	24.71	21.10	115	43
1999	24.41	20.80	152	118
2000	24.31	20.70	205	143
2001	24.31	20.70	250	273
2002	29.00	26.00	372	373
2003	29.00	26.00	409	416
2004	30.00	27.00	440	678
2005	30.1	28.85	480	527

Sources and notes:

1. The primary source of information for impact on the costs of production is Qaim M & Traxler G (2002)
2. All values for prices and costs denominated in Argentine pesos have been converted to US dollars at the annual average exchange rate in each year
3. The second cropping benefits are based on the gross margin derived from second crop soybeans multiplied by the total area of second crop soybeans (less an assumed area of second crop soybeans that equals the second crop area in 1996). The source of gross margin data comes from Grupo CEO
4. Additional information is available in Appendix 1
5. The net savings to costs understate the total gains in recent years because up to 80% of GM HT plantings were to farm-saved seed on which no seed premium was payable (relative to the $3-$4/ha premium charged for new seed)

3.1.3 Brazil

GM HT soybeans were probably first planted in Brazil in 1997. Since then, the area planted has increased to 40% of the total crop in 2005[21].

The impact of using GM HT soybeans has been similar to that identified in the US and Argentina, although facilitation of double cropping of soybeans has not been apparent in Brazil. The net savings on herbicide costs have been larger in Brazil due to higher average costs of weed control. Hence, the average cost saving arising from a combination of reduced herbicide use, fewer spray runs, labour and machinery savings were between $74/ha and $88/ha in the period 2003 to 2005 (Table 13). The net cost saving after deduction of the technology fee (assumed to be about $15/ha in 2005) has been between $35/ha and $88/ha. At a national level, the adoption of GM HT soybeans increased farm income levels by $538 million in 2005. Cumulatively over the period 1997 to 2005, farm incomes have risen by $1,367 million (in nominal terms).

In added value terms, the increase in farm income from the use of the GM HT technology in 2005 was equivalent to an annual increase in production of +5% (about 2.47 million tonnes).

[21] Until 2003 all plantings were technically illegal

Table 13: Farm level income impact of using GM HT soybeans in Brazil 1997-2005

Year	Cost savings ($/ha)	Net cost saving after inclusion of technology cost ($/ha)	Impact on farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1997	38.8	35.19	3.8	0.06
1998	42.12	38.51	20.5	0.31
1999	38.76	35.15	43.5	0.96
2000	65.32	31.71	43.7	0.85
2001	46.32	42.71	58.7	1.02
2002	40.00	36.39	66.7	1.07
2003	77.00	68.00	214.7	1.62
2004	88.00	73.00	377.6	3.47
2005	74.00	57.43	538.4	4.98

Sources and notes:

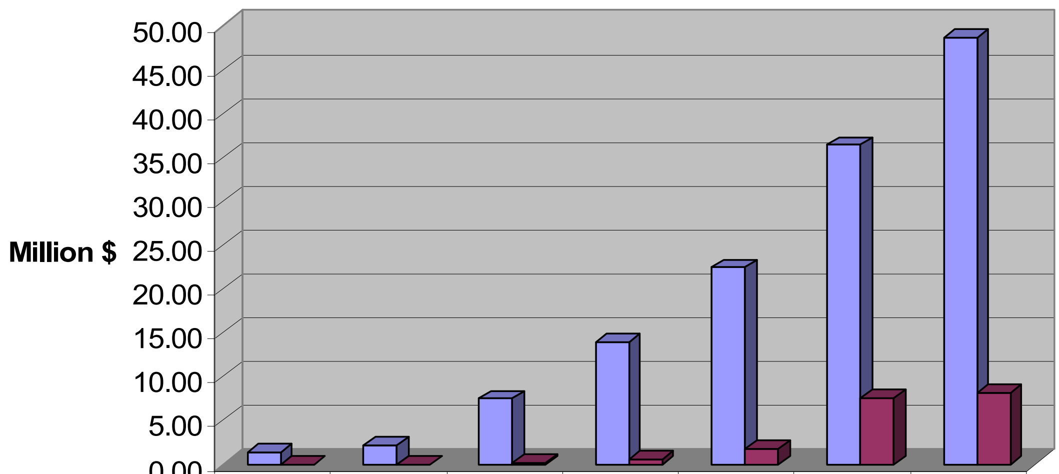
1. Impact data based on 2004 comparison data from the Parana Department of Agriculture (2004) Cost of production comparison: biotech and conventional soybeans, in USDA GAIN report BR4629 of 11 November 2004. www.fas.usad.gov/gainfiles/200411/146118108.pdf
2. Cost of the technology from 2003 is based on the royalty payments to be officially levied by the technology providers. For years up to 2002, the cost of technology is based on costs of buying new seed in Argentina (the source of the seed). This probably overstates the real cost of the technology and understates the cost savings
3. All values for prices and costs denominated in Brazilian Real have been converted to US dollars at the annual average exchange rate in each year

3.1.4 Paraguay and Uruguay

GM HT soybeans have been grown since 1999 and 2000 respectively in Paraguay and Uruguay. By 2005, they accounted for 93% of total soybean plantings in Paraguay and all of the soybean plantings in Uruguay. Using the farm level impact data derived from Argentine research and applying this to production in these two countries[22], Figure 6 summarises the national farm level income benefits that have been derived from using the technology. In 2005, the respective national farm income gains were $48.5 million in Paraguay and $8.2 million in Uruguay.

[22] Quam & Traxler (2002). The authors are not aware of any specific impact research having been conducted and published in Paraguay or Uruguay

Figure 6: National farm income benefit from using GM HT soybeans in Paraguay and Uruguay 1999-2005 (million $)



	1999	2000	2001	2002	2003	2004	2005
Paraguay	1.30	2.17	7.44	13.85	22.41	36.37	48.55
Uruguay	0.00	0.06	0.13	0.59	1.84	7.48	8.20

3.1.5 Canada

GM HT soybeans were first planted in Canada in 1997. By 2005 the share of total plantings accounted for by GM HT soybeans was 60% (0.71 million ha).

At the farm level, the main impacts of use have been similar to the impacts in the US. The average farm income benefit has been within a range of $15/ha-$40/ha and the increase in farm income at the national level was about $13 million in 2005 (Table 14). The cumulative increase in farm income since 1997 has been about $69 million (in nominal terms). In added value terms, the increase in farm income from the use of the GM HT technology in 2005 was equivalent to an annual increase in production of about 2.3% (72,000 tonnes).

Table 14: Farm level income impact of using GM HT soybeans in Canada 1997-2005

Year	Cost savings ($/ha)	Net cost saving/increase in gross margin (inclusive of technology cost: $/ha)	Impact on farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1997	64.28	41.17	0.041	0.01
1998	56.62	35.05	1.72	0.3
1999	53.17	31.64	6.35	1.29
2000	53.20	31.65	6.71	1.4
2001	49.83	29.17	9.35	3.4
2002	47.78	27.39	11.92	2.79
2003	49.46	14.64	7.65	1.47
2004	51.61	17.48	11.58	1.48
2005	55.65	18.85	13.30	2.26

Sources and notes:

1. Impact data based on Morris Centre Report 2004
2. All values for prices and costs denominated in Canadian dollars have been converted to US dollars at the annual average exchange rate in each year

3.1.6 South Africa

The first year GM HT soybeans were planted commercially in South Africa was 2001. By 2005, 156,000 hectares (65%) of total soybean plantings were to varieties containing the GM HT trait. In terms of impact at the farm level, net cost savings of between \$6/ha and \$9/ha have been achieved through reduced expenditure on herbicides (Table 15). At the national level, the increase in farm income was \$1.4 million in 2005.

Table 15: Farm level income impact of using GM HT soybeans in South Africa 2001-2005

Year	Cost savings (\$/ha)	Net cost saving/increase in gross margin after inclusion of technology cost (\$/ha)	Impact on farm income at a national level (\$ millions)
2001	26.72	7.02	0.042
2002	21.82	5.72	0.097
2003	30.40	7.90	0.24
2004	34.94	9.14	0.46
2005	36.17	9.12	1.42

Sources and notes:
1. Impact data (source: Monsanto South Africa)
2. All values for prices and costs denominated in South African Rand have been converted to US dollars at the annual average exchange rate in each year

3.1.7 Romania

In 2005, Romania planted 87,500 ha of GM HT soybeans (total soybean area 130,000 ha). This was its seventh year of commercial use of the technology.

The growing of GM HT soybeans in Romania has resulted in substantially greater net farm income gains per hectare than any of the other countries using the technology:

- Yield gains of an average of 31%[23] have been recorded. This yield gain has arisen from the substantial improvements in weed control[24];
- The cost of the technology to farmers in Romania has tended to be higher than other countries, with seed being sold in conjunction with the herbicide. For example, in 2004, the average cost of seed and herbicide per hectare was \$130/ha. This relatively high cost however, has not deterred adoption of the technology because of the major yield gains, improvements in the quality of soybeans produced (less weed material in the beans sold to crushers which resulted in price premia being obtained[25]) and cost savings derived;
- The average net increase in gross margin in 2005 was \$228/ha (an average of \$170/ha over the seven years of commercial use: Table 16);

[23] Source: Brookes (2003)

[24] Weed infestation levels, particularly of difficult to control weeds such as Johnson grass have been very high in Romania. This is largely a legacy of the economic transition during the 1990s which resulted in very low levels of farm income, abandonment of land and very low levels of weed control. As a result, the weed bank developed substantially and has been subsequently very difficult to control, until the GM HT soybean system became available (glyphosate has been the key to controlling difficult weeds like Johnson grass)

[25] Industry sources report that price premia for cleaner crops were no longer payable in 2005 by crushers and hence this element has not been included in the 2005 analysis

- At the national level, the increase in farm income amounted to almost $20 million in 2005. Cumulatively since 1999 the increase in farm income has been $60.7 million (in nominal terms);
- The yield gains in 2005 were equivalent to an 21% increase in national production[26] (the annual average increase in production over the six years is equal to 13%);
- In added value terms, the combined effect of higher yields, improved quality of beans and reduced cost of production on farm income in 2005 was equivalent to an annual increase in production of about 33% (83,000 tonnes).

Table 16: Farm level income impact of using herbicide tolerant soybeans in Romania 1999-2005

Year	Cost saving ($/ha)	Cost savings net of cost of technology ($/ha)	Net increase in gross margin ($/ha)	Impact on farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1999	162.08	2.08	105.18	1.63	4.0
2000	140.30	-19.7	89.14	3.21	8.2
2001	147.33	-0.67	107.17	1.93	10.3
2002	167.80	32.8	157.41	5.19	14.6
2003	206.70	76.7	219.01	8.76	12.7
2004	260.25	130.25	285.57	19.99	27.4
2005	239.07	118.09	227.98	19.95	33.0

Sources and notes:

1. Impact data (source: Brookes 2003). Average yield increase 31% applied to all years, average improvement in price premia from high quality 2% applied to years 1999-2004
2. All values for prices and costs denominated in Romanian Lei have been converted to US dollars at the annual average exchange rate in each year
3. Technology cost includes cost of herbicides

3.1.8 Summary of global economic impact

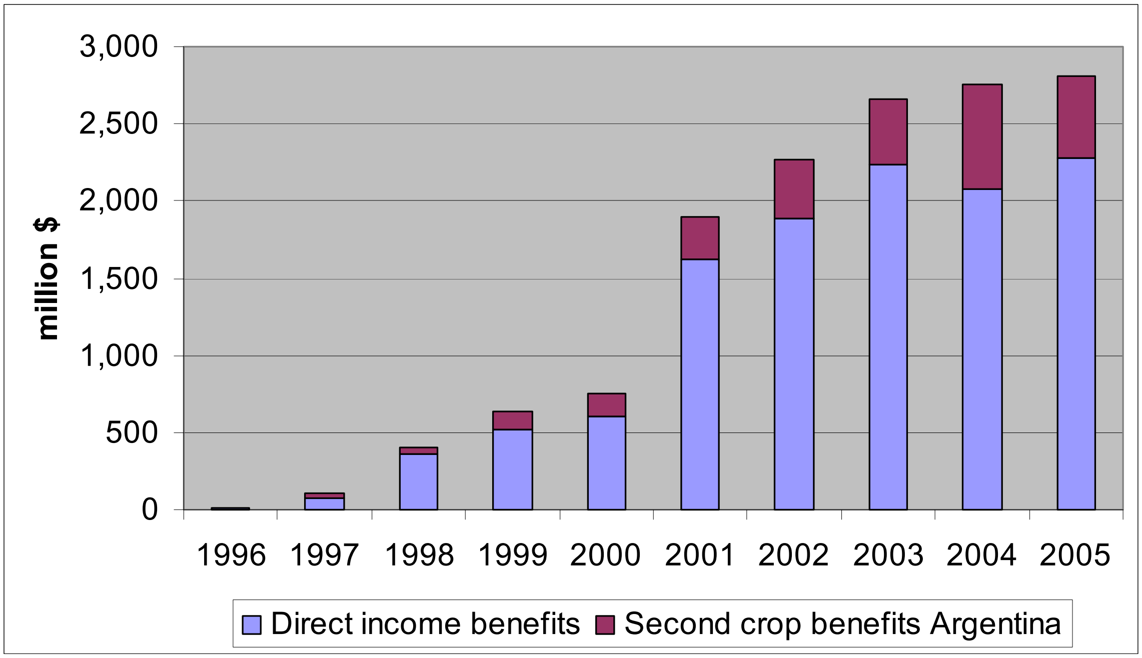
In global terms, the farm level impact of using GM HT technology in soybeans was $2.28 billion in 2005 (Figure 8). If the second crop benefits arising in Argentina are included this rises to $2.84 billion. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $11.7 billion ($14.4 billion if second crop gains in Argentina are included).

In terms of the total value of soybean production from the countries growing GM HT soybeans in 2005, the additional farm income (inclusive of Argentine second crop gains) generated by the technology is equal to a value added equivalent of 7.1%. Relative to the value of global soybean production in 2005, the farm income benefit added the equivalent of 6%.

These economic benefits should be placed within the context of a significant increase in the level of soybean production in the main GM adopting countries since 1996 (a 58% increase in the area planted in the leading soybean producing countries of the US, Brazil and Argentina).

[26] Derived by calculating the yield gains made on the GM HT area and comparing this increase in production relative to total soybean production

Figure 7: Global farm level income benefits derived from using GM HT soybeans 1996-2005 (million $)



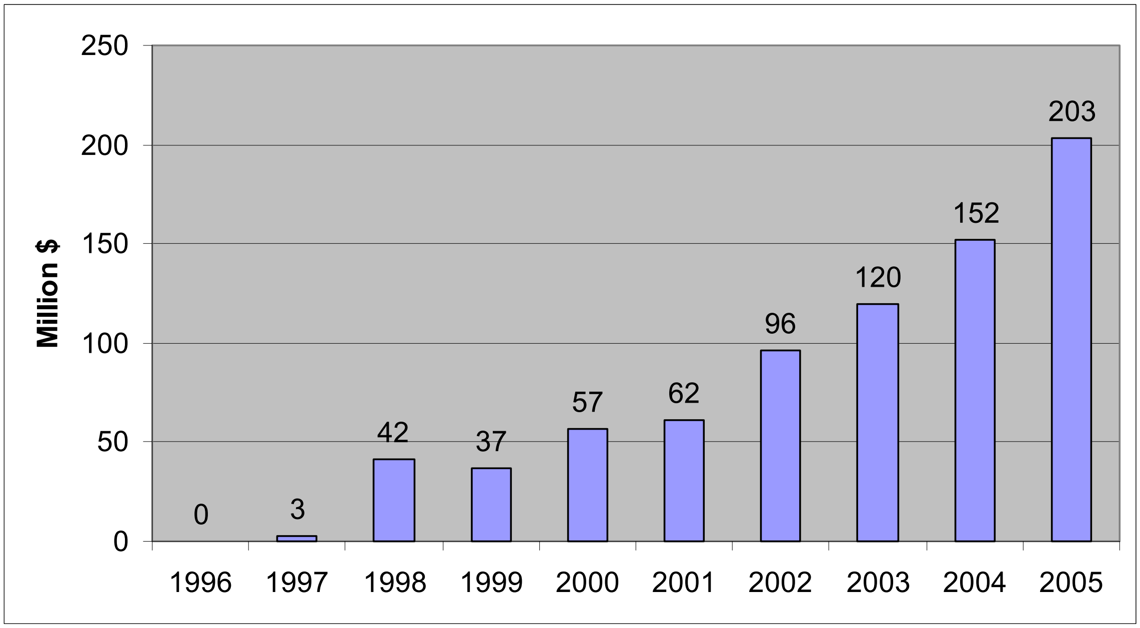
3.2 Herbicide tolerant maize

3.2.1 The US

Herbicide tolerant maize[27] has been used commercially in the US since 1997 and by 2005 was planted on half of the total US maize crop. The impact of using this technology at the farm level is summarised in Figure 8. As with herbicide tolerant soybeans, the main benefit has been to reduce costs, and hence improve profitability levels. Average profitability improved by about $25/ha, resulting in a net gain to farm income in 2005 of about $203 million. Cumulatively, since 1997 the farm income benefit has been $771 million. In added value terms, the effect of reduced costs of production on farm income in 2005 was equivalent to an annual increase in production of 0.93% (2.64 million tonnes).

[27] Tolerant to glufosinate ammonium or to glyphosate, although cultivars tolerant to glyphosate has accounted for the majority of plantings

Figure 8: National farm income impact of using GM HT maize in the US 1997-2005

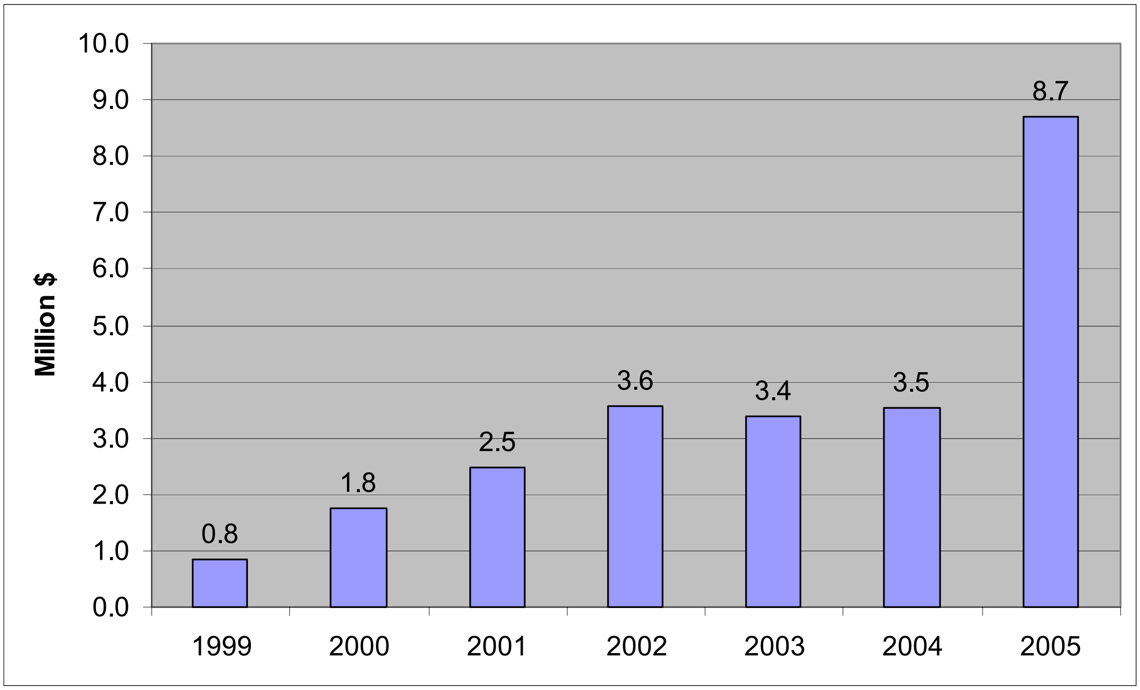


Source and notes: Impact analysis based on NCFAP 2001,2003 and 2005. Estimated cost of the technology $14.83/ha, cost savings (mostly from lower herbicide use) $40.55/ha in 2004 and 2005

3.2.2 Canada

In Canada, GM HT maize was first planted commercially in 1997. By 2005 the proportion of total plantings accounted for by varieties containing GM HT was 37%. As in the US, the main benefit has been to reduce costs and to improve profitability levels. Average annual profitability has improved by between $14/ha and $18/ha since 1999. In 2005 the net increase in farm income was $8.7 million and cumulatively since 1999 the farm income benefit has been $24 million. In added value terms, the effect of reduced costs of production on farm income in 2005 was equivalent to an annual increase in production of 1% (105,000 tonnes: Figure 9).

Figure 9: National farm income impact of using GM HT maize in Canada 1999-2005



Source and notes: Impact analysis based on data supplied by Monsanto Canada. Estimated cost of the technology $18-$21/ha, cost savings (mostly from lower herbicide use) $31-$37/ha

3.2.3 Other countries

Herbicide tolerant maize has been grown commercially in South Africa since 2003, and in 2005 19,000 hectares out of total plantings of 1.54 million ha were herbicide tolerant. The estimated cumulative farm income benefit earned (industry source estimates of the cost savings per hectare based on about $4/ha) has been $273,000.

Herbicide tolerant maize was also first planted commercially in 2004 in Argentina and the 2005 area planted to GM HT maize was about 70,000 ha (2.5% of the total maize crop). The estimated cumulative farm income benefit earned from using this technology, by 2005 was $237,000.

3.2.4 Summary of global economic impact

In global terms, the farm level economic impact of using GM HT technology in maize was $212 million in 2005 (96% of which was in the US). Cumulatively since 1997, the farm income benefit has been (in nominal terms) $795 million.

In terms of the total value of maize production in the two main countries using this technology in 2005 (US and Canada), the additional farm income generated by the technology is equal to a value added equivalent of 0.82%.

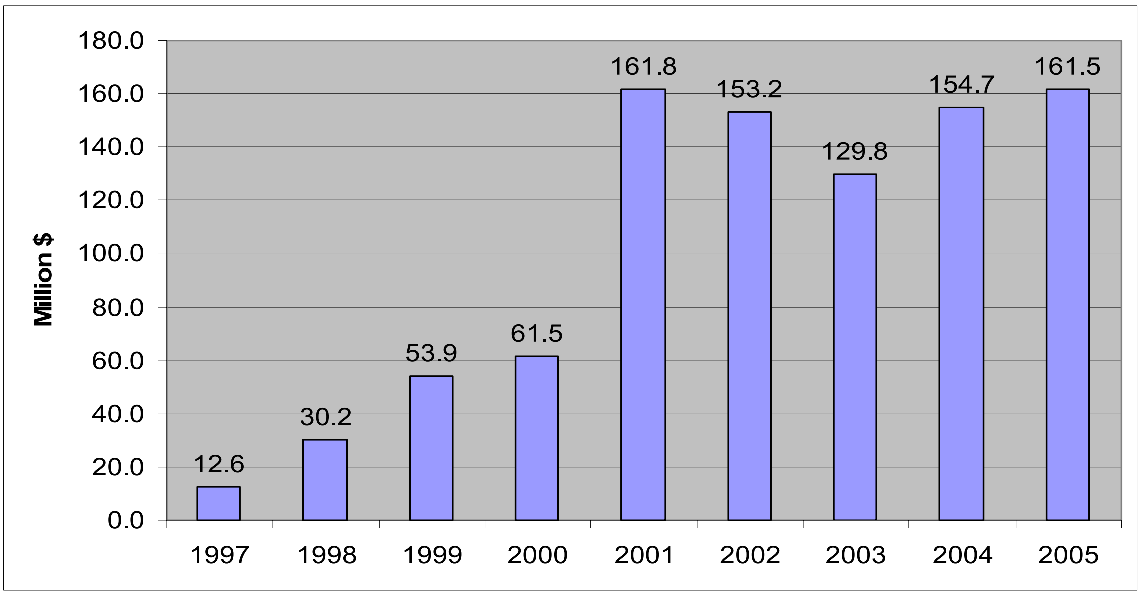
3.3 Herbicide tolerant cotton

3.3.1 The US

GM HT cotton was first grown commercially in the US in 1997 and by 2005, was planted on 61% of total cotton plantings[28].

The farm income impact of using GM HT cotton is summarised in Figure 10. The primary benefit has been to reduce costs, and hence improve profitability levels with average profitability increasing by between $21/ha and $49/ha[29], resulting in a net gain to farm income in 2005 of $161 million. Cumulatively since 1997 the farm income benefit has been $919 million. In added value terms, the effect of reduced cost of production on farm income in 2005 was equivalent to an annual increase in production of 3% (151,000 tonnes).

