GM crops: global socio-economic and environmental impacts 1996-2010

Graham Brookes & Peter Barfoot

PG Economics Ltd, UK

Dorchester, UK
May 2012

Table of contents

Table of tables

Table of figures

Foreword

This paper is intended for use by a wide range of people with interests in agriculture across the world – farmers, farmer organisations, industry associations, inter-professional bodies, input suppliers, users of agricultural products, government departments, intenational organisations, non governmental organisations, politicians, academics, researchers, students and interested citizens.

The material contained in the paper, which is the seventh annual report on the global economic and environmental impact of biotech crops, aims to provide insights into the reasons why so many farmers around the world have adopted crop biotechnology and continue to use it in their production systems since the technology first became available on a widespread commercial basis in the mid 1990s.

The paper draws, and is largely based on, the considerable body of peer reviewed literature available that has examined the economic and other reasons behind farm level crop biotechnology adoption, together with the environmental impacts associated with the changes[1].

Given the controversy that the use of this technology engenders in some debates and for some people, the work contained in this paper has been submitted and accepted for publication in a peer reviewed publication. The length of this paper, at nearly 200 pages, is too long for acceptance for publication as a single document in peer reviewed journals. Therefore the authors submitted two papers focusing separately on the economic and environmental impacts of the technology. These papers have been accepted for publication in the peer reviewed journal, GM crops (www.landesbioscience.com). The environmental impact paper (Global impact of biotech crops: environmental effects 1996-2010) is available in the April-June 2012 edition (GM Crops 3:2, pp 1-9) and the economic impact paper (The income and production effects of biotech crops globally 1996-2010) is scheduled to be published in edition 3:4 October-December 2012 (and is available on open access at the journal's website). These papers follow on from 11 previous peer reviewed papers by the authors on the subject of crop biotechnology impact[2].

[1] Data from other sources, including industry,are used where no other sources of representatative data are available. All sources and assumptions used are detailed in the paper

[2] For example last year's global impact report covering the years 1996-2009 can be found in the International Journal of Biotechnology, 2011, vol 12 nos 1 to 2, pp 1-49 (on the economic impacts 1996-2009) and GM crops 2011, 2:1, 1-16, Jan-March 2011 (on the environmental impacts). See also www.pgeconomics.co.uk for a full list of these peer review papers

Executive summary and conclusions

This study presents the findings of research into the global socio-economic and environmental impact of biotech crops in the fifteen 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 the 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[3]

GM technology has had a significant positive impact on farm income derived from a combination of enhanced productivity and efficiency gains (Table 1). In 2010, the direct global farm income benefit from biotech crops was $14 billion. This is equivalent to having added 4.3% to the value of global production of the four main crops of soybeans, maize, canola and cotton. Since 1996, farm incomes have increased by $78.4 billion.

The largest gains in farm income in 2010 have arisen in the cotton sector, largely from yield gains. The $5 billion additional income generated by GM insect resistant (GM IR) cotton in 2010 has been equivalent to adding 14% to the value of the crop in the biotech growing countries, or adding the equivalent of 11.9% to the $42 billion value of the global cotton crop in 2010.

Substantial gains have also arisen in the maize sector through a combination of higher yields and lower costs. In 2010, maize farm income levels in the biotech adopting countries increased by almost $5 billion and since 1996, the sector has benefited from an additional $21.6 billion. The 2010 income gains are equivalent to adding 6% to the value of the maize crop in these countries,

[3] See section 3 for details

or 3.5% to the $139 billion value of total global maize production. This is a substantial increase in value added terms for two new maize seed technologies.

Significant increases to farm incomes have also resulted in the soybean and canola sectors. The GM HT technology in soybeans has boosted farm incomes by $3.3 billion in 2010, and since 1996 has delivered over $28 billion of extra farm income (the highest cumulative increase in farm income of the biotech traits). In the canola sector (largely North American) an additional $2.7 billion has been generated (1996-2010).

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, Bolivia, 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, Mexico and Colombia.

