GM crops: global socio-economic and environmental impacts 1996-2007

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Executive summary and conclusions

This study presents the findings of research into the global socio-economic and environmental impact of biotech crops in the twelve years since they were first commercially planted on a significant area. It focuses on the farm level economic effects, the production 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, biotech 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 biotech production systems with the most likely conventional alternative, if biotechnology 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 biotech 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]

Biotechnology has had a significant positive impact on farm income derived from a combination of enhanced productivity and efficiency gains (Table 1):

- In 2007, the direct global farm income benefit from biotech crops was $10.1 billion. This is equivalent to having added 4.4% to the value of global production of the four main crops of soybeans, maize, canola and cotton;
- Since 1996, farm incomes have increased by $44.1 billion;
- The largest gains in farm income have arisen in the soybean sector, largely from cost savings. The $3.9 billion additional income generated by GM herbicide tolerant (GM HT) soybeans in 2007 has been equivalent to adding 7.2% to the value of the crop in the biotech growing countries, or adding the equivalent of 6.4% to the $60 billion value of the global soybean crop in 2007. These economic benefits should, however be placed within the context of a significant increase in the level of soybean production in the main biotech adopting countries. Since 1996, the soybean area in the leading soybean producing countries of the US, Brazil and Argentina increased by 58%;

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[1] See section 3 for details

- Substantial gains have also arisen in the cotton sector through a combination of higher yields and lower costs. In 2007, cotton farm income levels in the biotech adopting countries increased by $3.2 billion and since 1996, the sector has benefited from an additional $12.6 billion. The 2007 income gains are equivalent to adding 16.5% to the value of the cotton crop in these countries, or 10.2% to the $27.5 billion value of total global cotton production. This is a substantial increase in value added terms for two new cotton seed technologies;
- Significant increases to farm incomes have also resulted in the maize and canola sectors. The combination of GM insect resistant (GM IR) and GM HT technology in maize has boosted farm incomes by $7.2 billion since 1996. In the North American canola sector an additional $1.44 billion has been generated;
- Of the total cumulative farm income benefit, $20.5 billion (46.5%) has been due to yield gains (and second crop facilitation), with the balance arising from reductions in the cost of production. Within this yield gain component, 68% derives from the GM IR technology and the balance to GM HT crops.

Table 1: Global farm income benefits from growing biotech crops 1996-2007: million US $

Trait	Increase in farm income 2007	Increase in farm income 1996-2007	Farm income benefit in 2007 as % of total value of production of these crops in biotech adopting countries	Farm income benefit in 2007 as % of total value of global production of crop
GM herbicide tolerant soybeans	3,935	21,814	7.2	6.4
GM herbicide tolerant maize	442	1,508	0.7	0.4
GM herbicide tolerant cotton	25	848	0.1	0.1
GM herbicide tolerant canola	346	1,439	7.65	1.4
GM insect resistant maize	2,075	5,674	3.2	1.9
GM insect resistant cotton	3,204	12,576	16.5	10.2
Others	54	209	Not applicable	Not applicable
Totals	**10,081**	**44,068**	**6.9**	**4.4**

Notes: All values are nominal. Others = Virus resistant papaya and squash. Totals for the value shares exclude 'other crops' (ie, relate to the 4 main crops of soybeans, maize, canola and cotton). Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality and key variable costs of production (eg, payment of seed premia, impact on crop protection expenditure)

Table 2 summarises farm income impacts in key biotech adopting countries. This highlights the important farm income benefit arising from GM HT soybeans in South America (Argentina, Brazil, Paraguay and Uruguay), GM IR cotton in China and India and a range of GM cultivars in the US. It also illustrates the growing level of farm income benefits being obtained in South Africa, the Philippines and Mexico.

Table 2: GM crop farm income benefits 1996-2007 selected countries: million US $

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton	Total
US	10,422	1,402.9	804	149.2	4,778.8	2,232.7	***19,789.6***
Argentina	7,815	46	28.6	N/a	226.8	67.9	***8,184.3***
Brazil	2,868	N/a	N/a	N/a	N/a	65.5	***2,933.5***
Paraguay	459	N/a	N/a	N/a	N/a	N/a	***459***
Canada	103.5	42	N/a	1,289	208.5	N/a	***1,643***
South Africa	3.8	5.2	0.2	N/a	354.9	19.3	***383.4***
China	N/a	N/a	N/a	N/a	N/a	6,740.8	***6,740.8***
India	N/a	N/a	N/a	N/a	N/a	3,181	***3,181***
Australia	N/a	N/a	5.2	N/a	N/a	190.6	***195.8***
Mexico	8.8	N/a	10.3	N/a	N/a	65.9	***85***
Philippines	N/a	11.4	N/a	N/a	33.2	N/a	***44.6***
Romania	92.7	N/a	N/a	N/a	N/a	N/a	***92.7***
Uruguay	42.4	N/a	N/a	N/a	2.7	N/a	***45.1***
Spain	N/a	N/a	N/a	N/a	60.0	N/a	***60***
Other EU	N/a	N/a	N/a	N/a	12.6	N/a	***12.6***
Columbia	N/a	N/a	N/a	N/a	N/a	10.4	***10.4***

Notes: All values are nominal. Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality and key variable costs of production (eg, payment of seed premia, impact on crop protection expenditure). 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 2007, 58% of the farm income benefits 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[2]. Over the twelve years, 1996-2007, the cumulative farm income gain derived by developing country farmers was $22.1 billion (50.1% of the total).

Table 3: GM crop farm income benefits 2007: developing versus developed countries: million US $

	Developed	Developing
GM HT soybeans	1,375	2,560
GM IR maize	1,773	302
GM HT maize	402	41
GM IR cotton	286	2,918
GM HT cotton	16	8
GM HT canola	346	0
GM virus resistant papaya and squash	54	0
Total	**4,252**	**5,829**

Developing countries = all countries in South America, Mexico, India, China, the Philippines and South Africa

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[2] The authors acknowledge that the classification of different countries into developing or developed country status affects the distribution of benefits between these two categories of country. The definition used in this paper is consistent with the definition used by James (2007)

Examining the cost farmers pay for accessing GM technology, Table 4 shows that across the four main biotech crops, the total cost in 2007 was equal to 24% of the total technology gains (inclusive of farm income gains plus cost of the technology payable to the seed supply chain[3]).

For farmers in developing countries the total cost was equal to 14% of total technology gains, whilst for farmers in developed countries the cost was 34% of the total technology gains. Whilst circumstances vary between countries, the higher share of total technology gains accounted for by farm income gains in developing countries relative to the farm income share in developed countries reflects factors such as weaker provision and enforcement of intellectual property rights in developing countries and the higher average level of farm income gain on a per hectare basis derived by developing country farmers relative to developed country farmers.

Table 4: Cost of accessing GM technology (million $) relative to the total farm income benefits 2007

	Cost of technology : all farmers	Farm income gain: all farmers	Total benefit of technology to farmers and seed supply chain	Cost of technology : developing countries	Farm income gain: developing countries	Total benefit of technology to farmers and seed supply chain: developing countries
GM HT soybeans	931	3,935	4,866	326	2,560	2,886
GM IR maize	714	2,075	2,789	79	302	381
GM HT maize	531	442	973	20	41	61
GM IR cotton	670	3,204	3,874	535	2,918	3,453
GM HT cotton	226	25	251	8	8	16
GM HT canola	102	346	448	N/a	N/a	N/a
Total	**3,174**	**10,081**	**13,255**	**968**	**5,829**	**6,797**

N/a = not applicable. Cost of accessing the technology is based on the seed premia paid by farmers for using GM technology relative to its conventional equivalents. Total farm income gain excludes £26 million associated with virus resistant crops in the US

Non pecuniary benefits (see section 3.8)

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;

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[3] The cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers

- 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 insecticides);
- Shorter growing season (eg, for some cotton growers in India) which allows some farmers to plant a second crop in the same season[4]. Also some Indian cotton growers have reported knock on benefits for bee keepers as fewer bees are now lost to insecticide spraying.

Since the early 2000s a number of farmer-survey based studies in the US have attempted to better quantify these non pecuniary benefits. These studies have usually employed contingent valuation techniques[5] to obtain farmers valuations of non pecuniary benefits. Drawing on this analysis (see section 3.8), the estimated value for non pecuniary benefits derived from biotech crops in the US (1996-2007) is $5.11 billion. Relative to the value of the direct US farm income benefits, the non pecuniary benefits were equal to 26% of the total cumulative (1996-2007) direct farm income. This highlights the important contribution this category of benefit has had on biotech trait adoption levels in the US, especially where the direct farm income benefits have been identified to be relatively small (eg, HT cotton).

It is also evident that biotech-using farmers in other countries also value the technology for a variety of non pecuniary/intangible reasons. However, it is not possible to quantify these benefits in other countries due to the lack of studies into non pecuniary benefits outside the US.

In relation to the nature and size of biotech crop 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 biotech crops. Size of operation has not been a barrier to adoption. In 2007, 12 million farmers were using the technology globally, 90% plus of which were resource-poor farmers in developing countries.

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[4] Notably maize in India

[5] Survey based method of obtaining valuations of non market goods that aim to identify willingness to pay for specific goods (eg, environmental goods, peace of mind, etc) or willingness to pay to avoid something being lost

Production impacts (see section 3.10)

Based on the yield assumptions used in the direct farm income benefit calculations presented above, biotech crops have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (Table 5):

- The biotech IR traits, used in the corn and cotton sectors, have accounted for 99% of the additional corn production and all of the additional cotton production;
- Since, 1996 the average yield impact across the total area planted to these traits over the 12 year period has been +6.1% for corn traits and +13.4% for cotton traits;
- Although the primary impact of biotech HT technology has been to provide more cost effective (less expensive) and easier weed control versus improving yields from better weed control (relative to weed control obtained from conventional technology), improved weed control has, nevertheless occurred, delivering higher yields in some countries (eg, HT soybeans in Romania, HT corn in Argentina and the Philippines);
- Biotech HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added the vast majority of the extra soybean production arising from biotech usage in the sector;
- In 2007, at the global level, world production levels of soybeans, corn, cotton lint and canola were respectively +6.5%, +1.9%, +7.7% and +1.1% higher than levels would have otherwise been if biotech traits had not been used by farmers;
- In area equivalent terms, if the biotech traits used by farmers in 2007 had not been available, maintaining global production levels at the 2007 levels would have required additional (conventional crop) plantings of 5.89 million ha of soybeans, 3 million ha of corn, 2.54 million ha of cotton and 0.32 million ha of canola.

Table 5: Additional crop production arising from positive yield effects of biotech crops

	1996-2007 additional production (million tonnes)	2007 additional production (million tonnes)
Soybeans	67.80	14.46
Corn	62.42	15.08
Cotton	6.85	2.01
Canola	4.44	0.54

Environmental impact from changes in insecticide and herbicide use[6]

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

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[6] See section 4.1

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

Table 6 summarises the environmental impact over the last twelve years and shows that there have been important environmental gains associated with adoption of biotechnology. More specifically:

- Since 1996, the use of pesticides on the biotech crop area was reduced by 359 million kg of active ingredient (8.8% reduction), and the overall environmental impact associated with herbicide and insecticide use on these crops was reduced by 17.2%;
- In absolute terms, the largest environmental gain has been associated with the adoption of GM HT soybeans and reflects the large share of global soybean plantings accounted for by biotech soybeans. The volume of herbicides used in biotech soybean crops decreased by 73 million kg (1996-2007), a 4.6% reduction, and, the overall environmental impact associated with herbicide use on these crops decreased by 20.9% (relative to the volume that would have probably been used if this cropping area had been planted to conventional soybeans). It should be noted that in some countries, such as in South America, the adoption of GM HT soybeans coincided with increases in the volume of herbicides used relative to historic levels. 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 other environmental benefits (notably reductions in greenhouse gas emissions: see below and reduced soil erosion). Despite this net increase in the volume of herbicides used in some countries, the associated environmental impact (as measured by the EIQ methodology) still fell, as farmers switched to herbicides with a more environmentally benign profile;
- Major environmental gains have also been derived from the adoption of GM IR cotton. These gains were the largest of any crop on a per hectare basis. Since 1996, farmers have used 147.6 million kg less insecticide in GM IR cotton crops (a 23% reduction), and this has reduced the associated environmental impact of insecticide use on this crop area by 27.8%;
- Important environmental gains have also arisen in the maize and canola sectors. In the maize sector, herbicide & insecticide use decreased by 92 million kg and the associated environmental impact of pesticide use on this crop area decreased, due to a combination of reduced insecticide use (5.9%) and a switch to more environmentally benign herbicides (6%). In the canola sector, farmers reduced herbicide use by 9.7 million kg (a 13.9% reduction) and the associated environmental impact of herbicide use on this crop area fell by 25.8% (due to a switch to more environmentally benign herbicides).

Table 6: Impact of changes in the use of herbicides and insecticides from growing biotech crops globally 1996-2007

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 on biotech crops	% change in environmental impact associated with herbicide & insecticide use on biotech crops
GM herbicide	-73.0	-6,283	-4.6	-20.9

tolerant soybeans				
GM herbicide tolerant maize	-81.8	-1,934	-6.0	-6.8
GM herbicide tolerant cotton	-37.0	-748	-15.1	-16.0
GM herbicide tolerant canola	-9.7	-443	-13.9	-25.8
GM insect resistant maize	-10.2	-528	-5.9	-6.0
GM insect resistant cotton	-147.6	-7,133	-23.0	-27.8
Totals	**-359.3**	**-17,069**	**-8.8**	**-17.2**

The impact of changes in insecticide and herbicide use at the country level (for the main biotech adopting countries) is summarised in Table 7.

Table 7: Changes in the 'environmental impact' from changes in pesticide use associated with biotech crop adoption 1996-2007 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	-7	-16	-42	-6	-33
Argentina	-21	-1	-20	N/a	0	-7
Brazil	-9	N/a	N/a	N/a	N/a	-14
Paraguay	-16	N/a	N/a	N/a	N/a	N/a
Canada	-11	-9	N/a	-25	-61	N/a
South Africa	-9	-3	-8	N/a	-33	NDA
China	N/a	N/a	N/a	N/a	N/a	-35
India	N/a	N/a	N/a	N/a	N/a	-10
Australia	N/a	N/a	-5	N/a	N/a	-24
Mexico	N/a	N/a	N/a	N/a	N/a	-7
Spain	N/a	N/a	N/a	N/a	-37	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 8 shows 52% of the environmental benefits (1996-2007) associated with lower insecticide and herbicide use have been in developing countries. The vast majority of these environmental gains have been from the use of GM IR cotton and GM HT soybeans.

Table 8: Biotech crop environmental benefits from lower insecticide and herbicide use 1996-2007: developing versus developed countries

	Change in field EIQ impact (in terms of million field EIQ/ha units): developed countries	Change in field EIQ impact (in terms of million field EIQ/ha units): developing countries
GM HT soybeans	-3,559	-2,724
GM IR maize	-516	-12
GM HT maize	-1,910	-24
GM IR cotton	-1,053	-6,080

GM HT cotton	-726	-22
GM HT canola	-444	Not applicable
Total	**-8,208**	**-8,862**

Impact on greenhouse gas (GHG) emissions[7]
The scope for biotech 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 2007 this amounted to about 1,144 million kg (arising from reduced fuel use of 416 million litres). Over the period 1996 to 2007 the cumulative permanent reduction in fuel use is estimated at 7,090 million kg of carbon dioxide (arising from reduced fuel use of 2,578 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 3,570 million kg of soil carbon is estimated to have been sequestered in 2007 (equivalent to 13,103 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 confidently estimate cumulative soil sequestration gains.

Placing these carbon sequestration benefits within the context of the carbon emissions from cars, Table 9, shows that:

- In 2007, the permanent carbon dioxide savings from reduced fuel use were the equivalent of removing nearly 0.495 million cars from the road;
- The additional probable soil carbon sequestration gains in 2007 were equivalent to removing nearly 5,823 million cars from the roads;
- In total, the combined biotech crop-related carbon dioxide emission savings from reduced fuel use and additional soil carbon sequestration in 2007 were equal to the removal from the roads of nearly 6.3 million cars, equivalent to about 24% of all registered cars in the UK;
- It is not possible to confidently estimate the soil carbon sequestration gains since 1996 (see above). If the entire biotech crop in reduced or no tillage agriculture

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[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

during the last eleven years had remained in permanent reduced/no tillage then this would have resulted in a carbon dioxide saving of 83.18 million kg, equivalent to taking 36.97 million cars off the road. This is, however a maximum possibility and the actual levels of carbon dioxide reduction are likely to be lower.

Table 9: Context of carbon sequestration impact 2007: 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 ('000s)	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 ('000s)
US: GM HT soybeans	247	110	3,999	1,777
Argentina: GM HT soybeans	609	271	6,136	2,727
Other countries: GM HT soybeans	91	40	1,341	596
Canada: GM HT canola	131	58	1,627	723
Global GM IR cotton	37	16	0	0
Total	**1,115**	**495**	**13,103**	**5,823**

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

Biotechnology 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 12 million adopting farmers who have applied the technology to over 111 million hectares in 2007.

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

The biotechnology 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);
- both IR and HT traits have made important contributions to increasing world production levels of soybeans, corn, cotton and canola.

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 is beginning to be found and the extent to which this may develop, 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 biotechnology.

1 Introduction

2007 represents the twelth planting season since biotech crops were first grown in 1996. 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 over this twelve year period[10]. It also quantifies the production impact of the technology on the key crops where it has been used.

1.1 Objectives

The principal objective of the study was to identify the global socio-economic and environmental impact of biotech crops over the first twelve 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 twelve 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;
- Indirect (non pecuniary) impacts of the technology;
- Production effects;
- 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

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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 earlier studies produced in 2005, 2006 and 2008, covering the first nine, ten and eleven years of biotech crop adoption globally. Readers should, however note that some data presented in this report are not directly comparable with data presented in the earlier papers 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) – see references

[12] See References

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

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:

- Section one: introduction
- Section two: overview of biotech crop plantings by trait and country
- Section three: farm level profitability impacts by trait and country, intangible (non pecuniary) benefits, structure and size, prices, production impact 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 biotech crops

This section provides a broad overview of the global development of biotech crops over the twelve year period.

2.1 Global plantings

Although the first commercial biotech 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 biotech traits. Since then there has been a dramatic increase in plantings and by 2007/08, the global planted area reached over 111 million hectares. This is equal to 68% of the total utilised agricultural area of the European Union, over twice the EU 27 area devoted to cereals or seven times the total agricultural area of the UK.

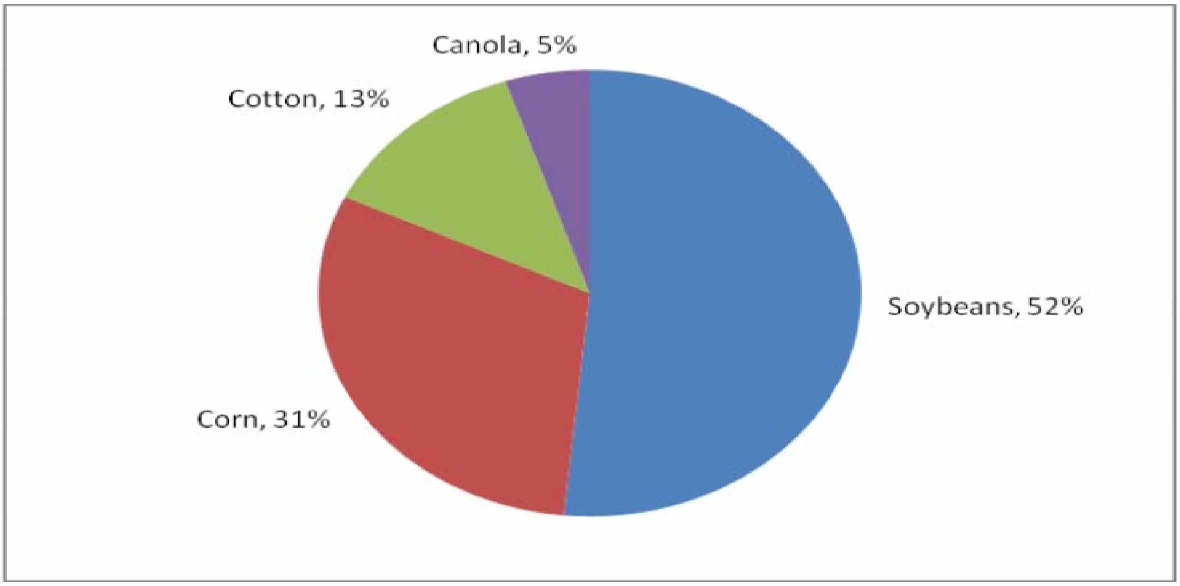
In terms of the share of the main crops in which biotech traits have been commercialised (soybeans, corn, cotton and canola), biotech traits accounted for 36% of the global plantings to these four crops in 2007.

2.2 Plantings by crop and trait

2.2.1 By crop

Almost all of the global biotech crop area derives from soybeans, corn, cotton and canola (Figure 1)[14]. In 2007, biotech soybeans accounted for the largest share (52%), followed by corn (31%), cotton (13%) and canola (5%).

Figure 1: Biotech crop plantings 2007 by crop (base area: 111.2 million hectares)



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

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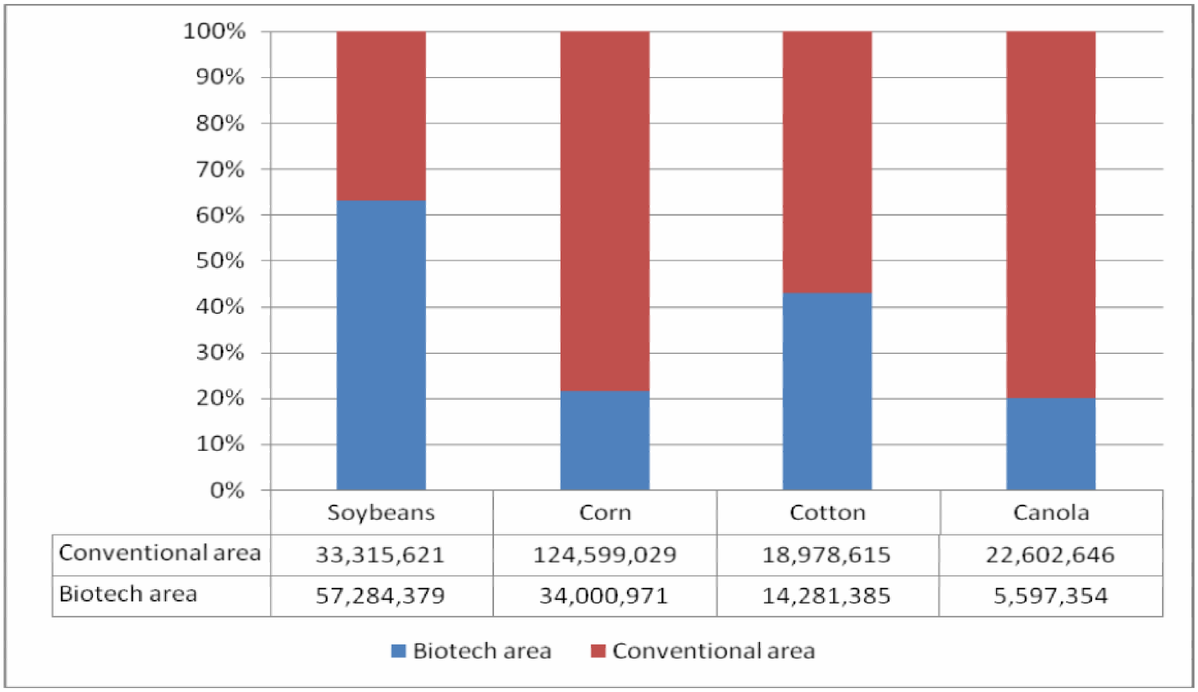
[14] In 2007 there were also additional GM crop plantings of papaya (780 hectares), squash (3,000 hectares) and alfalfa (100,000 ha) in the USA. There were also 3,500 hectares of papaya in China

In terms of the share of total global plantings to these four crops, biotech traits accounted for a majority of soybean plantings (63%) in 2007. For the other three main crops, the biotech shares in 2007 were 21% for corn, 43% for cotton and 20% for canola (Figure 2).