Figure 10: National farm income impact of using GM HT cotton in the US 1997-2005



Source and notes: Impact analysis based on NCFAP 2001, 2003 and 2005. Estimated cost of the technology $12.85/ha (1997-2000) and $21.32/ha 2001-2003 and $34.55 onwards, cost savings excluding cost of technology (mostly from lower herbicide use) $34.12/ha (1997-2000), $65.59/ha (2001-2003) and $83.35/ha onwards)

3.3.2 Other countries

Australia, Argentina and South Africa are the other three countries where GM HT cotton is commercially grown; from 2000 in Australia, 2001 in South Africa and 2002 in Argentina. In 2005, 74% (225,000 ha), 38% (11,500 ha) and 44% (165,000 ha) respectively of the total Australian, South African and Argentine cotton crops were planted to GM HT cultivars.

We are not aware on any published research into the impact of GM HT cotton in South Africa or Argentina. In Australia, although research has been conducted into the impact of using GM HT

[28] Although there have been GM HT cultivars tolerant to glyphosate and bromoxynil, glyphosate tolerant cultivars have dominated

[29] The only published source that has examined the impact of HT cotton in the US is work by the NCFAP in 2001, 2003 and 2005. In the 2001 study the costs saved were based on historic patterns of herbicides used on conventional cotton in the mid/late 1990s. The latter studies estimated cost savings on the basis of the conventional herbicide treatment that would be required to deliver the same level of weed control as GM HT cotton

cotton (eg, Doyle B et al (2003)) this does not provide quantification of the impact[30]. Drawing on industry source estimates[31], the main impact has been to deliver small savings in herbicide costs equal to about \$3/ha-\$9/ha in South Africa, \$6/ha to \$7/ha in Australia and \$3/ha to \$3/ha to \$16/ha in Argentina. At a national level, in 2005 these savings amounted to \$1.55 million in Australia, \$107,000 in South Africa and \$2.6 million in Argentina. The cumulative savings since 2000 across these three countries have been \$8.4 million. In added value terms, the effect of reduced costs of production on farm income in 2005 was equivalent to an annual increase in production of 1.6% in Australia, 0.5% in South Africa and 1.9% in Argentina.

3.3.3 Summary of global economic impact

Within the four countries using GM HT cotton in 2005, the total farm income benefit derived from using GM HT cotton was \$166 million, and cumulatively since 1997, the gains have been \$927 million (97% of this benefit has been in the US).

3.4 Herbicide tolerant canola

3.4.1 Canada

Canada was the first country to commercially use GM HT canola in 1996. Since then the area planted to varieties containing GM HT traits has increased significantly to 82% of the total crop in 2005 (4.3 million ha).

The farm level impact of using GM HT canola in Canada since 1996 is summarised in Table 17. The key features are as follows:

- The primary impact has been to increase yields by almost 11% (in 2005 this yield increase was equivalent to an increase in total Canadian canola production of nearly 9%). In addition, a small additional price premia has been achieved from crushers through supplying cleaner crops (lower levels of weed impurities);
- Cost of production (excluding the cost of the technology) has fallen, mainly through reduced expenditure on herbicides and some savings in fuel and labour. These savings have annually been between about \$25/ha and \$32/ha. The cost of the technology has however been marginally higher than these savings resulting in a net increase in costs of \$3/ha to \$5/ha;
- The overall impact on profitability (inclusive of yield improvements and higher quality) has been an increase of between \$22/ha and \$45/ha;
- The annual total national farm income benefit from using the technology has risen from \$6 million in 1996 to \$175 million in 2005. The cumulative farm income benefit over the 1996-2005 period (in nominal terms) was \$792 million;
- In added value terms, the increase in farm income in 2005 has been equivalent to an annual increase in production of almost 8%.

[30] This largely survey based research observed a wide variation of impact with yield and income gains widely reported for many farmers

[31] Sources: Monsanto Australia, Argentina and South Africa

Table 17: Farm level income impact of using GM HT canola in Canada 1996-2005

Year	Cost savings ($/ha)	Cost savings inclusive of cost of technology ($/ha)	Net cost saving/increase in gross margins ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1996	28.59	-4.13	45.11	6.23	0.4
1997	28.08	-4.05	37.11	21.69	1.17
1998	26.21	-3.78	36.93	70.18	3.43
1999	26.32	-3.79	30.63	90.33	5.09
2000	26.32	-3.79	22.42	59.91	5.08
2001	25.15	-1.62	23.10	53.34	5.69
2002	24.84	-3.59	29.63	61.86	6.17
2003	28.04	-4.04	41.42	132.08	6.69
2004	29.84	-4.31	32.65	120.94	7.15
2005	32.18	-4.65	40.66	175.15	7.95

Sources and notes:

1. Impact data based on Canola Council study (2001). Includes a 10.7% yield improvement and a 1.27% increase in the price premium earned (cleaner crop with lower levels of weed impurities)
2. All values for prices and costs denominated in Canadian dollars have been converted to US dollars at the annual average exchange rate in each year

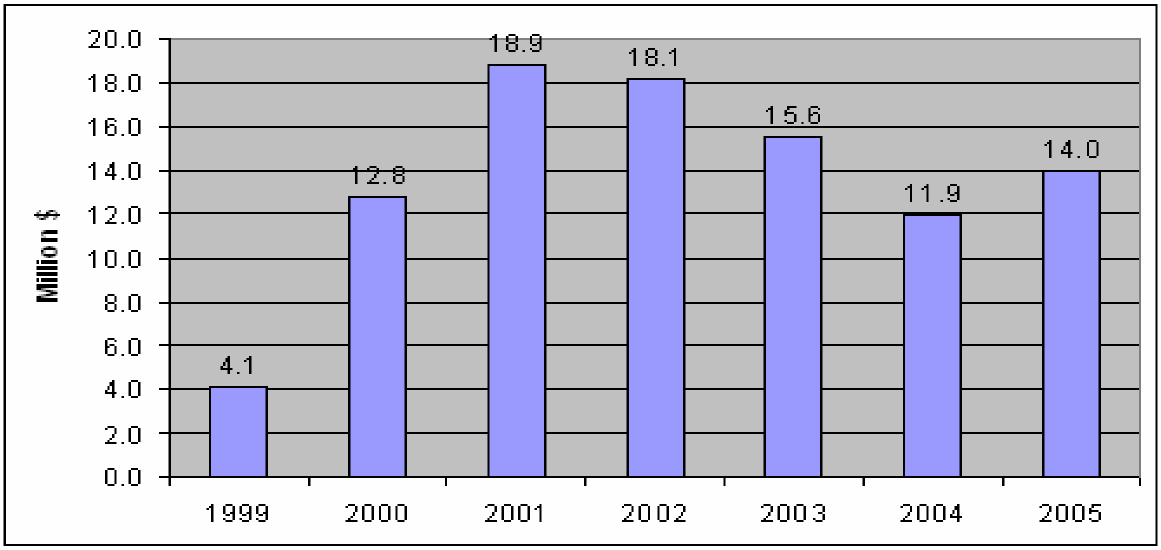
3.4.2 The US

The only other country growing GM HT canola on a commercial basis has been the US, where the first plantings took place in 1999. In 2005, 95% of the US canola crop was GM HT (431,000 ha).

The farm level impact has been similar to the impact identified in Canada. More specifically:

- Average yields increased by about 6%. In 2004, this added the equivalent of 5.7% to total US canola production;
- The cost of the technology has been between $17/ha (glufosinate tolerant) and $29-$33/ha (glyphosate tolerant). Cost savings (before inclusion of the technology costs) have been $45/ha for glufosinate tolerant canola and $61-$67/ha for glyphosate tolerant canola;
- The net impact on gross margins has been between +$40/ha and +$48/ha for glufosinate tolerant canola, and +$47/ha and +$55/ha for glyphosate tolerant canola;
- At the national level the total farm income benefit in 2005 was $19.9 million and the cumulative benefit since 1999 has been $101 million;
- In added value terms, the increase in farm income in 2005 has been equivalent to an annual increase in production of about 20%.

Figure 11: National farm income impact of using GM HT canola in the US 1999-2005



Source and notes: Impact analysis based on NCFAP 2001, 2003 and 2005. Decrease in total farm income impact 2002-2004 is due to decline in total plantings of canola in the US (from 612,000 in 2002 to 316,000 ha in 2004)

3.4.3 Summary of global economic impact

In global terms, the farm level impact of using GM HT technology in canola in Canada and the US was $195 million in 2005. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $893 million.

In terms of the total value of canola production in these two countries in 2005, the additional farm income generated by the technology is equal to a value added equivalent of 9.4%. Relative to the value of global canola production in 2005, the farm income benefit added the equivalent of 1.9%.

3.5 GM Insect resistant (GM IR) maize

3.5.1 US

GM IR maize was first planted in the US in 1996 and by 2005, GM IR maize accounted for 35% (10.64 million ha) of total US maize plantings.

The farm level impact of using GM IR maize in the US since 1996 is summarised in Table 18:

- The primary impact has been increased average yields of about 5% (in 2005 this additional production is equal to an increase in total US maize production of +1.75%);
- The net impact on cost of production has been a small increase of between $5/ha and $9/ha (additional cost of the technology being higher than the estimated average insecticide cost savings of $15-$16/ha);
- The annual total national farm income benefit from using the technology has risen from $8.76 million in 1996 to $306 million in 2005. The cumulative farm income benefit over the 1996-2005 period (in nominal terms) was $1.92 billion;
- In added value terms, the increase in farm income in 2005 was equivalent to an annual increase in production of 1.37%.

Table 18: Farm level income impact of using GM IR maize in the US 1996-2005

Year	Cost saving ($/ha)	Cost savings (net after cost of technology ($/ha)	Net increase in gross margins ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1996	15.50	-9.21	29.2	8.76	0.03
1997	15.50	-9.21	28.61	70.47	0.27
1998	15.50	-4.8	27.04	167.58	0.77
1999	15.50	-4.8	25.51	206.94	1.04
2000	15.50	-6.74	24.32	146.76	0.71
2001	15.50	-6.74	26.76	155.87	0.72
2002	15.50	-6.74	30.74	240.61	0.96
2003	15.50	-6.74	31.54	291.45	1.14
2004	15.88	-6.36	31.30	328.13	1.27
2005	15.88	-6.36	28.80	306.28	1.37

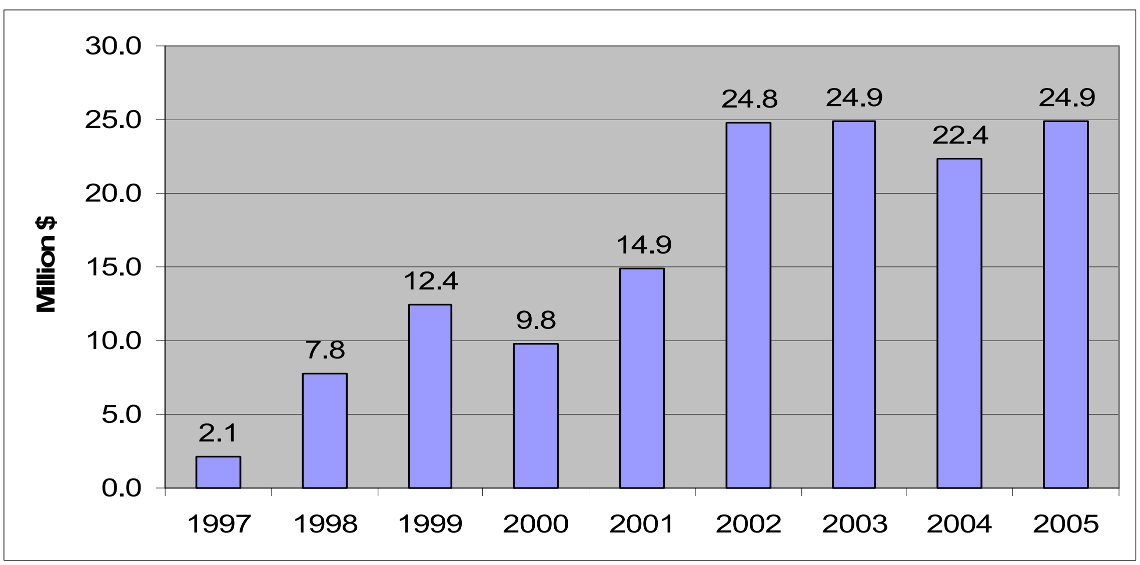
Sources and notes:

1. Impact data based on a combination of studies including ISAAA review (2002), Marra et al and NCFAP 2001, 2003 and 2005
2. Yield impact +5% based on average of findings of above studies
3. Insecticide cost savings based on NCFAP 2003 and 2005

3.5.2 Canada

GM IR maize has also been grown commercially in Canada since 1996. In 2005 it accounted for two-thirds of the total Canadian maize crop of 1.3 million ha. The impact of GM IR maize in Canada has been very similar to the impact in the US (similar yield and cost of production impacts). At the national level, in 2005 the additional farm income generated from the use of GM IR maize was about $25 million and cumulatively since 1996 the additional farm income (in nominal terms) was $144 million (Figure 12).

Figure 12: National farm income impact of using GM IR maize in Canada 1996-2005



Notes: 1. Yield increase of 5% based on industry assessments (consistent with US analysis). Cost of technology and insecticide cost savings based on US analysis, 2. Bt area planted in 1996 = 1,000 ha, 3. All values for prices and costs denominated in Canadian dollars have been converted to US dollars at the annual average exchange rate in each year

3.5.3 Argentina

In 2005, GM IR maize accounted for 62% of total maize plantings (GM IR was first planted in 1998).

The main impact of using the technology on farm profitability has been a 9% average yield increase. No savings in costs of production have arisen because very few maize growers in Argentina have traditionally used insecticides as a method of control for corn boring pests. As such, average costs of production have increased by about $22/ha (the cost of the technology).

The net impact on farm profit margins (inclusive of the yield gain) has been an increase of about $20/ha and in 2005 the national level impact on profitability was an increase of $32 million (an added value equal to 2.4% of the total value of production). Cumulatively, the farm income gain since 1997 has been $159 million.

3.5.4 South Africa

GM IR maize has been grown commercially in South Africa since 2000. In 2005, 25% of the country's total maize crop of 1.54 million ha was to GM IR cultivars.

The impact on farm profitability is summarised in Table 19. The main impact has been an average yield improvement of about 11%, although there has also been a small net saving in cost of production of $1/ha-$2/ha.

At the national level, the increase in farm income in 2005 was almost $15 million and cumulatively since 2000 it has been nearly $59 million. In terms of national maize production, the use of Bt technology on 25% of the planted area has resulted in a net increase in national maize production of 2.78% in 2005. The value of the additional income generated was also equivalent to an annual increase in production of about 2.66%.

Table 19: Farm level income impact of using GM IR maize in South Africa 2001-2005

Year	Cost savings ($/ha)	Net cost savings inclusive of cost of technology ($/ha)	Net increase in gross margin ($/ha)	Impact on farm income at a national level ($ millions)
2000	13.98	1.87	43.77	3.31
2001	11.27	1.51	34.60	4.46
2002	8.37	1.12	40.04	6.81
2003	12.82	1.72	45.25	10.41
2004	14.73	1.97	46.64	18.93
2005	15.25	2.20	37.54	14.68

Sources and notes:

1. Impact data (source: Morse et al (2004))
2. All values for prices and costs denominated in South African Rand have been converted to US dollars at the annual average exchange rate in each year

3.5.5 Spain

Spain has been commercially growing GM IR maize since 1998 and in 2005, about 11% (48,000 ha) of the country's maize crop was planted to varieties containing a GM IR trait.

As in the other countries planting GM IR maize, the main impact on farm profitability has been increased yields (an average increase in yield of 6.3% across farms using the technology), although in Spain there has also been a net annual average saving on cost of production (from lower insecticide use) of between $37/ha and $51/ha[32] (Table 20). At the national level, these yield gains and cost savings have resulted in farm income being boosted, in 2005 by $5.5 million and cumulatively since 1998 the increase in farm income (in nominal terms) has been $28 million.

Relative to national maize production, the yield increases derived from GM IR maize were equivalent to a 0.69% increase in national production (2004). The value of the additional income generated from Bt maize was also equivalent to an annual increase in production of 0.87%.

Table 20: Farm level income impact of using GM IR maize in Spain 1998-2005

Year	Cost savings ($/ha)	Net cost savings inclusive of cost of technology ($/ha)	Net increase in gross margin ($/ha)	Impact on farm income at a national level ($ millions)
1998	37.40	3.71	95.16	2.38
1999	44.81	12.80	102.20	2.55
2000	38.81	12.94	89.47	2.24
2001	37.63	21.05	95.63	2.39
2002	39.64	22.18	100.65	2.52
2003	47.50	26.58	121.68	3.89
2004	51.45	28.79	111.93	6.49
2005	52.33	29.28	114.97	5.52

Sources and notes:

1. Impact data (based on Brookes (2002)
2. All values for prices and costs denominated in Euros have been converted to US dollars at the annual average exchange rate in each year

3.5.6 Other countries

GM IR maize has been grown commercially in:

- the Philippines since 2003. In 2005, 70,000 hectares out of total plantings of 2.8 million (2.5%) were GM IR. Estimates of the impact of using GM IR (sources: Gonzales (2004), Yorobe (2004) and Ramon (2005)) show annual average yield increases in the range of 14.3% to 34%. Taking the mid point of this range (+24.15%), coupled with a small average annual insecticide cost saving of about $3/ha, an average cost of the technology of about $36/ha and a quality-related price premium of 10%[33], the net impact on farm profitability has been between $52/ha and $64/ha. In 2005, the national farm income benefit derived from using the technology was $4.5 million and cumulative farm income gain since 2003 has been $8.5 million;
- in Uruguay since 2004, and in 2005, 30,000 ha (47% of the total crop) were GM IR. Using Argentine data as the basis for assessing impact, the cumulative farm income gain over the two years has been $1.7 million;
- in Honduras since 2003 (2,000 ha planted in 2005). We are not aware of any impact analysis of these crops having yet been undertaken.

3.5.7 Summary of economic impact

In global terms, the farm level impact of using GM IR maize was $389 million in 2005. Cumulatively since 1996, the benefit has been (in nominal terms) $2.32 billion.

[32] Source: Brookes (2002) and Alcade (1999)

[33] Larger, cleaner and more uniform kernels. A premium as high as 20% has been reported. A more conservative average of 10% has been used in this analysis (based on Yorobe 2004)

In terms of the total value of maize production from the countries growing GM IR maize in 2005, the additional farm income generated by the technology is equal to a value added equivalent of 1.46%. Relative to the value of global maize production in 2005, the farm income benefit added the equivalent of 0.72%.

3.6 Insect resistant (Bt) cotton (GM IR)

3.6.1 The US

GM IR cotton has been grown commercially in the US since 1996 and by 2005, was planted on 52% (2.8 million ha) of total cotton plantings.

The farm income impact of using GM IR cotton is summarised in Table 21. The primary benefit has been increased yields (by 9%-11%[34]), although small net savings in costs of production have also been obtained (reduced expenditure on insecticides being marginally greater than the cost of the technology). Overall, average profitability levels increased by $53/ha-$115/ha with Bollgard I cotton (with a single Bt gene) between 1996 and 2002 and by between $108/ha and $120/ha in 2003-2005 with Bollgard II (containing two Bt genes and offering a broader spectrum of control). This resulted in a net gain to farm income in 2005 of $306 million. Cumulatively, since 1996 the farm income benefit has been $1.63 billion. In added value terms, the effect of the increased yields and reduced costs of production on farm income in 2005 was equivalent to an annual increase in production of 5.4% (285,000 tonnes).

Table 21: Farm level income impact of using GM IR cotton in the US 1996-2005

Year	Cost savings (net after cost of technology ($/ha)	Net increase in gross margins ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1996	4.98	115.32	94.69	1.19
1997	4.98	103.47	87.28	1.30
1998	4.98	88.54	80.62	1.47
1999	4.98	65.47	127.29	2.89
2000	4.98	74.11	162.88	3.10
2001	4.98	53.04	125.22	3.37
2002	4.98	69.47	141.86	3.11
2003	5.78	120.49	239.98	4.27
2004	5.78	107.47	261.23	4.82
2005	5.78	108.44	305.97	5.44

Sources and notes:

1. Impact data based on NCFAP 2001, 2003 and 2005, Marra M (2002) and Mullins & Hudson (2004)
2. Yield impact +9% 1996-2002 Bollgard I and +11% 2003-2005 Bollgard II
3. Cost of technology: 1996-2002 Bollgard I $58.27/ha, 2003-2005 Bollgard II $68.32/ha
4. Insecticide cost savings $63.26/ha 1996-2002, $74.10/ha 2003-2005

3.6.2 China

China first planted GM IR cotton in 1997, since when the area planted to GM IR varieties has increased to 65% of the total 5.1 million ha crop in 2005.

As in the US, a major farm income impact has been via higher yields of 8% to 10% on the crops using the technology, although there have also been significant cost savings on insecticides used

[34] In relation to total US cotton production in 2005 the positive effect of Bt cotton on yields effectively increased US production by 5.7%

and the labour previously used to undertake spraying. Overall, annual average costs have fallen by about $194/ha and annual average profitability improved by about $300/ha. In 2005, the net national gain to farm income was just over $1 billion (Table 22). Cumulatively since 1997 the farm income benefit has been $5.17 billion. In added value terms, the effect of the increased yields and reduced costs of production on farm income in 2005 was equivalent to an annual increase in production of nearly 16% (0.96 million tonnes).

Table 22: Farm level income impact of using GM IR cotton in China 1997-2005

Year	Cost savings (net after cost of technology ($/ha)	Net increase in gross margins ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1997	194	333	11.33	0.13
1998	194	310	80.97	1.15
1999	200	278	181.67	4.62
2000	-14	123	150.18	2.61
2001	378	472	1,026.26	20.55
2002	194	327	687.27	11.19
2003	194	328	917.00	12.15
2004	194	299	1,105.26	16.89
2005	194	305	1,007.83	16.17

Sources and notes:

1. Impact data based on Prey et al (2002) which covered the years 1999-2001. Other years based on average of the 3 years
2. Negative cost savings in 2000 reflect a year of high pest pressure (of pests not the target of GM IR technology) which resulted in above average use of insecticides on GM IR using farms
3. Yield impact +8% 1997-1999 and +10% 2000 onwards
4. All values for prices and costs denominated in Chinese Yuan have been converted to US dollars at the annual average exchange rate in each year

3.6.3 Australia

Australia planted about 81% of its 2005 cotton crop (total crop of 306,000 ha) to varieties containing GM IR traits (Australia first planted commercial GM IR cotton in 1996).

Unlike the other main countries using GM IR cotton, Australian growers have not derived yield gains from using the technology, with the primary farm income benefit being derived from lower costs of production (Table 23). More specifically:

- In the first two years of adoption of the technology (Ingard, single gene Bt cotton), small net income losses were derived, mainly because of the relatively high price charged for the seed. Since this price was lowered in 1998, the net income impact has been positive, with cost saving of between $70/ha and $90/ha, mostly derived from lower insecticide costs (including application) more than offsetting the cost of the technology;
- For the last two years of use, Bollgard II cotton (containing two Bt genes) has been available offering effective control of a broader range of cotton pests. Despite the higher costs of this technology, users have continued to make significant net cost savings of $186/ha to $193/ha;
- At the national level in 2005, the net farm income gains have been about $48 million and cumulatively since 1996 the gains have been almost $150 million;
- In added value terms, the effect of the reduced costs of production on farm income in 2005 was equivalent to an annual increase in production of 57% (310,000 tonnes).

Table 23: Farm level income impact of using GM IR cotton in Australia 1996-2004

Year	Cost of technology ($/ha)	Net increase in gross margins/cost saving after cost of technology ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1996	-191.7	-41.0	-1.63	-0.75
1997	-191.7	-35.0	-2.04	-1.25
1998	-97.4	91.0	9.06	5.8
1999	-83.9	88.1	11.80	5.6
2000	-89.9	64.9	10.71	6.3
2001	-80.9	57.9	7.87	7.2
2002	-90.7	54.3	3.91	5.1
2003	-119.3	256.1	16.3	28.1
2004	-179.5	185.8	45.7	42.6
2005	-229.2	193.4	47.9	57.6

Sources and notes:

1. Impact data based on Fitt (2002) and CSIRO for bollgard II since 2003
2. All values for prices and costs denominated in Australian dollars have been converted to US dollars at the annual average exchange rate in each year

3.6.4 Argentina

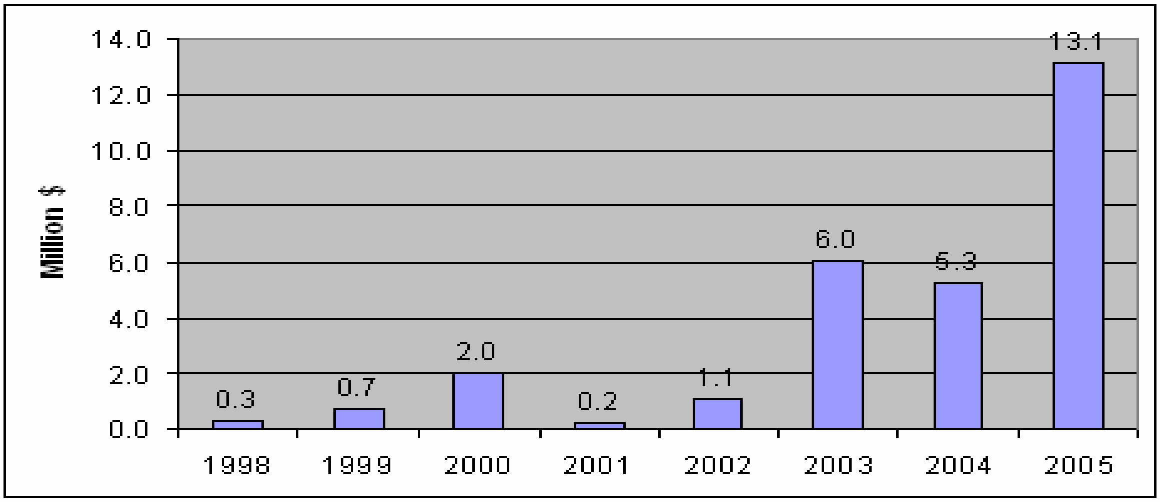
GM IR cotton has been planted in Argentina since 1998. In 2005, it accounted for 50% of total cotton plantings.