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 2010, 54.8% 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[4]. Over the fifteen years, 1996-2010, the cumulative farm income gain derived by developing country farmers was 50% ($39.24 billion).

Examining the cost farmers pay for accessing GM technology, Table 4 shows that across the four main biotech crops, the total cost in 2010 was equal to 28% of the total technology gains (inclusive of farm income gains plus cost of the technology payable to the seed supply chain[5]).

For farmers in developing countries the total cost was equal to 17% of total technology gains, whilst for farmers in developed countries the cost was 37% 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 1: Global farm income benefits from growing biotech crops 1996-2010: million US $

Trait	Increase in farm income 2010	Increase in farm income 1996-2010	Farm income benefit in 2010 as % of total value of production of these crops in biotech adopting countries	Farm income benefit in 2010 as % of total value of global production of crop

[4] 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 (2009)

[5] 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

GM herbicide tolerant soybeans	3,299.8	28,389.2	3.5	3.2
GM herbicide tolerant maize	438.5	2,672.8	0.5	0.3
GM herbicide tolerant cotton	148.3	1,062.4	0.4	0.3
GM herbicide tolerant canola	472.4	2,657.8	5.7	1.4
GM insect resistant maize	4,522.3	18,969.3	5.4	3.2
GM insect resistant cotton	5,030.1	24,371.9	14.0	11.9
Others	90.2	301.5	Not applicable	Not applicable
Totals	**14,001.6**	**78,424.9**	**6.25**	**4.3**

Notes: All values are nominal. Others = Virus resistant papaya and squash and herbicide tolerant sugar beet. 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: GM crop farm income benefits 1996-2010 selected countries: million US $

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton	Total
US	12,109.0	2,225.0	875.4	225.5	16,326.4	3,267.4	***35,028.7***
Argentina	11,217.3	314.2	68.6	N/a	309.2	246.4	***12,155.9***
Brazil	3,888.3	17.8	36.4	N/a	655.5	3.8	***4,601.8***
Paraguay	655.0	N/a	N/a	N/a	N/a	N/a	***655.0***
Canada	163.3	57.7	N/a	2,418.9	637.8	N/a	***3,277.7***
South Africa	7.2	3.2	2.7	N/a	769.0	27.1	***809.2***
China	N/a	N/a	N/a	N/a	N/a	10,911.2	***10,911.2***
India	N/a	N/a	N/a	N/a	N/a	9,395.2	***9,395.2***
Australia	N/a	N/a	31.5	13.4	N/a	362.8	***407.7***
Mexico	4.7	N/a	36.7	N/a	N/a	95.0	***136.4***
Philippines	N/a	54.6	N/a	N/a	115.7	N/a	***170.3***
Romania	44.6	N/a	N/a	N/a	N/a	N/a	***44.6***
Uruguay	76.4	N/a	N/a	N/a	8.0	N/a	***84.4***
Spain	N/a	N/a	N/a	N/a	113.9	N/a	***113.9***
Other EU	N/a	N/a	N/a	N/a	13.6	N/a	***13.6***
Colombia	N/a	0.3	11.1	N/a	15.6	11.4	***38.4***
Bolivia	223.1	N/a	N/a	N/a	N/a	N/a	***223.1***

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. US total figure also includes $296.4 million for other crops/traits (not included in the table). Also not included in the table is $4.3 million extra farm income from GM HT sugar beet in Canada

Table 3: GM crop farm income benefits 2010: developing versus developed countries: million US $

	Developed	Developing
GM HT soybeans	970.8	2,329.0
GM IR maize	3,868.6	653.7
GM HT maize	274.3	164.2
GM IR cotton	586.0	4,444.1
GM HT cotton	65.3	83.0
GM HT canola	472.4	0
GM virus resistant papaya and squash and GM HT sugar beet	90.2	0
Total	**6,327.6**	**7,674.0**

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

Table 4: Cost of accessing GM technology (million $) relative to the total farm income benefits 2010