Figure 2: 2007's share of biotech crops in global plantings of key crops (hectares)

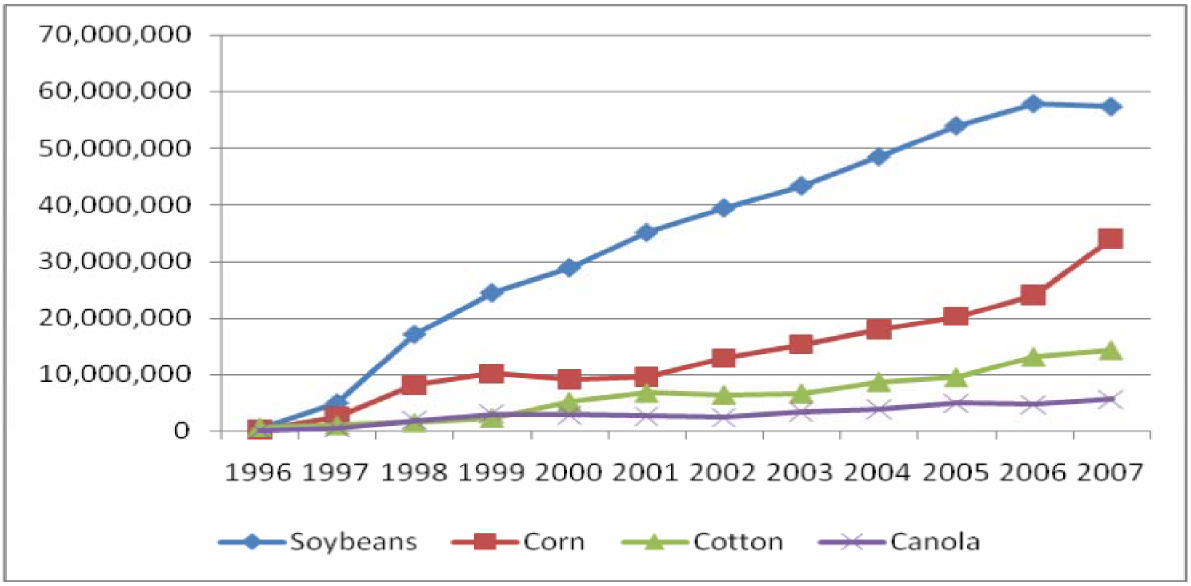


	Soybeans	Corn	Cotton	Canola
Conventional area	33,315,621	124,599,029	18,978,615	22,602,646
Biotech area	57,284,379	34,000,971	14,281,385	5,597,354

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

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

Figure 3: Global biotech crop plantings by crop 1996-2007 (hectares)

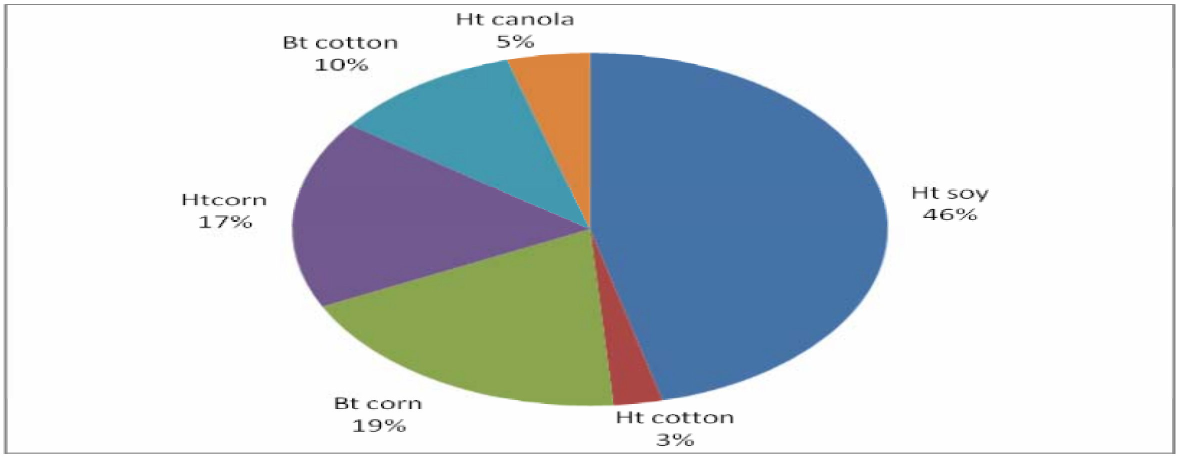


Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

2.2.2 By trait

Figure 4 summarises the breakdown of the main biotech traits planted globally in 2007. Biotech herbicide tolerant soybeans dominate accounting for 46% of the total followed by insect resistant (largely Bt) corn, herbicide tolerant corn and insect resistant cotton with respective shares of 19%, 17% and 10%[15]. In total, herbicide tolerant crops account for 71%, and insect resistant crops account for 29% of global plantings.

Figure 4: Global biotech crop plantings by main trait and crop: 2007

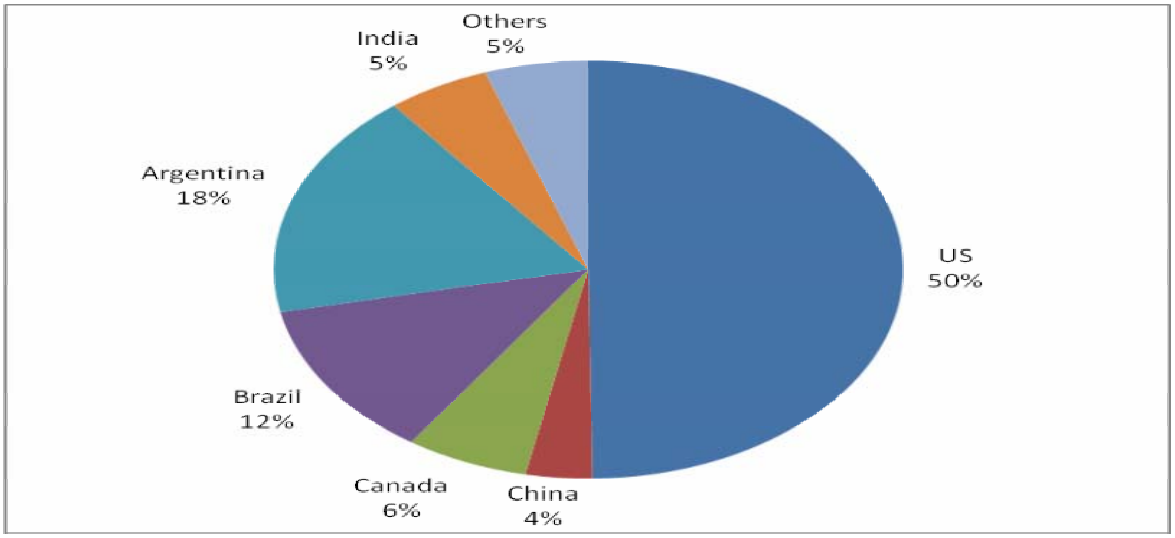


Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio

2.2.3 By country

The US had the largest share of global biotech crop plantings in 2007 (50%: 55.3 million ha), followed by Argentina (19.7 million ha: 18% of the global total). The other main countries planting biotech crops in 2007 were Canada, Brazil, India and China (Figure 5).

Figure 5: Global biotech crop plantings 2007 by country



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

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[15] The reader should note that the total plantings by trait produces a higher global planted area (124.3 million ha) than the global area by crop (111.2 million ha) because of the planting of some crops containing the stacked traits of herbicide tolerance and insect resistance

In terms of the biotech share of production in the main biotech technology adopting countries, Table 10 shows that, in 2007, the technology accounted for important shares of total production of the four main crops, in several countries. Biotech 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: Biotech share of crop plantings in 2007 by country (% of total plantings)

	Soybeans	**Maize**	**Cotton**	**Canola**
USA	91	73	87	91
Canada	58	73	N/a	87
Argentina	99	95	87	N/a
South Africa	87	58	79	N/a
Australia	N/a	N/a	95	N/a
China	N/a	N/a	61	N/a
Paraguay	93	N/a	N/a	N/a
Brazil	63	N/a	32	N/a
Uruguay	99	62	N/a	N/a

Note: N/a = not applicable

3 The farm level economic impact of biotech crops 1996-2007

This section examines the farm level economic impact of growing biotech 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;
- Production effects.

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 twelve 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 2007, 91% of the total US soybean crop was planted to genetically modified herbicide 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 $40/ha and $61/ha (based on a

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[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 – see appendix 4 for additional information

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 savings have come from lower herbicide costs[17] plus a $6/ha to $10/ha savings in labour and machinery costs;

- Against the background of underlying improvements in average yield levels over the 1996-2007 period (via improvements in plant breeding), the specific yield impact of the GM HT technology used up to 2007 has been neutral[18];
- The annual total national farm income benefit from using the technology has risen from $5 million in 1996 to $1.36 billion in 2007. The cumulative farm income benefit over the 1996-2007 period (in nominal terms) was $10.42 billion;
- In added value terms, the increase in farm income in recent years has been equivalent to an annual increase in production of between +5% and +10%.

Table 11: Farm level income impact of using GM HT soybeans in the US 1996-2007

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	9.57
2004	60.1	40.33	1,096.8	4.57
2005	69.4	44.71	1,201.4	6.87
2006	81.7	56.96	1,549.4	7.51
2007	82.7	57.96	1,358.2	5.76

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, 2006 & 2008)
2. Cost of technology: $14.82/ha 1996-2002, $17.3/ha 2003, $19.77/ha 2004, $24.71/ha 2005 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

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[17] Whilst there were initial cost savings in herbicide expenditure, these increased when glyphosate came off-patent in 2000. Growers of GM HT soybeans initially applied Monsanto's Roundup herbicide but over time, and with the availability of low cost generic glyphosate alternatives, many growers (eg, 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 may have 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

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 and almost all soybeans grown in Argentina are 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:

- 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 \$1-\$4/hectare compared to \$15-\$25/ha in the US) mainly because the main technology provider (Monsanto) was not able to obtain patent protection for the technology in Argentina. As such, Argentine farmers have been free to save and use biotech seed without paying any technology fees or royalties (on farm-saved seed) for many years and estimates of the proportion of total soybean seed used that derives from a combination of declared saved seed and uncertified seed in 2007 were about 75% (ie, 25% of the crop was planted to certified seed);
- 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-\$29/ha[19];
- The price received by farmers for GM HT 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 \$480 million in 2007. Since 1996, the cumulative benefit (in nominal terms) has been \$3.39 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, 30% of the total Argentine soybean crop was second crop in 2007[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 \$1.134 billion in 2007 and \$4.4 billion cumulatively since 1996;
- The total farm income benefit inclusive of the second cropping was \$1.6 billion in 2007 and \$7.8 billion cumulatively between 1996 and 2007;
- 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 +7%. The additional production

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[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 4.9 million ha in 2007

from second soybean cropping facilitated by the technology in 2007 was equal to 30% of total output.

Table 12: Farm level income impact of using GM HT soybeans in Argentina 1996-2007

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	27.82	372	373
2003	29.00	27.75	400	416
2004	30.00	28.77	436	678
2005	30.20	28.96	471	527
2006	28.72	26.22	465	699
2007	28.61	26.11	480	1,134

Sources and notes:

1. The primary source of information for impact on the costs of production is Qaim M & Traxler G (2002 & 2005)
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 – this was discontinued from 2004 because of the importance farmers attach to the GM HT system in facilitating them remaining in no tillage production systems). 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 two-thirds to 80% of GM HT plantings have been 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 63% of the total crop in 2007[21].

The impact of using GM HT soybeans has been similar to that identified in the US and Argentina. 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 $64/ha and $88/ha in the period 2003 to 2007 (Table 13). The net cost saving after deduction of the technology fee (assumed to be about $19/ha in 2007) has been between $32/ha and $68/ha. At a national level, the adoption of GM HT soybeans increased farm income levels by $830 million in 2007. Cumulatively over the period 1997 to 2007, farm incomes have risen by $2.87 billion (in nominal terms).

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[21] Until 2003 all plantings were technically illegal

In added value terms, the increase in farm income from the use of the GM HT technology in 2007 was equivalent to an annual increase in production of +4.7% (about 2.95 million tonnes).

Table 13: Farm level income impact of using GM HT soybeans in Brazil 1997-2007

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	76.66	61.66	320.9	2.95
2005	73.39	57.23	534.6	5.45
2006	81.09	61.32	730.6	6.32
2007	75.97	57.20	830.0	4.75

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 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 2007, they accounted for 93% of total soybean plantings in Paraguay and 99% of the soybean plantings in Uruguay[22]. Using the farm level impact data derived from Argentine research and applying this to production in these two countries[23], Figure 6 summarises the national farm level income benefits that have been derived from using the technology. In 2007, the respective national farm income gains were $57.5 million in Paraguay and $12.8 million in Uruguay.

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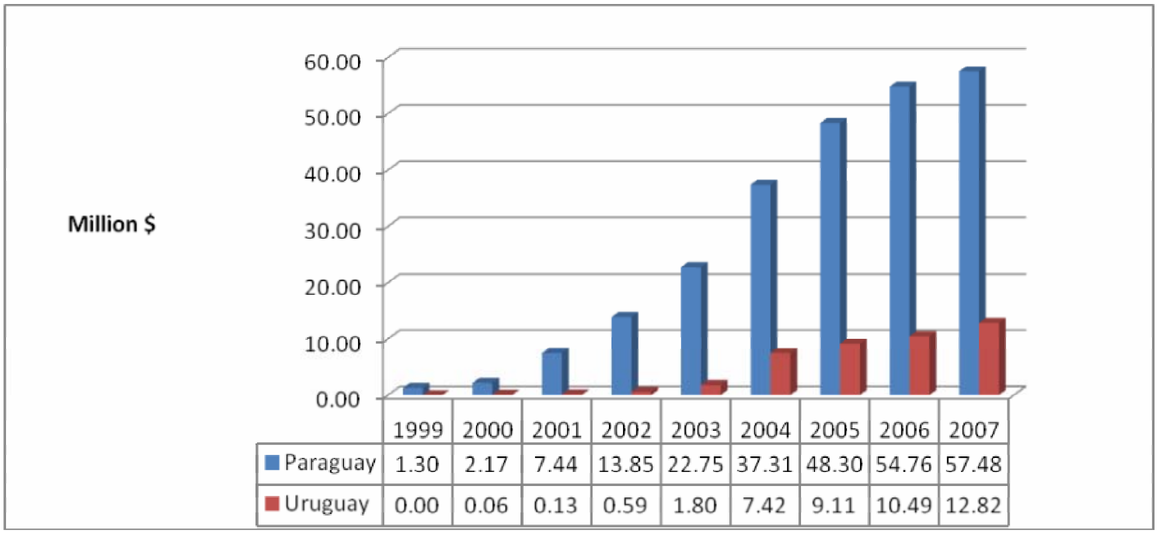
[22] As in Argentina, the majority of plantings are to farm saved or uncertified seed. For example, about two-thirds of plantings in Paraguay in 2007 were estimated to be uncertified seed

[23] Quam & Traxler (2002 & 2005). 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 1999-2007 (million $)



	1999	2000	2001	2002	2003	2004	2005	2006	2007
🟦 Paraguay	1.30	2.17	7.44	13.85	22.75	37.31	48.30	54.76	57.48
🟥 Uruguay	0.00	0.06	0.13	0.59	1.80	7.42	9.11	10.49	12.82

3.1.5 Canada

GM HT soybeans were first planted in Canada in 1997. By 2007 the share of total plantings accounted for by GM HT soybeans was 58% (0.69 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 $16.9 million in 2007 (Table 14). The cumulative increase in farm income since 1997 has been $103.5 million (in nominal terms). In added value terms, the increase in farm income from the use of the GM HT technology in 2007 was equivalent to an annual increase in production of about 1.6% (42,690 tonnes).

Table 14: Farm level income impact of using GM HT soybeans in Canada 1997-2007

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
2006	59.48	23.53	17.99	2.22
2007	61.99	24.52	16.87	1.57

Sources and notes:

1. Impact data based on George 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 2007, 132,000 hectares (87%) 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 $5/ha and $9/ha have been achieved through reduced expenditure on herbicides (Table 15). At the national level, the increase in farm income was $0.72 million in 2007. Cumulatively the farm income gain since 2001 has been $3.81 million.

Table 15: Farm level income impact of using GM HT soybeans in South Africa 2001-2007

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
2006	33.96	5.17	0.83
2007	32.95	5.01	0.72

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 2007, Romania was not officially permitted to plant GM HT soybeans, having joined the EU at the start of 2007 (the EU has not permitted the growing of GM HT soybeans to date) The impact data presented below therefore covers the period 1999-2006.

The growing of GM HT soybeans in Romania had 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%[24] have been recorded. This yield gain has arisen from the substantial improvements in weed control[25];
- The cost of the technology to farmers in Romania tended to be higher than other countries, with seed being sold in conjunction with the herbicide. For example, in the 2002-2006 period, the average cost of seed and herbicide per hectare was $120/ha to $130/ha. This relatively high cost however, did not deter adoption of the technology because of the major yield gains, improvements in the quality of soybeans produced

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[24] Source: Brookes (2005)

[25] 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)

(less weed material in the beans sold to crushers which resulted in price premia being obtained[26]) and cost savings derived;

- The average net increase in gross margin in 2006 was $220/ha (an average of $175/ha over the eight years of commercial use: Table 16);
- At the national level, the increase in farm income amounted to $28.6 million in 2006. Cumulatively in the period1999-2006 the increase in farm income was $92.7 million (in nominal terms);
- The yield gains in 2006 were equivalent to an 21% increase in national production[27] (the annual average increase in production over the eight years was equal to 14.9%);
- In added value terms, the combined effect of higher yields, improved quality of beans and reduced cost of production on farm income in 2006 was equivalent to an annual increase in production of 33% (124,000 tonnes).

Table 16: Farm level income impact of using herbicide tolerant soybeans in Romania 1999-2006

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	277.76	156.76	266.68	23.33	38.6
2006	239.07	113.6	220.55	28.67	33.2

Sources and notes:

1. Impact data (source: Brookes 2005). 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
4. The technology was not permitted to be planted in 2007 – due to Romania joining the EU

3.1.8 Mexico

GM HT soybeans were first planted commercially in Mexico in 1997 (on a trial basis) and in 2007, a continued trial area of 5,000 ha (out of total plantings of 73,000 ha) were varieties containing the GM HT trait.

At the farm level, the main impacts of use have been a combination of yield increase (+9.1%) and (herbicide) cost savings. The average farm income benefit has been within a range of $153/ha-$174/ha (inclusive of yield gain, cost savings and after payment of the technology fee/seed

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[26] Industry sources report that price premia for cleaner crops were no longer payable from 2005 by crushers and hence this element has been discontinued in the subsequent analysis

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

premium of $34.5/ha) and the increase in farm income at the national level was $0.84 million in 2007 (Table 17). The cumulative increase in farm income since 2004 has been $5.9 million (in nominal terms). In added value terms, the increase in farm income from the use of the GM HT technology in 2007 was equivalent to an annual increase in production of about 2% (2,340 tonnes).

Table 17: Farm level income impact of using GM HT soybeans in Mexico 2004-2007

Year	Cost savings ($/ha)	Net cost saving/increase in gross margin (inclusive of technology cost & yield gain: $/ha)	Impact on farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
2004	154.5	152.90	2,17	6.3
2005	154.5	158.21	1,67	3.8
2006	154.5	174.45	1,21	2.4
2007	154.5	168.48	0.84	2.0

Sources and notes:

1. Impact data based on Monsanto, 2007. Reporte final del programa Soya Solución Faena en Chiapas. Monsanto Comercial
2. 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

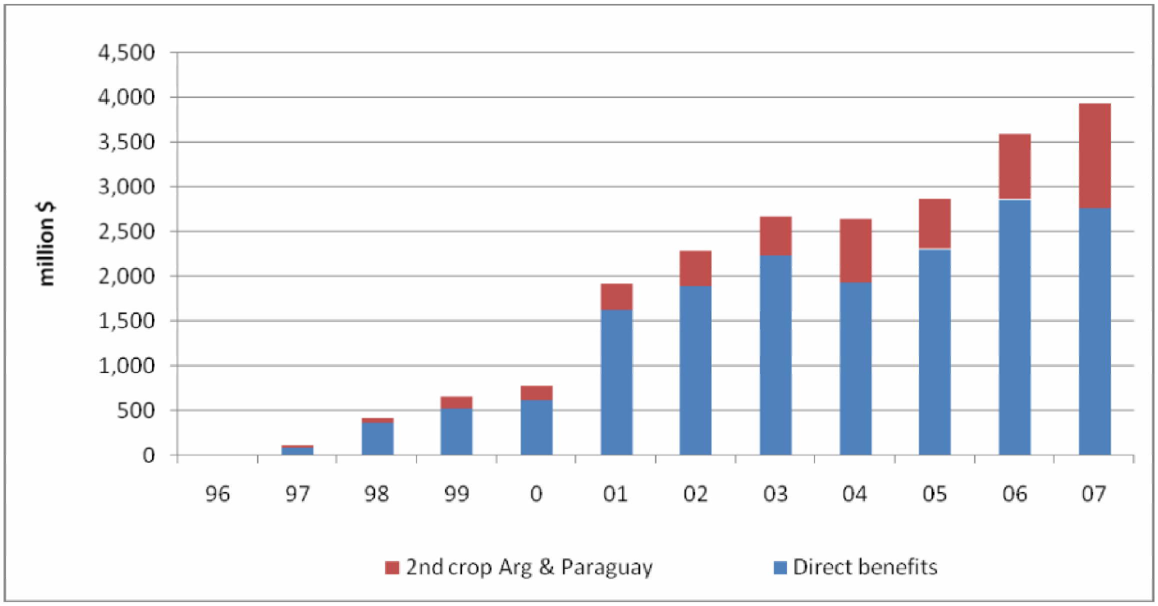
3.1.9 Summary of global economic impact

In global terms, the farm level impact of using GM HT technology in soybeans was $2.76 billion in 2007 (Figure 7). If the second crop benefits arising in Argentina are included this rises to $3.93 billion. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $17.1 billion ($21.8 billion if second crop gains in Argentina and Paraguay are included).

In terms of the total value of soybean production from the countries growing GM HT soybeans in 2007, the additional farm income (inclusive of Argentine second crop gains) generated by the technology is equal to a value added equivalent of 7.22%. Relative to the value of global soybean production in 2007, the farm income benefit added the equivalent of 6.42%.

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).

Figure 7: Global farm level income benefits derived from using GM HT soybeans 1996-2007 (million $)



These economic benefits mostly derive from cost savings although farmers in Mexico and Romania also obtained yield gains (from significant improvements in weed control levels relative to levels applicable prior to the introduction of the technology). If it is also assumed that all of the second crop soybean gains are effectively additional production that would not have otherwise occurred without the GM HT technology (the GM HT technology facilitated major expansion of second crop soybeans in Argentina and to a lesser extent in Paraguay) then these gains are *de facto* 'yield' gains. Under this assumption, of the total cumulative farm income gains from using GM HT soy, $4.69 billion (21.5%) is due to yield gains/second crop benefits and the balance, 78.5% is due to cost savings.

3.2 Herbicide tolerant maize

3.2.1 The US

Herbicide tolerant maize[28] has been used commercially in the US since 1997 and in 2007 was planted on 52% 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 $20/ha-$25/ha, resulting in a net gain to farm income in 2007 of $392 million. Cumulatively, since 1997 the farm income benefit has been $1.4 billion. In added value terms, the effect of reduced costs of production on farm income in 2007 was equivalent to an annual increase in production of 0.81% (2.89 million tonnes).

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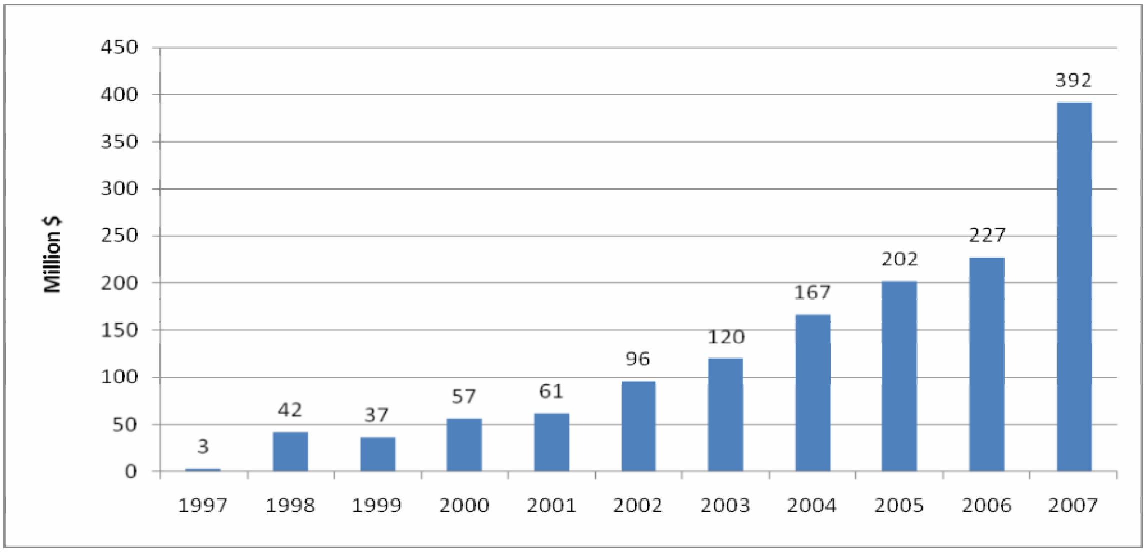
[28] Tolerant to glufosinate ammonium or to glyphosate, although cultivars tolerant to glyphosate has accounted for the majority of plantings

Figure 8: National farm income impact of using GM HT maize in the US 1997-2007

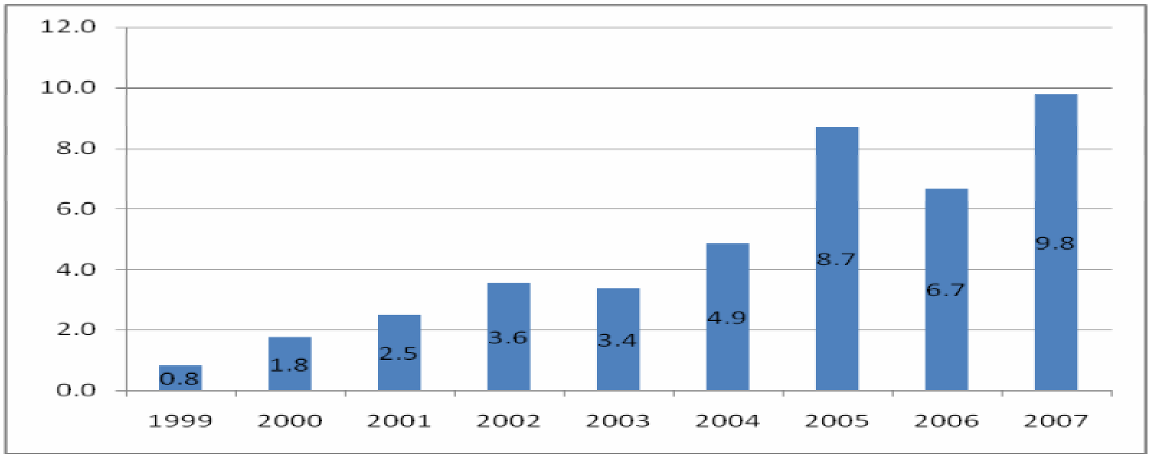


Source and notes: Impact analysis based on NCFAP 2001,2003, 2006 & 2008. Estimated cost of the technology $14.83/ha, cost savings (mostly from lower herbicide use) $40.55/ha in 2004, $40.75/ha 2005 & $44.6 2006 onwards

3.2.2 Canada

In Canada, GM HT maize was first planted commercially in 1997. By 2007 the proportion of total plantings accounted for by varieties containing a GM HT trait was 47%. As in the US, the main benefit has been to reduce costs and to improve profitability levels. Average annual profitability has improved by between $12/ha and $18/ha since 1999. In 2007, the net increase in farm income was $9.8 million and cumulatively since 1999 the farm income benefit has been $42 million. In added value terms, the effect of reduced costs of production on farm income in 2007 was equivalent to an annual increase in production of 0.43% (59,000 tonnes: Figure 9).