The main impact in Argentina has been yield gains of about 35% (which has resulted in a net increase in total cotton production (2005) of 15%). This has more than offset the cost using the technology[35]. In terms of gross margin, cotton farmers have gained annually between $33/ha and $93/ha during the period 1998-2005[36]. At the national level, the annual farm income gains in the last three years have been in the range of $5.2 million to $13 million (Figure 13). Cumulatively since 1998, the farm income gain from use of the technology has been $28.8 million. In added value terms, the effect of the yield increases (partially offset by higher costs of production) on farm income in 2005 was equivalent to an annual increase in production of 8.8%.

[35] The cost of the technology used in the years up to 2004 was $86/ha (source: Qaim & DeJanvry). For 2005, the cost used was $40/ha (source: Monsanto Argentina). The insecticide cost savings about $17.5/ha, leaving a net increase in costs of $68.5/ha up to 2004 and $22.5/ha in 2005

[36] The variation in margins has largely been due to the widely fluctuating annual price of cotton

Figure 13: National farm income impact of using GM IR cotton in Argentina 1998-2005



Sources and notes:

1. Impact data (source: Qaim & De Janvry (2002), although cost of technology in 2005 from Monsanto Argentina. Area data : source ArgenBio
2. Yield impact +35%, cost of technology $86/ha ($40/ha 2005), cost savings (reduced insecticide use) $17.47/ha
3. All values for prices and costs denominated in Argentine Pesos have been converted to US dollars at the annual average exchange rate in each year

3.6.5 Mexico

GM IR cotton has been planted commercially in Mexico since 1996. In 2005 GM IR cotton was planted on 120,000 ha (95% of total cotton plantings)[37].

The main farm income impact of using the technology has been yield improvements of about 14% per year. In addition, there have been important savings in the cost of production (lower insecticide costs)[38]. Overall, the annual net increase in farm profitability has been within the range of $112/ha and $354/ha between 1996 and 2005 (Table 24). At the national level, the farm income benefit in 2005 was $13.6 million and the impact on total cotton production was an increase of 7.2%. Cumulatively since 1996, the farm income benefit has been $55 million. In added value terms, the combined effect of the yield increases and lower cost of production on farm income in 2004 was equivalent to an annual increase in production of 10.5%.

[37] Source ISAAA

[38] Cost of technology has annually been between $48/ha and $65/ha, insecticide cost savings between $88/ha and $121/ha and net savings on costs have been between $38/ha and $48/ha (derived from and based on Traxler et al (2001)

Table 24: Farm level income impact of using GM IR cotton in Mexico 1996-2005

Year	Cost savings (net after cost of technology ($/ha)	Net increase in gross margins ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1996	58.1	354.5	0.32	0.1
1997	56.1	103.4	1.72	0.5
1998	38.4	316.4	11.27	2.71
1999	46.5	316.8	5.27	2.84
2000	47.0	282.4	6.85	5.76
2001	47.6	120.6	3.04	3.74
2002	46.1	120.8	1.84	3.81
2003	41.0	146.6	3.82	3.46
2004	39.2	112.5	7.29	6.58
2005	40.8	113.3	13.60	10.52

Sources and notes:

1. Impact data based on Traxler et al (2001) covering the years 1997 and 1998. Yield changes in other years based on official reports submitted to the Mexican Ministry of Agriculture by Monsanto Comercial (Mexico)
2. Yield impacts: 1996 +37%, 1997 +3%, 1998 +20%, 1999 +27%, 2000 +17%, 2001 +9%, 2002 +7%, 2003 +6%, 2004 and 2005 +8%
3. All values for prices and costs denominated in Mexican Pesos have been converted to US dollars at the annual average exchange rate in each year

3.6.6 South Africa

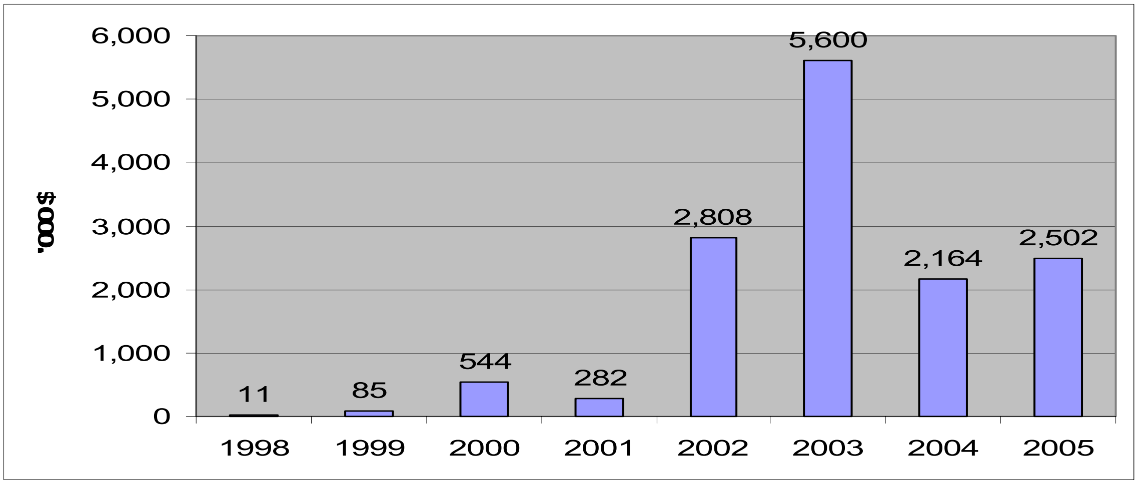
In 2005, GM IR cotton[39] was planted on 17,000 ha in South Africa (57% of the total crop).

The main impact on farm incomes has been significantly higher yields (an annual average increase of about 24%). In terms of cost of production, the additional cost of the technology (between $17/ha and $24/ha) has been marginally greater than the insecticide cost and labour (for water collection and spraying) savings ($12/ha to $23/ha), resulting in a small increase in overall cost of production of $2/ha to $5/ha. Combining the positive yield effect and the small increase in cost of production, the net effect on profitability has been an annual increase of between $34/ha and $207/ha.

At the national level, farm incomes, over the last three years have annually increased by between $2 million and $5 million (Figure 14). Cumulatively since 1998, the farm income benefit has been $14 million. The impact on total cotton production was an increase of 14% in 2005. In added value terms, the combined effect of the yield increases and lower costs of production on farm income in 2005 was equivalent to an annual increase in production of 10.8% (based on 2005 production levels).

[39] First planted commercially in 1998

Figure 14: National farm income impact of using GM IR cotton in South Africa 1998-2005



Sources and notes:

1. Impact data based on Ismael et al (2002)
2. Yield impact +24%, cost of technology \$14/ha-\$24/ha, cost savings (reduced insecticide use) \$12/ha-\$23/ha
3. All values for prices and costs denominated in South African Rand have been converted to US dollars at the annual average exchange rate in each year
4. The decline in the total farm income benefit 2004 and 2005 relative to earlier years reflects the decline in total cotton plantings. This was caused by relatively low farm level prices for cotton in 2004 and 2005 (reflecting a combination of relatively low world prices and a strong South African currency)

3.6.7 India

GM IR cotton has been planted commercially in India since 2002. In 2005 1.3 million ha were officially recorded as planted to GM IR cotton which is equal to about 16% of total plantings)[40].

The main impact of using GM IR cotton has been major increases in yield[41]. With respect to cost of production, the average cost of the technology (about \$54/ha) has been greater than the average insecticide cost savings of \$31/ha-\$42/ha resulting in a net increase in costs of production. However, the yield gains have resulted in important net gains to levels of profitability of \$139/ha, \$324/ha, \$171/ha and \$260/ha respectively in 2002, 2003, 2004 and 2005. At the national level, the farm income gain in 2005 was \$339 million and cumulatively since 2002 the farm income gains have been \$463 million.

Table 25: Farm level income impact of using GM IR cotton in India 2002-2005

Year	Cost savings (net after cost of technology ($/ha)	Net increase in gross margins ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
2002	-12.42	138.91	6.18	0.16
2003	-16.2	323.68	32.4	0.47
2004	-13.56	171.40	85.7	2.06
2005	2.54	260.47	338.6	6.48

[40] Trade sources also estimate that a further 1.3 million ha are planted to local/unapproved varieties. The analysis in this report does not take these plantings into consideration

[41] Bennett et al (2004) found average yield increases of 45% in 2002 and 63% in 2003 (average over the two years of 54%) relative to conventionally produced cotton. More recent survey data from Monsanto (2005) confirms this high yield impact (+58% reported in 2004) and from IMRB (2006) which found an average yield increase of 64% in 2005

Sources and notes:
1. Impact data based on Bennett et al (2004) and IMRB (2006)
2. All values for prices and costs denominated in Indian Rupees have been converted to US dollars at the annual average exchange rate in each year

The impact on total cotton production was an increase of 10% in 2005 and in added value terms, the combined effect of the yield increases and higher costs of production on farm income in 2005 was equivalent to an annual increase in production of 6.5% (based on the 2005 production level that is inclusive of the GM IR related yield gains).

3.6.8 Other countries

GM IR cotton has been grown commercially in Columbia since 2002 (28,000 ha planted in 2005 out of a total cotton crop of 76,000 ha). We are not aware of any impact analysis of these crops having yet been undertaken. Drawing on the analysis of impact in Mexico and applying this to Columbia (an 11.5% yield increase and a net reduction in costs of production of about $40/ha), this would put the national gain to farm income in 2005 at $2.4 million and the cumulative farm income gain since 2002 has been $3.9 million.

3.6.9 Summary of global impact

In global terms, the farm level impact of using GM IR cotton was $1.73 billion in 2005. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $7.51 billion.

In terms of the total value of cotton production from the countries growing GM IR in 2005, the additional farm income generated by the technology is equal to a value added equivalent of 12.1% (based on the 2005 production level inclusive of the GM IR related yield gains). Relative to the value of global cotton production in 2005, the farm income benefit added the equivalent of 6.7%.

3.7 Other GM crops

3.7.1 Maize/corn rootworm resistance

GM rootworm resistant (CRW) corn has been planted commercially in the US for three years. In 2005, there were 1.66 million ha of CRW corn (5% of the total US crop).

The main farm income impact[42] has been higher yields of about 3% relative to conventionally treated corn. The impact on average costs of production has been -$5/ha (based on an average cost of the technology of $42/ha and an insecticide cost saving of $37/ha). As a result, the net impact on farm profitability has been +$13.1/ha in 2003, +$17.6/ha in 2004 and +$16.1/ha in 2005.

At the national level, farm incomes increased by $2.12 million in 2003, $12.9 million in 2004 and $26.8 million in 2005.

CRW cultivars were also planted commercially for the first time in 2004 in Canada. In 2005 the area planted to CRW resistant varieties was 26,000 ha. Based on US costs, insecticide cost savings and yield impacts, this has resulted in additional income at the national level of $410,000 in 2005 ($505,000 inclusive of 2004).

[42] Impact data based on NCFAP (2003 and 2005) and Rice (2004)

At the global level, the extra farm income derived from GM CRW maize has added the equivalent of 0.05% to global maize production.

3.7.2 Virus resistant papaya

Ringspot resistant papaya has been commercially grown in the US (State of Hawaii) since 1999, and in 2005 about 55% of the state's papaya crop was GM virus resistant (535 ha).

The main farm income impact of this GM crop has been to significantly increase yields relative to conventional varieties. Compared to the average yield in the last year before the first GM cultivation (1998), the annual average yield increase of GM papaya relative to conventional crops has been within a range of +16% to +77% (average of about +44%). At a state level this is equivalent to a 26% increase in total papaya production in 2005.

In terms of profitability[43], the net annual impact has been an improvement of between \$3,032/ha and \$11,412/ha, and in 2004 this amounted to a total state level benefit of \$4.7 million. Cumulatively, the farm income benefit since 1999 has been \$24 million.

3.7.3 Virus resistant squash

GM virus resistant squash has also been grown in some states of the US since 2003 and is estimated to have been planted on about 2,300 ha in 2005[44] (about 10% of the total crop in the US).

Based on analysis from NCFAP (2005), the primary farm income impact of using GM virus resistant squash has been derived from higher yields, which in 2005 added a net gain to users of \$21 million.

3.7.4 Insect resistant potatoes

GM insect resistant potatoes were also grown commercially in the US between 1996 and 2000 (planted on 4% of the total US potato crop in 1999 (30,000 ha). This technology was withdrawn in 2001 when the technology provider (Monsanto) withdrew from the market to concentrate on GM trait development in maize, soybeans, cotton and canola. This commercial decision was also probably influenced by the decision of some leading potato processors and fast food outlets to stop using GM potatoes because of perceived concerns about this issue from some of their consumers, even though the GM potato provided the producer and processor with a lower cost, higher yielding and more consistent product. It also delivered significant reductions in insecticide use (NCFAP 2001).

3.8 Other farm level economic impacts of using GM crops

As well as the tangible and quantifiable impacts on farm profitability presented in the sub-sections above, there are other important, more intangible (difficult to quantify) impacts of an economic nature.

Many of the studies[45] of the impact of GM crops have identified the following reasons as being important influences for adoption of the technology:

[43] Impact data based on NCFAP 2003 and 2005

[44] Mostly found in Georgia and Florida where the total squash area is about 7,890 ha

[45] For example, relating to HT soybeans; USDA 1999, Gianessi & Carpenter 2000, Quam & Traxler 2002, Brookes 2003; relating to insect resistant maize Brookes 2002, Rice 2004; relating to insect resistant cotton Ismael et al 2002, Pray et al 2002

Herbicide tolerant crops

- increased management flexibility that comes from a combination of the ease of use associated with broad-spectrum, post emergent herbicides like glyphosate and the increased/longer time window for spraying;
- In a conventional crop, post-emergent weed control relies on herbicide applications before the weeds and crop are well established. As a result, the crop may suffer 'knock-back' to its growth from the effects of the herbicide. In the GM HT crop, this problem is avoided because the crop is both tolerant to the herbicide and spraying can occur at a later stage when the crop is better able to withstand any possible "knock-back" effects;
- Facilitates the adoption of conservation or no tillage systems. This provides for additional cost savings such as reduced labour and fuel costs associated with ploughing;
- Improved weed control has contributed to reduced harvesting costs – cleaner crops have resulted in reduced times for harvesting. It has also improved harvest quality and led to higher levels of quality price bonuses in some regions (eg, Romania);
- Elimination of potential damage caused by soil-incorporated residual herbicides in follow-on crops.

Insect resistant crops

- Production risk management/insurance purposes – it takes away the worry of significant pest damage occurring;
- A 'convenience' benefit derived from having to devote less time to crop walking and/or applying insecticides;
- savings in energy use – mainly associated with less use of aerial spraying;
- savings in machinery use (for spraying and possibly reduced harvesting times);
- A perception that the quality of Bt maize is superior to non Bt maize from the perspective of having lower levels of mycotoxins. Evidence from, for example, Bakan et al (2002) who examined *Fusarium* infection levels in Bt versus non Bt corn trial plots in five locations (three in France and two in Spain) found that Bt maize had up to ten times less fumonisin content than the non Bt varieties. In terms of revenue from sales of corn, however, no reported premia for delivering product with lower levels of mycotoxin levels have, to date, been reported;
- Improved health and safety for farmers and farm workers (from reduced handling and use of pesticides);
- Shorter growing season (eg, for some cotton growers in India) which allows some farmers to plant a second crop in the same season[46]. Also some Indian cotton growers have reported knock on benefits for bee keepers as fewer bees are now lost to insecticide spraying.

As indicated above, quantifying these impacts is difficult. Some studies have attempted to quantify some of these benefits (eg, Quam & Traxler (2002) quantified some of these in Argentina (a $3.65/hctare saving (-7.8%) in labour costs and a $6.82/ha (-28%) saving in machinery/fuel costs). Where identified, these cost savings have been included in the analysis presented in the preceding parts of section 3. Nevertheless, it is important to recognise that these largely intangible benefits are considered by many farmers as a primary reason for adoption of GM technology, and in some cases farmers have been willing to adopt for these reasons alone, even when the measurable impacts on yield and direct costs of production suggest marginal or no direct economic gain. As such, the estimates of the farm level benefits presented in the preceding sections probably understate the real vale of the technology to farmers.

[46] Notably maize in India

3.9 GM technology adoption and size of farm

This issue has been specifically examined in few pieces of research. Examples include:

- Fernandez-Cornejo & McBride (2000) examined the effect of size on adoption of GM crops in the US (using 1998 data). The a priori hypothesis used for the analysis was that the nature of the technology embodied in a variable input like seed (which is completely divisible and not a 'lumpy' input like machinery) should show that adoption of GM crops is not related to size. The analysis found that mean adoption rates appeared to increase with size of operation for herbicide tolerant crops (soybeans and maize) up to 50 hectares in size and then were fairly stable, whilst for Bt maize adoption appeared to increase with size. This analysis did, however not take into other factors affecting adoption such as education, awareness of new technology and willingness to adopt, income, access to credit and whether a farm was full or part time – all these are considered to affect adoption yet are also often correlated to size of farm. Overall, the study suggested that farm size has not been an important factor influencing adoption of GM crops;
- Brookes (2002) identified in Spain that the average size of farmer adopting Bt maize was 50 hectares and that many were much smaller than this (under 20 hectares). Size was not therefore considered to be an important factor affecting adoption, with many small farmers using the technology;
- Brookes (2003) also identified in Romania that the average size of farmer adopting HT soybeans was not related to size of farm;
- Pray et al (2002). This research into GM insect resistant cotton adoption in China illustrated that adoption has been by mostly small farmers (the average cotton grower in China plants between 0.3 and 0.5 ha of cotton);
- Adopters of insect resistant cotton and maize in South Africa have been drawn from both large and small farmers (see Morse et al 2005, Ismael et al 2002).

Overall, the nature of findings from most studies where the nature and size of adopter has been a focus of research has shown that size of farm has not been a factor affecting use of GM technology. Both large and small farmers have adopted. Size of operation has not been a barrier to adoption and in 2005, 8.5 million farmers were using the technology globally, 90% of which were resource-poor farmers in developing countries.

3.10 Trade flows and related issues

a) Share of global production

As indicated in section 2, in 2005, GM plantings accounted for 29% of the global area planted to the crops of soybeans, maize, cotton and canola. At the crop level, the GM share of global plantings was 59%, 13%, 27% and 18% respectively for soybeans, maize, cotton and canola.

b) Share of global exports

Looking at the extent to which the leading GM producing countries are traders (exporters) of these crops and key derivatives (Table 26 and Table 27) show the following:

- *Soybeans*: in 2005, 30% of global production was exported and 98% of this trade came from countries which grow GM soybeans. Assuming that the same proportion of production in these GM exporting countries that was GM in 2005 was also exported, then 77% of globally traded soybeans was GM, although if it is assumed that there is no active segregation of exported soybeans from these countries into GM versus non GM product (ie, exported soybeans is likely to comprise a mix of both GM and non GM) then the GM share of global exports can reasonably be expected to have been 98% in 2005. As there has been some development of a GM versus non GM maize market (mostly in the EU, Japan and South Korea), which has necessitated some segregation of exports into GM versus non GM supplies, the likely share of global trade accounted for by GM soybean exports is at least 77% and may be as high as 98%. Based on estimates of the size of the non GM soy markets in the EU and SE Asia (the main non GM markets)[47], about 10% of global trade in soybeans is required to be certified as non GM, and if it is assumed that this volume of soybeans traded is segregated from GM soybeans, then the GM share of global trade is 90%. A similar pattern occurs in soymeal where about 69% of globally traded meal probably contains GM material;

- *Maize*: about 11% of global production was traded in 2005[48]. Within the leading exporting nations, the GM maize growers of the US, Argentina, South Africa and Canada are important players (80% of global trade). Assuming that the proportion of production in these countries that was GM in 2005 is also exported, then 53% of globally traded maize was GM, although if it is assumed that there is no active segregation of exported maize from these countries into GM versus non GM product (ie, exported maize is likely to comprise a mix of both GM and non GM maize) then the GM share of global exports can reasonably be expected to have been 80% in 2004. As there has been some, limited development of a GM versus non GM maize market (mostly in the EU, and to a lesser extent in Japan and South Korea, which has necessitated some segregation of exports into GM versus non GM supplies, the likely share of global trade accounted for by GM maize exports is within the range of 53% and 80%, but closer to the higher end of this range;
- *Cotton*: in 2005/06, about 26% of global production was traded. Of the leading exporting nations, the GM cotton growing countries of the US and Australia are prominent exporters accounting for 54% of global trade. Based on the proportion of production in the countries that was GM in 2005, then 47% of globally traded cotton was GM, although if it is assumed that there is no active segregation of exported cotton from these countries into GM versus non GM product (ie, exported cotton is likely to comprise a mix of both GM and non GM cotton) then the GM share of global exports can reasonably be expected to have been 57% in 2005[49]. In terms of cottonseed meal the GM share of global trade is about 37%;
- *Canola*: 12% of global canola production in 2005 was exported, with Canada being the main global trading country. The share of global canola exports accounted for by the two GM canola producing countries (Canada and the US) was 73% in 2005 (98% of this came from Canada). Based on the share of total production accounted for by GM production in each of the two countries, 60% of global canola trade in 2005 was GM. As there has been no significant development of a GM versus non GM canola market (the highest level of non GM demand is in the EU, which is largely self sufficient and hence imports very little canola/rapeseed), exports from Canada/US have not been segregated into GM and non GM supplies and hence, the likely share of global trade accounted for by GM canola is probably nearer the 73% level of global trade rather than the 60% level. For canola/rapemeal, the GM share of global trade is about 61%.

[47] Brookes (2004), Brookes et al (2005) and PG Economics (2003)

[48] Maize is an important subsistence crop in many parts of the world and hence the majority of production is consumed within the country of production

[49] We consider this to be a reasonable assumption; we are not aware of any significant development of a non GM versus GM cotton market and hence there is little evidence of any active segregation of exports from the US and Australia into these two possible streams of product. This includes the exports from other GM growing countries such as China and Argentina

Table 26: Share of global crop trade accounted for GM production 2005 (million tonnes)

	Soybeans	Maize	Cotton	Canola
Global production	210	695	24.2	46.4
Global trade (exports)	62.9	76.2	6.3	5.45
Share of global trade from GM producers	61.9 (98%)	61.24 (80%)	0.6 (57%)	3.98 (73%)
Share of global trade from GM producers if GM share of production used as proxy for share of exports	48.7	32.55	0.5	3.3
Estimated size of market requiring certified non GM (in countries that have import requirements)	5.0	Less than 1.0	Negligible	Negligible
Estimated share of global trade that may contain GM (ie, not required to be segregated)	56.88	61	0.61	3.98
Share of global trade that may be GM	90%	80%	57%	73%

Sources: USDA & Oil World statistics, PG Economics (2003), Brookes (2004), Brookes et al (2005)
Notes: Estimated size of non GM market for soybeans in the EU 15%, and in Japan and South Korea 40%

Table 27: Share of global crop derivative (meal) trade accounted for GM production 2005 (million tonnes)

	Soymeal	Cottonseed meal	Canola/rape meal
Global production	140	19.2	24.2
Global trade (exports)	47	0.59	2.4
Share of global trade from GM producers	42.2 (90%)	0.2 (39%)	1.46 (61%)
Share of global trade from GM producers if GM share of production used as proxy for share of exports	32.5	0.157	0.96
Estimated size of market requiring certified non GM (in countries that have import requirements)	4.5	Negligible	Negligible
Estimated share of global trade that may contain GM (ie, not required to be segregated)	32.4	0.22	1.46
Share of global trade that may be GM	69%	37%	61%

Sources: USDA & Oil World statistics, PG Economics (2003), Brookes (2004), Brookes et al (2005)
Notes: Estimated size of non GM market for soymeal in the EU 15%, and in Japan and South Korea 40%

c) Impact on prices

Assessing the impact of the GM agronomic, cost saving technology such as herbicide tolerance and insect resistance on the prices of soybeans, maize, cotton and canola (and derivatives) is difficult. Current and past prices reflect a multitude of factors of which the introduction and adoption of new, cost saving technologies is one. This means that disaggregating the effect of different variables on prices is far from easy, and in the case of the impact of a single example of cost saving technology, it is virtually impossible. Whilst this means that it is not possible to be precise about the past/current impact of GM technology to date, the following comments and assessments can be made.

a) The real price of food and feed products has fallen consistently over the last 50 years. This has not come about 'out of the blue' but from enormous improvements in productivity by producers. These productivity improvements have arisen from the adoption of new technologies and techniques.

b) In preceding sub-sections of this report, the extent of use of GM technology adoption globally identified that:

- For soybeans the majority of both global production and trade is accounted for by GM production;
- For maize and canola, whilst the majority of global production is still non GM, the majority of globally traded produce contains materials derived from GM production;
- For cotton, the majority of global production and trade continues to be non GM.