	Cost of technology : all farmers	Farm income gain: all farmers	Total benefit of technology to farmers and seed supply chain	Cost of technology : developin g countries	Farm income gain: developing countries	Total benefit of technology to farmers and seed supply chain: developing countries
GM HT soybeans	1,605.1	3,299.8	4,904.9	564.4	2,329.0	2,893.4
GM IR maize	1,767.5	4,522.3	6,289.8	515.2	653.7	1,168.9
GM HT maize	789.6	438.5	1,228.1	94.6	164.2	258.8
GM IR cotton	610.3	5,030.1	5,640.4	400.8	4,444.1	4,844.9
GM HT cotton	348.0	148.3	496.3	32.8	83.0	115.8
GM HT canola	122.8	472.4	595.2	N/a	N/a	N/a
Others	72.0	90.2	162.2	N/a	N/a	N/a
Total	**5,315.3**	**14,001.6**	**19,316.9**	**1,607.8**	**7,674.0**	**9,281.8**

N/a = not applicable. Cost of accessing technology based on the seed premia paid by farmers for using GM technology relative to its conventional equivalents

As indicated in the methodology section, the analysis presented above is largely based on estimates of average impact in all years. Recognising that pest and weed pressure varies by region and year, additional sensitivity analysis was conducted for the crop/trait combinations where yield impacts were identified in the literature. This sensitivity analysis (see Appendix 2 for details) was undertaken for two levels of impact assumption; one in which all yield effects in all years were assumed to be 'lower than average' (level of impact that largely reflected yield impacts in years of low pest/weed pressure) and one in which all yield effects in all years were assumed to be 'higher than average' (level of impact that largely reflected yield impacts in years of high pest/weed pressure). The results of this analysis suggest a range of positive direct farm income gains in 2010 of +$12 billion to +$18.5 billion and over the 1996-2010 period, a range of

+$68.5 billion to +$93.1 billion (Table 5). This range is broadly within 87% to 119% of the main estimates of farm income presented above.

Table 5: Direct farm income benefits 1996-2010 under different impact assumptions (million $)

Crop	Consistent below average pest/weed pressure	Average pest/weed pressure (main study analysis)	Consistent above average pest/weed pressure
Soybeans	28,220	28,389.2	28,558
Corn	15,772	21,642.1	27,618
Cotton	22,065	25,434.3	33,520
Canola	2,281	2,657.8	2,793
Others	159	301.5	631
Total	**68,497**	**78,424.9**	**93,120**

Note: No significant change to soybean production under all three scenarios as almost all gains due to cost savings and second crop facilitation

Indirect (non pecuniary) farm level impacts

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

Many of the studies[6] 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 after the weeds and crop are 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 tolerant to the herbicide;
- 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);
- 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 a switch to more environmentally benign products.

[6] 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)

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. Piloted in 2008 and more widely operational from 2009, US farmers using stacked corn traits (containing insect resistant and herbicide tolerant traits together) are being offered discounts on crop insurance premiums (for crop losses) equal to $12.97/ha in 2010. Over the three years, this has applied to 12.7 million ha, resulting in insurance premia savings of $137.8 million;
- A 'convenience' benefit derived from having to devote less time to crop walking and/or applying insecticides;
- Savings in energy use – mainly associated with less use of aerial spraying;
- Savings in machinery use (for spraying and possibly reduced harvesting times);
- 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[7]. 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, Yorobe J (2004): see above). 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 GM technology, and in some cases farmers have been willing to adopt for these reasons alone, even when the measurable impacts on yield and direct costs of production suggest marginal or no direct economic gain.

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

[7] Notably maize in India

valuation techniques[8] to obtain farmers valuations of non pecuniary benefits. A summary of these findings is shown in (Table 6).