Figure 9: National farm income impact of using GM HT maize in Canada 1999-2007 ($ million)



Source and notes: Impact analysis based on data supplied by Monsanto Canada. Estimated cost of the technology $18-$32/ha, cost savings (mostly from lower herbicide use) $31-$45/ha

3.2.3 Argentina

GM HT maize was first planted commercially in Argentina in 2004 (369,000 ha in 2007). It has been adopted in two distinct types of area, the majority (80%) in the traditional 'corn production belt' and 20% in newer maize-growing regions, which have been traditionally known as more marginal areas that surround the 'Corn Belt'. The limited adoption of GM HT technology in Argentina up to 2006 was mainly due to the technology only being available as a single gene, not stacked with the GM IR trait, which most maize growers have also adopted. Hence, faced with an either GM HT or GM IR trait available for use, most farmers have chosen the GM IR trait because the additional returns derived from adoption have tended to be (on average) greater from the GM IR trait than the GM HT trait (see below for further details of returns from the GM HT trait). Stacked traits became available in 2007 and contributed to the 70% increase in the GM HT maize area relative to 2006.

In relation to impact on farm income:

- In all regions the cost of the technology (about $20/ha) has been broadly equal to the saving in herbicide costs;
- In the Corn Belt area, use of the technology has resulted in an average 3% yield improvement via improved weed control. In the more marginal areas, the yield impact has been much more significant (+22%) as farmers have been able to significantly improve weed control levels;
- In 2007, the additional farm income at a national level from using GM HT technology has been +$27.6 million, and cumulatively since 2004, the income gain has been $46 million.

3.2.4 South Africa

Herbicide tolerant maize has been grown commercially in South Africa since 2003, and in 2007 453,000 hectares out of total plantings of 2.55 million hectares were herbicide tolerant. Farmers using the technology have found that small net savings in the cost of production have occurred (ie, the cost saving from reduced expenditure on herbicides has been greater than the cost of the technology). In 2007, the total farm income gain arising from using GM HT technology was $2.72 million and since 2003, the cumulative income gain has been $5.2 million.

3.2.5 Philippines

GM HT maize was first grown commercially in 2006, and 2007 was planted on 191,000 hectares. Information about the impact of the technology is limited, although industry sources estimate that, on average farmers using it have derived a 15% increase in yield. Based on a cost of the technology of $24-$27/ha (and assuming no net cost savings), the net national impact on farm income was +$10.4 million in 2007. Cumulatively for the two years of adoption, the total farm income gain has been $11.4 million

3.2.6 Summary of global economic impact

In global terms, the farm level economic impact of using GM HT technology in maize was $442 million in 2007 (89% of which was in the US). Cumulatively since 1997, the farm income benefit has been (in nominal terms) $1.51 billion. Of this, 95% has been due to cost savings and 5% to yield gains (from improved weed control relative to the level of weed control achieved by farmers using conventional technology).

In terms of the total value of maize production in the main countries using this technology in 2007, the additional farm income generated by the technology is equal to a value added equivalent of 0.4% of global maize production.

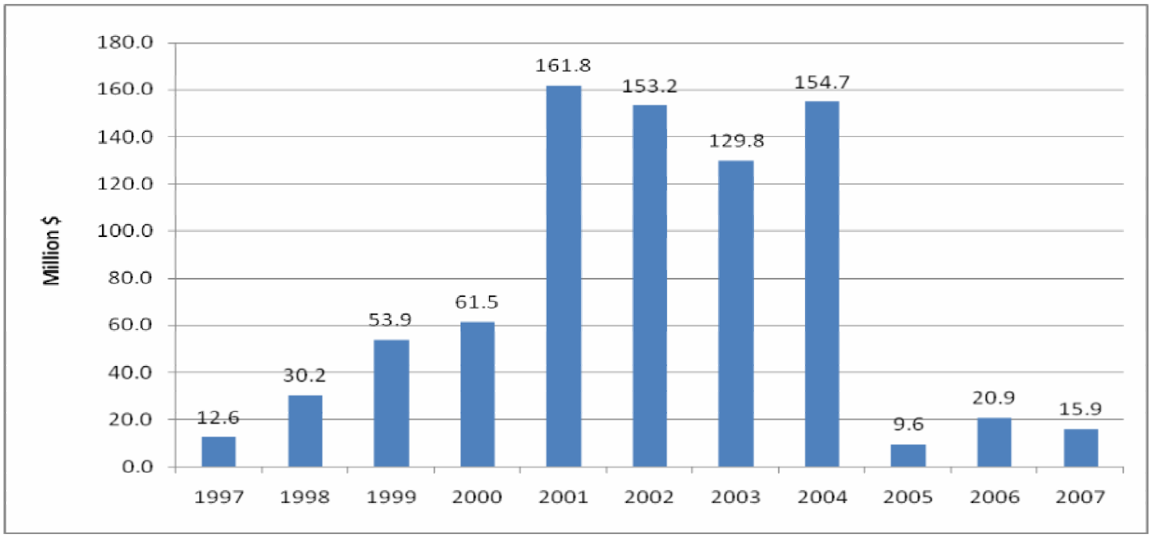
3.3 Herbicide tolerant cotton

3.3.1 The US

GM HT cotton was first grown commercially in the US in 1997 and in 2007, was planted on 70% of total cotton plantings[29].

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 annual average profitability increasing by between $3/ha and $49/ha[30], resulting in a net gain to farm income in 2007 of $16 million. Cumulatively since 1997 the farm income benefit has been $804 million. In added value terms, the effect of reduced cost of production on farm income in 2007 was equivalent to an annual increase in production of 0.31% (15,900 tonnes).

Figure 10: National farm income impact of using GM HT cotton in the US 1997-2007



Source and notes: Impact analysis based on NCFAP 2001, 2003, 2006 & 2008. Estimated cost of the technology $12.85/ha (1997-2000) and $21.32/ha 2001-2003 and $34.55 2004, $68.22/ha 2005 and $70.35 2006 onwards, cost savings excluding cost of technology (mostly from lower herbicide use) $34.12/ha (1997-2000), $65.59/ha (2001-2003), $83.35/ha 2004, $71.12/ha 2005, $75.55 2006 onwards

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

[30] The only published source that has examined the impact of HT cotton in the US is work by the NCFAP in 2001, 2003, 2006 & 2008. 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

3.3.2 Other countries

Australia, Argentina, South Africa and Mexico are the other countries where GM HT cotton is commercially grown; from 2000 in Australia, 2001 in South Africa, 2002 in Argentina and 2005 in Mexico. In 2007, 79% (50,460 ha), 38% (124,000 ha), 75% (9,750 ha) and 40% (50,000 ha) respectively of the total Australian, Argentine, South African and Mexican 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, Argentina or Mexico. In Australia, although research has been conducted into the impact of using GM HT cotton (eg, Doyle B et al (2003)) this does not provide quantification of the impact[31]. Drawing on industry source estimates[32], the main impact has been to deliver small net savings in costs equal to about $1/ha-$9/ha in South Africa, $6/ha to $8/ha in Australia and about $39/ha in Mexico. In Argentina the cost of the technology has tended to be greater than herbicide cost savings although farmers have derived a net farm income gain from a 17% average yield gain (from improved weed control). In Mexico, there have also been yield gains of about 3% to 4%. At a national level, in 2007 the farm income gains in these four countries amounted to $8.6 million. The cumulative savings since 2000 across these countries have been $44.3 million.

3.3.3 Summary of global economic impact

Within the five countries using GM HT cotton in 2007, the total farm income benefit derived from using GM HT cotton was $24.6 million, and cumulatively since 1997, the gains have been $848 million (95% of this benefit has been in the US). Of this, 96% has been due to cost savings and 4% to yield gains (from improved weed control relative to the level of weed control achieved using conventional technology).

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 87% of the total crop in 2007 (5.14 million ha).

The farm level impact of using GM HT canola in Canada since 1996 is summarised in Table 18. The key features are as follows:

- The primary impact in the early years of adoption was increased yields of almost 11% (eg, in 2002 this yield increase was equivalent to an increase in total Canadian canola production of nearly 7%). In addition, a small additional price premia was achieved from crushers through supplying cleaner crops (lower levels of weed impurities). With the development of hybrid varieties using conventional technology, the yield advantage of GM HT canola relative to conventional alternatives[33] has been eroded. As a result, our

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

[32] Sources: Monsanto Australia, Argentina, South Africa & Mexico

[33] The main one of which is 'Clearfield' conventionally derived herbicide tolerant varieties, which in 2007 were planted on 11% of the Canadian canola crop, leaving only 2% to non herbicide tolerant conventional varieties. Hybrid canolas now account for the majority

analysis has applied the yield advantage of +10.7% associated with the GM HT technology in its early years of adoption (source: Canaola Council study of 2001) to 2003. From 2004 the yield gain has been based on differences between average annual variety trial results for Clearfields (conventional herbicide tolerant varieties) and biotech alternatives. The biotech alternatives have also been differentiated into glyphosate tolerant and glufosinate tolerant. This resulted in; for GM glyphosate tolerant varieties no yield difference for 2004 and 2005 and +4% 2006 and 2007. For GM glufosinate tolerant varieties, the yield differences were +12% 2004, +19% 2005, +10% 2006 & 2007. The quality premia associated with cleaner crops (see above) has not been included in the analysis from 2004;

- Cost of production (excluding the cost of the technology[34]) 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 to 2003 was however marginally higher than these savings resulting in a net increase in costs of $3/ha to $5/ha. On the basis of comparing GM HT canola with 'Clearfields' HT canola (from 2004), there has been a net cost saving of between $5/ha and $10/ha;
- The overall impact on profitability (inclusive of yield improvements and higher quality) has been an increase of between $22/ha and $48/ha up to 2003. On the basis of comparing GM HT canola with 'Clearfields' HT canola (from 2004), the net increase in profitability has been between $23/ha and $61/ha;
- The annual total national farm income benefit from using the technology has risen from $6 million in 1996 to $317 million in 2007. The cumulative farm income benefit over the 1996-2007 period (in nominal terms) was $1.29 billion;
- In added value terms, the increase in farm income in 2007 has been equivalent to an annual increase in production of almost 6.97%.

Table 18: Farm level income impact of using GM HT canola in Canada 1996-2007

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	26.31	+5.33	22.71	84.11	5.28
2005	20.45	+4.83	38.70	174.23	7.61
2006	29.91	+9.75	49.06	218.78	7.85

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of plantings (including some GM hybrids) with the hybrid vigour delivered by conventional breeding techniques (even in the GM HT (to glyphosate) varieties

[34] In Candian $ terms the cost of technology has remained constant at about Can $45/ha. Due the recent depreciation of the US $ against the Canadian $, this equates to a rise in the cost of technology in US $ terms

2007	28.23	+9.44	61.35	316.65	6.97

Sources and notes:

1. Impact data based on Canola Council study (2001) to 2003. Includes a 10.7% yield improvement and a 1.27% increase in the price premium earned (cleaner crop with lower levels of weed impurities) until 2003. After 2004 the yield gain has been based on differences between average annual variety trial results for Clearfields and biotech alternatives. The biotech alternatives have also been differentiated into glyphosate tolerant and glufosinate tolerant. This resulted in; for GM glyphosate tolerant varieties no yield difference for 2004 and 2005 and +4% 2006 and 2007. For GM glufosinate tolerant varieties, the yield differences were +12% 2004, +19% 2005, +10% 2006 & 2007On the basis of comparing GM HT canola with 'Clearfields' HT canola
2. Negative values denote a net increase in the cost of production (ie, the cost of the technology was greater than the other cost (eg, on herbicides) reductions
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

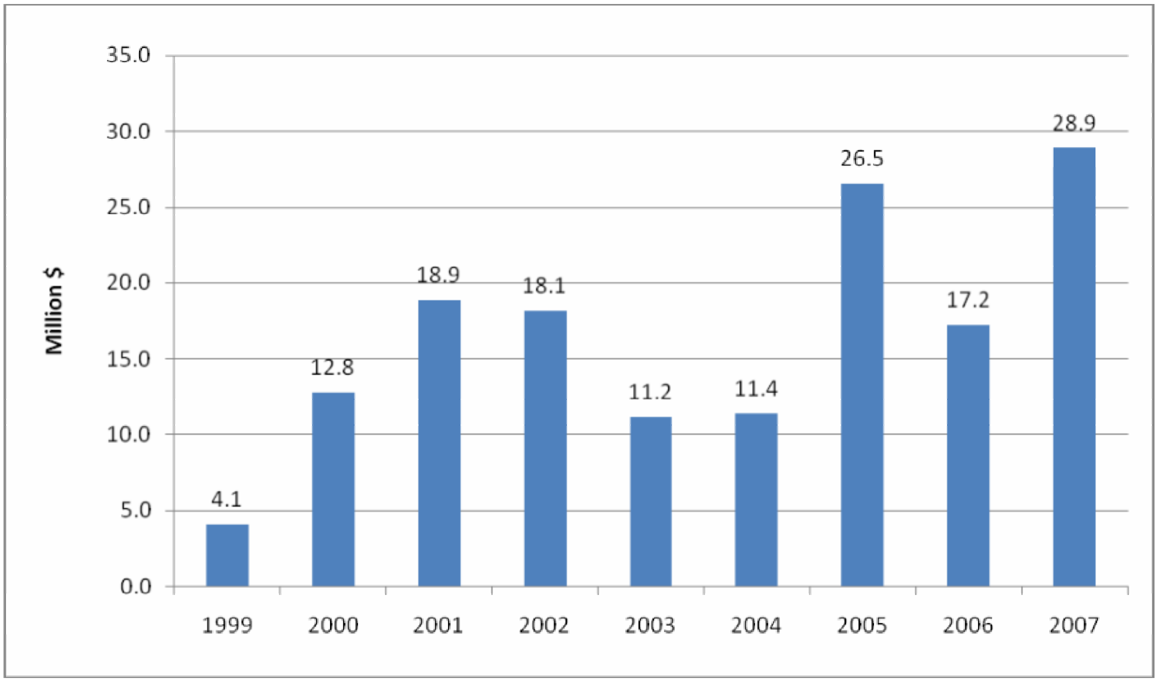
3.4.2 The US

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 2007, 91% of the US canola crop was GM HT (387,500 ha).

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

- Average yields increased by about 6% in the initial years of adoption. As in Canada (see section 3.4.1) the availability of high yielding hybrid conventional varieties has eroded some of this yield gain in recent year relative to conventional alternatives. As a result, the positive yield impacts post 2004 have been applied on the same basis as in Canada (comparison with Clearfields: see section 3.4.1);
- The cost of the technology has been \$12/ha-\$17/ha for glufosinate tolerant varieties and \$12/ha-\$33/ha for glyphosate tolerant varieties. Cost savings (before inclusion of the technology costs) have been \$35/ha-\$45/ha for glufosinate tolerant canola and \$40-\$67/ha for glyphosate tolerant canola;
- The net impact on gross margins has been between +\$22/ha and +\$90/ha for glufosinate tolerant canola, and +\$22/ha and +\$51/ha for glyphosate tolerant canola;
- At the national level the total farm income benefit in 2007 was \$28.9 million and the cumulative benefit since 1999 has been \$149 million;
- In added value terms, the increase in farm income in 2007 has been equivalent to an annual increase in production of about 10.3%.

Figure 11: National farm income impact of using GM HT canola in the US 1999-2007



Source and notes: Impact analysis based on NCFAP 2001, 2003, 2006 & 2008. 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). Positive yield impact applied in the same way as Canada from 2004 – see section 3.4.1

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 $346 million in 2007. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $1.44 billion. Within this, 87% has been due to yield gains and the balance (13%) has been from cost savings.

In terms of the total value of canola production in these two countries in 2007, the additional farm income generated by the technology is equal to a value added equivalent of 7.65%. Relative to the value of global canola production in 2007, the farm income benefit added the equivalent of 1.4%.

3.5 GM insect resistant[35] (GM IR) maize

3.5.1 US

GM IR maize was first planted in the US in 1996 and in 2007, was planted on 49% (18.56 million ha) of the total US maize crop.

The farm level impact of using GM IR maize in the US since 1996 is summarised in Table 19:

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[35] Resistant to corn boring pests

- The primary impact has been increased average yields of about 5% (in 2007 this additional production is equal to an increase in total US maize production of +2.45%);
- The net impact on cost of production has been a small increase of between $1/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 $1.14 billion in 2007. The cumulative farm income benefit over the 1996-2007 period (in nominal terms) was $3.89 billion;
- In added value terms, the increase in farm income in 2007 was equivalent to an annual increase in production of 2.28%.

Table 19: Farm level income impact of using GM IR maize in the US 1996-2007

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	24.71	-9.21	29.20	8.76	0.03
1997	24.71	-9.21	28.81	70.47	0.27
1998	20.30	-4.8	27.04	167.58	0.77
1999	20.30	-4.8	25.51	206.94	1.04
2000	22.24	-6.74	24.32	148.77	0.71
2001	22.24	-6.74	26.76	155.87	0.72
2002	22.24	-6.74	30.74	240.45	0.96
2003	22.24	-6.74	31.54	291.00	1.14
2004	15.88	-6.36	33.82	363.41	1.32
2005	15.88	-1.42	34.52	399.91	1.60
2006	15.88	-1.42	55.78	707.23	1.86
2007	15.88	-1.42	61.22	1,136.21	2.28

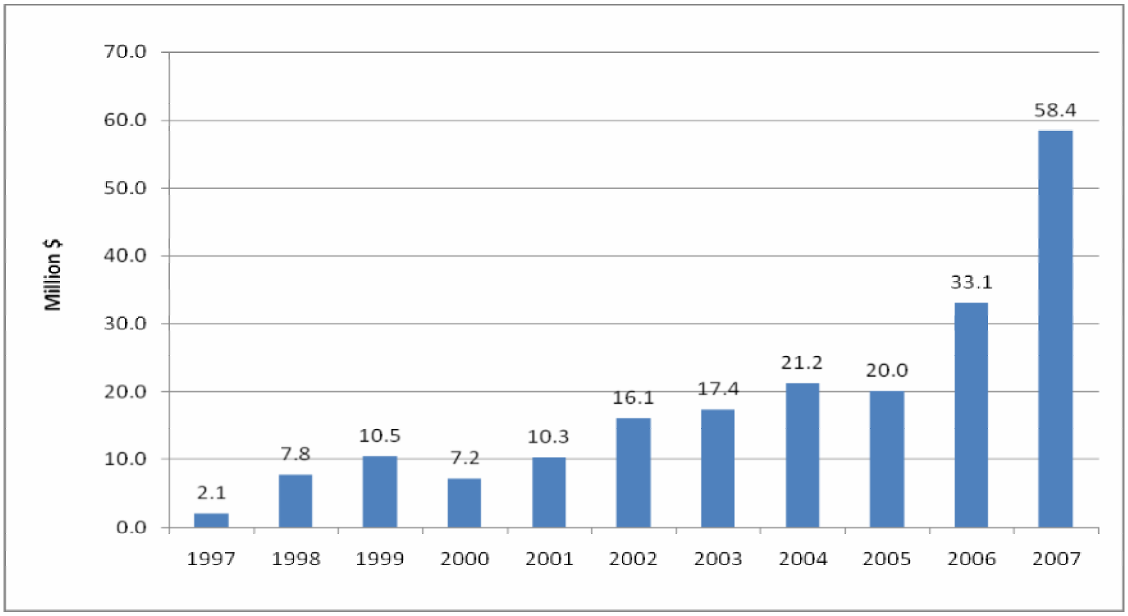
Sources and notes:

1. Impact data based on a combination of studies including the ISAAA (James) review (2002), Marra et al and NCFAP 2001, 2003, 2006 & 2008
2. Yield impact +5% based on average of findings of above studies
3. Insecticide cost savings based on NCFAP 2003, 2006 and 2008
4. –ve value for net cost savings means the cost of the technology is greater than the other cost savings

3.5.2 Canada

GM IR maize has also been grown commercially in Canada since 1996. In 2007 it accounted for 52% of the total Canadian maize crop of 1.6 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 2007 the additional farm income generated from the use of GM IR maize was $58.4 million and cumulatively since 1996 the additional farm income (in nominal terms) was $204.2 million (Figure 12).

Figure 12: National farm income impact of using GM IR maize in Canada 1996-2007



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 2007, GM IR maize traits were planted on 81% of the total Argentine maize crop (GM IR varieties were first planted in 1998).

The main impact of using the technology on farm profitability has been via yield increases. Various studies (eg, see ISAAA review in James (2002)) have identified an average yield increase in the region of 8% to 10%, hence an average of 9% has been used in the analysis up to 2004. More recent trade source estimates provided to the authors put the average yield increased in the last 2-3 years to be between 5% and 6%. Accordingly our analysis uses a yield increase value of 5.5% for the years from 2004.

No savings in costs of production have arisen for most farmers 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 $20/ha-$22/ha (the cost of the technology).

The net impact on farm profit margins (inclusive of the yield gain) has, in recent years, been an increase of about $20/ha. In 2007, the national level impact on profitability was an increase of $56 million (an added value equal to 2.23% of the total value of production). Cumulatively, the farm income gain since 1997 has been $226.8 million.

3.5.4 South Africa

GM IR maize has been grown commercially in South Africa since 2000. In 2007, 44% of the country's total maize crop of 2.8 million ha used GM IR cultivars.

The impact on farm profitability is summarised in Table 20. The main impact has been an average yield improvement of between 5% and 32% in the years 2000-2004, with an average of about 15% (used as the basis for analysis from 2005). The cost of the technology $8-$17/ha has broadly been equal to the average cost savings from no longer applying insecticides to control corn borer pests.

At the national level, the increase in farm income in 2007 was $222.6 million and cumulatively since 2000 it has been $355 million. In terms of national maize production, the use of Bt technology on 44% of the planted area has resulted in a net increase in national maize production of 6.1% in 2007. The value of the additional income generated was also equivalent to an annual increase in production of about 6.2%.

Table 20: Farm level income impact of using GM IR maize in South Africa 2000-2007

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	0.6	113.98	19.35
2003	12.82	0.4	63.72	14.66
2004	14.73	0.46	20.76	8.43
2005	15.25	0.47	48.66	19.03
2006	14.32	-2.36	63.75	63.05
2007	13.90	-2.29	180.39	222.60

Sources and notes:

1. Impact data (sources: Gouse (2005 & 2006))
2. Negative value for the net cost savings = a net increase in costs (ie, the extra cost of the technology was greater than the other (eg, less expenditure on insecticides) cost savings
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

3.5.5 Spain

Spain has been commercially growing GM IR maize since 1998 and in 2007, 21% (75,150 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 in the early years of adoption). With the availability and widespread adoption of the Mon 810 trait from 2003, the reported average positive yield impact is about +10%[36]. There has also been a net annual average saving on cost of production (from lower insecticide use) of between $37/ha and $57/ha[37] (Table 21). At the national level, these yield gains and cost savings have resulted in farm income being boosted, in 2007 by $20.6 million and cumulatively since 1998 the increase in farm income (in nominal terms) has been $60 million.