This means for a crop such as soybeans, that GM production now effectively influences and sets the baseline price for commodity traded soybeans and derivatives on a global basis. Given that GM soybean varieties have provided significant cost savings and farm income gains (eg, $2.79 billion in 2005) to growers, it is likely that some of the benefits of the cost saving will have been passed on down the supply chain in the form of lower real prices for commodity traded soybeans. Thus, the current baseline price for all soybeans, including non-GM soy is probably at a lower real level than it would otherwise (in the absence of adoption of the technology) have been. A similar process of 'transfer' of some of the farm income benefits of using GM technology in the other three crops has also probably occurred, although to a lesser extent because of the lower penetration of global production and trade of GM in these crops.

c) Building on this theme of the impact of the technology to lower real soybean prices, some (limited) economic analysis has been undertaken to estimate the impact of GM technology on global prices of soybeans. Moschini et al (2000) estimated that by 2000 the influence of GM soybean technology on world prices of soybeans had been between -0.5% and -1%, and that as adoption levels increased this could increase up to -6% (if all global production was GM). Quam & Traxler (2002) estimated the impact of RR soybean technology adoption on global soybean prices to have been -1.9% by 2001.

4 The environmental impact of GM crops

This section examines the environmental impact of using GM crops over the last ten years. The two key aspects of environmental impact explored are:

a) Impact on insecticide and herbicide use.
b) Impact on carbon emissions.

These are presented in the sub-sections below.

4.1 Use of insecticides and herbicides

The most common way in which changes in pesticide use on GM crops has been presented is in terms of the volumes (quantities) of pesticides applied. Whilst comparisons of total volumes of pesticide use in a crop production system can be a useful indicator of environmental impacts, it is an imperfect measure because:

- different active ingredients and amounts may be applied in GM or conventional systems;
- the environmental behaviour and toxicity profile of individual pesticides varies.

To provide a more robust measurement of the environmental impact of GM crops, the analysis presented in the sub-sections below includes both an assessment of pesticide active ingredient use, as well as the assessment of the specific pesticides used via an indicator known as the Environmental Impact Quotient (EIQ). This universal indicator, developed by Kovach et al (1992 & updated annually), effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare'. This provides a more balanced assessment of the impact of GM crops on the environment as it draws on all of the key toxicity and environmental exposure data related to individual products (as applicable to impacts on farm workers, consumers and ecology) and hence provides not only a consistent but a fairly comprehensive measure of environmental impact. Readers should however note that the EIQ is an indicator only and therefore does not take into account all environmental issues/impacts.

To provide a meaningful measure of environmental impact, the EIQ value is multiplied by the amount of pesticide active ingredient (ai) used per hectare to produce a field EIQ value. For example, the EIQ rating for glyphosate is 15.3. By using this rating multiplied by the amount of glyphosate used per hectare (eg, an hypothetical example of 1.1 kg applied per ha), the field EIQ value for glyphosate would be equivalent to 16.83/ha.

The EIQ indicator used is therefore a comparison of the field EIQ/ha for conventional versus GM crop production systems, with the total environmental 'foot print' or load of each system, a direct function of respective field EIQ/ha values and the area planted to each type of production (GM versus non GM).

4.1.1 GM herbicide tolerant (to glyphosate) soybeans (GM HT)

a) The USA

In examining the impact on herbicide usage in the US, two main sources of information have been drawn on: USDA (NASS) national pesticide usage data and private farm level pesticide usage survey data from Doane Marketing Research Inc. Based on these sources of information, the main features relating to herbicide usage on US soybeans over the last ten years have been (Table 28 and Table 29):

- The amount of herbicide active ingredient (ai) used per hectare on the US soybean crop has been fairly stable (a possible small increase in usage 3-4 years ago);
- The average field EIQ/ha load has also been fairly consistent;
- A comparison of conventionally grown soybeans (per ha) with GM HT soybeans (Table 29) shows that herbicide ai use on conventional soybeans has been fairly constant (around 1.1 to 1.2kg/ha). The herbicide ai use on GM HT soybeans has also been fairly stable but within a slightly higher level of 1.3 to 1.4kg/ha). This higher average usage level for GM HT soybeans partly reflects the changes in cultivation practices in favour of low/no tillage[50], which accounted for 73.7% of soybean production in 1996 and 80% by 2005 (low/no tillage systems tend to favour the use of glyphosate as the main burn-down treatment between crops (see section 4.2));
- A comparison of average field EIQs/ha also shows fairly stable values for both conventional and GM HT soybeans, although the average load rating for GM HT soybeans has been lower than the average load rating for conventional soybeans despite the continued shift to no/low tillage production systems that rely much more on herbicide-based weed control than conventional tillage systems;
- The comparison data between the GM HT crop and the conventional alternative presented above, may however, for the most recent years, not be a reasonable representation of average herbicide usage on the average GM HT crop compared with the average conventional alternative. It probably understates the herbicide usage for an average conventional soybean grower, especially as the level of GM HT soybean usage has increased. This is because the first users of the technology tend to be those with greatest levels of weed problems and the more intensive producers (with average, to above average levels of herbicide use). Thus, once uptake of the technology began to account for a significant part of the total US soybean area (from 1999 when the GM HT share became over 50% of the total crop), the residual conventional soybean growers have been those in locations with lower than average weed infestation levels and/or regions with a tradition of growing soybeans on a less intensive basis (and hence have historically used below average levels of inputs such as herbicides). The use of no/low tillage production systems also tends to be less prominent amongst conventional soybean growers compared to GM HT growers. As such, the average herbicide ai/ha and EIQ/ha values recorded for all remaining conventional soybean growers tends to fall and be lower than the average would have been if all growers had still been using conventional technology. One way of addressing this deficiency is to make comparisons between a typical herbicide treatment regime for GM HT soybeans and a typical herbicide treatment regime for an average conventional soybean grower that would deliver a similar level of weed control to the level delivered in the GM HT system. This is the methodology used by the NCFAP (2003). Based on this approach and adjusting the typical GM HT usage levels to the mid-range of the actual recorded usage in recent years (Table 29) the respective values are for conventional soybeans; average herbicide ai use 1.49 kg/ha and a field EIQ/ha of 36.9/ha (range 33/ha to 85/ha), and for GM HT soybeans, average herbicide ai use 1.35 kg/ha and a field EIQ of 20.7/ha.

[50] The availability of the simple and effective GM HT production system has played a major role in facilitating and maintaining this move into low/no tillage systems (see section 4.2)

Table 28: Herbicide usage on soybeans in the US 1996-2005

Year	Average ai use (kg/ha): NASS data	Average ai use: Doane data	Average field EIQ/ha: NASS data	Average field EIQ/ha: Doane data
1996	1.02	N/a	22.9	N/a
1997	1.22	N/a	26.8	N/a
1998	1.09	1.30	21.9	27.0
1999	1.05	1.23	19.9	24.2
2000	1.09	1.25	20.7	23.9
2001	0.73	1.30	13.7	24.2
2002	1.23	1.27	21.9	22.2
2003	N/a	1.36	N/a	23.1
2004	1.29	1.38	15.5	23.0
2005	1.23	1.38	20.6	23.0

Sources: NASS data no collection of data in 2003. Doane 1998-2005, N/A = not available

Table 29: Herbicide usage on GM HT and conventional soybeans in the US 1996-2005

Year	Average ai use (kg/ha): conventional	Average ai use (kg/ha): GM HT	Average field EIQ/ha: conventional	Average field EIQ/ha: GM HT
1996	N/a	N/a	N/a	N/a
1997	N/a	N/a	N/a	N/a
1998	1.28	1.33	30	22
1999	1.15	1.29	28	22
2000	1.11	1.32	26	22
2001	1.17	1.34	28	23
2002	1.09	1.30	26	21
2003	1.07	1.39	26	22
2004	1.08	1.41	26	22
2005	1.1	1.40	26	23

Source: derived from Doane, Marketing Research Inc, N/A = not available, NASS data does not differentiate between GM and conventional crops.

Extrapolating this (NCFAP basis) analysis to a national level to identify the changes in herbicide use and the environmental impact associated with the adoption of GM HT soybeans[51]. Table 30 shows:

- in 2005, there have been savings in herbicide ai use of 8.74% (3.76 million kg). The EIQ load was also lower by 41.1% compared with the conventional (no/low tillage) alternative (ie, if all of the US soybean crop had been planted to conventional soybeans);
- Cumulatively since 1996, the savings using this methodology have been 5.3% for ai use (23 million kg) and 29% for the field EIQ load.

[51] The approach taken to quantify the national impact has been to compare the level of herbicide use (herbicide ai use and field EIQ/ha values) on the respective areas planted to conventional and GM HT soybeans in each year with the level of herbicide use that would otherwise have probably occurred if the whole crop (in each year) had been produced using conventional technology. The level of weed control achieved was equal to the level derived from GM HT soybeans

Table 30: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in the US 1996-2005

Year	ai decrease (kg)	eiq saving (units)	% decrease in ai	% saving eiq
1996	56,658	8,002,604	0.15	0.83
1997	535,500	75,636,171	1.27	7.23
1998	1,428,000	201,696,456	3.29	18.74
1999	2,100,000	296,612,436	4.72	26.92
2000	2,279,189	321,921,782	5.07	28.92
2001	2,855,048	403,258,448	6.39	36.42
2002	3,101,700	438,096,567	7.05	40.16
2003	3,368,652	475,801,940	7.61	43.38
2004	3,602,725	420,115,367	7.99	37.58
2005	3,762,040	438,696,123	8.74	41.14

b) Canada

Our analysis of impact in Canada is based on a comparison of typical herbicide regimes used for GM HT and non GM soybeans and identification of the main herbicides that are no longer used since GM HT soybeans have been adopted[52]. This identified that, at the farm level, there has been a small increase in the average amount of herbicide active ingredient used (0.86 kg/ha compared to 0.84 kg/ha for conventional soybeans), but a decrease in the average field EIQ/ha of almost 6/ha (19.1/ha for conventional versus 13.2/ha for GM HT soybeans).

At the national level[53], in 2005, there was a net increase in the volume of active ingredient used of 1.1% (+11,400 kg) but a 19% decrease in the number of field EIQ/ha units (-4.16 million). Cumulatively since 1997, the volume of active ingredient used has increased by 0.6% (50,000 kg) but the total field EIQ value fell 9% (-18.3 million units: Table 31).

Table 31: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Canada 1996-2005

Year	ai saving (kg: negative sign denotes increase)	eiq saving (units)	% decrease in ai (- = increase)	% saving eiq
1996	0	0	0.0	0.0
1997	-16	5,898	0.0	0.03
1998	-792	289,057	-0.1	1.55
1999	-3,244	1,184,424.	-0.38	6.19
2000	-3,428	1,251,313	-0.38	6.19
2001	-5,181	1,891,480	-0.57	9.29
2002	-7,030	2,566,537	-0.81	13.15
2003	-8,436	3,079,915	-0.96	15.48
2004	-10,705	3,908,275	-1.05	17.02
2005	-11,400	4,162,000	-1.15	18.57

[52] Source: George Morris Center (2004)

[53] Savings calculated by comparing the ai use and EIQ load if all of the crop was planted to a conventional (non GM) crop relative to the ai and EIQ levels on the actual areas of GM and non GM crops in each year

c) Brazil

Drawing on herbicide usage data for the period 2001-2003[54], the following changes in herbicide usage have occurred (Table 32):

- The annual average use of herbicide active ingredient per hectare in 2001-2003 was about 2.83 kg/ha for GM HT soybeans and 3.06 kg/ha for conventional soybeans[55];
- The average field EIQ/ha value for the two production systems was 43.3/ha for GM HT soybeans compared to 59/ha for conventional soybeans;
- In 2005, the total herbicide active ingredient and field EIQ savings were 2.9% (2 million kg) and 14.4% (141 million EIQ/ha units);
- Cumulatively since 1997, there has been a 1.2% saving in herbicide active ingredient use (5.16 million kg) and a 5.8% reduction in the environmental impact (361 million field EIQ/ha units).

Table 32: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Brazil 1997-2005

Year	ai saving (kg)	eiq saving (units)	% decrease in ai (- = increase)	% saving eiq
1997	22,333	1,561,667	0.1	0.3
1998	111,667	7,808,333	0.3	1.4
1999	263,533	18,427,667	0.7	3.3
2000	290,333	20,301,667	0.7	3.4
2001	292,790	20,473,450	0.7	3.4
2002	389,145	27,211,105	0.8	3.8
2003	670,000	46,850,000	1.2	5.9
2004	1,116,667	78,083,333	1.7	8.4
2005	2,010,000	140,550,000	2.9	14.4

d) Argentina

In assessing the changes in herbicide use associated with the adoption of GM HT soybeans in Argentina, it is important to take into consideration the following contextual factors:

- Prior to the first adoption of GM HT soybeans in 1996, 5.9 million ha of soybeans were grown, mostly using conventional tillage systems. The average use of herbicides was limited (1.1 kg ai/ha with an average field EIQ/ha value of 21[56]);
- By 2005, the area planted to soybeans had increased by 158% (to 15.2 million ha), with the majority (13.2 million ha) using no/reduced tillage systems that rely more on herbicide-based weed control programmes than conventional tillage systems. Ninety nine per cent of the total crop in 2005 was GM HT and 15% of the total crop was 'second crop soybeans' which followed on immediately behind a wheat crop in the same season.

Against this background, the use of herbicides in Argentine soybean production since 1996, has increased, both in terms of the volume of herbicide ai used and the average field EIQ/ha loading. In 2005, the average herbicide ai use was 2.97 kg/ha and the average field EIQ was 46/ha[57].

[54] Source: Derived from Kynetec herbicide usage data

[55] Inclusive of herbicides (mostly glyphosate) used in no/low tillage production systems for burndown

[56] Derived from Kynetec herbicide usage data

[57] Derived from Kynetec herbicide usage data

These changes should, however be assessed within the context of the fundamental changes in tillage systems that have occurred over the last ten years (some of which may possibly have taken place in the absence of the GM HT technology[58]). Also, the expansion in soybean plantings has included some areas that had previously been considered too weedy for profitable soybean cultivation. This means that comparing current herbicide use patterns with those of 10 years ago is not a reasonably representative comparison of the levels of herbicide use under a GM HT reduced/no tillage production system and a conventional reduced/no tillage soybean production system.

Making such a comparison (see Appendix 3 for examples of herbicide regimes that would be required to deliver a GM HT equivalent level of weed control for a conventional no/low tillage system) for the herbicide treatment programmes for these two production systems suggests that the current GM HT, largely no tillage production system, has a slightly lower volume of herbicide ai use (2.97 kg/ha compared to 3.22 kg/ha) than its conventional no tillage alternative. Also, in field EIQ/ha terms, there would be a saving of about 15 units/ha (GM HT field EIQ of 46/ha compared to 61/ha for conventional no/low tillage soybeans).

At the national level these reductions in herbicide use[59] are equivalent to:

- In 2005, a 7.7% reduction in the volume of herbicide ai used (3.76 million kg) and a 24.5% cut in the field EIQ load (226 million EIQ/ha units);
- Cumulatively since 1996, herbicide ai use is 6.5% lower (22 million kg) and the field EIQ load is 21% lower (1,320 million field EIQ/ha units) than the level that might reasonably be expected if the total Argentine soybean area had been planted to non GM cultivars using a no/low tillage production system.

e) Paraguay and Uruguay

The analysis presented below for these two countries is based on the experiences in Brazil and Argentina[60]. Thus, the respective differences for herbicide ai use and field EIQ values for GM HT and conventional soybeans used as the basis for the analysis are:

- Conventional soybeans: average volume of herbicide used 3.14 kg/ha and a field EIQ/ha value of 59.8/ha;
- GM HT soybeans: average volume of herbicide used 2.9 kg/ha and a field EIQ/ha value of 44.5/ha.

Based on these values the level of herbicide ai use and the total EIQ load, in 2005 were respectively 7.2% (0.5 million kg) and 24% (32.6 million EIQ/ha units) lower than would have been expected if the total crop had been conventional non GM soybeans. Cumulatively, since 1999, herbicide ai use has been 3.7% lower (1.28 million kg) and the total EIQ load nearly 12.7% lower (83 million EIQ/ha units).

[58] It is likely that the trend to increased use of reduced and no till systems would have continued in the absence of GM HT technology. However, the availability of this technology has probably played a major role in facilitating and maintaining reduced and no till systems at levels that would otherwise have not arisen

[59] Based on comparing the current GM HT no till usage with what would reasonably be expected if the same area and tillage system was planted to a conventional (non GM) crop and a similar level of weed control was achieved

[60] The authors are not aware of any published herbicide usage data for these two countries and have not been able to identify typical herbicide treatment regimes. Consequently, analysis has been based on the average of findings (differences between the average ai/ha and field EIQ/ha values in Brazil and Argentina)

f) Romania

Based on herbicide usage data for the years 2000-2003 from Brookes (2003), the adoption of GM HT soybeans in Romania has resulted in a small net increase in the volume of herbicide active ingredient applied, but a net reduction in the EIQ load (Table 33). More specifically:

- The average volume of herbicide ai applied has increased by 0.09 kg/ha from 1.26 kg/ha to 1.35 kg/ha);
- The average field EIQ/ha has decreased from 23/ha for conventional soybeans to 21/ha for GM HT soybeans;
- The total volume of herbicide ai use[61] is about 3% higher (equal to about 29,000 kg) than the level of use if the crop had been all non GM since 1999 (in 2005 usage was about 5.2% higher);
- The field EIQ load has fallen by 4% (equal to about 658,000 field EIQ/ha units) since 1999 (in 2005 the EIQ load was about 6.4% lower).

Table 33: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Romania 1999-2005

Year	Ai use (negative sign denotes an increase in use: kg)	eiq saving (units)	% decrease in ai (- = increase)	% saving eiq
1999	-1,502	34,016	-1.22	1.52
2000	-3,489	79,005	-3.06	3.81
2001	-1,744	39,502	-3.2	3.97
2002	-3,198	72,421	-3.55	4.41
2003	-3,876	87,783	-2.53	3.14
2004	-6,783	153,620	-4.48	5.57
2005	-8,479	192,025	-5.59	6.45

g) South Africa

GM HT soybeans have been grown in South Africa since 2000 (156,000 ha in 2005). Analysis of impact on herbicide use and the associated environmental impact of these crops (based on typical herbicide treatment regimes for GM HT soybeans and conventional soybeans: see Appendix 3) shows the following:

- Since 1999, the total volume of herbicide ai use has been about 3.6% higher (equal to about 44,000 kg of ai) than the level of use if the crop had been all non GM (in 2005 usage was about 6.8% higher);
- The field EIQ load has fallen by 6.6 (equal to about 1,691,000 field EIQ/ha units) since 1999 (in 2005 the EIQ load was 12.5% lower).

h) Summary of impact

Across all of the countries that have adopted GM HT soybeans since 1996, the net impact on herbicide use and the associated environmental impact[62] has been (Figure 15):

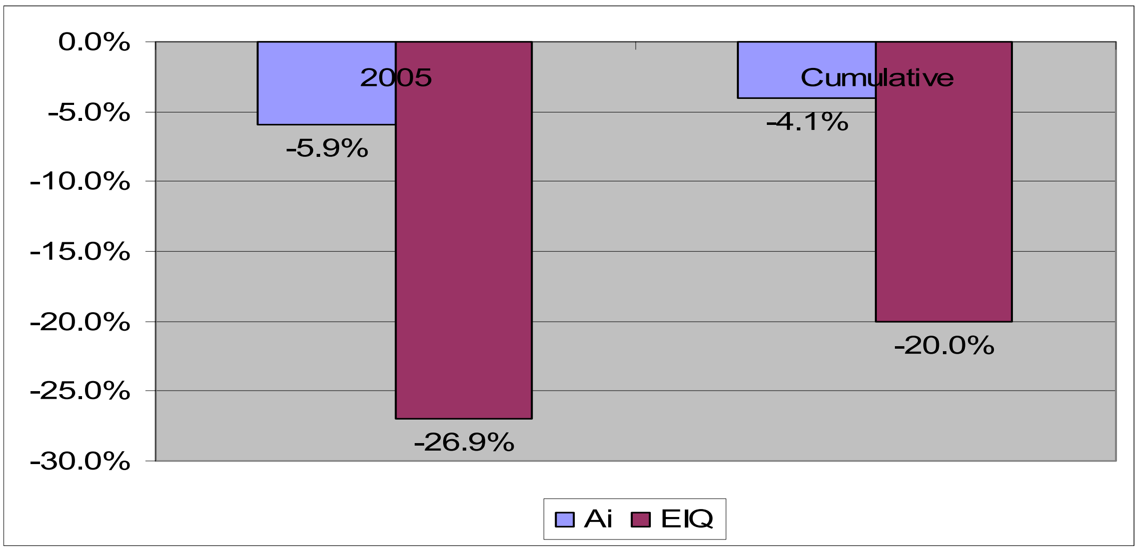
[61] Savings calculated by comparing the ai use and EIQ load if all of the crop was planted to a conventional (non GM) crop relative to the ai and EIQ levels based on the actual areas of GM and non GM crops in each year

[62] Relative to the expected herbicide usage if all of the GM HT area had been planted to conventional varieties, using the same tillage system (largely no/low till) and delivering an equal level of weed control to that obtained under the GM HT system

- In 2005, a 5.9% decrease in the total volume of herbicide ai applied (10 million kg) and a 26.9% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 4.1% less herbicide ai has been used (51 million kg) and the environmental impact applied to the soybean crop has fallen by 18.4%.

This suggests that over the period 1996-2005, there has been a significant net environmental gain directly associated with the application of the GM HT technology. This level of net environmental benefit has been increasing as the area planted to GM HT soybeans has expanded.

Figure 15: Reduction in herbicide use and the environmental load from using GM HT soybeans in all adopting countries 1996-2005



4.1.2 Herbicide tolerant maize

a) The USA

Drawing on the two main statistical sources of pesticide usage data (USDA and Doane Marketing Research Inc), Table 34 and Table 35 summarise the key features:

- Both average herbicide ai use and the average field EIQ/ha rating on the US maize crop have fallen by between 15% and 20% since 1996;
- The average herbicide ai/ha used on a GM HT maize crop has (over the last five years) been about 0.6 to 0.7 kg/ha lower than the corresponding conventional crop treatment;
- The average field EIQ/ha used on a GM HT crop has been about 20/ha units lower than the non GM equivalent.

Table 34: Herbicide usage on maize in the US 1996-2005

Year	Average ai use (kg/ha): NASS data	Average ai use (kg/ha): Doane data	Average field EIQ/ha: NASS data	Average field EIQ/ha: Doane data
1996	2.64	N/a	54.4	N/a
1997	2.30	N/a	48.2	N/a
1998	2.47	2.95	51.3	63
1999	2.19	2.60	45.6	61
2000	2.15	2.59	46.2	60
2001	2.30	2.56	48.8	59
2002	2.06	2.43	43.4	56
2003	2.29	2.45	47.5	56
2004	N/a	2.36	N/a	54
2005	2.1	2.38	51.1	53

Sources and notes: derived from NASS pesticide usage data 1996-2003 (no data collected in 2002), Doane Marketing Research Inc data from 1998-2005. N/a = not available

Table 35: Average US maize herbicide usage and environmental load 1997-2005: conventional and GM HT

Year	Average ai/ha (kg): conventional	Average ai/ha (kg): GMHT	Average field EIQ: conventional	Average field EIQ: GMHT
1997	2.76	1.85	69	40
1998	2.99	1.87	69	42
1999	2.63	1.86	75	40
2000	2.67	1.83	62	38
2001	2.63	1.98	62	42
2002	2.55	1.86	60	38
2003	2.61	1.87	61	37
2004	2.55	1.89	60	38
2005	2.63	2.04	61	41

Sources and notes: derived from Doane Marketing Research Inc 1998-2005. 1997 based on the average of the years 1997-1999

The analysis above comparing the GM HT crop with the conventional alternative may however, understate the herbicide usage for an average conventional maize grower. This is because the first users of the technology tend to be those with greatest levels of weed problems and more intensive producers, with average to above average levels of herbicide use. Also, as the uptake of the technology increases, the residual conventional maize growers tend to be those with lower than average weed infestation levels and/or with a tradition of growing maize on an extensive basis (and hence have historically used below average levels of inputs such as herbicides). The extent to which average herbicide use for conventional maize growers may be understated is nevertheless, likely to have been less important than in soybeans (or cotton) in the US, because of the relatively lower levels of GM HT adoption in the US maize crop to date (about 50% of the total crop in 2005).