Table 6: Values of non pecuniary benefits associated with biotech crops in the US

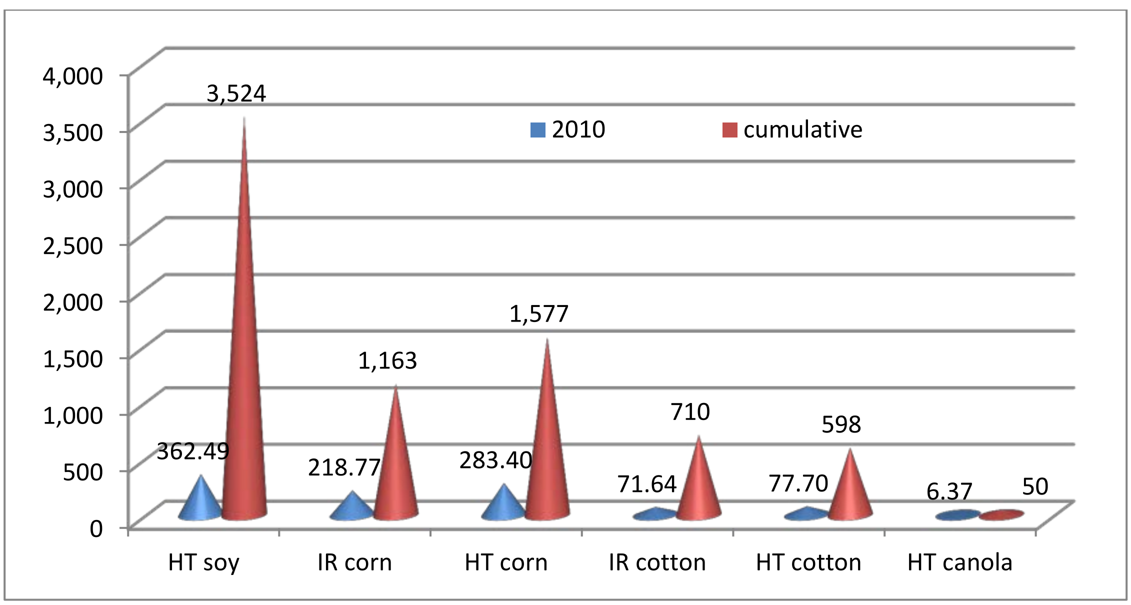
Survey	Median value ($/hectare)
2002 IR (to rootworm) corn growers survey	7.41
2002 soybean (HT) farmers survey	12.35
2003 HT cropping survey (corn, cotton & soybeans) – North Carolina	24.71
2006 HT (flex) cotton survey[9]	12.35 (relative to first generation HT cotton)

Source: Marra & Piggot (2006) and (2007)

Aggregating the impact to US crops 1996-2010

The approach used to estimate the non pecuniary benefits derived by US farmers from biotech crops over the period 1996-2010 has been to draw on the values identifed by Marra and Piggot (2006 & 2007: Table 6) and to apply these to the biotech crop planted areas during this 15 year period. Figure 1 summarises the values for non pecuniary benefits derived from biotech crops in the US (1996-2010) and shows an estimated (nominal value) benefit of $1,020 million in 2010 and a cumulative total benefit (1996-2010) of $7.62 billion. Relative to the value of direct farm income benefits presented above, the non pecuniary benefits were equal to 18.5% of the total direct income benefits in 2010 and 21.6% of the total cumulative (1996-2010) 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).

Figure 1: Non pecuniary benefits derived by US farmers 1996-2010 by trait ($ million)



---

[8] 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

[9] 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

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 these 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.

Production effects of the technology
Based on the yield assumptions used in the direct farm income benefit calculations presented above (see Appendix 1) and taking account of the second soybean crop facilitation in South America, biotech crops have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (Table 7).

Table 7: Additional crop production arising from positive yield effects of biotech crops

	1996-2010 additional production (million tonnes)	2010 additional production (million tonnes)
Soybeans	97.5	13.07
Corn	159.4	28.29
Cotton	12.5	2.06
Canola	6.1	0.65

The biotech IR traits, used in the corn and cotton sectors, have accounted for 98% of the additional corn production and 99.4% 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[10]) when compared to average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). The average yield impact across the total area planted to these traits over the 15 year period since 1996 has been +9.6% for corn traits and +14.4% for cotton traits (Figure 2).

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, Bolivia and Mexico, HT corn in Argentina and the Philippines: see Appendix 2).