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[36] The cost of using this trait has been higher than the pre 2003 trait (Bt 176) – rising from about €20/ha to €35/ha

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

Relative to national maize production, the yield increases derived from GM IR maize were equivalent to a 2% increase in national production (2007). The value of the additional income generated from Bt maize was also equivalent to an annual increase in production of 1.94%.

Table 21: Farm level income impact of using GM IR maize in Spain 1998-2007

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	2.14
1999	44.81	12.80	102.20	2.56
2000	38.81	12.94	89.47	2.24
2001	37.63	21.05	95.63	1.10
2002	39.64	22.18	100.65	2.10
2003	47.50	26.58	121.68	3.93
2004	51.45	28.79	111.93	6.52
2005	52.33	8.72	144.74	7.70
2006	52.70	8.78	204.5	10.97
2007	57.30	9.55	274.59	20.63

Sources and notes:

1. Impact data (based on Brookes (2002 & Brookes (2008)). Yield impact +6.3% to 2004 and 10% used thereafter (originally Bt 176, latterly Mon 810). Cost of technology based on €18.5/ha to 2004 and €35/ha from 2005
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 EU countries

A summary of the impact of GM IR technology in other countries of the EU is presented in Table 22. This shows that in 2007, the additional farm income derived from using GM IR technology in these seven countries was +$7.4 million, and cumulatively over the 2005-2007 period, the total income gain was $8.6 million.

Table 22: Farm level income impact of using GM IR maize in other EU countries 2005-2007

	Year first planted GM IR maize	Area 2007 (hectares)	Yield impact (%)	Cost of technology 2007 ($/ha)	Cost savings 2007 (before deduction of cost of technology: $/ha)	Net increase in gross margin 2007 ($/ha)	Impact on farm income at a national level 2007 (million $)
France	2005	22,135	+10	54.57	68.21	254.73	5.64
Germany	2005	2,685	+4	54.57	68.21	117.32	0.32
Portugal	2005	4,263	+12.5	47.75	0	143.94	0.61
Czech Republic	2005	5,000	+10	47.75	24.56	146.25	0.73
Slovakia	2005	900	+12.3	47.75	0	102.35	0.09
Poland	2006	327	+12.5	47.75	0	123.33	0.04
Romania	2007	360	+7.1	43.66	0	34.66	0.01

Total other EU (excluding Spain)		**35,670**					**7.44**

Source and notes:

1. Source: based on Brookes (2008)
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

3.5.7 Other countries

GM IR maize has been grown commercially in:

- the Philippines since 2003. In 2007, 194,000 hectares out of total plantings of 2.72 million (7%) were GM IR. Estimates of the impact of using GM IR (sources: Gonzales (2005), 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 $12/ha-$13/ha and average cost of the technology of about $33/ha, the net impact on farm profitability has been between $37/ha and $109/ha. In 2007, the national farm income benefit derived from using the technology was $21 million and cumulative farm income gain since 2003 has been $33 million;
- Uruguay since 2004, and in 2007, 105,000 ha (62% of the total crop) were GM IR. Using Argentine data as the basis for assessing impact, the cumulative farm income gain over the three years has been $2.7 million.

3.5.8 Summary of economic impact

In global terms, the farm level impact of using GM IR maize was $1.52 billion in 2007. Cumulatively since 1996, the benefit has been (in nominal terms) $4.78 billion. This farm income gain has mostly derived from improved yields (less pest damage) although in some countries farmers have derived a net cost saving associated with reduced expenditure on insecticides.

In terms of the total value of maize production from the countries growing GM IR maize in 2007, the additional farm income generated by the technology is equal to a value added equivalent of 2.32%. Relative to the value of global maize production in 2006, the farm income benefit added the equivalent of 1.42%.

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 2007, was used in 59% (2.6 million ha) of total cotton plantings.

The farm income impact of using GM IR cotton is summarised in Table 23. The primary benefit has been increased yields (by 9%-11%), 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 $87/ha and $118/ha in 2003-2007 with Bollgard II (containing two Bt genes and offering a broader spectrum of control). This resulted in a net gain to farm income in 2007 of $274 million. Cumulatively, since 1996 the farm income benefit has been $2.23 billion. In added value terms, the effect of the increased yields and reduced costs of production on farm income in 2007 was equivalent to an annual increase in production of 5.1% (228,000 tonnes).

Table 23: Farm level income impact of using GM IR cotton in the US 1996-2007

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	24.48	117.81	332.41	5.97
2006	-5.77	86.61	305.17	4.86
2007	-5.77	106.02	274.08	5.09

Sources and notes:

1. Impact data based on NCFAP 2001, 2003, 2006 and 2008, Marra M (2002) and Mullins & Hudson (2004)
2. Yield impact +9% 1996-2002 Bollgard I and +11% 2003 onwards Bollgard II
3. Cost of technology: 1996-2002 Bollgard I $58.27/ha, 2003-2004 Bollgard II $68.32/ha, $49.62/ha 2005, $46.95 2006 & 2007
4. Insecticide cost savings $63.26/ha 1996-2002, $74.10/ha 2003-2005, $41.18 2006 & 2007

3.6.2 China

China first planted GM IR cotton in 1997, since when the area planted to GM IR varieties has increased to 61% of the total 6.2 million ha crop in 2007.

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 and the labour previously used to undertake spraying. Overall, annual average costs have fallen by about $145/ha-$201/ha and annual average profitability improved by $123/ha-$472/ha. In 2007, the net national gain to farm income was $943 million (Table 24). Cumulatively since 1997 the farm income benefit has been $6.74 billion. In added value terms, the effect of the increased yields and reduced costs of production on farm income in 2007 was equivalent to an annual increase in production of nearly 14.5% (1.17 million tonnes).

Table 24: Farm level income impact of using GM IR cotton in China 1997-2007

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	145	256	845.58	13.57
2006	146	226	792.28	16.86
2007	152	248	942.7	14.46

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, except 2005 onwards based on Shachuan (2006) – personal communication
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. Negative value for the net cost savings in 2000 = a net increase in costs (ie, the extra cost of the technology was greater than the savings on insecticide expenditure – a year of lower than average bollworm problems
5. 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 86% of its 2007 cotton crop (total crop of 64,000 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 rarely derived yield gains from using the technology (reflecting the effective use of insecticides for pest control prior to the availability of GM IR cultivars), with the primary farm income benefit being derived from lower costs of production (Table 25). 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 $54/ha and $90/ha, mostly derived from lower insecticide costs (including application) more than offsetting the cost of the technology;
- For the last few 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 $212/ha;
- At the national level in 2007, the net farm income gains was $11.7 million and cumulatively since 1996 the gains have been $190.6 million;

- In added value terms, the effect of the reduced costs of production on farm income in 2007 was equivalent to an annual increase in production of 41% (50,000 tonnes).

Table 25: Farm level income impact of using GM IR cotton in Australia 1996-2007

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	-0.59
1997	-191.7	-35.0	-2.04	-0.88
1998	-97.4	91.0	9.06	0.43
1999	-83.9	88.1	11.80	4.91
2000	-89.9	64.9	10.71	4.38
2001	-80.9	57.9	7.87	5.74
2002	-90.7	54.3	3.91	3.43
2003	-119.3	256.1	16.3	11.49
2004	-179.5	185.8	45.7	21.33
2005	-229.2	193.4	47.9	23.75
2006	-225.9	190.7	22.49	26.01
2007	-251.33	212.1	11.73	40.9

Sources and notes:

1. Impact data based on Fitt (2001) and CSIRO for bollgard II since 2004
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 2007, it accounted for 49% of total cotton plantings.

The main impact in Argentina has been yield gains of 30% (which has resulted in a net increase in total cotton production (2007) of 15%). This has more than offset the cost using the technology[38]. In terms of gross margin, cotton farmers have gained annually between $25/ha and $249/ha during the period 1998-2007[39]. At the national level, the annual farm income gains in the last five years have been in the range of $2 million to $26 million (Figure 13). Cumulatively since 1998, the farm income gain from use of the technology has been $67.9 million. In added value terms, the effect of the yield increases (partially offset by higher costs of production) on farm income in 2007 was equivalent to an annual increase in production of 10%.

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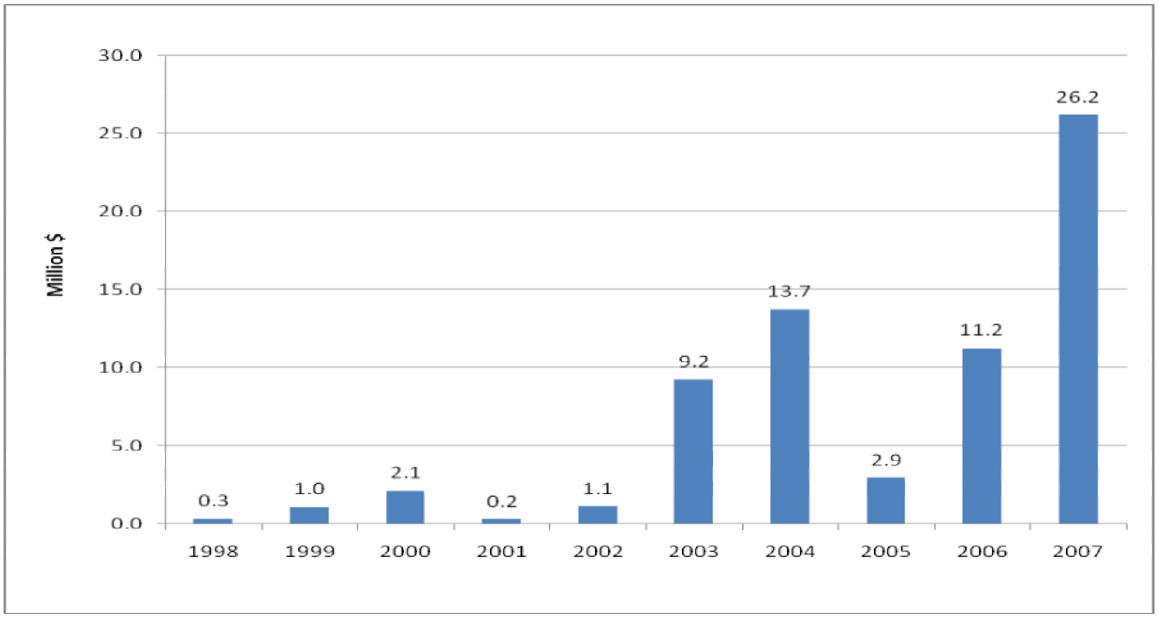
[38] The cost of the technology used in the years up to 2004 was $86/ha (source: Qaim & DeJanvry). From 2005, the cost used was $40/ha (source: Monsanto Argentina). The insecticide cost savings is about $17.5/ha, leaving a net increase in costs of $68.5/ha up to 2004 and $22.5/ha from 2005

[39] 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 1998-2007



Sources and notes:

1. Impact data (source: Qaim & De Janvry (2002) and for 2005 and 2006 Monsanto LAP, although cost of technology in 2005 from Monsanto Argentina. Area data : source ArgenBio
2. Yield impact +30% to 2004 and +25% 2005 onwards, 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 2007, GM IR cotton was planted on 60,000 ha (48% of total cotton plantings).

The main farm income impact of using the technology has been yield improvements of between 6% and 9% over the last six years. In addition, there have been important savings in the cost of production (lower insecticide costs)[40]. Overall, the annual net increase in farm profitability has been within the range of $104/ha and $354/ha between 1996 and 2007 (Table 26). At the national level, the farm income benefit in 2007 was $8.3 million and the impact on total cotton production was an increase of 4.4%. Cumulatively since 1996, the farm income benefit has been $65.9 million. In added value terms, the combined effect of the yield increases and lower cost of production on farm income in 2007 was equivalent to an annual increase in production of 4.7%.

Table 26: Farm level income impact of using GM IR cotton in Mexico 1996-2007

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

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[40] Cost of technology has annually been between $48/ha and $70/ha, insecticide cost savings between $88/ha and $121/ha and net savings on costs have been between $20/ha and $48/ha (derived from and based on Traxler et al (2001)

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	262.4	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	127.7	3.33	3.67
2004	39.3	130.4	6.24	4.51
2005	40.8	132.3	10.4	7.64
2006	20.4	124.4	6.44	4.06
2007	20.5	139.7	8.38	4.74

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 +7.6%, 2005 onwards +9.25%
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 2007, GM IR cotton[41] was planted on 9,900 ha in South Africa (76% 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 for Bollgard I and about $50/ha for Bollgard II (2006 onwards) has been greater than the insecticide cost and labour (for water collection and spraying) savings ($12/ha to $23/ha), resulting in an increase in overall cost of production of $2/ha to $32/ha. Combining the positive yield effect and the increase in cost of production, the net effect on profitability has been an annual increase of between $27/ha and $232/ha.

At the national level, farm incomes, over the last five years have annually increased by between $1.2 million and $5.7 million (Figure 14). Cumulatively since 1998, the farm income benefit has been $19.3 million. The impact on total cotton production was an increase of 18.3% in 2007. In added value terms, the combined effect of the yield increases and lower costs of production on farm income in 2007 was equivalent to an annual increase in production of 12.4% (based on 2007 production levels).

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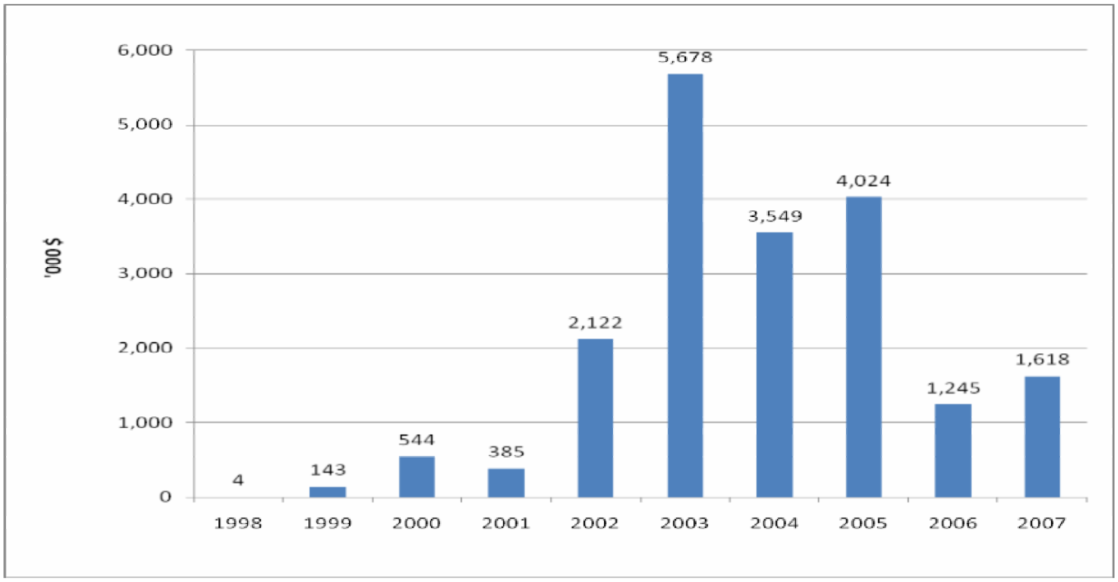
[41] First planted commercially in 1998

Figure 14: National farm income impact of using GM IR cotton in South Africa 1998-2007



Sources and notes:

1. Impact data based on Ismael et al (2002)
2. Yield impact +24%, cost of technology \$14/ha-\$24/ha for Bollgard I and about \$50/ha for Bollgard II, 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 2007, 5.87 million ha were planted to GM IR cotton which is equal to about 63% of total plantings.

The main impact of using GM IR cotton has been major increases in yield[42]. With respect to cost of production, the average cost of the technology (seed premium: \$49/ha to \$54/ha) has been greater than the average insecticide cost savings of \$31/ha-\$58/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 between \$82/ha and \$322/ha. At the national level, the farm income gain in 2007 was \$1.89 billion and cumulatively since 2002 the farm income gains have been \$3.18 billion.

Table 27: Farm level income impact of using GM IR cotton in India 2002-2007

Year	Cost savings (net after cost of	Net increase in gross margins (\$/ha)	Increase in farm income at a national level (\$	Increase in national farm income as % of

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[42] 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 & IMRB (2007) which found a yield impact of +50% in 2006

	technology ($/ha)		millions)	farm level value of national production
2002	-12.42	82.66	3.69	0.26
2003	-16.2	209.85	20.98	0.47
2004	-13.56	193.36	96.68	1.86
2005	-22.25	255.96	332.74	5.26
2006	3.52	221.02	839.89	14.04
2007	-8.86	321.57	1,886.99	20.58

Sources and notes:

1. Impact data based on Bennett et al (2004) and IMRB (2005 & 2007)
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 32% in 2007 and in added value terms, the combined effect of the yield increases and higher costs of production on farm income in 2007 was equivalent to an annual increase in production of 21% (based on the 2007 production level that is inclusive of the GM IR related yield gains).

3.6.8 Brazil

GM IR cotton was planted commercially in Brazil for the first time in 2006, and in 2007 was planted on 358,000 ha (32% of the total crop). On the basis of industry estimates of impact; an average yield gains were +6% and the net cost saving (reduced expenditure on insecticides after deduction of the premium paid for using the technology) was about +$25/ha. In total the average farm income gain in 2007 was $136/ha and at a national level this amounts to +$48.5 million. Cumulatively, the total farm income gain from use of the technology has been $65.5 million.

3.6.9 Other countries

GM IR cotton has been grown commercially in Columbia since 2002 (21,670 ha planted in 2007 out of a total cotton crop of 46,100 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, this would put the national gain to farm income in 2007 at $3.7 million and the cumulative farm income gain since 2002 has been $12.6 million.

3.6.10 Summary of global impact

In global terms, the farm level impact of using GM IR cotton was $3.2 billion in 2007. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $12.58 billion. Within this, 65% of the farm income gain has derived from yield gains (less pest damage) and the balance (35%) from reduced expenditure on crop protection (spraying of insecticides).

In terms of the total value of cotton production from the countries growing GM IR in 2007, the additional farm income generated by the technology is equal to a value added equivalent of 16.5% (based on the 2007 production level inclusive of the GM IR related yield gains). Relative to the value of global cotton production in 2007, the farm income benefit added the equivalent of 10.2%.

3.7 Other biotech crops

3.7.1 Maize/corn rootworm resistance

GM rootworm resistant (CRW) corn has been planted commercially in the US since 2003. In 2007, there were 8.4 million ha of CRW corn (22.2% of the total US crop).

The main farm income impact[43] has been higher yields of about 5% relative to conventional corn. The impact on average costs of production has been +$2/ha to -$10/ha (based on an average cost of the technology of $35/ha-$42/ha and an insecticide cost saving of $32/ha-$37/ha). As a result, the net impact on farm profitability has been +$28/ha to +$65/ha.

At the national level, farm incomes increased by $4.6 million in 2003, rising to $548 million in 2007. Cumulatively since 2003, the total farm income gain from the use of CRW technology in the US corn crop has been $883 million.

CRW cultivars were also planted commercially for the first time in 2004 in Canada. In 2007, the area planted to CRW resistant varieties was 39,250 ha. Based on US costs, insecticide cost savings and yield impacts, this has resulted in additional income at the national level of $2.79 million in 2007 (cumulative total since 2004 of $4.3 million).

At the global level, the extra farm income derived from biotech CRW maize use since 2003 has been $888 million. In 2007, the additional farm income generated from use of the technology was equal to 0.52% of the value of the global maize crop.

3.7.2 Virus resistant papaya

Ringspot resistant papaya has been commercially grown in the US (State of Hawaii) since 1999, and in 2007 (90% of the state's papaya crop was GM virus resistant (780 ha).

The main farm income impact of this biotech crop has been to significantly increase yields relative to conventional varieties. Compared to the average yield in the last year before the first biotech cultivation (1998), the annual average yield increase of biotech papaya relative to conventional crops has been within a range of +15% to +77% (15% in 2006 and 2007). At a state level this is equivalent to a 13% increase in total papaya production in 2007.

In terms of profitability[44], the net annual impact has been an improvement of between $2,725/ha and $11,412/ha, and in 2007 this amounted to a total state level benefit of $2.2 million. Cumulatively, the farm income benefit since 1999 has been $25.8 million.

Virus resistant papaya are also reported to have been grown in China in 2007, on 3,500 ha. No impact data on this technology has been identified.

3.7.3 Virus resistant squash

Biotech virus resistant squash has also been grown in some states of the US since 2004 and is estimated to have been planted on 3,000 ha in 2007[45] (13% of the total crop in the US).

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[43] Impact data based on NCFAP (2003, 2006 & 2008) and Rice (2004)

[44] Impact data based on NCFAP 2003, 2006 & 2008

Based on analysis from NCFAP (2008), the primary farm income impact of using biotech virus resistant squash has been derived from higher yields, which in 2007, added a net gain to users of $52 million. Cumulatively, the farm income benefit since 2004 has been $183 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 Indirect (non pecuniary) farm level economic impacts of using biotech crops

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

Many of the studies[46] of the impact of biotech crops have identified the following reasons as being important influences for adoption of the technology:

Herbicide tolerant crops

- increased management flexibility and convenience 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. This not only frees up management time for other farming activities but also allows additional scope for undertaking off-farm, income earning activities;
- 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, additional moisture retention and reductions in levels of soil erosion;
- 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 and years (eg, HT soybeans and HT canola in the early years of adoption respectively in Romania and Canada);

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[45] Mostly found in Georgia and Florida

[46] For example, relating to HT soybeans; USDA 1999, Gianessi & Carpenter 2000, Qaim & Traxler 2002, Brookes 2008; relating to insect resistant maize , Rice 2004; relating to insect resistant cotton Ismael et al 2002, Pray et al 2002

- Elimination of potential damage caused by soil-incorporated residual herbicides in follow-on crops and less need to apply herbicides in a follow-on crop because of the improved levels of weed control;
- A contribution to the general improvement in human safety (as manifest in greater peace of mind about own and worker safety) from reduced exposure to herbicides and a switch to more environmentally bengin products.

Insect resistant crops

- Production risk management/insurance purposes – the technology takes away much of the worry of significant pest damage occurring and is, therefore, highly valued. Although not applicable in 2007 (piloted in 2008 and likely to be more widely operational from 2009), US farmers using stacked corn traits (containing insect resistance and herbicide tolerant traits) are being offered discounts on crop insurance premiums equal to $7.41/hectare;
- 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 and less tillage;
- savings in machinery use (for spraying and possibly reduced harvesting times);
- Higher quality of crop. There is a growing body of research evidence relating to the superior quality of GM IR corn relative to conventional and organic corn from the perspective of having lower levels of mycotoxins. Evidence from Europe (as summarised in Brookes (2008) has shown a consistent pattern in which GM IR corn exhibits significantly reduced levels of mycotoxins compared to conventional and organic alternatives. In terms of revenue from sales of corn, however, no premia for delivering product with lower levels of mycotoxins have, to date, been reported although where the adoption of the technology has resulted in reduced frequency of crops failing to meet maximum permissible fumonisin levels in grain maize (eg, in Spain), this delivers an important economic gain to farmers selling their grain to the food using sector. GM IR corn farmers in the Philippines have also obtained price premia of 10%(Yorobe J (2004) relative to conventional corn because of better quality, less damage to cobs and lower levels of impurities;
- Improved health and safety for farmers and farm workers (from reduced handling and use of pesticides, especially in developing countries where many apply pesticides with little or no use of protective clothing and equipment);
- Shorter growing season (eg, for some cotton growers in India) which allows some farmers to plant a second crop in the same season[47]. Also some Indian cotton growers have reported knock on benefits for bee keepers as fewer bees are now lost to insecticide spraying.

Some of the economic impact studies have attempted to quantify some of these benefits (eg, Qaim & Traxler (2002) quantified some of these in Argentina (a $3.65/hectare saving (-7.8%) in labour costs and a $6.82/ha (-28%) saving in machinery/fuel costs associated with the adoption of GM HT soybeans). Where identified, these cost savings have been included in the analysis presented above. Nevertheless, it is important to recognise that these largely intangible benefits are considered by many farmers as a primary reason for adoption of biotechnology, and in some

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[47] Notably maize in India

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.

Since the early 2000s a number of farmer-survey based studies in the US have also attempted to better quantify these non pecuniary benefits. These studies have usually employed contingent valuation techniques[48] to obtain farmers valuations of non pecuniary benefits. Examples include:

- A 2002 survey of 600 US corn farmers explored opinions and valuations of the then new IR corn trait resistant to Corn Rootworm which was introduced in the following year of 2003. Respondents were asked to value any potential time and equipment savings, additional farmer and worker safety, additional environmental benefits and production risk management benefits (from more consistent control of rootworm) that they thought might arise from use of the technology relative to existing corn rootworm control methods. The production risk management benefit was most highly valued by farmers, followed by operator/worker safety and environmental gains. The average value of all the non pecuniary benefits was $17.89/hectare for likely adopters, $9.54/hectare for unlikely adopters and an overall average of $16.33/hectare across all farmers surveyed;
- A 2002 survey of 610 US soybean farmers sought farmers views on the benefits associated with their use (since 1996) of GM HT soybeans. Respondents were asked to value additional farmer and worker safety, the environmental impact of the technology and the additional convenience and flexibility the technology provided for weed control relative to the conventional alternatives. All of these benefits were valued by the soybean farners, with convenience given the highest value. Overall, the average benefit attributed to these three categories of non pecuniary benefits was $27/hectare (58% of which came from the convenience benefit);
- A 2003 survey of nearly 300 farmers of GM HT crops (soybeans, corn and cotton) that asked respondents to value additional farmer and worker safety, the environmental impact of the technology and the additional conveneince and flexibility the technology provided for weed control relative to the conventional alternatives. Similar results were obtained to those in the 2002 soybean farmer survey referred to above. In terms of valuations, the average benefit attributed to these three categories of non pecuniary benefits were respectively $32/hectare for HT corn farmers, $35.7/hectare for HT soybean farmers and $39.4/hectare for HT cotton farmers.