Analysis by the NCFAP (2005) compared a typical herbicide treatment regime for a GM HT and an average conventional maize grower that would deliver a similar level of weed control to that level delivered in the GM HT system. This suggested that the values for conventional maize grower average were 3.74 kg herbicide ai/ha and a field EIQ rating of 76.6/ha (mix of herbicides such as acetochlor, atrazine, primsulfuron and dicamba). This compares with GM glyphosate tolerant maize (2.59 kg herbicide ai/ha and a field EIQ rating of 48.4/ha (use of glyphosate plus smaller doses of acetochlor and atrazine than conventional crops)) and GM glufosinate tolerant maize (2.22 kg herbicide ai/ha and a field EIQ/ha rating of 48.05/ha).

At the national level (Table 36), in 2005, there has been an annual saving in the volume of herbicide active ingredient use of 8% (9.3 million kg). The annual field EIQ load on the US maize crop has also fallen by about 11.5% in 2005 (equal to about 223 million field EIQ/ha units). The cumulative decrease in active ingredient use since 1997 has been 3% (35 million kg), and the cumulative reduction in the field EIQ load has been 4%.

Table 36: National level changes in herbicide ai use and field EIQ values for GM HT maize in the US 1997-2005

Year	ai decrease (kg)	eiq saving (units)	% decrease in ai	% saving eiq
1997	150,669	2,838,353	0.15	0.14
1998	2,035,698	40,343,821	2.03	1.95
1999	1,691,777	36,734,004	1.75	1.84
2000	2,637,395	55,876,620	2.65	2.73
2001	2,735,453	62,147,095	2.88	3.18
2002	4,230,314	97,606,088	4.28	4.80
2003	5,237,022	122,046,475	5.31	6.01
2004	7,009,440	166,797,955	5.72	7.99
2005	9,270,665	223,797,955	8.15	11.54

b) Canada

The impact on herbicide use in the Canadian maize crop has been similar to the impact reported above in the US. Using industry sourced information[63] about typical herbicide regimes for conventional and GM herbicide tolerant maize (see Appendix 3), the key impact findings are:

- The herbicide ai/ha load on a GM HT crop has been between 0.88 kg/ha (GM glyphosate tolerant) and 1.069 kg/ha (GM glufosinate tolerant) lower than the conventional maize equivalent crop (average herbicide ai use at 2.71 kg/ha);
- The field EIQ/ha values for GM glyphosate and GM glufosinate tolerant maize are respectively 37/ha and 39/ha compared to 62/ha for conventional maize;
- At the national level in 2005 (based on the plantings of the different production systems), the reductions in herbicide ai use and the total field EIQ load were respectively 13.2% (466,000 kg) and 14.3% (11.5 million: Table 37);
- Cumulatively since 1997, total national herbicide ai use has fallen by 4.8% (1.49 million kg) and the total EIQ load has fallen by 5.1% (35.9 million field EIQ units).

[63] Including the Weed Control Guide (2004) from the Departments' of Agriculture in Manitoba and Saskatchewan (available on the Canola Council's web-site www.canola-council.org)

Table 37: Change in herbicide use and environmental load from using GM HT maize in Canada 1999-2005

Year	Total active ingredient saving (kg)	Total field EIQ reductions (in units per hectare)
1999	59,176	1,324,689
2000	121,676	2,777,245
2001	177,444	4,143,290
2002	254,643	6,015,394
2003	208,998	5,110,911
2004	202,771	5,060,887
2005	465,835	11,520,577
Total	**1,490,543**	**35,952,993**

c) Other countries

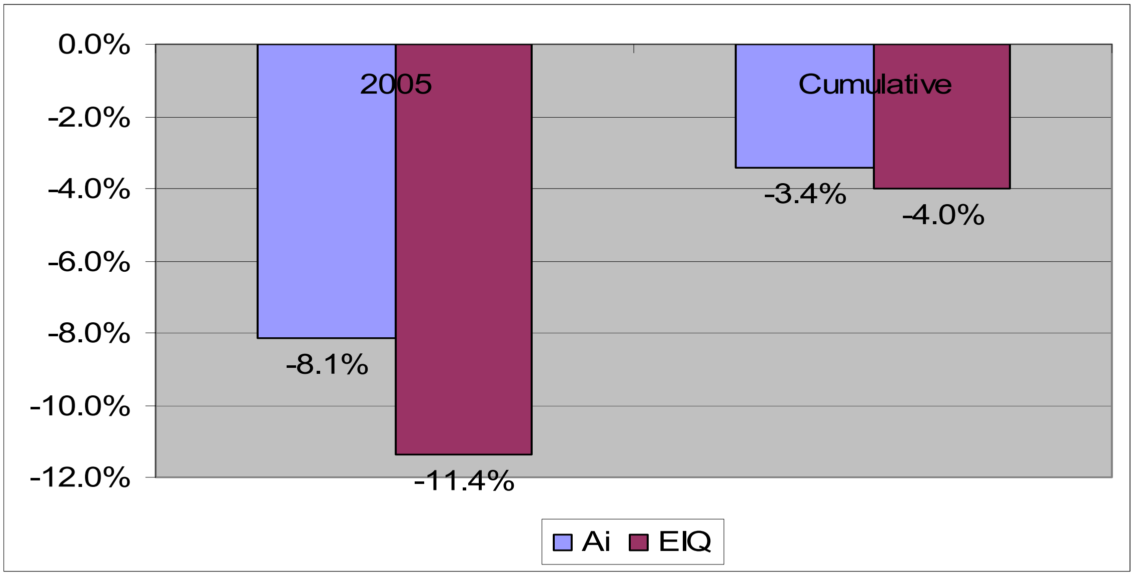
Relatively small areas of GM HT maize have also been grown in South Africa, since 2003 (19,000 ha in 2005) and in Argentina, since 2004 (70,000 ha in 2005). In South Africa, the impact has been to reduce both the volume of herbicide use and the environmental load (see Appendix 3), although because of relatively low level of adoption by 2005, the impact at the national level has been small. Analysis of impact on herbicide use and the associated environmental impact in Argentina are not presented, although it is expected that similar impacts to those in North America and South Africa will have occurred.

d) Summary of impact

In the two North American countries where GM HT maize has been most widely adopted, and South Africa, there has been a net decrease in both the volume of herbicides applied to maize and a net reduction in the environmental impact applied to the crop (Figure 16). More specifically:

- In 2005, total herbicide ai use was 8.1% lower (9.7 million kg) than the level of use if the total crop had been planted to conventional non GM (HT) varieties. The EIQ load was also lower by 11.4%;
- Cumulatively since 1997, the volume of herbicide ai applied is 3.4% lower than its conventional equivalent (a saving of 36.5 million kg). The EIQ load has been reduced by 4%.

Figure 16: Reduction in herbicide use and the environmental load from using GM HT maize in the US, Canada and South Africa 1997-2005



4.1.3 Herbicide tolerant cotton

a) The USA

Drawing on the herbicide usage data from the USDA and Doane Marketing Research Inc, both the volume of ai used and the average field EIQ/ha on the US cotton crop has remained fairly stable over the last ten years (Table 38).

Table 38: Herbicide usage on cotton in the US 1996-2005

Year	Average ai use (kg/ha): NASS data	Average ai use (kg/ha): Doane data	Average field EIQ/ha: NASS data	Average field EIQ/ha: Doane data
1996	1.98	N/a	39.2	N/a
1997	2.43	N/a	51.8	N/a
1998	2.14	2.25	41.3	53.6
1999	2.18	2.06	41.9	45.5
2000	2.18	2.21	39.4	47.4
2001	1.89	2.34	34.2	46.3
2002	N/a	2.29	N/a	45.1
2003	2.27	2.30	37.9	43.5
2004	N/a	2.49	N/a	46.0
2005	N/p	2.6	N/p	46.0

Sources and notes: derived from NASS pesticide usage data 1996-2003 (no data collected in 2002), Doane data from 1998-2005. N/p = Not presented - 2005 results based on NASS data are significantly different and inconsistent with previous trends and Doane data. These results have therefore not been presented

Looking at a comparison of average usage data for GM HT versus conventional cotton, the Doane dataset[64] shows that the average level of herbicide ai use (per ha) has been consistently higher than the average level of usage on conventional cotton. In terms of the average field EIQ/ha, the Doane dataset suggests that there has been a marginally lower average field EIQ rating for GM

[64] The NASS dataset does allow for comparisons between the two types of production systems

HT cotton in the years 1997 to 2000, but since 2000, the average field EIQ/ha rating has been lower for conventional cotton (Table 39).

Table 39: Herbicide usage and its associated environmental load: GM HT and conventional cotton in the US 1997-2005

Year	Average ai use (kg/ha): conventional cotton	Average ai use (kg/ha): GM HT cotton	Average field EIQ/ha: conventional cotton	Average field EIQ/ha: GM HT cotton
1997	2.1	2.38	48	46
1998	2.27	2.52	52	51
1999	1.92	2.27	44	43
2000	2.11	2.34	49	44
2001	1.93	2.51	45	47
2002	1.87	2.50	43	46
2003	1.65	2.53	37	46
2004	1.63	2.71	36	49
2005	1.60	2.79	36	48

Sources and notes: derived from Doane 1998-2005. 1997 based on the average of the years 1997-1999

The reader should, however note that this comparison between the GM HT crop and the conventional alternative is not a representative comparison of the average GM HT crop with the average conventional alternative and probably understates the herbicide usage for an average conventional cotton grower, especially as the level of GM HT cotton usage has increased. This is because the first users of the technology were those with greatest levels of weed problems and more intensive producers, with average to above average levels of herbicide use. Also, once uptake of the technology began to account for a significant part of the total US cotton area (from 1999 when the GM HT share became over 40% of the total crop), the residual conventional cotton growers have been those in locations with lower than average weed infestation levels and/or regions with a tradition of growing cotton on an extensive basis (and hence have historically used below average levels of inputs such as herbicides, eg, West Texas). As such, the average herbicide ai/ha and EIQ/ha values recorded for all remaining conventional cotton growers tends to fall and be lower than the average would have been if all growers had still been using conventional technology. One way of addressing this deficiency is to make comparisons between a typical herbicide treatment regime for GM HT and a typical herbicide treatment regime for an average conventional cotton grower that would deliver a similar level of weed control to that level delivered in the GM HT system in the same location.

This is the methodology used by the NCFAP (2003 and 2005). Based on this approach the respective values are, for conventional cotton, average herbicide ai use 5.67 kg/ha and a field EIQ/ha of 130/ha, and for GM GT cotton, herbicide ai use 3.72 kg/ha and a field EIQ of 63.8/ha. Given that these values are significantly higher than the average values for use across the US cotton in any year, we have therefore adjusted these values downwards to reflect actual average usage levels. On this basis the comparison level of usage recorded (and used in the national level analysis below) is:

- conventional cotton average, herbicide ai use 3.5 kg/ha and a field EIQ/ha of 95.6/ha;
- GM GT cotton, herbicide ai use 2.29 kg/ha and a field EIQ of 46.9/ha.

At the national level (Table 40), this equates to 21% and 31% savings respectively in ai use and the field EIQ value for 2005. Cumulatively since 1997, the savings using this methodology have been 16% for ai use (28.7 million kg) and 24% (1,156 million field EIQ units).

Table 40: National level changes in herbicide ai use and field EIQ values for GM HT cotton in the US 1997-2005

Year	ai decrease (kg)	eiq saving (units)	% decrease in ai	% saving eiq
1997	714,529	28,758,324	3.6	5.3
1998	1,718,248	69,155,948	9.1	13.3
1999	3,066,139	123,405,751	14.6	21.4
2000	3,495,448	140,684,560	15.9	23.4
2001	4,323,766	174,022,632	19.4	28.5
2002	4,094,301	164,787,164	20.1	29.6
2003	3,468,126	139,584,914	20.4	30.1
2004	3,836,184	154,398,480	20.7	30.6
2005	4,004,931	161,190,182	21.1	31.1

Note: based on adjusted NCFAP methodology

b) Australia

Drawing on information from the University of New England study from 2003[65], analysis of the typical herbicide treatment regimes for GM HT and conventional cotton (see Appendix 3) shows the following:

- The herbicide ai/ha load on a GM HT crop has been about 0.11 kg/ha higher (at 2.87 kg/ha) than the conventional cotton equivalent crop (2.77 kg/ha);
- The average field EIQ/ha value for GM GT cotton has been 51/ha compared to 66/ha for conventional cotton;
- At the national level (Table 41), in 2005 (based on the plantings of the different production systems), herbicide ai use has been 2.9% higher (24,235 kg) than the level expected if the whole crop had been planted to non GM cotton cultivars. The total field EIQ load was, however 16.6% lower;
- Cumulatively since 2000, total national herbicide ai use has increased by 0.7% (70,000 kg) although the total EIQ load had fallen by 3.9%.

Table 41: National level changes in herbicide ai use and field EIQ values for GM HT cotton in Australia 2000-2005 (negative sign denotes increase in use)

Year	ai increase (kg)	eiq saving (units)	% increase in ai	% saving eiq
2000	-1,290	178,358	0.1	0.5
2001	-8,051	1,113,148	0.8	4.8
2002	-9,756	1,348,907	1.5	8.9
2003	-9,028	1,248,239	1.7	9.7
2004	-17,624	2,436,743	2.0	11.8
2005	-24,235	3,350,739	2.9	16.6

c) Other countries

Cotton farmers in South Africa and Argentina have also been using GM HT technology (since 2000 in South Africa and since 2002 in Argentina). The plantings have, however been fairly

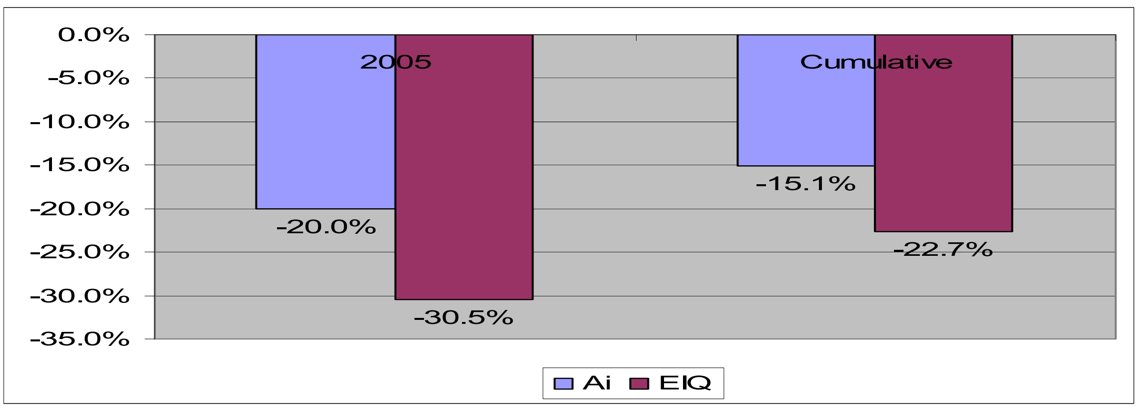
[65] Doyle B et al (2003)

small, with annual plantings of less than 10,000 hectares in each country[66](only 11,500 ha planted in South Africa in 2005). In South Africa, the impact has been to marginally increase the volume of herbicides used per hectare but to reduce the environmental load/ha (see Appendix 3). At the national level (recognising the small scale of adoption by 2005), the impact (since 2000) has been a marginal increase in the volume of herbicide used (1.51%) but a 6% decrease in the environmental impact. No analysis is presented for Argentina because of the limited availability of herbicide usage data.

d) Summary of impact

The overall effect of using GM HT cotton technology (Figure 17) in the US, Australia and South Africa in 2005, has been a reduction in herbicide ai use[67] of 20% and a decrease in the total environmental impact of 30%. Cumulatively since 1997, herbicide ai use has fallen by 15% and the total environmental impact has fallen by 23%.

Figure 17: Reduction in herbicide use and the environmental load from using GM HT cotton in the US, Australia and South Africa 1997-2005



4.1.4 Herbicide tolerant canola

a) The USA

Based on analysis of typical herbicide treatments for conventional, GM glyphosate tolerant and GM glufosinate tolerant canola identified in NCFAP 2005 (see Appendix 3), the changes in herbicide use and resulting environmental impact arising from adoption of GM HT canola in the US since 1999[68] have been:

- A reduction in the average volume of herbicide ai applied of 0.012 kg/ha (GM glyphosate tolerant) or 0.696 kg/ha (GM glufosinate tolerant) up to 2003 and a reduction in the average volume of herbicide ai applied of 0.8 kg/ha (GM glyphosate tolerant) or 0.78 kg/ha (GM glufosinate tolerant) from 2004 onwards;
- A decrease in the average field EIQ/ha of 11/ha (GM GT) or 15/ha (GM glufosinate tolerant) for the period to 2003. The estimated decrease for 2004 and 2005 is a fall in the average field EIQ/ha of 23/ha (GM GT) or 17/ha (GM glufosinate tolerant);
- The reduction in the volume of herbicides used was equal to about 340,000 kg of active ingredient (two thirds reduction) in 2005;

[66] Except in 2004 in Argentina when there was a significant increase to over 100,000 ha

[67] Relative to the herbicide use expected if all of the GM HT area had been planted to conventional cultivars, using the same tillage system and providing the same level of weed control as delivered by the GM HT system

[68] The USDA pesticide usage survey does not include coverage of canola

- In terms of the EIQ load, this had fallen by 9 million field EIQ units (70%) compared to the load that would otherwise have been applied if the entire 2005 crop had been planted to conventional varieties;
- Cumulatively, since 1999, the amount of active ingredient use has fallen by 28%, and the EIQ load reduced by 38%.

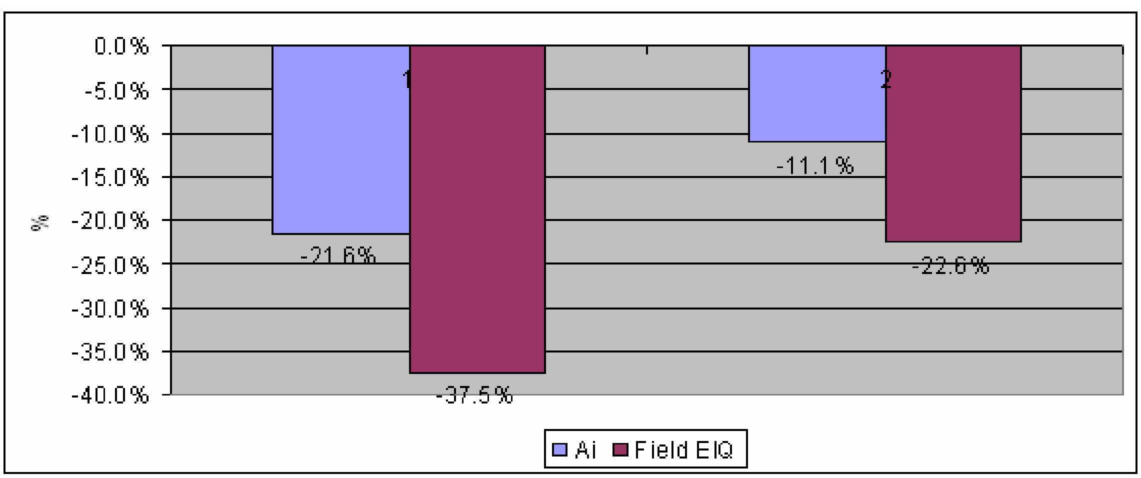
b) Canada
Similar reductions in herbicide use and the environmental 'foot print', associated with the adoption of GM HT canola have been found in Canada (see Appendix 3):

- The average volume of herbicide ai applied to GM HT canola has been 1.15 kg/ha (GM glyphosate tolerant) and 0.466 kg/ha (GM glufosinate tolerant), compared to 1.129 kg/ha for conventional canola;
- the average field EIQ/ha load for GM HT canola is significantly lower than the conventional counterpart (18/ha for GM glyphosate tolerant canola, 14/ha for GM glufosinate tolerant canola, 28/ha for conventional canola);
- the reduction in the volume of herbicide used was about 1.05 million kg (a reduction of about 17.7%) in 2005. Since 1996, the cumulative reduction in usage has been 10% (-5.1 million kg);
- in terms of the field EIQ load, the reduction in 2005 was 34.6% (-50.8 million) and over the period 1996-2005, the load factor fell by 22%.

c) Summary of overall impact
In the two North American countries where GM HT canola has been adopted, there has been a net decrease in both the volume of herbicides applied to canola and the environmental impact applied to the crop (Figure 18). More specifically:

- In 2005, total herbicide ai use was 22% lower (1.39 million kg) than the level of use if the total crop had been planted to conventional non GM varieties. The EIQ load was also significantly lower by 37%;
- Cumulatively since 1996, the volume of herbicide ai applied was 11% lower than its conventional equivalent (a saving of 6.2 million kg). The EIQ load had been reduced by 23%.

Figure 18: Reduction in herbicide use and the environmental load from using GM HT canola in the US and Canada 1996-2005



4.1.6 GM insect resistant (Bt) maize

a) The US

Since 1996, when GM insect resistant (Bt) maize (GM IR) was first used commercially in the US, the average volume of insecticide use has fallen (Table 42). Whilst levels of insecticide ai use have fallen for both conventional and Bt maize, usage by GM IR growers has consistently been lower than their conventional counterparts. A similar pattern has occurred in respect of the average field EIQ value.

At the national level, the use of GM IR maize has resulted in an annual saving in the volume of insecticide ai use of over 12% in 2005 (about 0.6 million kg) and the annual field EIQ load on the US maize crop has fallen by about 10% in 2005 (equal to about 21 million field EIQ/ha units). Since 1996, the cumulative decrease in insecticide ai use has been 4% (6.4 million kg), and the cumulative reduction in the field EIQ load has been 4.6% (Table 43).