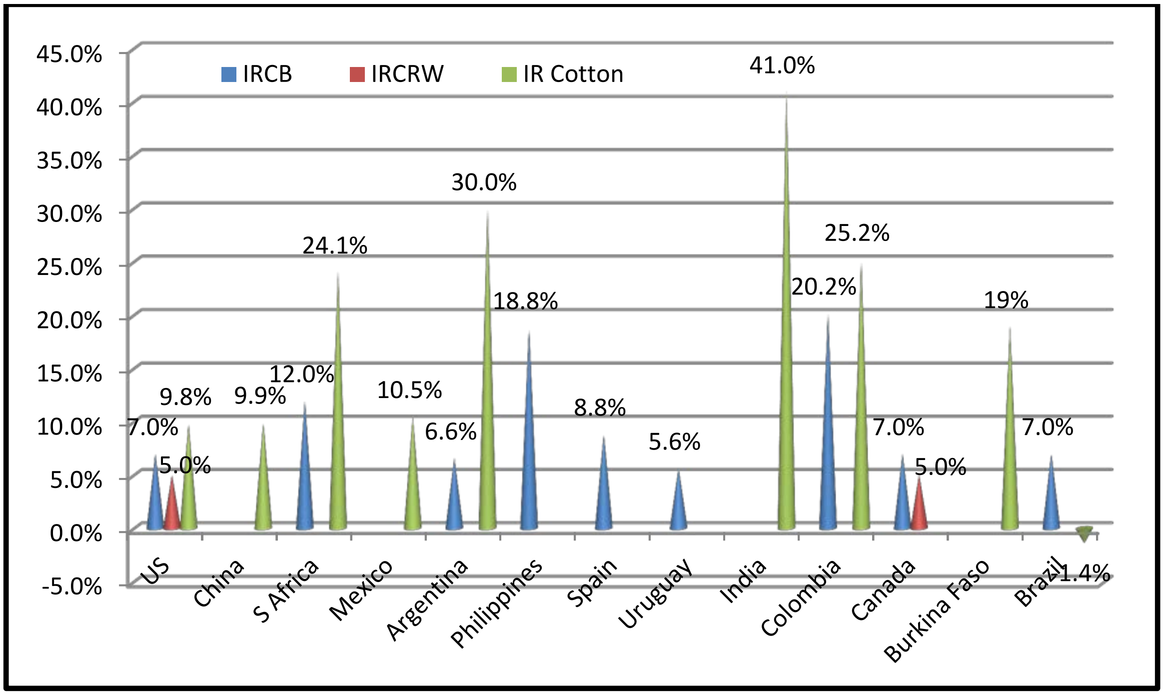
Biotech HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 96.1 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2010 (accounting for 98.5% of the total biotech-related additional soybean production).

Using the same sensitivity analysis as applied to the farm income estimates presented above to the production impacts (one scenario of consistent lower than average pest/weed pressure and

[10] 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

one of consistent higher than average pest/weed pressure), Table 8 shows the range of production impacts.

Figure 2: Average yield impact of biotech IR traits 1996-2010 by country and trait



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

Table 8: Additional crop production arising from positive yield effects of biotech crops 1996-2010 under different pest/weed pressure assumptions and impacts of the technology (million tonnes)

Crop	Consistent below average pest/weed pressure	Average pest/weed pressure (main study analysis)	Consistent above average pest/weed pressure
Soybeans	97.0	97.5	98.0
Corn	137.2	159.4	197.7
Cotton	8.8	12.5	18.2
Canola	4.6	6.1	6.5

Note: No significant change to soybean production under all three scenarios as 99% of production gain due to second cropping facilitation of the technology

Environmental impact from changes in insecticide and herbicide use[11]

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 key toxicity and environmental exposure data related to individual products. It therefore provides a better

[11] See section 4.1

measure to contrast and compare the impact of various pesticides on the environment and human health than weight of active ingredient alone. Readers should, however, note that the EIQ is an indicator only and does not take into account all environmental issues and impacts. In the analysis of GM HT technology we have assumed that the conventional alternative delivers the same level of weed control as occurs in the GM HT production system.