The values for non pecuniary benefits identified in these surveys are, however, usually subject to bias due to factors such as the hypothetical nature of the contingent valuation technique, the framing of questions and what is referred to as part-whole bias[49] . Marra and Piggott[50] (2006) examined bias (notably part-whole bias) in the three surveys referred to above and found most respondents tended to overstate the value of parts by more than 60% compared with the separately stated total values for all non pecuniary benefits. They subsequently rescaled[51] the

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[48] Survey based method of obtaining valuations of non market goods that aim to identify willingness to pay for specific goods (eg, environmental goods, peace of mind, etc) or willingness to pay to avoid something being lost

[49] In the case of non pecuniary benefits, the sum of values given by farmers to individual categories of benefit is greater than their stated total value of all non pecuniary benefits (farmers being asked to value each type of benefit separately in addition to separately valuing total non pecuniary benefits)

[50] Marra M & Piggott N (2006) The value of non pecuniary characteristics of crop biotechnologies: a new look at the evidence, North Carolina State University

[51] See Marra M & Piggott N (2006)

sum of the values given by respondents to each separate non pecuniary benefit and identified revised average (median) values for the non pecuniary benefits in each survey (Table 28). This suggests that US farmers who make widespread use biotech HT traits value the non pecuniary benefits of the technology at between $12.35/hectare and $24.71/hectare, with cotton farmers valuing the non pecuniary aspects highest and corn farmers having the lowest valuation. In terms of attributes most valued, convenience is perceived to provide between 50% and two-thirds of the total non pecuniary benefit of the HT technology. It is also interesting to note that the most recent survey of cotton farmers using HT (flex) technology have valued this technology as delivering an additional $12/hectare in terms of benefit from extra convenience relative to the first generation of biotech HT cotton technology. Corn producers value the non pecuniary benefits of the IR (rootworm resistance) technology at about $7.4/hectare, of which the risk reduction component accounted for the largest single share (about a third).

Table 28: Re-scaled values of non pecuniary benefits

Survey	Median value ($/hectare)
2002 IR (to rootworm) corn growers survey	7.41
2002 soybean (HT) farmers survey	12.35
2003 HT cropping survey (corn, cotton & soybeans) – North Carolina	24.71
2006 HT (flex) cotton survey[52]	12.35 (relative to first generation HT cotton)

Source: Marra & Piggot 2006 and 2007

Aggregating the impact to US crops 1996-2007

The approach used to estimate the non pecuniary benefits derived by US farmers from biotech crops over the period 1996-2007 has been to draw on the re-scaled values identified by Marra and Piggot (2006 & 2007: Table 28) and to apply these to the biotech crop planted areas during this 12 year period. Figure 15 summarises the values for non pecuniary benefits derived from biotech crops in the US (1996-2007) and shows an estimated (nominal value) benefit of $792 million in 2007 and a cumulative total benefit (1996-2007) of $5.11 billion. Relative to the value of direct farm income benefits presented above, the non pecuniary benefits were equal to 21%of the total direct income benefits in 2007 and 26% of the total cumulative (1996-2007) direct farm income. This highlights the important contribution this category of benefit has had on biotech trait adoption levels in the US, especially where the direct farm income benefits have been identified to be relatively small (eg, HT cotton).

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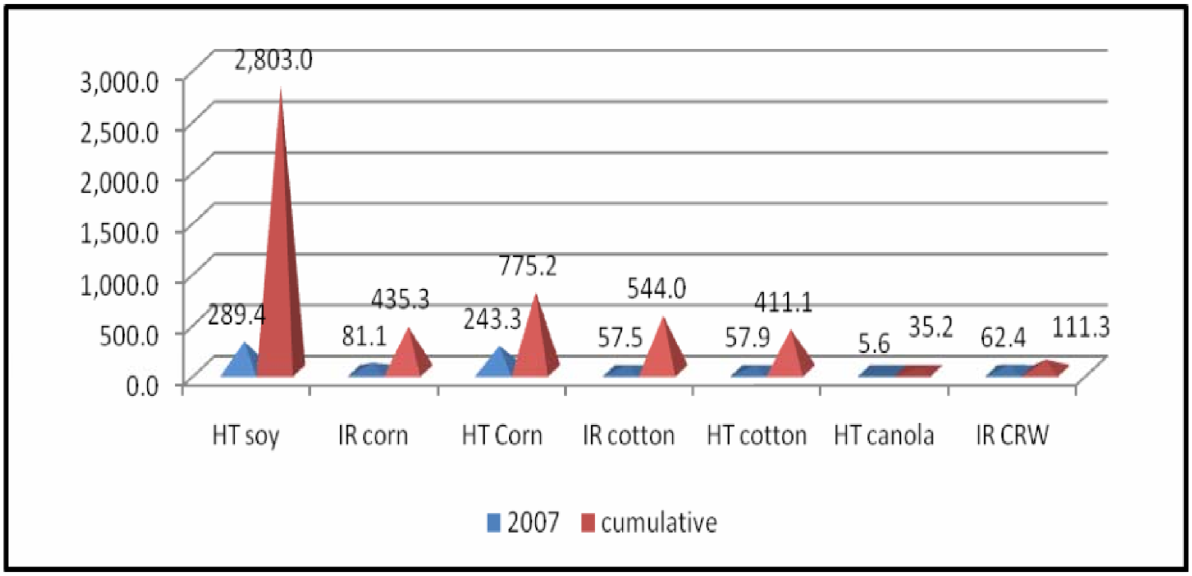
[52] Additionally cited by Marra & Piggott (2007) in 'The net gains to cotton farmers of a natural refuge plan for Bollgard II cotton', Agbioforum 10, 1, 1-10. www.agbioforum.org

Figure 15: Non pecuniary benefits derived by US farmers 1996-2007 by trait ($ million)



Estimating the impact in other countries
It is evident from the literature review that GM technology-using farmers in other countries also value the technology for a variety of non pecuniary/intangible reasons. The most appropriate methodology for identifying non pecuniary benefit valuations in other countries would be to repeat the type of US farmer-surveys in other countries. Unfortunately, the authors are not aware of any such studies having been undertaken to date.

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 biotech 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 biotech 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 GM IR 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 biotech crops;
- Brookes (2002) identified in Spain that the average size of farmer adopting GM IR 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 (2005) 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 IR 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 2004, Ismael et al 2002, Gouse (2006));
- In 2007, there were 3.8 million farmers growing GM IR cotton in India, with an average size of about 1.6 hectares (Manjunath T (2008).

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 biotechnology. Both large and small farmers have adopted. Size of operation has not been a barrier to adoption and in 2007, 12 million farmers were using the technology globally, 90% of which were resource-poor farmers in developing countries.

3.10 Production effects of the technology

Based on the yield impacts and second cropping effects (of GM HT soybeans) used in the direct farm income benefit calculations presented in sections 3.1 to 3.7 above, biotech crops have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (Table 29).

Table 29: Additional crop production arising from positive yield effects of biotech crops

	1996-2007 additional production (million tonnes)	2007 additional production (million tonnes)
Soybeans	67.80	14.46
Corn	62.42	15.08
Cotton	6.85	2.01
Canola	4.44	0.54

The biotech IR traits, used in the corn and cotton sectors, have accounted for 99% of the additional corn production and all of the additional cotton production. Positive yield impacts from the use of this technology have occurred in all user countries (except GM IR cotton in Australia[53]) when compared to average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). Since, 1996 the average yield impact across the total area planted to these traits over the 12 year period has been +6.1% for corn traits and +13.4% for cotton traits (Figure 16).

Although the primary impact of biotech HT technology has been to provide more cost effective (less expensive) and easier weed control versus improving yields from better weed control (relative to weed control obtained from conventional technology), improved weed control has, nevertheless occurred, delivering higher yields in some countries. Specifically, HT soybeans in

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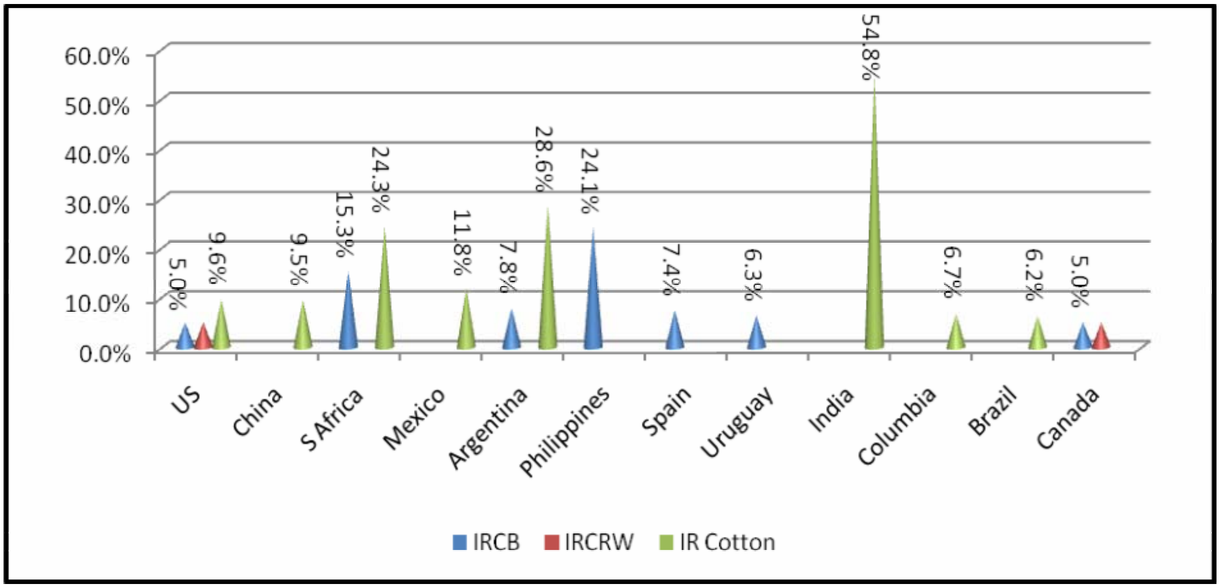
[53] This reflects the levels of *Heliothis* pest control previously obtained with intensive insecticide use. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings (on insecticides) and the associated environmental gains from reduced insecticide use

Romania improved the average yield by over 30% and biotech HT corn in Argentina and the Philippines delivered yield improvements of +9% and +15% respectively.

Biotech HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 67.5 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2006 (accounting for 99% of the total biotech-related additional soybean production).

Figure 16: Average yield impact of biotech IR traits 1996-2007 by country and trait



Notes: IRCB = resistant to corn boring pests, IRCRW = resistant to corn rootworm

In 2007, at the global level, world production levels of soybeans, corn, cotton lint and canola were respectively +6.5%, +1.9%, +7.7% and +1.1% higher than levels would have otherwise been if biotech traits had not been used by farmers.

In area equivalent terms, if the biotech traits used by farmers in 2007 had not been available, maintaining global production levels at the 2007 levels would have required additional (conventional crop) plantings of 5.89 million ha of soybeans, 3 million ha of corn, 2.54 million ha of cotton and 0.32 million ha of canola.

3.11 Trade flows and related issues

a) Share of global exports

Looking at the extent to which the leading biotech producing countries are traders (exporters) of these crops and key derivatives (Table 30 and Table 31) show the following:

- *Soybeans*: in 2007/08, 34% of global production was exported and 98.7% of this trade came from countries which grow biotech soybeans. As there has been some development of a market for certified conventional soybeans and derivatives (mostly in the EU, Japan and

South Korea), this has necessitated some segregation of exports into biotech versus conventional supplies or sourcing from countries that do not use biotech soybeans. Based on estimates of the size of the certified conventional soy markets in the EU and SE Asia (the main markets)[54], about 4.5%-6% of global trade in soybeans is required to be certified as conventional, and if it is assumed that this volume of soybeans traded is segregated from biotech soybeans, then the biotech share of global trade is 93%-94%. A similar pattern occurs in soymeal where about 80%-81% of globally traded meal probably contains biotech material;

- *Maize*: just over 12% of global production was internationally traded in 2007/08[55]. Within the leading exporting nations, the biotech maize growers of the US, Argentina, South Africa and Canada are important players (82% of global trade). As there has been some, limited development of a biotech versus certified conventional maize market (mostly in the EU, and to a lesser extent in Japan and South Korea), which has necessitated some segregation of exports into biotech versus certified conventional supplies, the likely share of global trade accounted for by biotech maize exports is about 81%;
- *Cotton*: in 2007/08, about 32% of global production was traded internationally. Of the leading exporting nations, the biotech cotton growing countries of the US, Australia, India and Brazil are prominent exporters accounting for 63% of global trade. Given that the market for certified conventional cotton is very small, virtually all of this 63% of global cotton trade from biotech cotton growing countries is probably not subject to any form of segregation and hence may contain biotech derived material[56]. In terms of cottonseed meal the biotech share of global trade is 31%;
- *Canola*: 17% of global canola production in 2007/08 was exported, with Canada being the main global trading country. The share of global canola exports accounted for by the two biotech canola producing countries (Canada and the US) was 75% in 2007/8. As there has been only a very small development of a market for certified conventional canola globally (the EU, the main market where certified conventional products are required has been largely self sufficient in canola and does not currently grow biotech canola), non segregated biotech exports from Canada/US probably account for 75% of global trade. For canola/rapemeal, the biotech share of global trade is about 52%.

Table 30: Share of global crop trade accounted for biotech production 2007/8 (million tonnes)

	Soybeans	Maize	Cotton	Canola
Global production	222.3	791.5	26.2	48.1
Global trade (exports)	76.7	96.0	8.3	8.3
Share of global trade from biotech producers	75.7 (98.7%)	78.7 (82%)	5.23 (63%)	6.25 (75%)
Estimated size of market requiring certified conventional (in countries that have import requirements)	3.5-4.5	Less than 1.0	Negligible	Negligible than 1
Estimated share of global trade	71.2-72.2	77.7	5.23	6.25

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[54] Brookes et al (2005) and updated from industry sources

[55] 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

[56] We consider this to be a reasonable assumption; we are not aware of any significant development of a certified conventional versus biotech 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 biotech growing countries such as China and Argentina

that may contain biotech (ie, not required to be segregated)				
Share of global trade that may be biotech	93%-94%	81%	63%	75%

Sources: derived from and updated - USDA & Oil World statistics, Brookes et al (2005)
Notes: Estimated size of market requiring certified conventional in countries with import requirements excludes countries with markets for certified conventional for which all requirements are satistifed by domestic production (eg, maize in the EU). Estimated size of certified conventional market for soybeans (based primarily on demand for derivatives used mostly in the food industry): EU 3-3.5 million tonnes bean equivalents, Japan and South Korea 0.5-1.0 million tonnes.

Table 31: Share of global crop derivative (meal) trade accounted for biotech production 2007/8 (million tonnes)

	Soymeal	**Cottonseed meal**	**Canola/rape meal**
Global production	163	20.8	28.3
Global trade (exports)	58.5	0.49	3.48
Share of global trade from biotech producers	50.3 (86%)	0.15 (31%)	1.8 (52%)
Estimated size of market requiring certified conventional (in countries that have import requirements)	2.75-3.25	Negligible	Negligible
Estimated share of global trade that may contain biotech (ie, not required to be segregated)	47.05-47.55	0.15	1.8
Share of global trade that may be biotech	80%-81%	31%	52%

Sources: derived from and updated - USDA & Oil World statistics, Brookes et al (2005)
Notes: Estimated size of certified conventional market for soymeal: EU 2.5-3.0 million tonnes, Japan and South Korea 0.25 million tonnes (derived largely from certified conventional beans referred to in above table)

b) Impact on prices

Assessing the impact of the biotech 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.

In general terms, it is important to recognise that 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.

In addition, as indicated in a) above, the extent of use of biotech adoption globally identified that:

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

This means for a crop such as soybeans, that biotech production now effectively influences and sets the baseline price for commodity traded soybeans and derivatives on a global basis. Given that biotech soybean varieties have provided significant cost savings and farm income gains (eg, $2.76 billion in 2007) 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 conventional 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 biotechnology in the other three crops has also probably occurred, although to a lesser extent because of the lower biotech penetration of global production and trade in these crops.

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 biotechnology on global prices of soybeans. Moschini et al (2000) estimated that by 2000 the influence of biotech 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 biotech). Qaim & Traxler (2002) estimated the impact of GM HT soybean technology adoption on global soybean prices to have been -1.9% by 2001. Based on this analysis, it is therefore likely that the current world price of soybeans may be lower by between 2% and 6% than it might otherwise have been in the absence of biotechnology. This benefit will have been dissipated through the post farm gate supply chain, with some of the gains having been passed onto consumers in the form of lower real prices.

Most recently, Brookes et al (2009 forthcoming) quantified the impact of biotech traits on production, usage, trade and prices in the corn, soybean and canola sectors. The analysis used the additional volumes of production arising from biotech crops in 2006, estimated in Brookes & Barfoot (2008)[57], as the base for imputing into of a broad modelling system of the world agricultural economy comprised of US and international multi-market, partial-equilibrium models of production, use and trade in key agricultural commodities[58]. The analysis of the potential impact of no longer using these biotech traits in world agriculture shows that the world prices of these commodities, their key derivatives and related cereal and oilseed crops would be significantly affected. World prices of corn, soybeans and canola would probably be respectively +5.8%, +9.6% and +3.8% higher than current levels. Prices of key derivatives of soybeans (meal and oil) would also be between +5% (oil) and +9% (meal) higher than current levels, with rapeseed meal and oil prices being about 4% higher than current levels. World prices of related cereals and oilseeds would also be expected to rise by +3% to +4%.

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[57] Brookes G & Barfoot P (2008) Global impact of biotech crops: socio-economic and environmental effects, Agbioforum 11 (1), 21-38, also a longer version available on www.pgeconomics.co.uk

[58] These agricultural models developed at the University of Iowa, are also used to generate ten-year annual projections for the US and global agricultural sectors

4 The environmental impact of biotech crops

This section examines the environmental impact of using biotech crops over the last twelve 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 biotech 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 biotech or conventional systems;
- the environmental behaviour and toxicity profile of individual pesticides varies.

To provide a more robust measurement of the environmental impact of biotech 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 biotech 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 biotech 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 (biotech versus convenrtional).

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 DMR Kynetec. Based on these sources of information, the main features relating to herbicide usage on US soybeans over the last twelve years have been (Table 32 and Table 33):

- 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 over the last five years);
- The average field EIQ/ha load has also been fairly consistent;
- A comparison of conventionally grown soybeans (per ha) with GM HT soybeans (Table 33) shows that herbicide ai use on conventional soybeans has been fairly constant (around 1.1 to 1.3kg/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 marginally higher average usage level for GM HT soybeans partly reflects the changes in cultivation practices in favour of low/no tillage[59], which accounted for 73.7% of soybean production in 1996 and 80% in 2007 (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;

Table 32: Herbicide usage on soybeans in the US 1996-2007

Year	Average ai use (kg/ha): NASS data	Average ai use: DMR Kynetec data	Average field EIQ/ha: NASS data	Average field EIQ/ha: DMR Kynetec 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
2006	1.53	1.31	17.2	23.7
2007	N/a	1.46	N/a	26.2

Sources: NASS data no collection of data in 2003 & 2007. DMR Kynetec 1998-2007, N/A = not available

Table 33: Herbicide usage on GM HT and conventional soybeans in the US 1996-2007

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

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[59] 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)

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
2006	1.02	1.33	24	21
2007	1.16	1.48	26	23

Source: derived from DMR Kynetec, N/A = not available, NASS data does not differentiate between biotech and conventional crops and therefore cannot be used as a source for this comparison

- The comparison data between the GM HT crop and the conventional alternative presented above, is however, not a reasonable representation of average herbicide usage on the average GM HT crop compared with the average conventional alternative for recent years. It probably understates the herbicide usage for an average conventional soybean grower, 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, 2006 & 2008). Based on this approach the respective values for conventional soybeans in 2006 were; average herbicide ai use 1.44 kg/ha and a field EIQ/ha of 30.23/ha, and for GM HT soybeans; average herbicide ai use 1.154 kg/ha and a field EIQ of 17.66/ha. Given that the vast majority of the total US soybean crop in recent years has used GM HT technology the values used in this analysis for GM HT soybeans are the market research data findings (source: DMR Kynetec), whilst for conventional soybeans, we have used the NCFAP estimated values. For example, in 2006, GM HT soybeans 1.33 kg/ha active ingredient use and an average field EIQ/ha value of 21, compared to 1.44 kg/ha active ingredient use and an average field EIQ/ha value of 30.23 for conventional soybeans. For 2007, as no NCFAP analysisis available, the NCFAP values for 2006 were adjusted (upwards[60]) by the same % change recorded for herbicide usage on the residual conventional soybean crop in the DMR Kynetec data (see Table 33)[61].

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[60] For consistency purposes

[61] In other words, the 2007 conventional values were adjusted upwards from 1.44 kg/ha (2006 value) to 1.6 kg/ha and the field EIQ/ha value adjusted upwards from 30.23/ha (2006 value) to 33.1/ha

Based on these assumptions, the national level changes in herbicide use and the environmental impact associated with the adoption of GM HT soybeans[62] (Table 34) shows:

- in 2007, there have been savings in herbicide ai use of 6.8% (2.8 million kg). The EIQ load was also lower by 28% 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 5.76% for ai use (29.9 million kg) and 28.6% for the field EIQ load.

Table 34: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in the US 1996-2007

Year	ai decrease (kg)	eiq saving (units)	% decrease in ai	% saving eiq
1996	67,989	9,345,424	0.18	0.97
1997	447,542	61,524,084	1.06	5.89
1998	1,648,725	226,626,708	3.8	21.07
1999	2,294,618	315,408,289	5.16	28.65
2000	2,549,575	350,453,672	5.68	31.5
2001	3.104,816	426,774,679	6.95	38.57
2002	3,399,433	467,271,543	7.72	42.87
2003	3,603,399	495,307,836	8.14	45.19
2004	3,807,365	443,286,112	8.44	39.68
2005	3,055,412	247,979,126	7.33	28.41
2006	3,092,895	251,021,276	7.01	27.17
2007	2,812,022	236,678,479	6.83	27.77

b) Canada

Our analysis of impact in Canada is based on a comparison of typical herbicide regimes used for GM HT and conventional soybeans and identification of the main herbicides that are no longer used since GM HT soybeans have been adopted[63]. 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[64], in 2007, there was a net increase in the volume of active ingredient used of 1.12% (+11,120 kg) but a 18% decrease in the number of field EIQ/ha units (-4.01 million). Cumulatively since 1997, the volume of active ingredient used has increased by 0.7% (73,700 kg) but the total field EIQ value fell 11% (-26.91 million units: Table 35).

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[62] 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

[63] Source: George Morris Center (2004)

[64] 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

Table 35: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Canada 1996-2007

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
2006	-12,357	4,511,312	-1.21	19.5
2007	-11,116	4,058,187	-1.12	18.05

c) Brazil

Drawing on herbicide usage data for the period 2001-2003 (period immediately before the plantings of GM HT soybeans was legalised)[65], the following changes in herbicide usage have occurred (Table 36):

- 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[66];
- 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 2007, the total herbicide active ingredient and field EIQ savings were 4.6% (2.55 million kg) and 22.5% (212 million EIQ/ha units);
- Cumulatively since 1997, there has been a 1.9% saving in herbicide active ingredient use (10.7 million kg) and a 9.3% reduction in the environmental impact (751 million field EIQ/ha units).

Table 36: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Brazil 1997-2007

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

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[65] The period immediately before the official approval for the planting of GM HT soybeans. Source: Derived from DMR Kynetec herbicide usage data

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

2004	1,116,667	78,083,333	1.7	8.4
2005	2,010,000	140,550,000	2.9	14.4
2006	2,546,000	178,030,000	4.0	19.8
2007	3,028,958	211,801,042	4.6	22.5

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[67]);
- By 2007, the area planted to soybeans had increased by 180% (to 16.6 million ha), with the vast majority (16.42 million ha) using GM HT technology and no/reduced tillage systems that rely more on herbicide-based weed control programmes than conventional tillage systems. Thirty per cent of the total crop was also ‘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 2007, the estimated average herbicide ai use was 2.97 kg/ha and the average field EIQ was 46/ha[68].