Table 42: Average US maize insecticide usage and its environmental load 1996-2005: conventional versus GM

Year	Average ai/ha (kg): conventional	Average ai/ha (kg): GM IR	Average field EIQ: conventional	Average field EIQ: GM IR
1996	0.58	0.49	31.1	25.2
1997	0.59	0.5	29.8	24.1
1998	0.65	0.55	34.8	28.1
1999	0.64	0.57	34.5	30.2
2000	0.61	0.54	31.7	27.6
2001	0.52	0.43	27.1	20.9
2002	0.51	0.36	25.5	17.1
2003	0.44	0.31	22.2	13.4
2004	0.3	0.2	14.2	9.0
2005	0.17	0.11	7.0	5.0

Sources: derived from Doane and USDA

Table 43: National level changes in insecticide ai use and field EIQ values for GM IR maize in the US 1996-2005

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% saving eiq
1996	27,000	1,770,000	0.1	0.2
1997	220,166	13,943,842	1.2	1.5
1998	619,642	41,516,027	2.9	3.7
1999	567,795	34,878,857	2.8	3.2
2000	428,140	25,076,789	2.2	2.5
2001	524,218	36,112,768	3.3	4.3
2002	1,174,126	63,402,791	7.2	7.9
2003	1,201,273	81,316,928	8.6	11.5
2004	1,048,416	54,307,949	10.7	11.7
2005	638,296	21,276,535	12.4	10.0

This analysis may understate the positive environmental impact of the technology because it may understate the average values for insecticide ai/ha use and field EIQ/ha of conventional producers as the level of GM IR maize usage increases. This is because the first users of the technology tend to be those with greatest and most frequent incidence of corn boring pest infestation and hence have been the greatest users of insecticides. Once uptake of the technology began to account for more than 10%-20% of total production (from 1998), the residual conventional maize growers have been those in lower infestation regions, who have probably rarely, if at all used insecticide treatments targeted at corn boring pests. Accordingly, the average ai/ha and EIQ/ha values recorded for all remaining conventional maize growers tends to fall and be lower than the average would have been if all growers had still been using conventional technology. One way of addressing this deficiency is to make comparisons between a typical insecticide treatment regime for GM IR and conventional maize growers in regions with average corn boring pest infestation levels and to use the average values for insecticide use in the 1996-1998 period as the baseline for measuring the changes post adoption. This is the methodology used by Gianessi and Carpenter (1999). Applying this approach, the impact of using GM IR maize has been to reduce the average volume of insecticides used by about 0.45 kg/ha and to reduce the average field EIQ by just over 21/ha. At the national level[69], this equates to 21% and 20% savings respectively in insecticide ai use and the field EIQ value for 2005. Cumulatively since 1996, the savings using this methodology have been 21.3% for insecticide ai use (12.6 million kg) and 21.4% (599 million field EIQ units)[70].

b) Canada

As in the US, the main impact has been associated with reduced use of insecticides. Based on analysis of a typical insecticide treatment regime targeted at corn boring pests prior to the introduction of GM IR technology that is now no longer required[71], this has resulted in a farm level saving of 0.43 kg/ha of ai use and a reduction of the field EIQ/ha of 20.7/ha. Applying this saving to the area devoted to GM IR maize in 1997 and then to a maximum of 5% of the total Canadian maize area in any subsequent year, the cumulative reduction in insecticide ai use has been 225,000 kg (25,000 kg/year). In terms of environmental load, the total EIQ/ha load has fallen by 11 million units[72].

c) Spain

Based on data for the years 1999-2001 from Brookes (2002), the adoption of GM IR maize, has resulted in a net decrease in both the volume of insecticide used and the field EIQ/ha load[73]. More specifically:

- The volume of insecticide ai use[74] was 48% lower than the level would probably have been if the crop had been all non GM in 2005 (-42,000 kg). Since 1998 the cumulative

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[69] The maximum area that the benefit could apply to was also constrained to 10% of the total US maize crop – the estimated pre-GM IR area that had traditionally received insecticide treatments targeted at corn boring pests

[70] The reader should note that the absolute values cited here are not directly comparable with the values derived above because of the different baselines used. The above methodology uses the current value for conventional insecticide use (ai and field EIQ) in each year whilst the latter methodology uses the 1996-98 average values as the baseline

[71] And limiting the national impact to about 5% of the total maize crop in Canada – the estimated maximum area that probably received insecticide treatments targeted at corn boring pests before the introduction of GM IR maize

[72] It has not been possible to place this in context with total insecticide use on the Canadian maize crop. If however it is assumed that total insecticide use on maize/ha in Canada has been similar to usage patterns in the US, the total annual savings in insecticide ai use and EIQ load since 1999 (the first year when the area planted to GM IR maize was greater than the previous area receiving insecticide treatments targeting corn boring pests) have been 70% and 65% respectively

[73] The average volume of insecticide ai used is 0.96 kg/ha and the average field EIQ is 42/ha

[74] Insecticides that target corn boring pests

saving (relative to the level of use if all of the crop had been non GM) was 239,000 kg of insecticide ai (a 34% decrease);
- The field EIQ/ha load has fallen by 30% since 1999 (-10.4 million units). In 2005, the field EIQ load was about 43% lower than its conventional equivalent.

d) Argentina

Although, GM IR maize has been grown commercially in Argentina since 1998, the environmental impact of the technology has been very small. This is because insecticides have not traditionally been used on maize in Argentina (the average expenditure on all insecticides has only been $1-$2/ha), and very few farmers have used insecticides targeted at corn boring pests. This absence of conventional treatments reflects several reasons including poor efficacy of the insecticides, the need to get spray timing right (at time of corn borer hatching), seasonal and annual variations in pest pressure and lack of awareness as to the full level of yield damage inflicted by the pest. As indicated in section 3, the main benefits from using the technology have been significantly higher levels of average yield and reduced production risk.

e) South Africa

Due to the limited availability of insecticide usage data in South Africa, the estimates of the impact on insecticide use from use of GM IR maize in South Africa presented below are based on the following assumptions:

- Irrigated crops are assumed to use two applications of cypermethrin to control corn boring pests. This equates to about 0.168 kg/ha of active ingredient and a field EIQ of 4.59/ha (applicable to area of 200,000 ha);
- A dryland crop area of about 1,768,000 ha is assumed to receive an average of one application of cypermethrin. This amounts to 0.084 kg/ha of active ingredient and has a field EIQ of 2.29/ha;
- The first 200,000 ha to adopt GM IR technology is assumed to be irrigated crops.

Based on these assumptions:

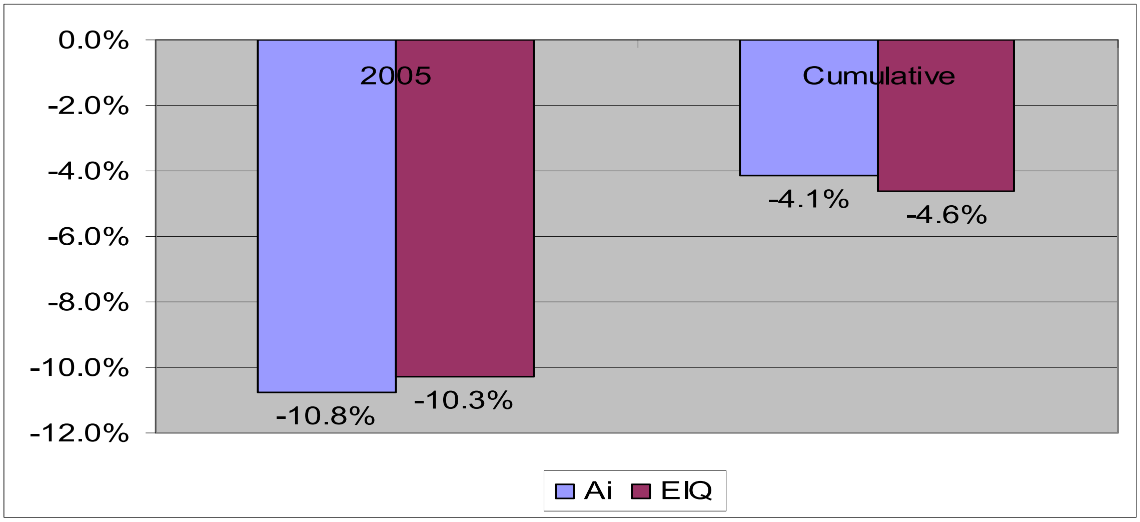
- In 2005, the adoption of GM IR maize resulted in a net reduction in the volume of insecticides used (relative to the volume that would probably have been used if 2.5 million ha had been treated with insecticides targeted at corn boring pests) and the EIQ load of 30% (-49,600 kg of ai);
- Cumulatively since 2000, the reductions in the volume of ai use and the associated environmental load from sprayed insecticides were both 20% (-200,000 kg ai).

f) Summary of impact

Across all of the countries that have adopted GM IR maize since 1996, the net impact on insecticide use and the associated environmental load (relative to what could have been expected if all maize plantings had been to conventional varieties) have been (Figure 19):

- In 2005, a 10.8% decrease in the total volume of insecticide ai applied (1.16 million kg) and a 10.3% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 4.1% less insecticide ai has been used (7 million kg) and the environmental impact from insecticides applied to the maize crop has fallen by 4.6%.

Figure 19: Reduction in insecticide use and the environmental load from using GM IR maize in adopting countries 1996-2005



4.1.7 GM insect resistant (Bt) cotton

a) The US

Whilst the annual average volume of insecticides used on the US cotton crop has fluctuated, there has been an underlying decrease in usage (Table 44). Applications on GM IR crops have also been consistently lower (by between 20% and 40% lower in terms of insecticide ai use). In field EIQ/ha terms, the GM IR crop also has a consistently lower value by 30% to 40%[75].

Table 44: Average US cotton insecticide usage and environmental impact 1996-2005: conventional versus GM

Year	Average ai/ha (kg): conventional	Average ai/ha (kg): GM IR	Average field EIQ: conventional	Average field EIQ: GM IR
1996	1.15	1.01	40.1	32.4
1997	1.65	1.49	53.0	44.1
1998	1.39	1.26	51.3	43.6
1999	1.14	0.98	67.0	40.9
2000	1.24	1.22	48.3	42.3
2001	1.23	0.95	49.1	32.4
2002	0.8	0.97	31.0	20.6
2003	1.39	0.83	51.0	28.7
2004	0.86	0.93	32.1	29.0
2005	0.90	0.81	30.0	26.0

Sources: derived from Doane and USDA

This analysis does however, probably understate the positive environmental impact of the technology because it may understate the average values for insecticide ai/ha use and field EIQ/ha

[75] It should be noted that in the last two years there has been a 'narrowing' of the gap between insecticide use on the non GM IR crop relative to the GM IR crop. This can be largely attributed to the non GM IR crop having become a minority element of total production on which average pest infestation levels tend to be lower than average and hence their average level of insecticide use tends to be below average)

for conventional producers (as the level of GM IR cotton usage increases). This is because the first users of the technology tend to be those with greatest and most frequent incidence of bollworm infestation and hence have been the greatest users of insecticides targeted at these pests. Once uptake of the technology began to account for more than a third of total production (from 1999), the residual growers of conventional cotton have been those in lower infestation regions, with below average levels of insecticide treatments. Accordingly, the average ai/ha and EIQ/ha values recorded for all conventional cotton growers tends to fall and be lower than the average would have been if all growers had only been using conventional technology. One way of addressing this deficiency is to make the comparisons between a typical insecticide treatment regime for GM IR and conventional cotton growers in regions with average infestation levels and to use the average values for insecticide use in the 1996-1998 period as the baseline for measuring the changes post adoption. This is the methodology used by the NCFAP in 2001, 2003 and 2005. Applying this approach, the impact of using GM IR cotton (Table 45) has been to reduce the average volume of insecticides used by 0.28 kg/ha and to reduce the average field EIQ by 34.4/ha. At the national level, this equates to 10% and 35% savings respectively in insecticide ai use and the field EIQ value in 2005. Cumulatively since 1996, the savings using this methodology have been 6% for insecticide ai use (5.14 million kg) and 23% (632 million field EIQ units)[76].

Table 45: National level changes in insecticide ai use and field EIQ values for GM IR cotton in the US 1996-2005

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% saving eiq
1996	229,909	28,245,978	3	10
1997	236,208	29,019,840	3	11
1998	254,957	31,323,264	3	12
1999	544,358	66,878,313	6	23
2000	615,440	75,611,200	7	25
2001	661,072	81,217,368	7	26
2002	571,732	70,241,360	7	25
2003	557,698	68,517,232	8	29
2004	680,579	83,611, 016	9	33
2005	790,026	97,060,288	10	35

b) China

Since the adoption of GM IR cotton in China there have been substantial reductions in the use of insecticides. In terms of the average volume of insecticide ai applied to cotton, the application to a typical hectare of GM IR cotton is about 1.35 kg/ha compared to 6.02 kg/ha for conventionally grown cotton (a 77% decrease: see Appendix 3)[77]. In terms of an average field EIQ load/ha the GM IR cotton insecticide load is 61/ha compared to 292/ha for conventional cotton.

Based on these differences the amount of insecticide ai used and its environmental load impact has been 51% lower in 2005 (Table 46) than the levels that would have occurred if only non GM cotton had been planted. Cumulatively since 1997, the volume of insecticide use has decreased by 30% (76 million kg ai) and the field EIQ load has fallen by 28% (3 billion field EIQ/ha units).

[76] The reader should note that the absolute values cited here are not directly comparable with the values derived above because of the different baselines used. The above methodology uses the current value for conventional insecticide use (ai and field EIQ) in each year whilst the latter methodology uses the 1996-98 average values as the baseline

[77] Sources: based on a combination of industry views and Prey et al (2001)

Table 46: National level changes in insecticide ai use and field EIQ values for GM IR cotton in China 1997-2005

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% saving eiq
1997	158,780	7,843,630	1	1
1998	1,218,870	60,211,395	4	5
1999	3,054,180	150,874,530	14	14
2000	5,678,720	280,525,120	25	25
2001	10,152,580	501,530,930	35	36
2002	9,807,000	484,459,500	39	40
2003	13,076,000	645,946,000	42	43
2004	17,279,000	853,571,500	50	51
2005	15,411,000	761,293,500	50	51

c) Australia

Using a combination of data from industry sources and CSIRO[78], the following changes in insecticide use on Australian cotton have occurred:

- There has been a significant reduction in both the volume of insecticides used and the environmental impact associated with this spraying (Table 47). The average field EIQ/ha value of the single Bt gene Ingard technology was less than half the average field EIQ/ha for conventional cotton. In turn, this saving has been further increased with the availability and adoption of the two Bt gene technology in Bollgard II cotton from 2003/04;
- The total amount of insecticide ai used and its environmental impact (Table 48) has been respectively 65% (2.18 million kg) and 67% lower in 2005, than the levels that would have occurred if only conventional cotton had been planted;
- Cumulatively, since 1996 the volume of insecticide use is 23% lower (9.26 million kg) than the amount that would have been used if GM IR technology had not been adopted and the field EIQ load has fallen by 22%.

Table 47: Comparison of insecticide ai use and field EIQ values for conventional, Ingard and Bollgard II cotton in Australia

	Conventional	Ingard	Bollgard II
Active ingredient use (kg/ha)	11.0	4.3	2.2
Field EIQ value/ha	220	97	39

Sources and notes: derived from Industry sources and CSIRO 2005. Ingard cotton grown from 1996, Bollgard from 2003/04

[78] The former making a direct comparison of insecticide use of Bollgard II versus conventional cotton and the latter a survey-based assessment of actual insecticide usage in the years 2002-03 and 2003-04

Table 48: National level changes in insecticide ai use and field EIQ values for GM IR cotton in Australia 1996-2005

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% saving eiq
1996	266,945	4,900,628	6.1	5.6
1997	390,175	7,162,905	9.1	8.4
1998	667,052	12,245,880	12.2	11.2
1999	896,795	16,463,550	15.2	14.0
2000	1,105,500	20,295,000	19.6	18.0
2001	909,538	16,697,496	23.8	21.9
2002	481,911	8,847,021	19.1	17.6
2003	427,621	7,850,352	20.1	18.4
2004	1,932,876	39,755,745	56.1	57.7
2005	2,177,393	44,785,011	64.7	66.6

d) Argentina

Adoption of GM IR cotton in Argentina has also resulted in important reductions in insecticide use[79]:

- The average volume of insecticide ai used by GM IR users is 44% lower than the average of 1.15 kg/ha for conventional cotton growers;
- The average field EIQ/ha is also significantly lower for GM IR cotton growers (53/ha for conventional growers compared to 21/ha for GM IR growers);
- The total amount of ai used and its environmental impact (Table 49) have been respectively 2.7% (11,475 kg) and 3.6% lower (720,000 units) in 2005, than the levels that would have occurred if only conventional cotton had been planted;
- Cumulatively since 1998, the volume of insecticide use is 2.9% lower (3.65 million kg) and the EIQ/ha load 3.9% lower (6.6 million units) than the amount that would have been used if GM IR technology had not been adopted.

Table 49: National level changes in insecticide ai use and field EIQ values for GM IR cotton in Argentina 1998-2005

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% saving eiq
1998	2,550	160,000	0.3	0.3
1999	6,120	384,000	0.8	1.1
2000	12,750	800,000	3.3	4.5
2001	5,100	320,000	1.1	1.6
2002	10,200	640,000	5.4	7.4
2003	29,580	1,856,000	17.6	23.9
2004	28,050	1,760,000	9.6	13.1
2005	11,475	720,000	2.7	3.6

Note: derived from sources including CASAFE and Kynetec

[79] Based on data from Quam and De Janvry (2005)

e) India

The analysis presented below is based on typical spray regimes for GM IR and non GM IR cotton (source: Monsanto India). The respective differences for ai use and field EIQ values for GM IR and conventional cotton used are:

- Conventional cotton: average volume of insecticide used was 3.57 kg/ha and a field EIQ/ha value of 107/ha;
- GM IR cotton: average volume of insecticide used was 1.44 kg/ha and a field EIQ/ha value of 54/ha.

Based on these values the level of insecticide ai use and the total EIQ load, in 2005 was respectively 9.8% (2.76 million kg) and 8.3% (70.5 million EIQ/ha units) lower than would have been expected if the total crop had been conventional non GM cotton. Cumulatively, since 2002, the insecticide ai use was 3.7% lower (4.13 million kg) and the total EIQ load 3.1% lower (3.36 million EIQ/ha units).

f) Other countries

Cotton farmers in South Africa, Mexico and Columbia have also been using GM IR technology in recent years (respectively since 1998, 1996 and 2002). The plantings have, however been fairly small (in 2005, 17,300 ha in South Africa, 120,000 ha in Mexico and 28,000 in Columbia).

In Mexico, there has been an annual average reduction in insecticide use over the 1996-2004 period of 15,650 kg of product used, which cumulatively since 1996 amounts to a reduction in use of 140,875 kg[80]. Analysis of the impact on insecticide use and the associated environmental 'foot print' are not presented for these crops because of the small scale and limited availability of insecticide usage data.

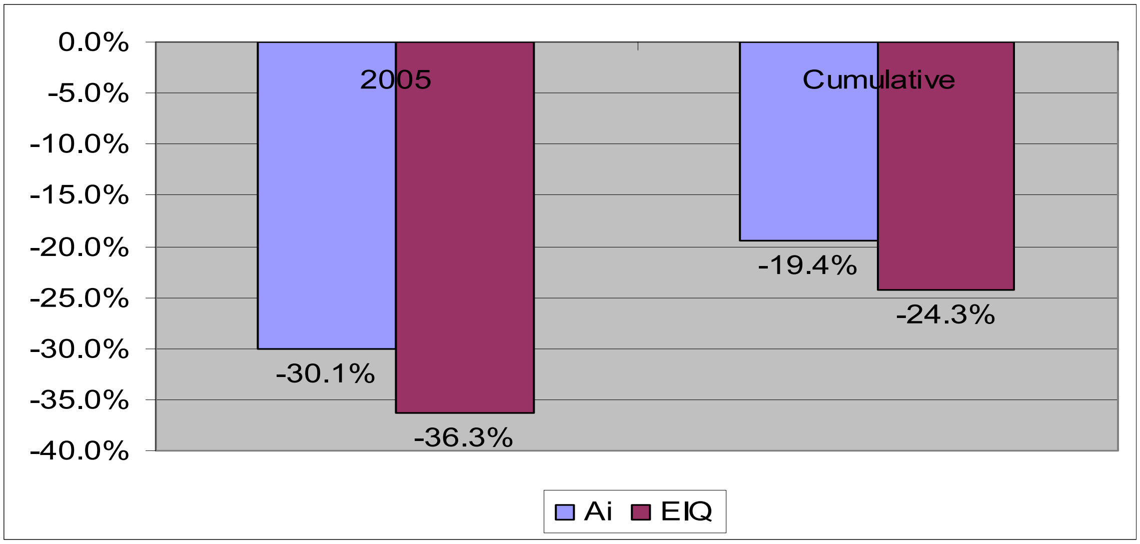
g) Summary of impact

Since 1996, the net impact on insecticide use and the associated environmental 'foot print' (relative to what could have been expected if all cotton plantings had been to conventional varieties) in the main GM IR adopting countries has been (Figure 20):

- In 2005, a 30% decrease in the total volume of insecticide ai applied (21 million kg) and a 36% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 19% less insecticide ai has been used (94 million kg) and the environmental impact from insecticides applied to the cotton crop has fallen by 24%.

[80] Source: Official report to the Ministry of Agriculture by Monsanto Comercial (2004)

Figure 20: Reduction in insecticide use and the environmental load from using GM IR cotton in adopting countries 1996-2005



4.2 Carbon sequestration

This section assesses the contribution of GM crop adoption to reducing the level of greenhouse gas (GHG) emissions. The scope for GM crops contributing to lower levels of GHG comes from two principle sources:

- Fewer herbicide or insecticide applications (eg, targeted insecticide programmes developed in combination with GM insect resistant (IR) cotton where the number of insecticide treatments has been significantly reduced and hence there are fewer tractor spray passes);
- The use of 'no-till' and 'reduced-till'[81] farming systems. These have increased significantly with the adoption of GM HT crops because the GM HT technology has improved growers ability to control competing weeds, reducing the need to rely on soil cultivation and seed-bed preparation as means to getting good levels of weed control. As a result, tractor fuel use for tillage is reduced, soil quality is enhanced and levels of soil erosion cut. In turn, more carbon remains in the soil and this leads to lower GHG emissions[82].

The mitigation of GHG can be measured in terms of the amount of carbon dioxide removed from the atmosphere (due to reduced consumption of tractor fuel and the storing of carbon in the soil) which would otherwise have been released as carbon dioxide.

4.2.1 Tractor fuel use

a) Reduced and no tillage

[81] No-till farming means that the ground is not ploughed at all, while reduced tillage means that the ground is disturbed less than it would be with traditional tillage systems. For example, under a no-till farming system, soybean seeds are planted through the organic material that is left over from a previous crop such as corn, cotton or wheat without any soil disturbance

[82] The International Panel on Climate Change (IPPC) has agreed that conservation/no till cultivation leads to higher levels of soil carbon

The traditional method of soil cultivation is based on the use of the moldbord plough followed by a range of seed bed preparations. This has, however been increasingly replaced in recent years by less intensive methods such as reduced tillage (RT: using reduced chisel or disc ploughing, ridge tilling) or no tillage (NT). These RT/NT systems rely much more on herbicide-based weed control, often comprising a pre-plant burn-down application and secondary applications post-emergent. The amount of tractor fuel used for seed-bed preparation, herbicide spraying (NT only) and planting for in each of these systems is shown in Table 50:

Table 50: Tractor fuel consumption by tillage method

	litre/ha
Traditional cultivation: moldbord plough, disc and seed planting etc	46.65
Conservation cultivation (RT): chisel plough, disc and seed planting	28.83
No-till (fertiliser knife, seed planting plus 2 sprays: pre-plant burn down and post-emergent)	14.12

Source: Adapted from Jasa (2002) and CTIC 2004

In terms of GHG each litre of tractor diesel consumed contributes an estimated 2.75 kg of carbon dioxide into the atmosphere[83]. The adoption of NT farming systems is therefore estimated to reduce cultivation and seed bed preparation fuel usage by an estimated 32.52 litres/ha compared with traditional conventional tillage and 14.7 litres/ha compared with (the average of) reduced till conservation cultivation. In turn, this results in reductions of carbon dioxide emissions of 89.44 kg/ha and 40.43 kg/ha respectively.

b) Reduced application of herbicides and insecticides

For both herbicide and insecticide spray applications, the quantity of energy required to apply the pesticides depends upon the application method. For example, in the US a typical method of application is with a self-propelled boom sprayer which consumes approximately 1.045 litres/ha (Lazarus & Selley 2005). One less spray application therefore reduces carbon dioxide emissions by 2.87 kg/ha[84].

The conversion of one hectare of conventional tillage to no till equates to approximately 596 km travelled by a standard family car[85] and one less spray pass is equal to nearly 19.2 km travelled.

4.2.2 Soil carbon sequestration

The most effective natural method of absorbing atmospheric carbon dioxide is by photosynthesis, where plants convert carbon dioxide into plant tissue (lignin, carbohydrates etc). When a plant dies, a portion of the stored carbon is left behind in the soil by decomposing plant residue (roots, stalks etc) and a larger portion is emitted back into the atmosphere. This organic carbon is maintained in soils through a dynamic process with plants acting as the primary vehicle. Decomposition rates tend to be proportional to the amount of organic matter in the soil. By enhancing the organic matter a higher Carbon-Stock Equilibrium (CSE) can be achieved. For example a shift from conventional tillage to RT/NT increases the amount of crop residue returned

[83] Source: http://www.unep.org/PCFV/Documents/FIA-EcoProtocol3.pdf

[84] Given that many farmers apply insecticides via sprayers pulled by tractors, which tend to use higher levels of fuel than self-propelled boom sprayers, the estimates used in this section (for reductions in carbon emissions), which are based on self-propelled boom application, probably understate the carbon benefits

[85] Assumed standard family car carbon dioxide emission rating = 150 grams/km. Therefore 89.44kg of carbon dioxide divided by 150g/km = 596 km

to the soil and decreases the decomposition rate of soil organic matter. Continuous use of NT will result in an increase in soil carbon over time until a higher CSE is reached.

Changes in cultivation management can therefore potentially increase the accumulation of soil organic carbon (SOC), thereby sequestering more carbon dioxide from the atmosphere. More specifically:

- The degradation of crop soils by the oxidation of soil carbon to carbon dioxide started in the 1850's with the introduction of large scale soil cultivation using the moldbord plough. The effect of ploughing on soil carbon has been measured by Reicosky (1995) for a selection of cultivation techniques (after tilling wheat). Using a mouldboard plough results in soil carbon losses far exceeding the carbon value of the previous wheat crop residue and depleting soil carbon by 1,990 kg/ha compared with a no tillage system;
- Lal (1999) estimated that the global release of soil carbon since 1850 from land use changes has been 136 +/- 55 Pg[86] (billion tons) of carbon. This is approximately half of the total carbon emissions from fossil fuels (270 +/- 30 Pg (billion tons)), with soil cultivation accounting for 78 +/- Pg 12 and soil erosion 26 +/- 9 Pg of carbon emissions. Lal also estimates that the potential of carbon sequestration in soil, biota and terrestrial ecosystem may be as much as 3 Pg C per year (1.41 parts per million of atmospheric carbon dioxide). A strategy of soil carbon sequestration over a 25 to 50 year period could therefore have a substantial impact on lowering the rate at which carbon dioxide is rising in the atmosphere providing the necessary time to adopt alterative energy strategies.