Biotech traits have contributed to a significant reduction in the environmental impact associated with insecticide and herbicide use on the areas devoted to biotech crops (Table 9). Since 1996, the use of pesticides on the biotech crop area was reduced by 448 million kg of active ingredient (9% reduction), and the environmental impact associated with herbicide and insecticide use on these crops, as measured by the EIQ indicator, fell by17.9%.

In absolute terms, the largest environmental gain has been associated with the adoption of GM insect resistant (IR) cotton (-23.9% reduction in the volume of active ingredient used and a 26% reduction in the EIQ indicator 1996-2010) and reflects the significant reduction in insecticide use that the technology has allowed, in what has traditionally been an intensive user of insecticides. The volume of herbicides used in biotech soybean crops also decreased by 28.8 million kg (1996-2010), a 1.4% reduction, whilst the overall environmental impact associated with herbicide use on these crops decreased by a significantly larger 16.2%. This highlights the switch in herbicides used with most GM herbicide tolerant (HT) crops to active ingredients with a more environmentally benign profile than the ones generally used on conventional crops.

Important environmental gains have also arisen in the maize and canola sectors. In the maize sector, herbicide and insecticide use decreased by 212.8 million kg (1996-2010) and the associated environmental impact of pesticide use on this crop area decreased, due to a combination of reduced insecticide use (37.7%) and a switch to more environmentally benign herbicides (11.5%). In the canola sector, farmers reduced herbicide use by14.4 million kg (a 18.2% reduction) and the associated environmental impact of herbicide use on this crop area fell by 27.4% (due to a switch to more environmentally benign herbicides).

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 10 shows a 55%:45% split of the environmental benefits (1996-2010) respectively in developed (55%) and developing countries (45%). Over three-quarters (76%) of the environmental gains in developing countries have been from the use of GM IR cotton.

Table 9: Impact of changes in the use of herbicides and insecticides from growing biotech crops globally 1996-2010

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	Area biotech trait 2010 (million ha)
GM herbicide tolerant soybeans	**-28.8**	**-6,261.7**	**-1.4**	**-16.2**	**71.6**

GM herbicide tolerant maize	**-169.9**	**-4,199.2**	**- 10.0**	**-11.5**	**27.0**
GM herbicide tolerant canola	**-14.4**	**-478.2**	**-18.2**	**-27.7**	**6.7**
GM herbicide tolerant cotton	**-12.1**	**-347.6**	**-5.2**	**-8.1**	**4.9**
GM insect resistant maize	**-42.9**	**-1,571.9**	**-41.9**	**-37.7**	**34.1**
GM insect resistant cotton	**-170.5**	**-7,615.1**	**-23.9**	**-26.0**	**17.7**
GM herbicide tolerant sugar beet	**+0.54**	**-2.8**	**+19.0**	**-5.0**	**0.46**
Totals	**-438.06**	**-20,476.5**	**-9.0**	**-17.9**	**162.46**

Table 10: Biotech crop environmental benefits from lower insecticide and herbicide use 1996-2010: 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	-4,571.9	-1,689.8
GM HT maize	-4,076.7	-122.5
GM HT cotton	-274.9	-72.7
GM HT canola	-478.2	0
GM IR corn	-1,267.9	-304.0
GM IR cotton	-577.1	-7,038.0
GM HT sugar beet	-2.8	0
Total	**-11,249.5**	**-9,227.0**

It should, however, be noted that in some regions where GM HT crops have been widely grown, some farmers have relied too much on the use of single herbicides like glyphosate to manage weeds in GM HT crops and this has contributed to the development of weed resistance. Worldwide, there are 21 weed species that are currently resistant to glyphosate (compared to, for example, 69 weed species resistant to triazine herbicides such as atrazine). A few of the glyphosate resistant species, such as marestail (*Conyza Canadensis*) and palmer pigweed (*Amaranthus Palmeri*) are now reasonably widespread in the US, especially marestail, where there are several million acres infested, and palmer pigweed, in southern states, where over a million acres are estimated to exhibit such resistance. In Argentina, development of resistance to glyphosate in weeds such as Johnson Grass (*Sorghum halepense*) is also reported.