These changes should, however be assessed within the context of the fundamental changes in tillage systems that have occurred over the last eleven years (some of which may possibly have taken place in the absence of the GM HT technology[69]). 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 12 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[70] are equivalent to:

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[67] Derived from DMR Kynetec herbicide usage data

[68] Derived from DMR Kynetec herbicide usage data

[69] 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

[70] 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

- In 2007, a 7.7% reduction in the volume of herbicide ai used (4.1 million kg) and a 24.5% cut in the field EIQ load (247 million EIQ/ha units);
- Cumulatively since 1996, herbicide ai use is 6.7% lower (30 million kg) and the field EIQ load is 21.5% lower (1,805 million field EIQ/ha units) than the level that might reasonably be expected if the total Argentine soybean area had been planted to conventional 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[71]. 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 2007 were respectively 7.2% (0.73 million kg) and 24.3% (47.2 million EIQ/ha units) lower than would have been expected if the total crop had been conventional soybeans. Cumulatively, since 1999, herbicide ai use has been 4.8% lower (2.54 million kg) and the total EIQ load nearly 16.2% lower (164 million EIQ/ha units).

f) Romania

Romania joined the EU at the beginning of 2007 and therefore was no longer officially permitted to grow GM HT soybeans. The analysis below therefore refers to the period 1999-2006. Based on herbicide usage data for the years 2000-2003 from Brookes (2005), 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 37). 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[72] is 4% higher (equal to about 42,000 kg) than the level of use if the crop had been all non GM since 1999 (in 2006 usage was 5.25% higher);
- The field EIQ load has fallen by 5% (equal to 943,000 field EIQ/ha units) since 1999 (in 2006 the EIQ load was 6.5% lower).

Table 37: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Romania 1999-2006

Year	Ai use (negative sign denotes an increase	eiq saving (units)	% decrease in ai (- = increase)	% saving eiq

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[71] 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)

[72] 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

	in use: kg)			
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
2006	-12,597	285,295	-5.25	6.53

With the banning of planting of GM HT soybeans in 2007, there will have been a net negative environmental impact associated with herbicide use on the Romanian soybean crop, as farmers will have had to resort to conventional chemistry to control weeds. On a per hectare basis, the EIQ load/ha will have probably increased by over 9%.

g) South Africa

GM HT soybeans have been grown in South Africa since 2000 (132,320 ha in 2007). 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 5.1% higher (equal to about 93,800 kg of ai) than the level of use if the crop had been conventional (in 2007 usage was 8.3% higher);
- The field EIQ load has fallen by 9.3% (equal to 3.6 million field EIQ/ha units) since 1999 (in 2007 the EIQ load was 15.3% 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[73] has been (Figure 17):

- In 2007, a 6.2% decrease in the total volume of herbicide ai applied (10.6 million kg) and a 24.7% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 4.6% less herbicide ai has been used (73 million kg) and the environmental impact applied to the soybean crop has fallen by 20.9%.

This suggests that over the period 1996-2007, 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.

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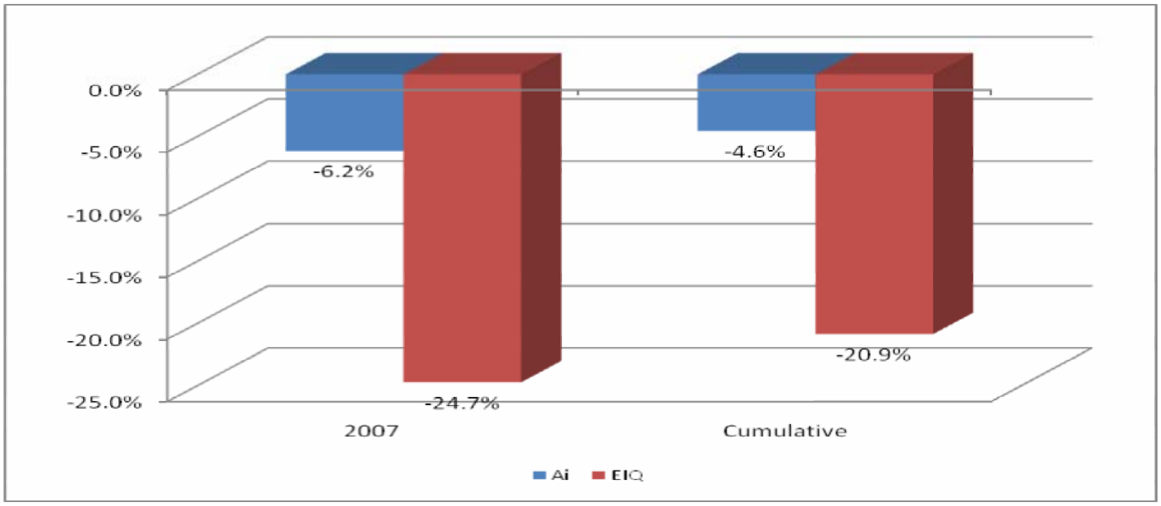
[73] Relative to the expected herbicide usage if all of the GM HT area had been planted to conventional varieties, using the same tillage system (largely no/low till) and delivering an equal level of weed control to that obtained under the GM HT system

Figure 17: Reduction in herbicide use and the environmental load from using GM HT soybeans in all adopting countries 1996-2007



4.1.2 Herbicide tolerant maize

a) The USA

Drawing on the two main statistical sources of pesticide usage data (USDA and DMR Kynetec), Table 38 and Table 39 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 38: Herbicide usage on maize in the US 1996-2007

Year	Average ai use (kg/ha): NASS data	Average ai use (kg/ha): DMR data	Average field EIQ/ha: NASS data	Average field EIQ/ha: DMR 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	48
2006	N/a	2.35	N/a	47
2007	N/a	2.51	N/a	49

Sources and notes: derived from NASS pesticide usage data 1996-2003 (no data collected in 2004, 2006 & 2007), DMR Kynetec data from 1998-2007. N/a = not available

Table 39: Average US maize herbicide usage and environmental load 1997-2007: 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	39
2006	2.63	2.09	56	40
2007	2.78	2.31	64	45

Sources and notes: derived from DMR Kynetec 1998-2007. 1997 based on the average of the years 1997-1999

The analysis presented 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 (52% of the total crop in 2007).

Analysis by the NCFAP (2003, 2006 & 2008) compared typical herbicide treatment regimes for GM HT and average conventional maize crops that would deliver similar levels of weed control to that level delivered in the GM HT systems. This identified (for 2006) average values for conventional maize of 3.48 kg herbicide ai/ha and a field EIQ rating of 77.15/ha (mix of herbicides such as metalochlor, atrazine, mesotrione and nicosulfuron). This compares with GM glyphosate tolerant maize (2.06 kg herbicide ai/ha and a field EIQ rating of 43.07/ha (use of glyphosate plus half doses of metalochlor and atrazine relative to conventional crops)) and GM glufosinate tolerant maize (2.04 kg herbicide ai/ha and a field EIQ/ha rating of 48.1/ha).

On the basis of the NCFAP data, at the national level (Table 40), in 2007, there has been an annual saving in the volume of herbicide active ingredient use of 21.3% (28.1 million kg). The annual field EIQ load on the US maize crop has also fallen by 22.2% in 2007 (equal to 647 million field EIQ/ha units). The cumulative decrease in active ingredient use since 1997 has been 6.2% (78.7 million kg), and the cumulative reduction in the field EIQ load has been 6.9%.

Table 40: National level changes in herbicide ai use and field EIQ values for GM HT maize in the US 1997-2007

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	55,881,629	2.65	2.73
2001	2,733,427	62,108,932	2.88	3.18
2002	4,227,123	97,545,980	4.28	4.80
2003	5,226,766	121,853,076	5.31	6.01
2004	7,918,178	183,818,420	6.52	7.39
2005	7,658,532	220,002,711	6.39	8.25
2006	16,289,458	375,094,639	14.75	15.34
2007	28,117,185	647,449,733	21.31	22.16

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[74] about typical herbicide regimes for conventional and GM HT 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 2007 (based on the plantings of the different production systems), the reductions in herbicide ai use and the total field EIQ load were respectively 16.1% (696,000 kg) and 18.4% (18.1 million: Table 41);
- Cumulatively since 1997, total national herbicide ai use has fallen by 8.5% (2.69 million kg) and the total EIQ load has fallen by 9.3% (66.9 million field EIQ units).

Table 41: Change in herbicide use and environmental load from using GM HT maize in Canada 1999-2007

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
2006	500,098	12,831,445
2007	696,021	18,090,048
Total	**2,686,662**	**66,874,486**

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[74] Including the Weed Control Guide (2004 and updated) from the Departments' of Agriculture in Ontario, Manitoba and Saskatchewan

c) South Africa

Drawing on industry level sources that compare typical herbicide treatment regimes for conventional and GM HT maize in South Africa (see appendix 3), the impact of using GM HT technology in the South African maize crop (453,000 ha in 2007) has been:

- On a per hectare basis, there has been a 0.257 kg decrease in the amount of herbicide active ingredient used and an improvement in the average field EIQ of 18.8/ha;
- In 2007, at the national level, the amount of herbicide used was 116,420 kgs (-2.8%) lower than the amount that would probably have been used if the crop had all been planted to conventional seed. The total field EIQ load was 9.8% lower;
- Cumulatively since 2003, total national herbicide ai use has fallen by 0.9% (202,260 kg) and the total EIQ load has fallen by 3.1%.

d) Argentina

Similar reductions in herbicide use and the environmental 'foot print', associated with the adoption of GM HT maize have been found in Argentina where this technology was first used in 2004 (see Appendix 3):

- The average volume of herbicide ai applied to GM HT maize has been 2.55kg/ha compared to 2.93 kg/ha for conventional maize;
- the average field EIQ/ha load for GM HT maize is significantly lower than the conventional counterpart (46/ha for GM HT maize, 59/ha for conventional maize);
- the reduction in the volume of herbicide used was 142,000 kg (-1.6%) in 2007. Since 2004, the cumulative reduction in usage has been 0.8% (- 258,000 kg);
- in terms of the field EIQ load, the reduction in 2007 was 2.6% (-4.86 million field/ha units) and over the period 2004-2007, the load factor fell by 1.4%.

e) *Other countries*

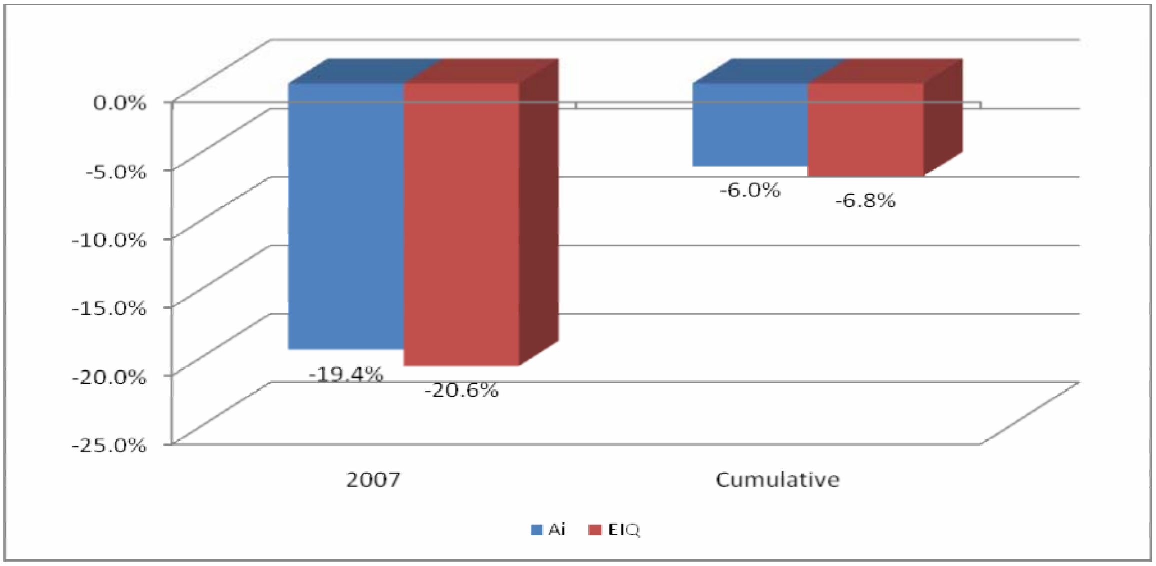
GM HT maize was also grown commercially in the Philippines, for the first time in 2006 (191,000 ha in 2007). Weed control practices in maize in the Philippines are based on a combination of use of herbicides and hand weeding. The authors are not aware of any analysis which has examined the impact on herbicide use and the associated environmental 'footprint' of using GM HT maize in the Philippines.

d) Summary of impact

In the countries where GM HT maize has been most widely adopted, 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 18). More specifically:

- In 2007, total herbicide ai use was 19.4% lower (29 million kg) than the level of use if the total crop had been planted to conventional varieties. The EIQ load was also lower by 20.6%;
- Cumulatively since 1997, the volume of herbicide ai applied is 6% lower than its conventional equivalent (a saving of 81.8 million kg). The EIQ load has been reduced by 6.8%.

Figure 18: Reduction in herbicide use and the environmental load from using GM HT maize in adopting countries 1997-2007



4.1.3 Herbicide tolerant cotton

a) The USA

Drawing on the herbicide usage data from the USDA and DMR Kynetec, both the volume of ai used and the average field EIQ/ha on the US cotton crop has remained fairly stable over the last twelve years (Table 42).

Table 42: Herbicide usage on cotton in the US 1996-2007

Year	Average ai use (kg/ha): NASS data	Average ai use (kg/ha): DMR data	Average field EIQ/ha: NASS data	Average field EIQ/ha: DMR 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	2.60	N/p	46.0
2006	N/a	2.53	N/a	47.5
2007	2.7	2.59	48.4	46.9

Sources and notes: derived from NASS pesticide usage data 1996-2003 (no data collected in 2002, 2004 & 2006), DMR Kynetec data from 1998-2007. N/p = Not presented - 2005 results based on NASS data are significantly different and inconsistent with previous trends and DMR data. These results have therefore not been presented

Looking at a comparison of average usage data for GM HT versus conventional cotton, the DMR Kynetec dataset[75] 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 DMR dataset suggests that there has been a marginally lower average field EIQ rating for GM HT cotton in the years 1997 to 2000, but since 2000, the average field EIQ/ha rating has been lower for conventional cotton (Table 43).

Table 43: Herbicide usage and its associated environmental load: GM HT and conventional cotton in the US 1997-2007

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	50
2006	1.74	2.69	36	49
2007	1.71	2.71	37	47

Sources and notes: derived from DMR 1998-2007. 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, 2006 and 2008). Based on this approach the values in 2006 were, for conventional cotton, average herbicide ai use 5.47 kg/ha and a field EIQ/ha of 124/ha, and for GM HT cotton, herbicide ai use 3.66 kg/ha and a field EIQ of 76/ha.

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

Given that these values are significantly higher than the average values for use across the US cotton in any year (see Table 43), we have therefore adjusted these values downwards to reflect the difference between the values for GM HT cotton identified by the NCFAP approach and the recorded usage data from DMR Kynetec. On this basis, the comparison level of usage recorded (and used in the national level analysis below) for 2006 and 2007 are:

- conventional cotton average, herbicide ai use 3.8 kg/ha and a field EIQ/ha of 70.34/ha;
- GM HT cotton, herbicide ai use 2.71 kg/ha and a field EIQ of 47/ha.

At the national level (Table 44), the impact of using the GM HT technology equates to 23.2% and 27.1% savings respectively in ai use and the field EIQ value for 2007. Cumulatively since 1997, the savings using this methodology have been 15.9% for ai use (36 million kg) and 16% for the EIQ load (714 million field EIQ units).

Table 44: National level changes in herbicide ai use and field EIQ values for GM HT cotton in the US 1997-2007

Year	ai decrease (kg)	eiq saving (units)	% decrease in ai	% saving eiq
1997	620,675	12,230,785	3.2	3.26
1998	1,580,353	32,410,303	8.0	8.12
1999	2,540,302	49,410,008	12.9	13.05
2000	2,985,289	57,366,525	14.1	14.26
2001	3,960,988	75,295,394	17.2	17.36
2002	3,735,833	69,627,162	17.8	17.98
2003	3,202,455	59,236,058	18.1	18.29
2004	3,794,341	69,368,400	18.4	18.60
2005	4,078,184	73,906,870	18.7	18.91
2006	5,359,057	121,797,410	21.52	25.13
2007	4,121,406	92,977,547	23.20	27.06

b) Australia

Drawing on information from the University of New England study from 2003[76], 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 HT cotton has been 51/ha compared to 66/ha for conventional cotton;
- At the national level (Table 45), in 2007 (based on the plantings of the different production systems), herbicide ai use has been 3.1% higher (5,425 kg) than the level expected if the whole crop had been planted to conventional cotton cultivars. The total field EIQ load was, however 17.7% lower;
- Cumulatively since 2000, total national herbicide ai use has increased by 0.8% (86,600 kg) although the total EIQ load had fallen by 4.6%.

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[76] Doyle B et al (2003)

Table 45: National level changes in herbicide ai use and field EIQ values for GM HT cotton in Australia 2000-2007 (negative sign denotes increase in use)

Year	ai increase (kg)	eiq saving (units)	% change 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
2006	-11,187	1,546,699	-2.7	15.6
2007	-5,425	750,055	-3.1	17.7

c) South Africa

Using industry level sources that compare typical herbicide treatment regimes for conventional and GM HT cotton in South Africa (see appendix 3), the impact of using GM HT technology in the South African cotton crop has been:

- there has been an average 0.127 kg increase in the amount of herbicide active ingredient used (-8% increasing to an average of 1.8 kg/ha) but a 28% decrease in the environmental impact, as measured by the EIQ indicator (-10.7 field EIQ/ha units);
- In 2007, at the national level, the amount of herbicide used was1,240 kgs (+5.8%) higher than the amount that would probably have been used if the crop had all been planted to conventional seed. The total field EIQ load was, however 23.5% lower;
- Cumulatively since 2001, total national herbicide ai use has increased by 1.9% (7,180 kg), whilst the total EIQ load fell by 7.8%. This shows that although the amount of herbicide used on the cotton crop has increased since the availability and use of GM HT cotton, the associated environmental impact of herbicide use on the cotton crop has fallen.

d) Argentina

GM HT cotton has been grown commercially in Argentina since 2002, and in 2007, there were 132,000 ha planted to GM HT cotton.

Based on industry level information relating to typical herbicide treatment regimes for GM HT and conventional cotton (see appendix 3), the impact of using this technology on herbicide use and the associated environmental impact has been:

- a 48% and 56% respective reduction in the amount of active ingredient (kg) and field EIQ rating per hectare;
- in 2007, the national level reduction in the amount of herbicide applied to the cotton crop was 208,820 kg (-18%) lower than would otherwise have occurred if the whole crop had been planted to conventional varieties. The associated EIQ load was 21% lower;
- cumulatively, since 2002, the amount of herbicide active ingredient applied had fallen 17% (-1.1 million kg). The field EIQ rating associated with herbicide use on the Argentine cotton crop fell 20% over the same period.

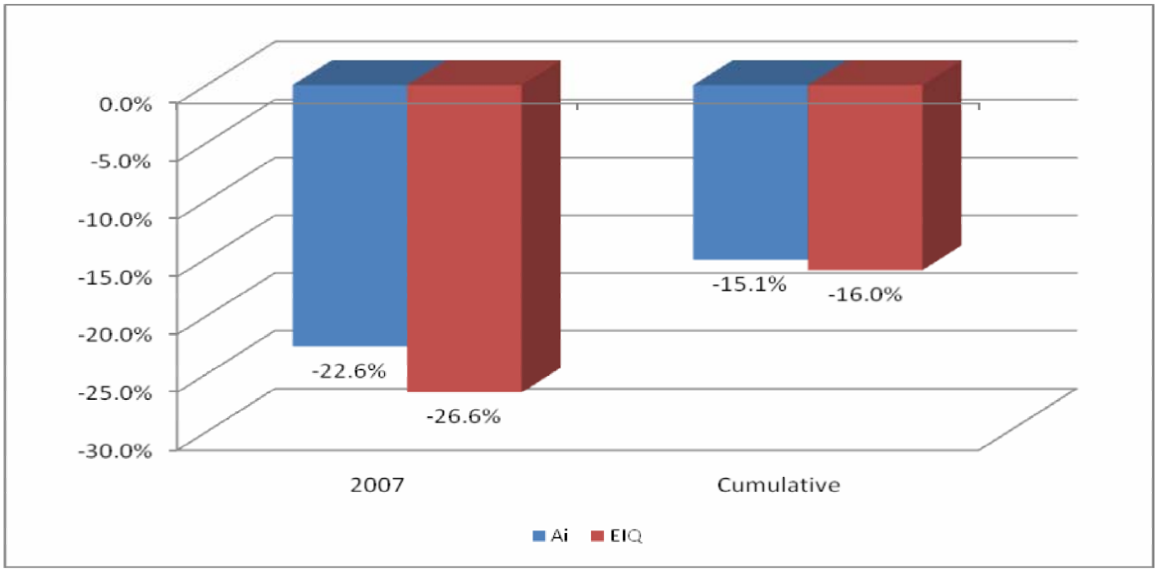
e) Other countries

Cotton farmers in Mexico have also been using GM HT technology since 2005. No analysis is presented for the impact of using this technology in Mexico because of the limited availability of herbicide usage data.

f) Summary of impact

The overall effect of using GM HT cotton technology (Figure 19) in the adopting countries in 2007, has been a reduction in herbicide ai use[77] of 22.6% and a decrease in the total environmental impact of 26.6%. Cumulatively since 1997, herbicide ai use fell by 15.1% (-37 million kg) and the associated environmental impact fell by 16%.

Figure 19: Reduction in herbicide use and the environmental load from using GM HT cotton in the US, Australia, Argentina and South Africa 1997-2007



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 2008 (see Appendix 3), the changes in herbicide use and resulting environmental impact arising from adoption of GM HT canola in the US since 1999[78] have been:

- A reduction in the average volume of herbicide ai applied of 0.63 kg/ha (GM glyphosate tolerant) or 0.696 kg/ha (GM glufosinate tolerant) up to 2003, a reduction in the average volume of herbicide ai applied of 0.8 kg/ha 2004 and 2005 and 0.7 kg/ha 2006 and 2007 (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 annually for 2004 and 2005 is a fall in the average field EIQ/ha of 23/ha (GM GT) and a decrease of 21.7/ha in 2006 and

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[77] 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

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

2007. For (GM glufosinate tolerant) canola the decrease since 2004 has annually been 17/ha;
- The reduction in the volume of herbicides used was equal to 333,000 kg of active ingredient (-57%) in 2007;
- In terms of the EIQ load, this had fallen by 8.9 million field EIQ units (-63%) compared to the load that would otherwise have been applied if the entire 2007 crop had been planted to conventional varieties;
- Cumulatively, since 1999, the amount of active ingredient use has fallen by 33%, and the EIQ load reduced by 44%.

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):

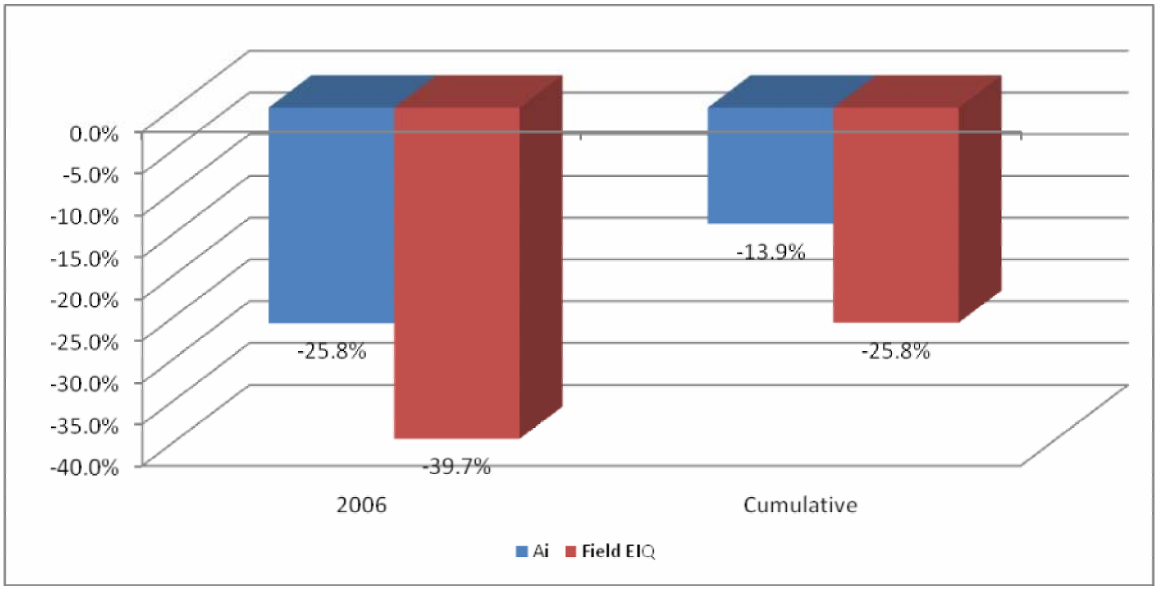
- The average volume of herbicide ai applied to GM HT canola has been 1.15 kg/ha (GM glyphosate tolerant) and 0.466 kg/ha (GM glufosinate tolerant), compared to 1.129 kg/ha for conventional canola;
- the average field EIQ/ha load for GM HT canola is significantly lower than the conventional counterpart (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 1.54 million kg (a reduction of 23.1%) in 2007. Since 1996, the cumulative reduction in usage has been 12% (-8.1 million kg);
- In terms of the field EIQ load, the reduction in 2007 was 37.7% (-62.2 million) and over the period 1996-2007, the load factor fell by 25%.