The contribution of a NT system as a means of sequestering soil carbon has been evaluated by West and Post (2002). This work analysed 67 long-term agricultural experiments, consisting of 276 paired treatments. These results indicate, on average, that a change from conventional tillage (CT) to no-till (NT) can sequester 57 +/- 14 g carbon per square metre per year (grams carbon m^{-2} $year^{-1}$), excluding a change to NT in wheat-fallow systems. The cropping system that obtained the highest level of carbon sequestration when tillage changed from CT to NT was corn-soybeans in rotation (– 90 +/- 59 grams carbon m^{-2} $year^{-1)}$.) This level of carbon sequestration equates to 900 +/- 590 kg/carbon/ha/yr, which would have decreased carbon dioxide level in the atmosphere by 3,303 +/- 2,165 kg of carbon dioxide per ha/year[87].

More recently Johnson et al (2005) summarised how alternative tillage and cropping systems interact to sequester soil organic carbon (SOC) and impact on GHG emissions from the main agricultural area in central USA. This analysis estimated that the rate of SOC storage in NT compared to CT has been significant, but variable, averaging 400 +/- 61 kg/carbon/ha/yr (Table 51).

An alternative IPCC estimate puts the rate of soil organic carbon (SOC) sequestration by the conversion from conventional to all conservation tillage (NT and RT) in North America within a range of 50 to 1,300 kg carbon/ha^{-1} yr^{-1} (it varies by soil type, cropping system and eco-region), with a mean of 300 kg carbon/ha^{-1} yr^{-1}.

[86] 1 Pg of soil carbon pool equates to 0.47 parts per million of atmospheric carbon dioxide
[87] Conversion factor for carbon sequestered into carbon dioxide = 3.67

Table 51: Summary of the potential; of NT cultivation systems

	Low kg/carbon/ha/yr	High kg/carbon/ha/yr	Average kg/carbon/ha/yr
West and Post (2002).	610	1,490	900 +/- 590
Johnson et al (2005)	339	461	400 +/- 61
Liebig (2005)	60	460	270 +/- 190
IPCC	50	1,300	300

As well as soil cultivation other key factors influencing the rate of SOC sequestration include the amount of crop residue, soil type and soil water potential. The optimum conditions for soil sequestration are high biomass production of both surface residue and decaying roots that decompose in moist soils where aeration is not limiting.

The adoption of NT systems has also had an impact on other GHG emissions. For example, methane and nitrous oxide which are respectively 21 and 310 times more potent than carbon dioxide. For example, Robertson, 2002 and Sexstone et al., 1985, suggested that the adoption of NT to sequester SOC could do so at the expense of increased nitrous oxide production where growers increase the use of nitrogen fertilizer in NT crop production systems.

Robertson et al (2000) measured gas fluxes for carbon dioxide, nitrous oxide and methane and other sources of global warming potential (GWP) in cropped and unmanaged ecosystems over the period 1991 to 1999 and found that the net GWP was highest for conventional tillage systems at 114 grams of carbon dioxide equivalents per square metre/year compared with 41 grams/ha for an organic system with legumes cover and 14 grams/ha for a no-till system (with liming) and minus 20 grams/ha for a NT system (without liming). The major factors influencing the beneficial effect of no-till over conventional and organic systems is the high level of carbon sequestration and reduced use of fuel resulting in emissions of 12 grams of CO_2 equivalents m^{-2} $year^{-1}$ compared with 16 grams in conventional tillage and 19 grams for organic tillage. The release of nitrous oxide in terms of carbon dioxide was equivalent in the organic and NT systems due to the availability of nitrogen under the organic system compared with the targeted use of nitrogen fertiliser under the NT systems.

Using IPCC emission factors, Johnson et al (2005) estimated the offsetting effect of alternative fertiliser management and cropping systems. For a NT cropping system that received 100 kg N per ha per year (net from all sources), the estimated annual nitrous oxide emission of 2.25 kg N per ha per year would have to increase by 32%-97% to completely offset carbon sequestration gains of 100-300 kg per ha per year.

Estimating the full actual contribution of NT systems to soil carbon sequestration is however, made difficult by the dynamic nature of the soil sequestration process. If a specific crop area is in continuous NT crop rotation, the full SOC benefits described above can be realised. However, if the NT crop area is returned to a conventional tillage system, a proportion of the SOC gain will be lost. The temporary nature of this form of carbon storage will only become permenant when farmers adopt continuous NT systems which, itself tends to be dependant upon herbicide based weed control systems.

Where the use of GM crop cultivars has resulted in a reduction in the number of spray passes or the use of less intensive cultivation practices this has provided and continues to provide for a permanent reduction in carbon dioxide emissions.

4.2.3 Herbicide tolerance and conservation tillage

The adoption of GM HT crops has impacted on the type of herbicides applied, the method of application (foliar, broadcast, soil incorporated) and the number of herbicide applications. For example, the adoption of GM HT canola in North America has resulted in applications of residual soil-active herbicides being replaced by post-emergence applications of broad-spectrum herbicides with foliar activity (Brimner et al 2004). Similarly, in the case of GM HT cotton the use of glyphosate to control both grass and broadleaf weeds, post-emergent, has replaced the use of soil residual herbicides applied pre- and post emergence (McClelland et al 2000). The type and number of herbicide applications have therefore changed, often resulting in a reduction in the number of herbicide applications (see section 3).

In addition to the reduction in the number of herbicide applications there has been a shift from conventional tillage to reduced/no till. This has had a marked affect on tractor fuel consumption due to energy intensive cultivation methods being replaced with no/reduced tillage and herbicide-based weed control systems. The GM HT crop where this is most evident is GM HT soybeans. Here adoption of the technology has made an important contribution to facilitating the adoption of reduced or no tillage farming[88]. Before the introduction of GM HT soybean cultivars, NT systems were practiced by some farmers using a number of herbicides and with varying degrees of success. The opportunity for growers to control weeds with a non residual foliar herbicide as a “burndown” pre-seeding treatment followed by a post-emergent treatment when the soybean crop became established has made the NT system more reliable, technically viable and commercially attractive. These technical advantages combined with the cost advantages have contributed to the rapid adoption of GM HT cultivars and the near doubling of the NT soybean area in the US (also more than a five fold increase in Argentina). In both countries, GM HT soybeans are estimated to account for 95% of the NT soybean crop area.

Substantial growth in NT production systems have also occurred in Canada, where the NT Canola area increased from 0.8 million ha to 2.6 million ha (equal to about half of the total canola area) between 1996 and 2005 (95% of the NT canola area is planted with GM HT cultivars). Similarly the area planted to NT in the US cotton crop increased from 0.2 million ha to 1 million ha over the same period (of which 86% is planted to GM HT cultivars). The increase in the NT cotton area has been substantial from a base of 200,000 ha to over 1.0 m ha between 1996 and 2005.

4.2.4 Herbicide tolerant soybeans

4.2.4.1 The US

Over the 1996-2005 period the area of soybeans cultivated in the USA increased by 11.1% to 28.9 million ha, 93% of which (by 2005) were GM HT cultivars. Over the same period, the area planted using conventional tillage fell 25.6% (to 5.8 million ha), the area planted using reduced tillage increased by 7.0% (to 11.9 million ha) and the area planted using no till increased 39.0% (to 11.1 million ha, equal to about 38.5% of the total 2005 crop).

The most rapid rate of adoption of the GM HT technology has been by growers using NT systems (GM HT cultivars accounted for about 99% of total NT soybeans in 2005). This compares with conventional tillage systems for soybeans where GM HT cultivars accounted for 80% of total conventional tillage soybean plantings (Table 52).

[88] See for example, CTIC 2002

Table 52: US soybean tillage practices and the adoption of GM HT cultivars 1996-2005 (million ha)

	Total area	No till	Reduced till	Conventional till	Total GM area	Total Non GM area	No till – GM area	Reduced till GM area	Conventional tillage GM area
1996	26.0	8.0	11.1	6.8	0.5	25.5	0.24	0.17	0.07
1997	28.3	8.7	12.0	7.6	3.2	25.1	1.91	1.20	0.08
1998	29.1	9.4	12.8	6.9	11.8	17.4	4.81	4.45	1.97
1999	29.8	9.7	12.9	7.3	16.4	13.4	6.12	7.07	3.2
2000	30.1	10.0	12.9	7.2	18.2	11.9	7.48	8.23	3.83
2001	30.0	10.2	12.6	7.2	22.2	7.8	8.38	9.39	4.39
2002	29.5	10.3	12.3	6.9	24.3	5.3	9.31	10.49	4.46
2003	29.7	11.0	12.4	6.3	25.7	4.0	10.46	11.18	4.07
2004	30.3	11.7	12.5	6.1	27.2	3.1	11.39	11.26	4.56
2005	28.9	11.1	11.9	5.8	26.9	2.0	11.02	11.33	4.54

Source: Adapted from Conservation Tillage and Plant Biotechnology (CTIC) 2002
NT = no-till + ridge till, RT = reduced tillage + mulch till, CT = conventional tillage, GM = GM HT varieties

The importance of GM HT soybeans in the adoption of a NT system has also been confirmed by an American Soybean Association (ASA) study (2001) of conservation tillage. This study found that the availability of GM HT soybeans has facilitated and encouraged farmers to implement reduced tillage practices; a majority of growers surveyed indicated that GM HT soybean technology had been the factor of ***greatest*** influence in their adoption of reduced tillage practices.

a) Fuel consumption

Based on the soybean crop area planted by tillage system, type of seed planted (GM and non-GM) and applying the fuel usage consumption rates presented in section 4.2.1[89], the total consumption of tractor fuel has increased by about 19.9 million litres (from 752.7 to 772.6 million litres 1996 to 2005: Table 53). As the area of soybeans increased by 2.9 million ha over the same period, the average fuel usage fell 7.7% (from 29.0 litres/ha to 26.8 litres/ha: Table 53). A comparison of GM versus non GM production systems shows that in 2005, the average tillage fuel consumption on the GM planted area was 25.8 litres/ha compared to 39.1 litres/ha for the conventional (non-GM) crop (primarily because of differences in the share of NT plantings).

[89] Our estimates are based on the following average fuel consumption rates: NT 14.12 litre/ha, RT 28.83 litres/ha (the average of fuel consumption for chisel ploughing and disking) and conventional tillage 46.65 litres/ha

Table 53: US soybean consumption of tractor fuel used for tillage 1996-2005

	Total fuel consumption (million litres)	Average (litre/ha)	Non GM average (litre/ha)	GM average (litres/ha)
1996	752.7	29.0	29.1	23.5
1997	825.0	29.1	30.2	20.4
1998	825.6	28.3	30.9	24.5
1999	846.9	28.4	30.3	26.8
2000	850.3	28.2	27.6	28.6
2001	842.8	28.1	31.9	26.8
2002	821.6	27.8	34.2	26.4
2003	806.1	27.1	36.8	25.7
2004	809.4	26.7	36.1	25.7
2005	772.6	26.8	39.1	25.8

The cumulative permanent reduction in tillage fuel use in US soybeans is summarised in Table 54. This amounted to a reduction in tillage fuel usage of 302.4 million litres which equates to a reduction in carbon dioxide emission of 831.7 million kg.

Table 54: US soybeans: permanent reduction in tractor fuel consumption and reduction in CO2 emissions

	Annual reduction based on 1996 average (litres/ha)	Crop area (million ha)	Total fuel saving (million litres)	Carbon dioxide (million kg)
1996	0.0	26.0	0.0	0.00
1997	-0.1	28.3	-4.1	-11.34
1998	0.6	29.1	18.9	51.91
1999	0.6	29.8	17.7	48.56
2000	0.8	30.1	23.2	63.68
2001	0.9	30.0	26.1	71.84
2002	1.2	29.5	34.2	94.18
2003	1.8	29.7	54.6	150.05
2004	2.2	30.3	67.8	186.33
2005	2.2	28.9	64.2	176.46
Total			302.4	831.66

Assumption: baseline fuel usage is the 1996 level of 29.0 litres/ha

b) Soil carbon sequestration

Based on the crop area planted by tillage system and type of seed planted (GM and non-GM) and using estimates of the soil carbon sequestered by tillage system for corn and soybeans in continuous rotation (the NT system is assumed to store 300 kg of carbon/ha/year, the RT system assumed to store 100 kg carbon/ha/year and the CT system assumed to release 100 kg carbon/ha/year)[90], our estimates of total soil carbon sequested are (Table 55):

[90] The actual rate of soil carbon sequestered by tillage system is, however dependent upon soil type, soil organic content, quantity and type of crop residue, so these estimates are indicative averages

- An increase of 1,115 million kg carbon/year (from 2,836 million kg in 1996 to 3,951 million kg carbon/year in 2005 due to the marginal increase in crop area planted and the increase in the NT soybean area);
- the average level of carbon sequestered per ha increased by 27.6 kg carbon/ha/year (from 109.2 to 136.8 kg carbon/ha/year).

Table 55: US soybeans: potential soil carbon sequestration (1996 to 2005)

	Total carbon sequestered million kg	Average (kg carbon/ha)
1996	2835.8	109.2
1997	3045.0	107.5
1998	3407.7	116.9
1999	3473.3	116.4
2000	3577.0	118.6
2001	3600.0	120.0
2002	3652.2	123.6
2003	3919.9	132.0
2004	4147.3	137.0
2005	3950.5	136.8

Cumulatively, since 1996 the increase in soil carbon due to the increase in RT and NT in US soybean production systems has been 3,753 million kg of carbon which, in terms of carbon dioxide emission equates to a saving of 10,320 million kg of carbon dioxide that would otherwise have been released into the atmosphere (Table 56). This estimate does not take into consideration the potential loss in carbon sequestration that might arise from a return to conventional tillage.

Table 56: US soybeans: potential additional soil carbon sequestration (1996 to 2005)

	Annual increase in carbon sequestered based on 1996 average (kg carbon/ha)	Crop area (million ha)	Total carbon sequestered (million kg)	Carbon dioxide (million kg)
1996	0.0	26.0	0.0	0.00
1997	-1.7	28.3	-47.6	-130.81
1998	7.8	29.1	225.9	621.28
1999	7.2	29.8	216.3	594.75
2000	9.5	30.1	286.1	786.79
2001	10.9	30.0	326.4	897.47
2002	14.5	29.5	427.7	1176.11
2003	22.8	29.7	677.2	1862.42
2004	27.8	30.3	842.5	2316.94
2005	27.6	28.9	798.1	2194.89
Total			3752.7	10319.84

Assumption: carbon sequestration remains at the 1996 level of 109.2 kg carbon/ha/year

4.2.4.2Argentina

Since 1996, the area planted to soybeans in Argentina has increased by 157% (from 5.9 to 15.2 million ha). Over the same period, the area planted using NT and RT practices also increased (by

538%, from 2.1 to 13.2 million ha), whilst the area planted using conventional tillage decreased by 1.8 million ha, from 3.8 to 2.0 million ha: Table 57).
As in the US, a key driver for the growth in NT soybean production has been the availability and rapid adoption of GM HT soybean cultivars, which in 2005 accounted for 99% of the total Argentine soybean area. As indicated in section 3, the availability of this technology has also provided an opportunity for growers to second crop soybeans in a NT system with wheat. Thus, whereas in 1996 when 6% of the total soybean crop was a second crop following on from wheat (in the same season), by 2005 the share of soybean plantings accounted for by second crop soybeans had risen to 15% of total plantings (about 2.3 million ha).

Table 57: Argentina soybean tillage practices and the adoption of GM cultivars 1996-2005 (million ha)

	Total area	No till	Conventional till	Total GM area	Total non GM area	No till GM area	Conventional tillage GM area
1996	5.9	2.1	3.8	0.04	5.88	0.04	0.00
1997	6.4	2.6	3.8	1.8	4.64	0.64	1.12
1998	7.0	3.5	3.5	4.8	2.15	2.26	2.54
1999	8.2	5.7	2.5	6.6	1.54	4.87	1.77
2000	10.6	6.9	3.7	9.0	1.59	6.56	2.44
2001	11.5	8.3	3.2	10.9	0.57	8.32	2.60
2002	13.0	9.7	3.3	12.4	0.52	9.70	2.74
2003	13.5	10.6	2.9	13.2	0.27	10.56	2.67
2004	14.3	12.6	1.8	14.1	0.29	12.57	1.49
2005	15.2	13.2	2.0	15.0	0.15	13.21	1.84

Adapted from Benbrook and Trigo
NT = No-till + reduced till, CT=conventional tillage

a) Fuel consumption

Between 1996 and 2005 total fuel consumption associated with soybean cultivation increased by an estimated 152.8 million litres (68%), from 223.7 to 376.5 million litres/year. However, during this period the average quantity of fuel used/ha fell 34.5% (13.1 litres/ha) from 37.8 to 24.7 litres/ha, due mostly to the widespread use of GM HT soybean cultivars and NT/RT systems. If the proportion of NT/RT soybeans in 2005 (applicable to the total 2005 area planted) had remained at the 1996 level, an additional 960.4 million litres of fuel would have been used. At this level of fuel usage an additional 2,641 million kg of carbon dioxide would have otherwise been released into the atmosphere (Table 58).

Table 58: Argentine soybeans: permanent reduction in tractor fuel consumption and reduction in CO2 emissions

	Annual reduction based on 1996 average of 37.8 litres/ha (litres/ha)	Crop area (million ha)	Total fuel saving million litres	Carbon Dioxide (million kg)
1996	0.0	5.9	0.0	0.00
1997	1.3	6.4	8.0	22.13
1998	3.8	7.0	26.3	72.19
1999	8.8	8.2	72.1	198.15
2000	7.6	10.6	80.6	221.76
2001	9.4	11.5	108.1	297.30
2002	10.0	13.0	130.0	357.42
2003	10.9	13.5	146.8	403.69
2004	13.2	14.3	189.9	522.28
2005	13.1	15.2	198.6	546.14
Total			960.4	2,641.04

Note: based on 21.48 litres/ha for NT and RT and 46.6 litres/ha for CT REVISE

b) Soil carbon sequestration

Over the two decades to the late 1990s, soil degradation levels are reported to have increased in the humid and sub-humid regions of Argentina. The main cause of this is attributed to leaving land fallow following a wheat crop in a wheat: first soybean crop rotation which resulted in soils being relatively free of weeds and crop residues but exposed to heavy summer rains which often led to extensive soil degradation and loss.

Research into ways of reducing soil degradation and loss was undertaken (mostly relating to the use of NT systems[91]) and this identified that NT systems could play an important role. As such, in the last ten years, there has been an intensive programme of research and technology transfer targeted at encouraging Argentine growers to adopt RT/NT systems.

Specific research into soil carbon sequestration in Argentina is, however limited, although Fabrizzi et al (2003) indicated that a higher level of total organic carbon was retained in the soil with NT system compared with a CT system, although no quantification was provided.

Applying a conservative estimate of soil carbon retention of 100 kg/carbon/ha/yr for NT/RT soybean cropping in Argentina a cumulative total of 7,632 million kg of carbon, which equates to a saving of 20,988 million kg of carbon dioxide that would otherwise have been released into the atmosphere (Table 59).

[91] Trials conducted by INTA show that direct sowing increases the yields of wheat and second soybean crop in rotation. Other benefits observed were: less soil inversion leaving a greater quantity of stubble on the surface, improvements in hydraulic conductivity, more efficient use of soil water, and higher soil organic matter contents

Table 59: Argentine soybeans: potential additional soil carbon sequestration (1996 to 2005)

	Annual increase in carbon sequestered based on 1996 average (kg carbon/ha)	Crop area (million ha)	Total carbon sequestered million kg	Carbon dioxide (million kg)
1996	0.0	5.9	0.0	0.00
1997	10.0	6.4	63.9	175.83
1998	30.0	7.0	208.6	573.71
1999	70.0	8.2	572.6	1,574.65
2000	60.5	10.6	640.8	1,762.27
2001	74.7	11.5	859.1	2,362.59
2002	79.7	13.0	1,032.9	2,840.36
2003	86.4	13.5	1,166.6	3,208.07
2004	105.2	14.3	1,509.3	4,150.47
2005	103.8	15.2	1,578.2	4,340.08
Cumulative total			7,632.0	20,988.03

Assumption: NT = +100 kg carbon/ha/yr, CT = -100 kg carbon/ha/yr

Recent research by Steinbach and Alvarez (2006) on the potential of NT cropping across the Argentine Pampas indicated a potential to increase SOC by 74 Tg Carbon if the whole pampean cropping area was converted to NT. This rate of carbon sequestration is about twice the annual Carbon emissions from fossil fuels consumption in Argentina.

4.2.4.3 Paraguay and Uruguay

NT/RT systems have also become important in soybean production in both Paraguay and Uruguay, where the majority of production in both countries are reported by industry sources to use NT/RT systems.

a) Fuel consumption

Using the findings and assumptions applied to Argentina (see above), the savings in fuel consumption for soybean production between 1996 and 2005 (associated with changes in no/reduced tillage systems, the adoption of GM HT technology and comparing the proportion of NT/RT soybeans in 2005 relative to the 1996 level) has possibly amounted to about 120.1 million litres. At this level of fuel saving the saving in the level of carbon dioxide release into the atmosphere has probably been lower by 330 million kg.

b) Soil carbon sequestration

Applying the same rate of soil carbon retention for NT/RT soybeans as Argentina the cumulative increase in soil carbon since 1996, due to the increase in NT/RT in Paraguay and Uruguay soybean production systems may have been 954 million kg of carbon. In terms of carbon dioxide emission this equates to a saving of 2,624 million kg of carbon dioxide that may otherwise have been released into the atmosphere.

4.2.5 Herbicide tolerant canola

The analysis presented below relates to Canada only and does not include the US GM HT canola crop. This reflects the lack of information about the level of RT/NT in the US canola crop. Also the area devoted to GM HT canola in the US is relatively small by comparison to the corresponding area in Canada (0.45 million ha in 2005 compared to 5.25 million ha).

The cumulative permanent reduction in tillage fuel use in Canadian canola since 1996 was 175.3 million litres which equates to reduction in carbon dioxide emission of 482.03 million kg (Table 60).

Table 60: Canadian canola: permanent reduction in tractor fuel consumption and reduction in CO2 emissions

	Annual reduction based on 1996 average 38.5 (litres/ha)	Crop area (million ha)	Total fuel saving m litres	Carbon dioxide (million kg)
1996	0.0	3.5	0.0	0.00
1997	1.6	4.9	7.9	21.78
1998	1.6	5.4	8.8	24.28
1999	1.6	5.6	9.0	24.88
2000	1.6	4.9	7.9	21.73
2001	3.3	3.8	12.3	33.85
2002	4.9	3.3	15.9	43.76
2003	6.5	4.7	30.5	83.88
2004	8.1	4.9	40.2	110.43
2005	8.1	5.3	42.7	117.45
Total			175.2	482.04

Notes: fuel usage NT = 14.12 litres/ha CT = 46.6 litres/ha

In terms of the increase in soil carbon associated with the increase in RT and NT in Canadian canola production, the estimated values are summarised in Table 61. The cumulative increase in soil carbon has been 1,617 million kg of carbon which in terms of carbon dioxide emission equates to a saving of 4,447 million kg of carbon dioxide that would otherwise have been released into the atmosphere.

Table 61: Canada canola: potential additional soil carbon sequestration (1996 to 2005)

	Annual increase in carbon sequestered based on 1996 average (kg carbon/ha)	Crop area (million ha)	Total carbon sequestered million kg	Carbon dioxide (million kg)
1996	0.0	3.5	0.0	0.00
1997	15.0	4.9	73.1	200.89
1998	15.0	5.4	81.4	223.94
1999	15.0	5.6	83.5	229.53
2000	15.0	4.9	72.9	200.44
2001	30.0	3.8	113.6	312.28
2002	45.0	3.3	146.8	403.64
2003	60.0	4.7	281.4	773.72
2004	75.0	4.9	370.4	1,018.67
2005	75.0	5.3	394.0	1,083.42
Total			1,617.1	4,446.53

Notes: NT/RT = +200 kg carbon/ha/yr CT = -100 kg carbon/ha/yr

4.2.6 Herbicide tolerant cotton and maize

The contribution to reduced levels of carbon sequestration arising from the adoption of GM HT maize and cotton is likely to have been very small and hence no assessments are presented. This conclusion is based on the following:

- although the area of NT cotton has increased significantly in countries such as the US (the largest user of GM HT cotton) since 1996 (from 0.2 million ha in 1996 to 1 million ha in 2005), this still only represented 18.4% of the total cotton crop in 2005 – no analysis has been undertaken on either the reduced fuel usage or soil carbon sequestration. However, the importance of GM HT cotton to facilitating NT tillage has been confirmed by a study conducted by Doane Marketing Research (2002) for the Cotton Foundation which identified the availability of GM HT cotton as a key driver for the adoption of NT production practices;
- the area of NT maize also represents only a small proportion of total maize plantings (eg, in the US NT maize accounted for 17% of total plantings in 1996 and by 2004 its share had risen to only 20%)
- there is limited research available on the impact of GM HT maize and cotton in all adopting countries and very little information about NT/RT areas of crops other than soybeans outside the US;
- as the soybean: maize rotation system is commonplace in the US, the benefits of switching to a NT system have largely been examined in section 4.2.4 above for soybeans;
- no significant changes to the average number of spray runs under a GM HT production system relative to a conventional production system have been reported.