Where this has occurred, farmers have had to adopt reactive weed management strategies incorporating the use of a mix of herbicides. In recent years, there has also been a growing consensus among weed scientists of a need for changes in the weed management programmes in GM HT crops because of the evolution of these weed populations that are resistant to glyphosate. While the overall level of weed resistance in areas planted to GM HT crops is still relatively low (equal to between 5% and 10% of the total US cropping area annually planted to GM HT crops), growers of GM HT crops are increasingly being advised to be more proactive and include other herbicides in combination with glyphosate in their weed management systems even where instances of weed resistance to glyphosate have not been found. This is because proactive weed management programmes generally require fewer herbicides and are more economical than reactive weed management programmes. At the macro level, the adoption of both reactive and proactive weed management programmes in GM HT crops has already begun to influence the mix, total amount and overall environmental profile of herbicides applied to GM HT soybeans, cotton, maize and canola and this is reflected in the data presented in this paper.

Impact on greenhouse gas (GHG) emissions[12]

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 2010 this amounted to about 1,715 million kg (arising from reduced fuel use of 642.2 million litres). Over the period 1996 to 2010 the cumulative permanent reduction in fuel use is estimated at 12,232 million kg of carbon dioxide (arising from reduced fuel use of 4,582 million litres);
- The use of 'no-till' and 'reduced-till'[13] 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 4,805 million kg of soil carbon is estimated to have been sequestered in 2010 (equivalent to 17,634 million tonnes of carbon dioxide that has not been released into the global atmosphere). Cumulatively, the amount of carbon sequestered may be higher than these estimates due to year-on-year benefits to soil quality, however it is equally likely that the total cumulative soil sequestration gains have been lower because only a proportion of the crop area will have remained in NT/RT. It is, nevertheless, not possible to confidently estimate cumulative soil sequestration gains that take into account reversions to conventional tillage because of a lack of data. Consequently, the estimate provided above of 133,639 million tonnes of carbon dioxide not released into the atmosphere should be treated with caution.

Placing these carbon sequestration benefits within the context of the carbon emissions from cars, Table 11 shows that:

- In 2010, the permanent carbon dioxide savings from reduced fuel use were the equivalent of removing 0.76 million cars from the road;
- The additional probable soil carbon sequestration gains in 2010 were equivalent to removing 7.84 million cars from the roads;

[12] See section 4.2

[13] 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

- In total, in 2010, the combined biotech crop-related carbon dioxide emission savings from reduced fuel use and additional soil carbon sequestration were equal to the removal from the roads of 8.6 million cars, equivalent to 27.7% of all registered cars in the UK;
- It is not possible to confidently estimate the probable soil carbon sequestration gains since 1996 (see above). If the entire biotech crop in reduced or no tillage agriculture during the last fifteen years had remained in permanent reduced/no tillage then this would have resulted in a carbon dioxide saving of 133,639 million kg, equivalent to taking 59.4 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 11: Context of carbon sequestration impact 2010: car equivalents

Crop/trait/country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Permanent fuel savings: as average family car equivalents removed from the road for a year ('000s)	Potential additional soil carbon sequestration savings (million kg of carbon dioxide)	Soil carbon sequestration savings: as average family car equivalents removed from the road for a year ('000s)
USA: GM HT soybeans	246	109	4,810	2,138
Argentina: GM HT soybeans	670	298	6,762	3,005
Brazil: GM HT soybeans	364	162	3,680	1,636
Bolivia, Paraguay, Uruguay: GM HT soybeans	183	81	1,850	822
Canada: GM HT canola	110	49	532	237
Global: GM IR cotton	64	29	0	0
Brazil: GM IR corn	78	35	0	0
Total	**1,715**	**763**	**17,634**	**7,838**

Notes: Assumption: an average family car produces 150 grams of carbon dioxide per km. A car does an average of 15,000 km/year and therefore produces 2,250 kg of carbon dioxide/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 15.4 million adopting farmers who have applied the technology, to 139 million hectares in 2010.