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 20). More specifically:

- In 2007, total herbicide ai use was 25.8% lower (1.87 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 39.7%;
- Cumulatively since 1996, the volume of herbicide ai applied was 13.9% lower than its conventional equivalent (a saving of 9.75 million kg). The EIQ load had been reduced by 25.8%.

Figure 20: Reduction in herbicide use and the environmental load from using GM HT canola in the US and Canada 1996-2007



4.1.6 GM IR maize

a) *The US*

Since 1996, when GM IR maize was first used commercially in the US, the average volume of insecticide use has fallen (Table 46). Whilst levels of insecticide ai use have fallen for both conventional and GM IR 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 29% in 2007 (1.67 million kg) and the annual field EIQ load on the US maize crop has fallen by 29% in 2007 (equal to 66 million field EIQ/ha units). Since 1996, the cumulative decrease in insecticide ai use has been 5.3% (9.1 million kg), and the cumulative reduction in the field EIQ load has been 5.6% (Table 47).

Table 46: Average US maize insecticide usage and its environmental load 1996-2007: conventional versus biotech

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	4.7
2006	0.14	0.07	6.0	2.9
2007	0.15	0.06	6.0	2.4

Sources: derived from DMR Kynetec

Table 47: National level changes in insecticide ai use and field EIQ values for GM IR maize in the US 1996-2007

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	428,180	25,077,126	2.2	2.5
2001	523,876	36,089,208	3.3	4.3
2002	1,173,354	63,361,116	7.2	7.9
2003	1,199,237	81,179,120	8.6	11.5
2004	1,071,444	55,500,799	11.0	12.0
2005	695,016	26,642,280	12.4	11.5
2006	887,558	39,306,143	20.0	20.7
2007	1,670,482	66,819,263	29.4	29.4

This analysis probably understates the positive environmental impact of the technology because it understates 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 and corn rootworm infestations 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[79], this equates to 28% and 27% savings respectively in insecticide ai use and the field EIQ value for 2007. Cumulatively since 1996, the savings using this methodology have been 21.6% for insecticide ai use (15.9 million kg) and 20.7% (752 million field EIQ units)[80].

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[79] 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

[80] 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

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[81], 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 296,640 kg (-65%). In terms of environmental load, the total EIQ/ha load has fallen by 14.5 million units (-61%)[82].

c) Spain

Based on data for early years of GM IR trait adoption when the areas planted with this trait were fairly low (1999-2001 – drawing on analysis in 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[83]. More specifically:

- The volume of insecticide ai use[84] was 82% lower than the level would probably have been if the crop had been all conventional in 2007 (-72,200 kg). Since 1998 the cumulative saving (relative to the level of use if all of the crop had been conventional) was 364,170 kg of insecticide ai (a 41% decrease);
- The field EIQ/ha load has fallen by 37% since 1999 (-15.8 million units). In 2007, the field EIQ load was 73% 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, reduced production risk and improved quality of grain.

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:

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[81] 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

[82] 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

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

[84] Insecticides that target corn boring pests

- 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 2007, the adoption of GM IR maize resulted in a net reduction in the volume of insecticides used of 135,600 kg (relative to the volume that would probably have been used if 1.968 million ha had been treated with insecticides targeted at corn boring pests). The EIQ load was 82% lower than it would otherwise have been in the absence of use of the GM IR technology);
- Cumulatively since 2000, the reductions in the volume of ai use and the associated environmental load from sprayed insecticides were both 33% (-435,000 kg ai).

f) Other countries

GM IR maize has also been grown on significant areas in the Philippines (since 2003: 194,000 ha planted in 2007) and in Uruguay (since 2004: 105,000 ha in 2007). Due to limited availability on insecticide use on maize crops (targeting corn boring pests)[85], it has not been possible to analyse the impact of reduced insecticide use and the associated environmental impact in these countries.

g) *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 21):

- In 2007, a 32% decrease in the total volume of insecticide ai applied (1.9 million kg) and a 31.6% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 5.9% less insecticide ai has been used (10.2 million kg) and the environmental impact from insecticides applied to the maize crop has fallen by 6%.

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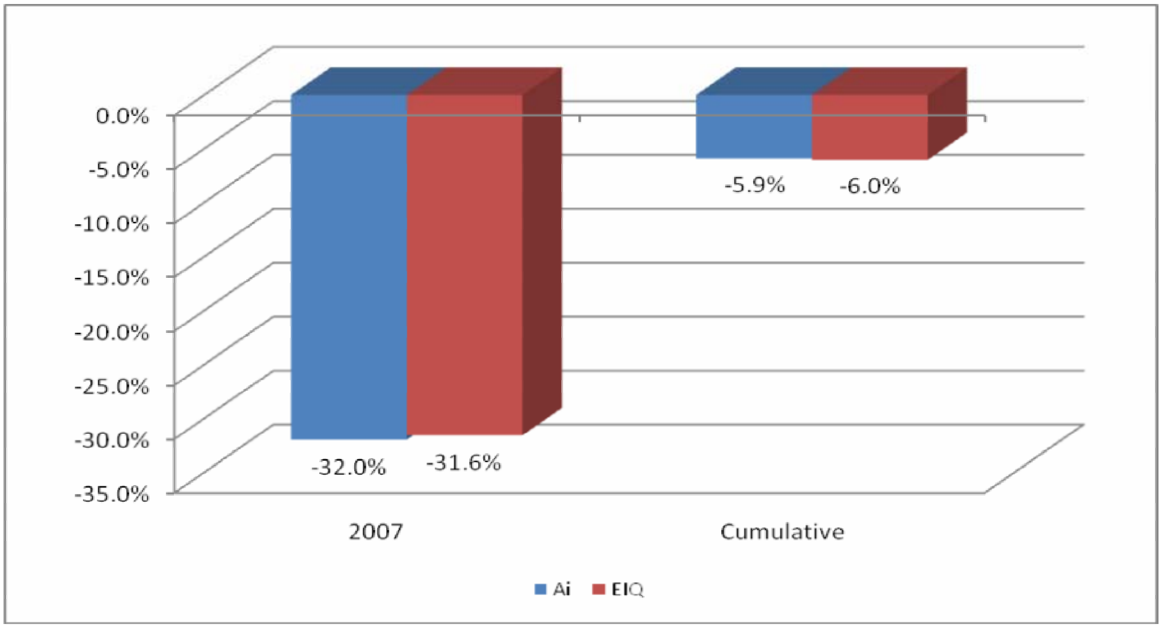
[85] Coupled with the 'non' application of insecticide measures to control corn boring pests by farmers in many countries and/or use of alternatives such as biological and cultural control measures

Figure 21: Reduction in insecticide use and the environmental load from using GM IR maize in adopting countries 1996-2007



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 48). Applications on GM IR crops and the associated environmental impact have also been consistently lower.

At the national level, the use of GM IR cotton has resulted in an annual saving in the volume of insecticide ai use of 6.7% in 2007 (0.362 million kg) and the annual field EIQ load on the US cotton crop also fell by 19.9% in 2007 (equal to 44.6 million field EIQ/ha units). Since 1996, the cumulative decrease in insecticide ai use has been 4.9% (3.67 million kg), and the cumulative reduction in the field EIQ load has been 9.2% (Table 49).

Table 48: Average US cotton insecticide usage and environmental impact 1996-2007: conventional versus biotech

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	44.9	40.9
2000	1.22	1.22	48.3	42.3
2001	1.23	0.95	49.1	32.4
2002	0.80	0.97	31.0	20.6
2003	1.39	0.83	49.5	28.7
2004	0.86	0.93	32.1	29.0
2005	0.9	0.81	30.0	26.0
2006	1.32	0.9	54.0	28.0

2007	1.23	1.09	51.24	34.0

Sources: derived from DMR Kynetec

Table 49: National level changes in insecticide ai use and field EIQ values for GM IR cotton in the US 1996-2007

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% saving eiq
1996	114,955	6,322,511	1.7	2.7
1997	134,976	7,592,400	1.5	2.5
1998	118,373	7,011,312	1.6	2.5
1999	311,062	7,776,548	4.5	2.9
2000	0	13,188,000	0	4.3
2001	661,072	39,428,199	8.4	12.6
2002	-347,123	21,235,760	-7.4	11.7
2003	1,115,397	41,429,024	16.5	17.2
2004	-170,145	7,534,984	-3.7	4.4
2005	253,937	11,286,080	5.2	6.9
2006	1,479,804	94,073,325	18.1	27.8
2007	361,922	44,568,156	6.7	19.9

This analysis probably understates the positive environmental impact of the technology because it may understate the average values for insecticide ai/ha use and field EIQ/ha 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 may 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, 2006 and 2008. Applying this approach, the impact of using GM IR cotton 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 12.7% and 42% savings respectively in insecticide ai use and the field EIQ value in 2007. Cumulatively since 1996, the savings using this methodology have been 8.3% for insecticide ai use (6.9 million kg) and 33% for the EIQ indicator (843 million field EIQ units)[86].

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

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[86] 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

grown cotton (a 77% decrease: see Appendix 3)[87]. 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 48% lower in 2007 (Table 50) than the levels that would have occurred if only conventional cotton had been planted. Cumulatively since 1997, the volume of insecticide use has decreased by 34.5% (110 million kg ai) and the field EIQ load has fallen by 35.1% (5.13 billion field EIQ/ha units).

Table 50: National level changes in insecticide ai use and field EIQ values for GM IR cotton in China 1997-2007

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
2006	16,325,600	806,971,110	51	52
2007	17,746,000	876,641,000	48	48

c) Australia

Using a combination of data from industry sources and CSIRO[88], 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 51).
- 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 52) has been respectively 69% (0.49 million kg) and 71% lower in 2007, than the levels that would have occurred if only conventional cotton had been planted;
- Cumulatively, since 1996 the volume of insecticide use is 25% lower (10.8 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 24.4%.

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

[88] 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 51: 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

Table 52: National level changes in insecticide ai use and field EIQ values for GM IR cotton in Australia 1996-2007

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	58.3	60.0
2005	2,177,393	44,785,011	64.4	66.2
2006	1,037,850	21,346,688	62.9	64.7
2007	486,886	10,014,368	69.2	71.1

d) Argentina

Adoption of GM IR cotton in Argentina has also resulted in important reductions in insecticide use[89]:

- 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 53) have been respectively 21.8% (82,770 kg) and 29.7% lower (5.2 million field EIQ/ha units) in 2007, than the levels that would have occurred if only conventional cotton had been planted;
- Cumulatively since 1998, the volume of insecticide use is 5.2% lower (333,480 kg) and the EIQ/ha load 7.1% lower (14.6 million field EIQ/ha units) than the amount that would have been used if GM IR technology had not been adopted.

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[89] Based on data from Qaim and De Janvry (2005)

Table 53: National level changes in insecticide ai use and field EIQ values for GM IR cotton in Argentina 1998-2007

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
2006	44,880	2,816,000	9.6	13.1
2007	82,773	5,193,600	21.8	29.7

Notes: derived from sources including CASAFE and Kynetec. Decrease in impact for 2005 associated with a decrease in GM IR plantings in that year

e) India

The analysis presented below is based on typical spray regimes for GM IR and non GM IR cotton (source: Monsanto Industry, India). The respective differences for ai use (see appendix 3) and field EIQ values for GM IR and conventional cotton used are:

- Conventional cotton: average volume of insecticide used was 3.55 kg/ha and a field EIQ/ha value of 118/ha;
- GM IR cotton: average volume of insecticide used was 1.92 kg/ha and a field EIQ/ha value of 68/ha.

Based on these values the level of insecticide ai use and the total EIQ load, in 2007 were respectively 29.1% (9.5 million kg) and 27.2% (298 million field EIQ/ha units) lower than would have been expected if the total crop had been conventional cotton. Cumulatively, since 2002, the insecticide ai use was 10.4% lower (18.9 million kg) and the total EIQ load 9.7% lower (590 million EIQ/ha units).

f) Brazil

GM IR cotton was first planted commercially in 2006 (on 358,000 ha in 2007, 13% of the total crop). Due to the limited availability of data, the analysis presented below is based on the experience in Argentina (see above). Thus, the respective differences for insecticide ai use and field EIQ values for GM IR and conventional cotton used as the basis for the analysis are:

- Conventional cotton: average volume of insecticide used is 1.15 kg/ha and a field EIQ/ha value of 53/ha;
- GM IR cotton: average volume of insecticide used 0.64 kg/ha and a field EIQ/ha value of 21/ha.

Based on these values the level of insecticide ai use and the total EIQ load, in 2007 were respectively 25% (182,500 kg) and 19% (11.4 million EIQ/ha units) lower than would have been expected if the total crop had been conventional cotton.

g) *Mexico*

GM IR cotton has been grown in Mexico since 1996, and in 2007, 64,350 ha (51% of the total crop) were planted to varieties containing GM IR traits.

Drawing on industry level data that compares typical insecticide treatments for GM IR and conventional cotton (see appendix 3), the main environmental impact associated with the use of GM IR technology in the cotton crop has been a significant reduction in the environmental impact associated with insecticide use on cotton. More specifically:

- On a per ha basis, GM IR cotton uses 31% less (-1.6 kg) insecticide than conventional cotton. The associated environmental impact, as measured by the EIQ indicator of the GM IR cotton is a 27% improvement on conventional cotton (a field EIQ/ha value of 74/ha compared to 259/ha for conventional cotton);
- In 2007, at a national level, there had been a 15.9% saving in the amount of insecticide active ingredient use (-97,320 kg) applied relative to usage if the whole crop had been planted to conventional varieties. The field EIQ load was 14.7% lower;
- Cumulatively since 1996, the amount of insecticide active ingredient applied was 7.4% (650,000 kg) lower relative to usage if the Mexican cotton crop had been planted to only conventional varieties over this eleven year period. The field EIQ load was 6.9% lower than it would have otherwise been if the whole crop had been using conventional varieties.

h) *Other countries*

Cotton farmers in South Africa and Columbia have also been using GM IR technology in recent years (respectively since 1998 and 2002). The plantings have, however been fairly small (in 2007, 9,900 ha in South Africa and 21,760 ha in Columbia).

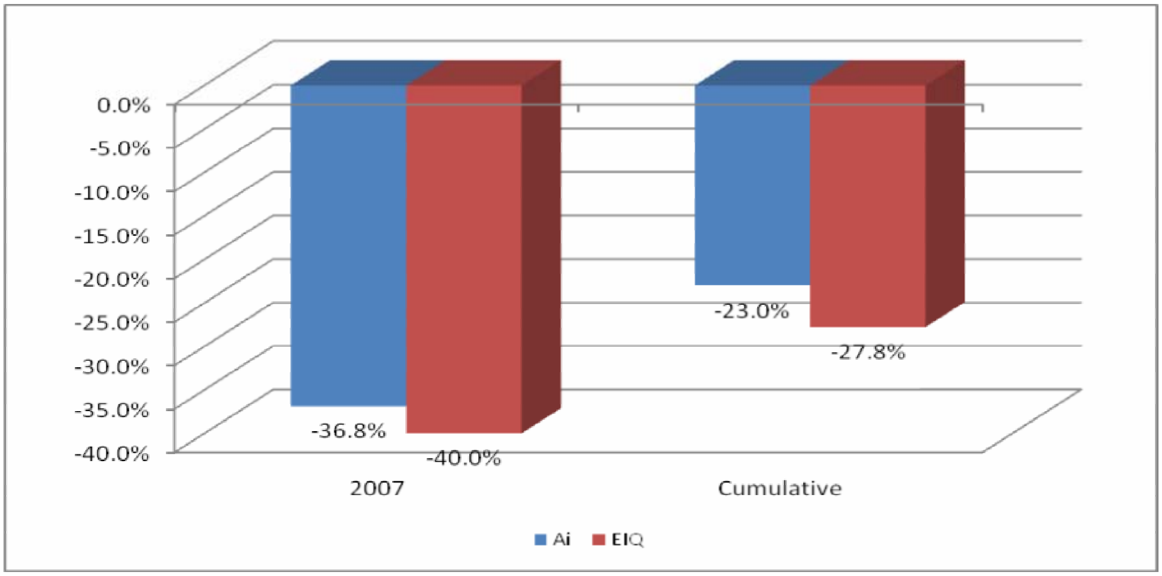
Analysis of the impact on insecticide use and the associated environmental 'foot print' are not presented for these crops because of the small scale and limited availability of insecticide usage data.

h) *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 22):

- In 2007, a 37% decrease in the total volume of insecticide ai applied (28.9 million kg) and a 40% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 23% less insecticide ai has been used (147.6 million kg) and the environmental impact from insecticides applied to the cotton crop has fallen by 27.8%.

Figure 22: Reduction in insecticide use and the environmental load from using GM IR cotton in adopting countries 1996-2007



4.1.8 Other environmental impacts - possible development of herbicide resistant weeds and weed shifts

These possible environmental impacts associated with the adoption of biotech herbicide tolerant technology have been raised in some literature and quarters. This section briefly examines the issues and evidence.

The development of weeds resistant to herbicides, or of gene flow from crops to wild relatives, are not new developments in agriculture and are, therefore not issues unique to the adoption of biotechnology in agriculture. All weeds have the ability to adapt to selection pressure, and there are examples of weeds that have developed resistance to a number of herbicides and to mechanical methods of weed control (eg, prostrate weeds such as dandelion which can survive mowing).

Weed resistance occurs mostly when the same herbicide (s), with the same mode of action have been applied on a continuous basis over a number of years. There are hundreds of resistant weed species confirmed in the International Survey of Herbicide Resistant Weeds (www.weedscience.org). Worldwide, there are 15 weed species that are currently[90] resistant to glyphosate, compared to 97 weed species resistant to ALS herbicides and 67 weed species resistant to triazine herbicides, such as atrazine. Several of the confirmed glyphosate resistant weed species have been found in areas where no GM HT crops have been grown.

Prior to the commercial planting of GM HT crops, glyphosate was used before planting to control weeds. With the adoption of GM HT technology farmers were able to use glyphosate in the crop to control a different set of weeds (to those in the pre-planting phase). As glyphosate is the primary herbicide used in GM HT crops planted globally, and the adoption of this technology has played a major role in facilitating the adoption of no and reduced tillage production

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[90] Accessed March 2009

techniques in North and South America (see section 4.2), it is possible that these factors are contributing to/could lead to the emergence of weeds resistant to herbicides like glyphosate and to weed shifts towards those weed species that are not well controlled by glyphosate. In addition, it is possible that herbicide tolerant plants could become volunteers in a subsequent crop which cannot be controlled by using glyphosate and/or there could be gene flow from the GMHT crop to wild relatives. This potential for out crossing of herbicide resistant plants with non transgenic seeds is reported to be more likely in crops such as canola and possibly sugar beet than other crops for which GM HT traits have/might be developed.

Control of glyphosate resistant weeds is achieved in the same way as control of other herbicide resistant weeds, via the use of other herbicides in mixtures or sequences. GM HT crops have no effect *per se* on weed control as it is the herbicide programme used with them that provides the selection pressure.

At the farm level, the practical consequences of glyphosate resistant weed biotypes being found are similar to the consequences of finding weeds resistant to other herbicides, namely the need to use an additional herbicide to control the resistant weed, the associated cost of this additional herbicide, and reduced management flexibility. To date, where GM HT farmers have been faced with the existence of weed species showing resistance to glyphosate these have been managed as part of a general weed control and resistance management strategy, essentially via the use of other herbicides in mixtures or sequence with glyphosate. Control of volunteer herbicide resistant crops has also been addressed in the same way, and few differences have been reported between volunteer management strategies in conventional crops compared to GM HT crops (see for example, Canola Council (2005) relating to volunteer canola management).

Clearly dealing with weed resistance adds cost to farmers. Where this has occurred it has tended to reduce, marginally, the average level of cost saving and profit gains cited in the most recent studies of GM herbicide tolerant crops (and used as the basis for the analysis in section 3). Equally, from an environmental perspective, the addition of, for example a small amount of a herbicide active ingredient such as cloransulam methyl (at 0.016 kg/ha) applied pre-planting (one of the recommendations for dealing with glyphosate resistant giant ragweed in Ohio USA[91]), marginally worsens the environmental profile/ha relative to the original GM HT 'recommended' practices, but continues to be significantly better than the conventional soybean herbicide regime alternative. For example, based on the NCFAP (2008) analysis referred to in section 4.1.1, the average field EIQ/ha for GM HT soybeans in 2006 was 17.6/ha (based on using only 1.154 kg/ha of glyphosate active ingredient to control all weeds). This compares with a field EIQ/ha of 17.87/ha if 0.016kg/ha of cloransulum methyl is added to the herbicide mix to deal with glyphosate resistant giant ragweed. The average field EIQ/ha for conventional soybeans (from the NCFAP analysis) is 30.23/ha.

Overall, it is important to place the possibility of negative environmental impacts associated with the use of GM HT technology occurring within the context of the current state of knowledge:

- All weeds have the ability to adapt to selection pressure;
- The development of weed resistance (singularly or stacked) to glyphosate and problems with volunteers has not had any significant impact on the economics of using herbicide

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[91] Source: Ohio State University Extension Service. www.agcrops.osu.edu/soybeans

tolerant crops to date[92] or on the environmental impact associated with herbicide use on GMHT crops;

- Similar problems of weed resistance build up to herbicides used on conventional arable crops have developed. The solutions are the same as in GM HT crops. Consequently, any assessment of the possible benefits and costs of biotech crops should recognise this point because to only examine the possible impact of weed/pest resistance build up in relation to biotech crops would not be comparing 'like for like' with the alternative production systems;
- New technology when introduced tends to deliver a level of benefit to farmers, who decide to adopt or, not based largely on their perception (and eventual experience) of the level of benefit for them. With time and repeated use of a specific piece of technology (eg, a particular herbicide, or seed), the effectiveness of the seed, herbicide etc declines, reducing the level of benefit derived. Eventually the technology is then replaced, itself by newer technology (eg, a new seed containing a different biotech herbicide tolerant trait, or a new herbicide that may have broad spectrum applications like glyphosate, or targets the weeds that glyphosate is less effective against).

In sum, the management practice changes required to address issues such as weed resistance are relatively minor (notably rotation of herbicides and/or addition of small amounts of supplementary herbicides). The environmental impact of management changes required to facilitate this control (in terms of herbicide use and cultural practices) is also low. Hence, the environmental benefits discussed above in section 4.1 associated with changes in herbicide (and insecticide) use would only be marginally reduced in order to deal with issues of weed resistance, out crossing and weed shifts. Therefore it is likely that there would continue to be important net environmental benefits associated with the adoption of biotech crops in the future.

4.2 Carbon sequestration

This section assesses the contribution of biotech crop adoption to reducing the level of greenhouse gas (GHG) emissions. The scope for biotech 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 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'[93] 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[94].

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[92] See for example, Canola Council (2005)

[93] 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

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

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

The traditional intensive method of soil cultivation is based on the use of the moldboard 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) or conservation tillage (mulch-till, ridge-till, strip-till and no-till (NT)). The strip-till and NT systems rely much more on herbicide-based weed control, often comprising a pre-plant burn-down application and secondary applications post-emergent.

To estimate fuel savings from the adoption of conservation tillage systems, noteably NT systems which are faciliated by the availability of GM herbicide tolerant crops, we have reviewed reports from the the following sources; the United States Department of Agriculture's (USDA) Energy Estimator for Tillage Model; the Voluntary Reporting of Greenhouse Gases Management Evaluation Tool (COMET-VR); Jasa (2002); and Illinois University (2006).

The USDA's Energy Estimator for Tillage model estimates diesel fuel use and costs in the production of key crops by specific locations across the USA and compares potential energy savings between conventional tillage and alternative tillage systems. Table 54 illustrates the energy saving for corn and soybeans across the three most important crop management zones (CMZ's). The adoption of NT in corn results in a 19.00 litre/ha saving compared with conventional tillage and in the case of soybeans, the NT saving is 28.50 litre/ha.

Table 54 Total farm diesel fuel consumption estimate (in litres per year/ha)

Crop (crop management zones)	**Conventional tillage**	**Mulch-till**	**Ridge-till**	**No-till**
Corn (Minnesota, Iowa & Illinois)				
Total fuel use	38.00	31.67	28.50	19.00
Potential fuel savings over conventional tillage		6.33	9.50	19.00
Saving		16.7%	25.0%	50.0%
Soybeans (Iowa, Illinois & Nebraska)				
Total fuel use	38.00	34.83	28.50	9.50
Potential fuel savings over conventional tillage		3.17	9.50	28.50
Saving		8%	25%	75%

The Voluntary Reporting of Greenhouse Gases-Carbon Management Evaluation Tool (COMET-VR) gives a higher reduction of 41.81 litres/ha when conventional tillage is replaced by no-till on non-irrigated corn and a reduction of 59.68 litres/ha in the case of soybeans in Nebraska.

The Univsity of Illinois (2006) compared the relative fuel use across four different tillage systems for both corn and soybeans. The 'deep' tillage and 'typical' intensive systems required

36.01litres/ha compared to the strip-till and no-till systems that used 22.92 litres/ha – a reduction of 13.09 litres/ha.