4.2.7 Insect resistant cotton

The cultivation of GM insect resistant cotton has resulted in a significant reduction in the number of insecticide spray applications. During the period 1996 to 2005 the proportion of the global cotton area planted with GM insect resistant cultivars has increased from 0.86 million ha to 8.0 million ha (accounting for 40% of the total crop area in the GM growing countries). Based on a conservative estimate of three fewer insecticide sprays being required for the cultivation of GM insect resistant cotton relative to conventional cotton, and applying this to the global area of GM insect resistant cotton in the period 1996-2005, this suggests that there has been a reduction of 116.3 million ha of cotton being sprayed. The cumulative saving in tractor fuel consumption has been 121.58 million litres. This represents a permanent reduction in carbon dioxide emissions of 328.23 million kg (Table 62).

Table 62: Permanent reduction in global tractor fuel consumption and CO2 emissions resulting from the cultivation of GM insect resistant cotton

	Total cotton area in countireis using GM IR cotton (million ha)	Insect resistant area (million ha)	Total spray runs saved (million ha)	Fuel saving (million litres)	CO2 emissions saved (million kg)
1996	19.79	0.86	2.59	2.70	7.30
1997	19.37	0.95	2.86	2.99	8.06
1998	19.41	1.31	3.94	4.11	11.10
1999	18.68	2.76	8.29	8.66	23.38
2000	19.02	3.65	10.94	11.43	30.86
2001	19.69	4.72	14.16	14.80	39.95
2002	18.36	4.32	12.95	13.54	36.55
2003	18.25	5.08	15.24	15.92	42.99
2004	19.64	7.11	21.32	22.28	60.14
2005	19.34	8.02	24.07	25.15	67.90
Total			**116.36**	**121.58**	**328.23**

Notes: assumptions: 3 tractor passes per ha, 1.045 litres/ha of fuel per insecticide application

4.2.8 Insect resistant maize

No analysis of the possible contribution to reduced level of carbon sequestration from the adoption of GM insect resistant maize (via fewer insecticide spray runs) is presented. This is because the impact of using this technology on carbon sequestration is likely to have been small for the following reasons:

- in some countries (eg, Argentina) insecticide use for the control of pests such as the corn borer has traditionally been negligible;
- even in countries where insecticide use for the control of corn boring pests has been practiced (eg, the US), the share of the total crop treated has been fairly low (under 10% of the crop) and varies by region and year according to pest pressure;
- whilst savings have also occurred in relation to the adoption of GM CRW maize in the US (commercially available to farmers from 2003), the total area planted to this GM trait to date has been small (5% of the US crop in 2005).

4.2.9 Summary of carbon sequestration impact

A summary of the carbon sequestration impact is presented in Table 63. This shows the following key points:

- The permanent savings in carbon dioxide emissions (arising from reduced fuel use of 1,679 million litres of fuel) since 1996 have been about 4,613 million kg;
- The additional amount of soil carbon sequestered since 1996 has been equivalent to 38,393 million tonnes of carbon dioxide that has not been released into the global atmosphere[92]. The reader should note that these soil carbon savings are based on saving arising from the rapid adoption of NT/RT farming systems in North and South America for which the availability of GM HT technology has been cited by many farmers as an important facilitator. GM HT technology has therefore probably been an important contributor to this increase in soil carbon sequestration but is not the only factor of influence. Other influences such as the availability of relatively cheap generic glyphosate (the real price of glyphosate fell threefold between 1995 and 2000 once patent protection for the product expired) have also been important, as illustrated by the rapid adoption of RT/NT production systems in the Brazilian soybean sector, largely in the absence of the GM HT technology[93]. Cumulatively the amount of carbon sequestered may be higher than these estimates due to year-on-year benefits to soil quality, however equally with only an estimated 15%-25% of the crop area in continuous no-till systems it is likely that the total cumulative soil sequestration gains have been lower. It is nevertheless, not possible to estimate cumulative soil sequestration gains that take into account reversions to conventional tillage. Consequently, the estimate provided above of 38,393 million tonnes of carbon dioxide not released into the atmosphere should be treated with caution.

Table 63: Summary of carbon sequestration impact 1996-2005

Crop/trait/country	Permanent fuel saving (million litres)	Potential additional carbon dioxide saving from fuel saving (million kg)	Potential additional carbon dioxide saving from soil carbon sequestration (million kg)
US: GM HT soybeans	302	832	10,320
Argentina: GM HT soybeans	960	2,641	20,988
Other countries: GM HT soybeans	120	330	2,624
Canada: GM HT canola	175	482	4461
Global GM IR cotton	122	328	0
Total	1,679	4,613	38,393

Notes: Other countries: GM HT soybeans Paraguay and Uruguay (applying US carbon sequestration assumptions). Brazil not included because of RT/NT adoption largely in the absence of GM HT technology

Examining further the context of the carbon sequestration benefits, Table 64, measures the carbon dioxide equivalent savings associated with planting of GM crops for the latest year (2005), in terms of the number of car use equivalents. This shows that in 2005, the permanent carbon dioxide savings from reduced fuel use was the equivalent of removing nearly 0.43 million cars from the road for a year and the additional soil carbon sequestration gains were equivalent to removing nearly 3.58 million cars from the roads. In total, GM crop-related carbon dioxide

[92] These estimates are based on fairly conservative assumptions and therefore the true values could be higher. Also, some of the additional soil carbon sequestration gains from RT/NT systems may be lost if subsequent ploughing of the land occurs. Estimating the possible losses that may arise from subsequent ploughing would be complex and difficult to undertake. This factor should be taken into account when using the estimates presented in this section of the report

[93] The reader should note that the estimates of soil carbon sequestration savings presented do not include any for soybeans in Brazil because we have assumed that the increase in NT/RT area has not been primarily related to the availability of GM HT technology in Brazil

emission savings in 2005 were equal to the removal from the roads of nearly 4.01 million cars, equal to about 17% of all registered cars in the UK.

Table 64: Context of carbon sequestration impact 2005: car equivalents

Crop/trait/country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the permanent fuel savings	Potential additional soil carbon sequestration savings (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the potential additional soil carbon sequestration
US: GM HT soybeans	176	78,222	2,195	975,556
Argentina: GM HT soybeans	546	242,667	4,340	1,928,889
Other countries: GM HT soybeans	55	24,444	435	193,333
Canada: GM HT canola	117	52,000	1,083	481,520
Global GM IR cotton	68	30,222	0	0
Total	**962**	**427,556**	**8,053**	**3,579,298**

Notes: Assumption: an average family car produces 150 grams of carbon dioxide of km. A car does an average of 15,000 km/year and therefore produces 2,250 kg of carbon dioxide/year

Appendix 1: Argentine second crop soybeans

Year	Second crop area (million ha)	Increase in income linked to GM HT system (million $)	Additional production (million tonnes)
1996	0.45	Negligible	Negligible
1997	0.65	24.8	0.3
1998	0.8	43.4	0.9
1999	1.4	117.8	2.3
2000	1.6	142.6	2.7
2001	2.4	272.8	5.7
2002	2.7	372.6	6.9
2003	2.8	416.1	7.7
2004	3.0	678.1	6.9
2005	2.3	526.7	6.3

Additional gross margin based on data from Grupo CEO

Appendix 2: The Environmental Impact Quotient (EIQ): a method to measure the environmental impact of pesticides

The material presented below is from the original by the cited authors of J. Kovach, C. Petzoldt, J. Degni, and J. Tette, IPM Program, Cornell University,

Methods

Extensive data are available on the environmental effects of specific pesticides, and the data used were gathered from a variety of sources. The Extension Toxicology Network (EXTOXNET), a collaborative education project of the environ-mental toxicology and pesticide education departments of Cornell University, Michigan State University, Oregon State University, and the University of California, was the primary source used in developing the database (Hotchkiss et al. 1989). EXTOXNET conveys pesticide-related information on the health and environmental effects of approximately 100 pesticides. A second source of information used was CHEM-NEWS of CENET, the Cornell Cooperative Extension Network. CHEM-NEWS is a computer program maintained by the Pesticide Management and Education Program of Cornell University that contains approximately 310 US EPA - Pesticide Fact Sheets, describing health, ecological, and environmental effects of the pesticides that are required for the re-registration of these pesticides (Smith and Barnard 1992).

The impact of pesticides on arthropod natural enemies was determined by using the SELCTV database developed at Oregon State (Theiling and Croft 1988). These authors searched the literature and rated the effect of about 400 agrichemical pesticides on over 600 species of arthropod natural enemies, translating all pesticide/natural enemy response data to a scale ranging from one (0% effect) to five (90-100% effect).

Leaching, surface loss potentials (runoff), and soil half-life data of approximately 100 compounds are contained in the National Pesticide/Soils Database developed by the USDA Agricultural Research Service and Soil Conservation Service. This database was developed from the GLEAMS computer model that simulates leaching and surface loss potential for a large number of pesticides in various soils and uses statistical methods to evaluate the interactions between pesticide properties (solubility, adsorption coefficient, and half-life) and soil properties (surface horizon thickness, organic matter content, etc.). The variables that provided the best estimate of surface loss and leaching were then selected by this model and used to classify all pesticides into risk groups (large, medium, and small) according to their potential for leaching or surface loss.

Bee toxicity was determined using tables by Morse (1989) in the 1989 New York State pesticide recommendations, which contain information on the relative toxicity of pesticides to honey bees from laboratory and field tests conducted at the University of California, Riverside from 1950 to 1980. More than 260 pesticides are listed in this reference.

In order to fill as many data gaps as possible, Material Safety Data Sheets (MSDS) and technical bulletins developed by the agricultural chemical industry were also used when available.

Health and environmental factors that addressed some of the common concerns expressed by farm workers, consumers, pest management practitioners, and other environmentalists were evaluated and are listed in Figure 1. To simplify the interpretation of the data, the toxicity of the active ingredient of each pesticide and the effect on each environmental factor evaluated were grouped into low, medium, or high toxicity categories and rated on a scale from one to five, with one having a minimal impact on the environment or of a low toxicity and five considered to be highly toxic or having a major negative effect on the environment.

All pesticides were evaluated using the same criteria except for the mode of action and plant surface persistence of herbicides. As herbicides are generally systemic in nature and are not normally applied to food crops we decided to consider this class of compounds differently, so all herbicides were given a value of one for systemic activity. This has no effect on the relative rankings within herbicides, but it does make the consumer component of the equation for herbicides more realistic. Also, since plant surface persistence is only important for post-emergent herbicides and not pre-emergent herbicides, all post-emergent herbicides were assigned a value of three and pre-emergent herbicides assigned a value of one for this factor.

The rating system used to develop the environmental impact quotient of pesticides (EIQ) model is as follows (l = least toxic or least harmful, 5 = most toxic or harmful):

- *Mode of Action*: non-systemic- 1, all herbicides – 1, systemic – 3
- *Acute Dermal LD50 for Rabbits/Rats(m&/kg)*: >2000 – 1, 200 - 2000 – 3, 0 - 200 – 5
- *Long-Term Health Effects*: little or none – 1, possible- 3, definite – 5
- *Plant Surface Residue Half-life*: l-2 weeks- 1, 2-4 weeks- 3, > 4 weeks – 5, pre-emergent herbicides – l, post-emergent herbicides – 3
- *Soil Residue Half-life:* Tl/2 <30 days – 1, Tl/2=30-100 days – 3, Tl/2 >100 days – 5
- *Toxicity to Fish-96 hr LC50*: > 10 ppm – 1, 1-10 ppm – 3, < 1 ppm – 5
- *Toxicity to Birds-8 day LC50*: > 1000 ppm – 1, 100-1000 ppm – 3, 1-100 ppm – 5
- *Toxicity to Bees*: relatively non toxic – 1, moderately toxic – 3, highly toxic – 5
- *Toxicity to Beneficials*: low impact- 1, moderate impact – 3, severe impact – 5
- *Groundwater and Runoff Potential*: small – 1, medium – 3, large -5

In order to further organise and simplify the data, a model was developed called the environmental impact quotient of pesticides (EIQ). This model reduces the environmental impact information to a single value. To accomplish this, an equation was developed based on the three principal components of agricultural production systems: a farm worker component, a consumer component, and an ecological component. Each component in the equation is given equal weight in the final analysis, but within each component, individual factors are weighted differently. Coefficients used in the equation to give additional weight to individual factors are also based on a one to five scale. Factors carrying the most weight are multiplied by five, medium-impact factors are multiplied by three, and those factors considered to have the least impact are multiplied by one. A consistent rule throughout the model is that the impact potential of a specific pesticide on an individual environmental factor is equal to the toxicity of the chemical times the potential for exposure. Stated simply, environmental impact is equal to toxicity times exposure. For example, fish toxicity is calculated by determining the inherent toxicity of the compound to fish times the likelihood of the fish encountering the pesticide. In this manner, compounds that are toxic to fish but short-lived have lower impact values than compounds that are toxic and long-lived.

The EIQ Equation

The formula for determining the EIQ value of individual pesticides is listed below and is the average of the farm worker, consumer, and ecological components:

$$EIQ=\{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+[(F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3$$

DT = dermal toxicity, C = chronic toxicity, SY = systemicity, F = fish toxicity, L = leaching potential, R = surface loss potential, D = bird toxicity, S = soil half-life, Z = bee toxicity, B = beneficial arthropod toxicity, P = plant surface half-life.

Farm worker risk is defined as the sum of applicator exposure (DT* 5) plus picker exposure (DT*P) times the long-term health effect or chronic toxicity (C). Chronic toxicity of a specific pesticide is calculated as the average of the ratings from various long-term laboratory tests conducted on small mammals. These tests are designed to determine potential reproductive effects (ability to produce offspring), teratogenic effects (deformities in unborn offspring), mutagenic effects (permanent changes in hereditary material such as genes and chromosomes), and oncogenic effects (tumor growth). Within the farm worker component, applicator exposure is determined by multiplying the dermal toxicity (DT) rating to small laboratory mammals (rabbits or rats) times a coefficient of five to account for the increased risk associated with handling concentrated pesticides. Picker exposure is equal to dermal toxicity (DT) times the rating for plant surface residue half-life potential (the time required for one-half of the chemical to break down). This residue factor takes into account the weathering of pesticides that occurs in agricultural systems and the days to harvest restrictions that may be placed on certain pesticides. The consumer component is the sum of consumer exposure potential (C*((S+P)/2)*SY) plus the potential groundwater effects (L). Groundwater effects are placed in the consumer component because they are more of a human health issue (drinking well contamination) than a wildlife issue. Consumer exposure is calculated as chronic toxicity (C) times the average for residue potential in soil and plant surfaces (because roots and other plant parts are eaten) times the systemic potential rating of the pesticide (the pesticide's ability to be absorbed by plants). The ecological component of the model is composed of aquatic and terrestrial effects and is the sum of the effects of the chemicals on fish (F*R), birds (D*((S+P)/2)*3), bees (Z*P*3), and beneficial arthropods(B*P*5). The environmental impact of pesticides on aquatic systems is determined by multiplying the chemical toxicity to fish rating times the surface runoff potential of the specific pesticide (the runoff potential takes into account the half-life of the chemical in surface water).

The impact of pesticides on terrestrial systems is determined by summing the toxicities of the chemicals to birds, bees, and beneficial arthropods. As terrestrial organisms are more likely to occur in commercial agricultural settings than fish, more weight is given to the pesticidal effects on these terrestrial organisms. Impact on birds is measured by multiplying the rating of toxicity to birds by the average half-life on plant and soil surfaces times three. Impact on bees is measured by taking the pesticide toxicity ratings to bees times the half-life on plant surfaces times three. The effect on beneficial arthropods is determined by taking the pesticide toxicity rating to beneficial natural enemies, times the half-life on plant surfaces times five. As arthropod natural enemies spend almost all of their life in agro ecosystem communities (while birds and bees are somewhat transient), their exposure to the pesticides, in theory, is greater. To adjust for this increased exposure, the pesticide impact on beneficial arthropods is multiplied by five. Mammalian wildlife toxicity is not included in the terrestrial component of the equation because mammalian exposure (farm worker and consumer) is already included in the equation, and these health effects are the results of tests conducted on small mammals such as rats, mice, rabbits, and dogs.

After the data on individual factors were collected, pesticides were grouped by classes (fungicides, insecticides/miticides, and herbicides), and calculations were conducted for each pesticide. When toxicological data were missing, the average for each environmental factor within a class was determined, and this average value was substituted for the missing values. Thus, missing data did not affect the relative ranking of a pesticide within a class.

The values of individual effects of each pesticide (applicator, picker, consumer, groundwater, aquatic, bird, bee, beneficials), the major components of the equation (farm worker, consumer, and ecological) and the average EIQ values are presented in separate tables (see references).

EIQ field use rating

Once an EIQ value has been established for the active ingredient of each pesticide, field use calculations can begin. To accurately compare pesticides and pest management strategies, the dose, the formulation or percent active ingredient of the product, and the frequency of application of each pesticide need to be determined. To account for different formulations of the same active ingredient and different use patterns, a simple equation called the EIQ field use rating was developed. This rating is calculated by multiplying the EIQ value for the specific chemical obtained in the tables by the percent active ingredient in the formulation by the rate per acre used (usually in pints or pounds of formulated product);

EIQ Field Use Rating = EIQ x % active ingredient x Rate

By applying the EIQ Field Use Rating, comparisons can be made between different pest management strategies or programs. To compare different pest management programs, EIQ Field Use Ratings and number of applications throughout the season are determined for each pesticide. and these values are then summed to determine the total seasonal environmental impact of the particular strategy.

Appendix 3: Additional information relating to the environmental impact

Estimated typical herbicide regimes for GM HT reduced/no till and conventional reduced/no till soybean production systems that will provide an equal level of weed control to the GM HT system in Argentina

	Active ingredient (kg/ha)	Field EIQ/ha value
GM HT soybeans		
Glyphosate (no till burndown)	1.89	28.92
Glyphosate post emergent use	1.01	15.45
2 4D	0.07	1.21
Total	**2.97**	**45.58**
Conventional soybeans		
Option 1		
Glyphosate	1.98	30.29
2 4 D	0.24	4.14
Acetochlor	0.72	13.18
Metribuzin	0.48	13.63
Quizalfop ethyl	0.18	9.31
Total	**3.6**	**70.55**
Option 2		
Glyphosate	1.98	30.29
2 4 D	0.24	4.14
Diclosulam	0.03	0.4
Chlorimuron	0.05	1.4
Quizalofop ethyl	0.18	9.31
Total	**2.48**	**45.54**
Option 3		
Glyphosate	1.98	30.29
2 4 D	0.24	4.14
Imazethepyr	0.04	1.09
S Metalochlor	0.96	21.12
Quizalofop ethyl	0.18	9.31
Total	**3.40**	**65.95**
Option 4		
Glyphosate	1.98	30.29
Dicamba	0.24	4.14
Acetochlor	0.9	16.47
Chlorimuron	0.05	1.4
Quizalofop ethyl	0.18	9.31
Total	**3.35**	**61.61**
Option 5		
Glyphosate	1.98	30.29
2 4 D	0.24	4.14
Imazaquin	0.2	3.90
Chlorimuron	0.04	1.12
Quizalofop ethyl	0.18	9.31
Total	**2.64**	**48.76**

Option 6		
Glyphosate	1.98	30.29
2 4 D	0.24	4.14
Acetochlor	1.35	24.70
Imazethepyr	0.1	2.73
Quizalofop ethyl	0.18	9.31
Total	**3.85**	**71.18**
Average all six conventional options	**3.22**	**60.60**

Sources: based on and derived from Kynetec herbicide usage data various years, AAPRESID and Monsanto Argentina

Typical herbicide regimes for GM HT soybeans in South Africa

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional soybeans		
Option one		
Alochlor	1.6	29.28
Chlorimuron	0.0112	0.31
Total	**1.6112**	**29.59**
Option two		
S Metalochlor	1.6	35.2
Imazethapyr	0.07	1.91
Total	**1.67**	**37.11**
Option 3		
S Metalochlor	1.6	35.2
Chlorimuron	0.0122	0.31
Total	**1.6112**	**35.51**
Average	**1.6308**	**34.07**
GM HT soybeans		
Glyphosate	**1.8**	**27.54**

Source: Monsanto South Africa

Typical herbicide regimes for GM HT maize in Canada

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional maize		
Metalochlor	1.3566	29.84
Atrazine	1.1912	27.28
Primsulfuron	0.0244	0.61
Dicamba	0.14	3.92
Total	**2.7122**	**61.65**
GM glyphosate tolerant maize		
Metalochlor	0.678	14.92
Atrazine	0.594	13.60
Glyphosate	0.56	8.57
Total	**1.832**	**37.09**
GM glufosinate tolerant maize		
Metalochlor	0.678	14.92
Atrazine	0.594	13.60
Glufosinate	0.37	10.45
Total	**1.642**	**38.98**

Sources: Weed Control Guide 2004, industry

Typical herbicide regimes for GM HT maize in South Africa

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional maize		
Acetochlor	1.73	38.06
Atrazine	1.19	27.25
Total	**2.92**	**65.31**
GM HT maize		
Acetochlor	0.863	19.0
Glyphosate	1.8	27.54
Total	**2.663**	**46.54**

Source: Monsanto South Africa

Typical herbicide regimes for GM HT cotton in South Africa

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional cotton		
Option one		
Trifluralin	1.12	21.06
Hand weeding	0	0
Total	**1.12**	**21.06**
Option two		
S Metalochlor	0.95	20.9
Flumeturon	0.4	8.13
Prometryn	0.5	17.0
Total	**1.85**	**46.03**
Option 3		
Trifluralin	1.12	21.06
Cyanazine	0.85	16.83
Total	**1.6308**	**37.89**
Option 4		
Trifluralin	0.745	14.01
Flumeturon	0.4	8.13
Prometryn	0.5	17.0
Acetochlor	0.32	5.86
Atrazine	0.128	2.93
Total	**2.093**	**47.93**
Average conventional	**1.673**	**38.23**
GM HT cotton		
Glyphosate	**1.8**	**27.54**

Source: Monsanto South Africa

Typical herbicide regimes for canola in the US and Canada

USA

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional canola		
Ethafluralin	1.053	24.54
Quizalofop	0.063	3.24
Ethametsulfuron	0.016	0.45
Total	**1.132**	**28.23**
GM glyphosate tolerant canola		
Glyphosate	**1.12**	**17.14**
GM glufosinate tolerant canola		
Glufosinate	0.41	11.7
Quizalofop	0.026	1.33
Total	**0.436**	**13.03**

Based on NCFAP 2003

Canada

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional canola		
Ethafluralin	1.06	24.7
Quizalofop	0.053	2.75
Ethametsulfuron	0.016	0.45
Total	**1.129**	**27.9**
GM glyphosate tolerant canola		
Glyphosate	**1.15**	**17.66**
GM glufosinate tolerant canola		
Glufosinate	0.44	12.44
Quizalofop	0.026	1.33
Total	**0.466**	**13.77**

Based on a combination of the Canola Council Weed control guide, Canola Council (2001) and NCFAP 2003

Typical insecticide regimes for cotton in China

Active ingredient	Amount (kg/ha of crop)
Conventional cotton	
Methamidophos	0.655
Dimethoate	0.3
Confidor	0.225
Monocrotophos	0.5775
Abamectin	0.0036
Phoxim	0.375
Parathion methyl	1.125
Carbaryl	2.1
Cypermethrin	0.06
Endosulfan	0.6025
Total	**6.0236**
GM IR cotton	
Methamidophos	0.1875
Dimethoate	0.3
Confidor	0.225
Monocrotophos	0.5775
Abamectin	0.0036
Cypermethrin	0.06
Total	**1.3536**

Sources: Prey et al (2001), Monsanto China

Typical insecticide regimes for cotton in India

Active ingredient	Amount (kg/ha of crop)
Conventional cotton	
Imidachlopid	0.02
Profenfos	1
Acetamoprid	0.02
Indoxacarb	0.15
Monocrotophos	1.4
Spinosad	0.075
Fenpropathrin	0.2
Acephate	0.7
Total	**3.565**
GM IR cotton	
Imidachlopid	0.02
Acetamoprid	0.02
Monocrotophos	1.4
Total	**1.44**

Sources: Monsanto India

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