Analysis by Jasa (2002) at the University of Nebraska calculated fuel use based on farm survey data for various crops and tillage systems. Intensive tillage (resulting in 0%-15% crop residue) using the moldboard plough uses 49.39 litres/ha; reduced tillage (15%-30% residue) based on a chisel plough and /or combination of disk passes uses 28.34-31.24 litres/ha; conservation tillage (>30% residue) based on ridge tillage 25.16 litre/ha; and no-till and strip tillage 13.38 lires/ha.

In our analysis presented below it is assumed that the adoption of NT farming systems in soybean production reduces cultivation and seedbed preparation fuel usage by 32.30 litres/ha compared with traditional conventional tillage and by 19.33 litres/ha compared with reduced tillage cultivation. These are conservative estimates compared with the COMET-VR analysis and in line with the USDA Fuel Estimator for soybeans. The amount of tractor fuel used for seed-bed preparation, herbicide spraying and planting in each of these systems is shown in Table 55:

Table 55: Soybean - tractor fuel consumption by tillage method

Tillage system	**litre/ha**
Intensive tillage: traditional cultivation: moldboard plough, disc and seed planting etc	43.70
Reduced tillage (RT): chisel plough, disc and seed planting	30.73
No-till (NT): fertiliser knife, seed planting plus 2 sprays: pre-plant burn down and post-emergent	11.40

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. The adoption of NT and RT systems in respect of fuel use therefore results in reductions of carbon dioxide emissions of 88.81 kg/ha and 35.66 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[95].

The conversion of one hectare of conventional tillage to no till equates to a saving of approximately 592 km travelled by a standard family car[96] and one less spray pass is equal to a saving of nearly 19.2 km travelled.

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[95] 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

[96] Assumed standard family car carbon dioxide emission rating = 150 grams/km. Therefore 88.81kg of carbon dioxide divided by 150g/km = 592 km

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 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 mouldboard 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[97] (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[98].

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

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[97] 1 Pg of soil carbon pool equates to 0.47 parts per million of atmospheric carbon dioxide

[98] Conversion factor for carbon sequestered into carbon dioxide = 3.67

compared to CT has been significant, but variable, averaging 400 +/- 61 kg/carbon/ha/yr (Table 56).

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}. Our analysis using the COMET-VR tool[99] and assuming the adoption of NT from CT for non-irrigated corn in the major corn producing states results in a projected 270 to 450 kg carbon per year being sequestered - Table 56.

Table 56: 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
COMET-VR (NT from CT in corn)			
Illinois	260	490	370
Minnesota	340	580	450
Nebraska	190	360	270

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}

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[99] The Voluntary Reporting of Greenhouse Gases-Carbon Management Evaluation Tool (COMET-VR) tool is a decision support tool for agricultural producers, land managers, soil scientists and other agricultural interests. COMET-VR provides an interface to a database containing land use data from the Carbon Sequestration Rural Appraisal (CSRA) and calculates in real time the annual carbon flux using a dynamic Century model simulation. - http://www.cometvr.colostate.edu/

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 permanent when farmers adopt continuous NT systems which, itself tends to be dependant upon herbicide based weed control systems.

Where the use of biotech 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-till and 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[100]. 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 "burn down" 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

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[100] See for example, CTIC 2002

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 over 95% of the NT soybean crop area.

4.2.4 Herbicide tolerant soybeans

4.2.4.1 The US

Over the 1996-2007 period the area of soybeans cultivated in the USA increased rapidly from 26.0 million ha to 30.56 million ha in 2006 before falling back to 25.8 million ha in 2007. Over the same period, the area planted using conventional tillage is estimated to have fallen by 33% (from 7.5 miilion ha to 5.0 million ha), whilst the area planted using no-till has increased by 39% (from 7.7 million ha to 10.7 million ha).

The most rapid rate of adoption of the GM HT technology has been by growers using NT systems (GM HT cultivars accounting for an estimated 95% of total NT soybeans by 2006). This compares with conventional tillage systems for soybeans where GM HT cultivars account for about 78% of total conventional tillage soybean plantings (Table 57).

Table 57: US soybean tillage practices and the adoption of GM HT cultivars 1996-2007 (million ha)

	Total area	**No till**	**Reduced till**	**Conventional till**	**Total biotech area**	**Total conventional area**	**No till biotech area**	**Reduced till biotech area**	**Con-ventional tillage biotech area**
1996	26.0	7.7	10.7	7.5	0.5	25.5	0.23	0.16	0.08
1997	28.3	8.7	12.0	7.6	3.2	25.1	1.92	1.20	0.08
1998	29.1	9.3	12.7	7.2	11.8	17.4	4.92	4.82	2.04
1999	29.8	9.7	12.8	7.4	16.4	13.4	6.08	7.03	3.26
2000	30.1	9.9	12.7	7.6	18.2	11.9	6.93	7.61	3.70
2001	30.0	10.2	12.5	7.3	22.2	7.8	8.63	9.02	4.53
2002	29.5	10.3	12.3	7.0	24.3	5.3	9.38	10.42	4.50
2003	29.7	10.9	12.3	6.5	25.7	4.0	10.37	11.07	4.28
2004	30.3	11.7	12.5	6.1	27.2	3.1	11.40	11.28	4.50
2005	28.9	12.3	12.1	4.5	26.9	2.0	12.13	11.18	3.58
2006	30.6	14.1	13.0	3.4	27.2	3.4	13.43	11.26	2.52
2007	25.8	10.7	10.0	5.0	23.4	2.3	10.42	9.10	3.92

Source: Adapted from Conservation Tillage and Plant Biotechnology (CTIC) 2002, 2006 and 2007
NT = no-till, RT = reduced tillage + mulch till + ridge 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 (biotech and conventional) and applying the fuel usage consumption rates presented in section 4.2.1[101], the total consumption of tractor fuel has decreased by 96.5 million litres (from 746.4 to 649.9 million litres 1996 to 2007: Table 58). Over the same period, the average fuel usage fell 12.2% (from 28.7 litres/ha to 25.2 litres/ha: Table 58). A comparison of biotech versus conventional production systems shows that in 2007, the average tillage fuel consumption on the biotech planted area was 24.3 litres/ha compared to 34.5 litres/ha for the conventional crop (primarily because of differences in the share of NT plantings).

Table 58: US soybean consumption of tractor fuel used for tillage 1996-2007

	Total fuel consumption (million litres)	Average (litre/ha)	Conventional average (litre/ha)	Biotech average (litres/ha)
1996	746.4	28.7	28.9	22.4
1997	800.3	28.2	29.4	19.4
1998	809.3	27.8	29.7	24.9
1999	826.5	27.7	29.6	26.1
2000	833.1	27.6	30.0	26.1
2001	820.0	27.3	31.5	25.9
2002	799.0	27.0	33.3	25.7
2003	786.0	26.5	35.4	25.1
2004	783.3	25.9	35.7	24.8
2005	709.3	24.6	35.5	23.7
2006	710.6	23.3	30.2	22.4
2007	649.9	25.2	34.5	24.3

The cumulative permanent reduction in tillage fuel use in US soybeans is summarised in Table 59. This amounted to a reduction in tillage fuel usage of 729.1 million litres which equates to a reduction in carbon dioxide emission of 2,005.1 million kg.

Table 59: 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	0.5	28.3	13.7	37.71
1998	1.0	29.1	28.2	77.60
1999	1.0	29.8	30.8	84.73
2000	1.1	30.1	33.1	90.95
2001	1.4	30.0	41.7	114.63
2002	1.7	29.5	49.7	136.70

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[101] 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

2003	2.3	29.7	67.5	185.52
2004	2.9	30.3	86.6	238.05
2005	4.2	28.9	120.4	331.18
2006	5.5	30.6	167.5	460.67
2007	3.5	25.8	90.0	247.40
Total			**729.1**	**2,005.1**

Assumption: baseline fuel usage is the 1996 level of 28.7 litres/ha

b) Soil carbon sequestration

Based on the crop area planted by tillage system and type of seed planted (biotech and conventional) 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)[102], our estimates of total soil carbon sequested are (Table 60):

- An increase of 1,066.5 million kg carbon/year (from 2,641 million kg in 1996 to 3,707.4 million kg carbon/year in 2007 due to the increase in crop area planted and the increase in the NT soybean area);
- the average level of carbon sequestered per ha increased by 42.3 kg carbon/ha/year (from 101.7 to 144 kg carbon/ha/year).

Table 60: US soybeans: potential soil carbon sequestration (1996 to 2007)

	Total carbon sequestered (million kg)	**Average (kg carbon/ha)**
1996	2,640.96	101.7
1997	3,061.99	108.1
1998	3,337.46	114.5
1999	3,431.70	115.0
2000	3,482.75	115.5
2001	3,569.75	119.0
2002	3,619.85	122.5
2003	3,855.54	129.8
2004	4,148.86	137.0
2005	4,432.87	153.5
2006	5,194.42	170.0
2007	3,707.41	144.0

Cumulatively, since 1996 the increase in soil carbon due to the increase in RT and NT in US soybean production systems has been 9,091.7 million kg of carbon which, in terms of carbon dioxide emission equates to a saving of 33,367 million kg of carbon dioxide that would otherwise have been released into the atmosphere (Table 61). This estimate does not take into consideration the potential loss in carbon sequestration that might arise from a return to conventional tillage.

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[102] 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

Table 61: US soybeans: potential additional soil carbon sequestration (1996 to 2007)

	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	6.4	28.3	181.9	667.69
1998	12.8	29.1	374.4	1,373.89
1999	13.4	29.8	398.5	1,462.32
2000	13.9	30.1	418.0	1,534.01
2001	17.4	30.0	521.0	1,912.23
2002	20.9	29.5	616.9	2,264.00
2003	28.1	29.7	835.7	3,067.05
2004	35.4	30.3	1,071.2	3,931.26
2005	51.8	28.9	1,497.1	5,494.36
2006	68.3	30.6	2,087.4	7,660.89
2007	42.3	25.8	1,089.6	3,998.89
Total			**9,091.7**	**33,366.60**

Assumption: carbon sequestration remains at the 1996 level of 101.7 kg carbon/ha/year

4.2.4.2Argentina

Since 1996, the area planted to soybeans in Argentina has increased by 181% (from 5.9 to 16.6 million ha). Over the same period, the area planted using NT and RT practices also increased by an estimated 643%, from 2.1 to 15.6 million ha, whilst the area planted using conventional tillage decreased 74%, from 3.8 to 0.99 million ha: Table 62).

As in the US, a key driver for the growth in NT soybean production has been the availability of GM HT soybean cultivars, which in 2007 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 1997 when 6% of the total soybean crop was a second crop following on from wheat (in the same season), in 2007 the share of soybean plantings accounted for by second crop soybeans had risen to 30% of total plantings (4.9 million ha).

Table 62: Argentina soybean tillage practices and the adoption of biotech cultivars 1996-2007 (million ha)

	Total area	No till	Conventional till	Total biotech area	Total conv tional area	No till biotech area	Conventional tillage biotech area
1996	5.91	2.07	3.84	0.04	5.88	0.04	0.00
1997	6.39	2.56	3.84	1.76	4.64	1.76	0.00
1998	6.95	3.48	3.48	4.80	2.15	3.48	1.32
1999	8.18	5.73	2.45	6.64	1.54	5.73	0.91
2000	10.59	6.91	3.68	9.00	1.59	6.91	2.09
2001	11.50	8.32	3.18	10.93	0.57	8.32	2.60
2002	12.96	9.70	3.26	12.45	0.52	9.70	2.74

2003	13.50	10.56	2.94	13.23	0.27	10.56	2.67
2004	14.34	12.57	1.78	14.06	0.29	12.57	1.49
2005	15.20	13.21	1.99	15.05	0.15	13.21	1.84
2006	16.15	15.18	0.97	15.84	0.31	15.18	0.66
2007	16.59	15.59	1.00	16.42	0.17	15.59	0.83

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

a) Fuel consumption

Between 1996 and 2007 total fuel consumption associated with soybean cultivation increased by an estimated 160.3 million litres (75.8%), from 211.6 to 371.9 million litres/year. However, during this period the average quantity of fuel used per ha fell 37.4% from 35.8 to 22.4 litres/ha, due predominantly to the widespread use of GM HT soybean cultivars and NT/RT systems. If the proportion of NT/RT soybeans in 2007 (applicable to the total 2007 area planted) had remained at the 1996 level, an additional 1,300.9 million litres of fuel would have been used. At this level of fuel usage, an additional 3,577.5 million kg of carbon dioxide would have otherwise been released into the atmosphere (Table 63).

Table 63: Argentine soybeans: permanent reduction in tractor fuel consumption and reduction in CO2 emissions

	Annual reduction based on 1996 average of 35.8 (l/ha)	Crop area (million ha)	Total fuel saving million litres	Carbon dioxide (million kg)
1996	0.0	5.9	0.0	0.00
1997	1.1	6.4	7.2	19.90
1998	3.4	7.0	23.6	64.93
1999	7.9	8.2	64.8	178.21
2000	6.8	10.6	72.5	199.44
2001	8.5	11.5	97.2	267.39
2002	9.0	13.0	116.9	321.46
2003	9.8	13.5	132.0	363.07
2004	11.9	14.3	170.8	469.73
2005	11.8	15.2	178.6	491.19
2006	13.4	16.2	215.7	593.11
2007	13.4	16.6	221.5	609.10
Total			**1,300.9**	**3,577.54**

Note: based on 21.07 litres/ha for NT and RT and 43.7 litres/ha for CT

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[103]) 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 150 kg/carbon/ha/yr for NT/RT soybean cropping in Argentina, a cumulative total of 9,260 million kg of carbon, which equates to a saving of 33,984 million kg of carbon dioxide has been retained in the soil that would otherwise have been released into the atmosphere (Table 64).

Table 64: Argentine soybeans: potential additional soil carbon sequestration (1996 to 2007)

	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	-0.9	6.4	-5.9	-21.57
1998	12.8	7.0	89.1	327.00
1999	52.8	8.2	432.0	1,585.47
2000	43.3	10.6	458.8	1,683.95
2001	57.5	11.5	661.5	2,427.60
2002	62.5	13.0	810.0	2,972.83
2003	69.2	13.5	934.5	3,429.77
2004	88.0	14.3	1,262.7	4,634.16
2005	86.6	15.2	1,317.0	4,833.27
2006	100.8	16.2	1,628.1	5,975.23
2007	100.8	16.6	1,672.0	6,136.31
Cumulative total			**9,260.0**	**33,984.03**

Assumption: NT = +150 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 total fossil fuels consumption in Argentina.

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[103] Trials conducted by INTA found 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

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 2007 (associated with changes in no/reduced tillage systems, the adoption of GM HT technology and comparing the proportion of NT/RT soybeans in 2007 relative to the 1996 level) has possibly amounted to 165.3 million litres. At this level of fuel saving the reduction in the level of carbon dioxide released into the atmosphere has probably been 454.6 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 has been 1,825.7 million kg of carbon. In terms of carbon dioxide emission this equates to a saving of 6,700.34 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 the US in 2007 compared to 5.1 million ha in Canada).

The cumulative permanent reduction in tillage fuel use in Canadian canola is, since 1996, estimated at 220.1 million litres which equates to reduction in carbon dioxide emission of 605.16 million kg (Table 65).

Table 65: Canadian canola: permanent reduction in tractor fuel consumption and reduction in CO2 emissions

	Annual reduction based on 1996 average 35.6 (l/ha)	Crop area (million ha)	Total fuel saving (million litres)	Carbon dioxide (million kg)
1996	0.0	3.5	0.0	0.00
1997	1.6	4.9	7.9	21.63
1998	1.6	5.4	8.8	24.11
1999	1.6	5.6	9.0	24.71
2000	1.6	4.9	7.8	21.58
2001	3.2	3.8	12.2	33.62
2002	4.8	3.3	15.8	43.46
2003	6.5	4.7	30.3	83.30
2004	8.1	4.9	39.9	109.68
2005	7.4	5.5	40.5	111.36
2006	9.1	5.2	47.9	131.71
2007	8.1	5.9	47.7	131.26

Total			**267.8**	**736.4**

Notes: fuel usage NT = 11.4 litres/ha CT = 43.7 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 66. The cumulative increase in soil carbon has been 2,487 million kg of carbon which in terms of carbon dioxide emission equates to a saving of 9,128 million kg of carbon dioxide that would otherwise have been released into the atmosphere.

Table 66: Canada canola: potential additional soil carbon sequestration (1996 to 2007)

	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	268.09
1998	15.0	5.4	81.4	298.86
1999	15.0	5.6	83.5	306.31
2000	15.0	4.9	72.9	267.50
2001	30.0	3.8	113.6	416.75
2002	45.0	3.3	146.8	538.67
2003	60.0	4.7	281.4	1,032.56
2004	75.0	4.9	370.4	1,359.46
2005	68.5	5.5	376.1	1,380.34
2006	84.9	5.2	444.8	1,632.54
2007	75.0	5.9	443.3	1,626.99
Total			**2,487.3**	**9,128.07**

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 marginal 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 it still only represents an estimated 20% of the total cotton crop in 2007 – 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 2007 its share is estimated to have risen to between 20% and 25%)
- 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 IR cotton has resulted in a significant reduction in the number of insecticide spray applications. During the period 1996 to 2007 the global cotton area planted with GM IR cultivars has increased from 0.86 million ha to 3.25 million ha. Based on a conservative estimate of four fewer insecticide sprays being required for the cultivation of GM IR cotton relative to conventional cotton, and applying this to the global area (excluding China and India[104]) of GM IR cotton over the period 1996-2007, suggests that there has been a reduction of 109.8 million ha of cotton being sprayed. The cumulative saving in tractor fuel consumption has been 114.7 million litres. This represents a permanent reduction in carbon dioxide emissions of 315.62 million kg (Table 67).

Table 67: Permanent reduction in global tractor fuel consumption and CO2 emissions resulting from the cultivation of GM IR cotton

	Total cotton area in GM IR growing countries excluding India and China (million ha)	GM IR area (million ha) excluding India and China	Total spray runs saved (million ha)	Fuel saving (million litres)	CO2 emissions saved (million kg)
1996	7.49	0.86	3.45	3.60	9.91
1997	7.07	0.92	3.67	3.84	10.56
1998	7.24	1.05	4.20	4.39	12.08
1999	7.46	2.11	8.44	8.82	24.25
2000	7.34	2.43	9.72	10.16	27.94
2001	7.29	2.55	10.18	10.64	29.27
2002	6.36	2.17	8.69	9.08	24.98
2003	5.34	2.17	8.70	9.09	24.99
2004	6.03	2.79	11.17	11.67	32.09
2005	6.34	3.21	12.84	13.41	36.89
2006	6.90	3.94	15.75	16.46	45.26
2007	4.95	3.25	13.0	13.59	37.37
Total			**109.81**	**114.75**	**315.57**

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[104] Excluded because all spraying is assumed to be undertaken by hand

Notes: assumptions: 4 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 IR maize (via fewer insecticide spray runs) and the adoption of Corn Rootworm Resistance maize is presented. This is because the impact of using these technologies 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;
- nominal application savings have occurred in relation to the adoption of GM CRW maize where over 8.4 million ha were planted in 2007. The adoption of the GM CRW may become increasing important with wider adoption of no-till cultivation systems due to the potential increase in soil-borne pests.

4.2.9 Summary of carbon sequestration impact

A summary of the carbon sequestration impact is presented in Table 68. This shows the following key points:

- The permanent savings in carbon dioxide emissions (arising from reduced fuel use of 2,578 million litres of fuel) since 1996 have been about 7,090 million kg;
- The additional amount of soil carbon sequestered since 1996 has been equivalent to 83,179 million tonnes of carbon dioxide that has not been released into the global atmosphere[105]. 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[106]. 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

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[105] 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

[106] 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

to conventional tillage. Consequently, the estimate provided above of 83,179 million tonnes of carbon dioxide not released into the atmosphere should be treated with caution.

Table 68: Summary of carbon sequestration impact 1996-2007

Crop/trait/country	Permanent fuel saving (million litres)	Potentiel additional carbon dioxide saving from fuel saving (million kg)	Potential additional carbon dioxide saving from soil carbon sequestration (million kg)
US: GM HT soybeans	729	2,005	33,367
Argentina: GM HT soybeans	1,301	3,578	33,984
Other countries: GM HT soybeans	165	455	6,700
Canada: GM HT canola	268	736	9,128
Global GM IR cotton	115	316	0
Total	**2,578**	**7,090**	**83,179**

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 69, measures the carbon dioxide equivalent savings associated with planting of biotech crops for the latest year (2007), in terms of the number of car use equivalents. This shows that in 2007, the permanent carbon dioxide savings from reduced fuel use was the equivalent of removing nearly 0.495 million cars from the road for a year and the additional soil carbon sequestration gains were equivalent to removing nearly 5.82 million cars from the roads. In total, biotech crop-related carbon dioxide emission savings in 2007 were equal to the removal from the roads of nearly 6.3 million cars, equal to about 24% of all registered private cars in the UK.

Table 69: Context of carbon sequestration impact 2007: 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 ('000s)	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 ('000s)
US: GM HT soybeans	247	110	3,999	1,777
Argentina: GM HT soybeans	609	271	6,136	2,727

Other countries: GM HT soybeans	91	40	1,341	596
Canada: GM HT canola	131	58	1,627	723
Global GM IR cotton	37	16	0	0
Total	**1,115**	**495**	**13,103**	**5,823**

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	25.4	0.3
1998	0.8	43.8	0.9
1999	1.4	116.6	2.3
2000	1.6	144.2	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
2006	3.2	698.9	11.2
2007	4.9	1,133.6	14.0

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 DMR 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 soybeans in Mexico

Active ingredient	**Amount (kg/ha of crop)**	**Field EIQ/ha**
Conventional soybeans		
Metribuzin	0.375	10.65
Imazethapyr	0.1	1.8
Paraquat	0.3	9.3
Quizalafop	0.042	2.17
Fluazafop	0.1875	8.25
Linuron	0.75	30.22
Total	**1.7545**	**62.39**
GM HT soybeans		
Glyphosate	**1.62**	**24.79**

Source: Monsanto Mexico

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 Ontario, 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 maize in Argentina

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional maize		
Acetochlor	1.68	30.74
Atrazine	1.25	28.63
Total	**2.93**	**59.37**
GM HT maize		
Acetochlor	0.84	15.37
Atrazine	0.625	14.31
Glyphosate	1.08	16.52
Total	**2.55**	**46.2**

Source: Monsanto Argentina

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	**1.97**	**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	**1.758**	**38.23**
GM HT cotton		
Glyphosate	**1.8**	**27.54**

Source: Monsanto South Africa

Typical herbicide regimes for GM HT cotton in Argentina

Active ingredient	**Amount (kg/ha of crop)**	**Field EIQ/ha**
Conventional cotton		
Glyphosate	1.8	27.54
Acetochlor	0.6	10.98
Diuron	1.034	21.20
Quizalofop	0.05	2.585
Total	**3.484**	**62.305**
GM HTcotton		
Glyphosate	**1.8**	**27.54**

Source: Monsanto Argentina

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, 2005 & 2008

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 and Canola Council (2001)

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 or Thiomethoxam	0.02 or 0.025
Profenofos	0.8
Acetamoprid	0.2
Indoxacarb	0.15
Chloropyrifos	1.0
Spinosad	0.075
Fenpropathrin or Ethion	0.2 or 1.0
Acephate	0.7
Total	**3.145 – 3.95**
GM IR cotton	
Imidachlopid or Thiomethoxam	0.02 or 0.025
Acetamoprid	0.02
Chloropyrifos	1.0
Acephate	0.7
Total	**1.92 – 1.925**

Sources: Monsanto India

Typical insecticide regimes for cotton in Mexico

Active ingredient	**Amount (kg/ha of crop)**
Conventional cotton	
Lambda cyhalothrin	0.04
Cypermethrin	0.16
Monocrotophos	0.6
Methidathion	0.622
Triazophos	0.6
Methomyl	0.225
Chlorpyrifos	0.96
Chlorfenapyr	0.12
Endosulfan	1.08
Azinphos methyl	0.315
Parathion methyl	0.5
Total	**5.222**
GM IR cotton	
Lambda cyhalothrin	0.02
Cypermethrin	0.08
Monocrotophos	0.3
Methomyl	0.225
Chlorpyrifos	0.96
Chlorfenapyr	0.12
Endosulfan	1.08
Azinphos methyl	0.315
Parathion methyl	0.5
Total	**1.622**

Source: Monsanto Mexico

Appendix 4: Base yields used where GM technology delivers a positive yield gain

In order to avoid over stating the positive yield effect of GM technology (where studies have identified such an impact) when applied at a national level, average (national level) yields used have been adjusted downwards (see example below). Production levels based on these adjusted levels were then cross checked with total production values based on reported average yields across the total crop.

Example: GM IR cotton (2007)

	US	China
Average yield across all forms of production (t/ha)	0.985	1.257
Total cotton area ('000 ha)	4,381.6	6,200.0
Total production ('000 tonnes)	4,315.9	7,793.4
GM IR area ('000 ha)	2,585.2	3,800.0
Conventional area ('000 ha)	1,796.5	2,400.0
Assumed yield effect of GM IR technology	+10%	+10%
Adjusted base yield for conventional cotton (t/ha)	0.93	1.184
GM IR production ('000 tonnes)	2,644.7	4,949.1
Conventional production ('000 tonnes)	1,670.7	2,841.6

Note: Figures subject to rounding

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