During the last fifteen 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.

In relation to GM HT crops, however, over reliance on the use of glyphosate by some farmers, in some regions, has contributed to the development of weed resistance. As a result, farmers are increasingly adopting a mix of reactive and proactive weed management strategies incorporating a mix of herbicides. Despite this, the overall environmental and economic gains arising from the use of biotech crops have been, and continues to be, substantial.

1 Introduction

This study[14] examines specific global socio-economic impact on farm income and environmental impacts in respect of pesticide usage and greenhouse gas (GHG) emissions, of crop biotechnology, over the fifteen year period 1996-2010[15]. 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 fifteen 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 fifteen 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[16];
- Greenhouse gas (GHG) emissions.

1.2 Methodology

The report has been compiled based largely on desk research and analysis. A detailed literature review[17] 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[18], although where relevant, primary analysis has been undertaken from base data (eg, calculation of the environmental impacts). More specific information about assumptions used and their origins are provided in each of the sections of the report.

[14] 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

[15] This study updates earlier studies produced in 2005, 2006, 2008, 2009, 2010 and 2011, covering the first nine, ten, eleven, twelve, thirteen and fourteen 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)

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

[17] See References

[18] 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

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 fifteen year period 1996-2010.

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 of crops containing biotech traits were planted (1.66 million hectares). Since then there has been a dramatic increase in plantings and by 2010/11, the global planted area reached over 139 million hectares. This is equal to 71% of the total utilised agricultural area of the European Union or two and a quarter times the EU 27 area devoted to cereals.

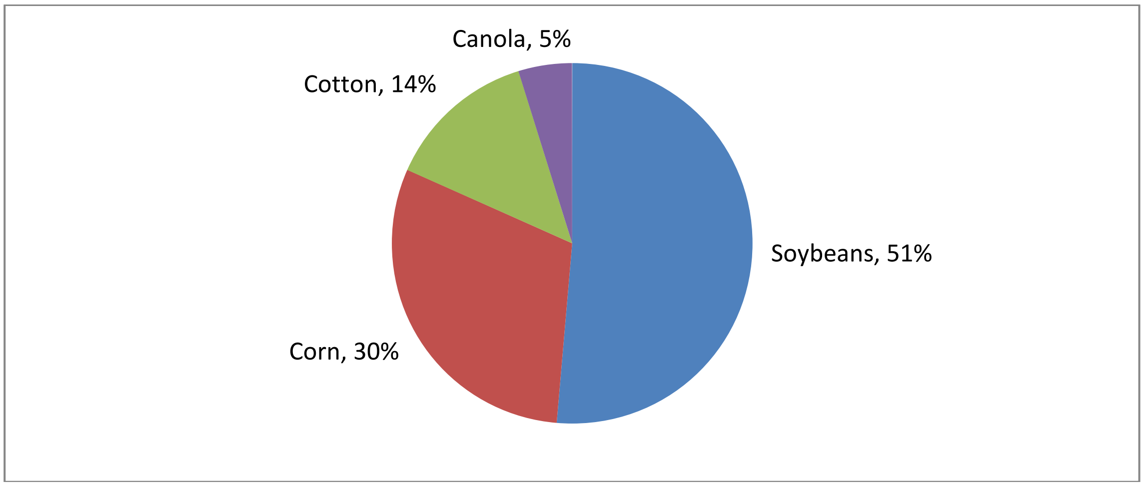
In terms of the share of the main crops in which biotech traits have been commercialised (soybeans, corn, cotton and canola), biotech traits accounted for 42% of the global plantings to these four crops in 2010.

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 3)[19]. In 2010, biotech soybeans accounted for the largest share (51%), followed by corn (30%), cotton (14%) and canola (5%).

Figure 3: Biotech crop plantings 2010 by crop (base area of the four crops: 139.3 million hectares (ha))

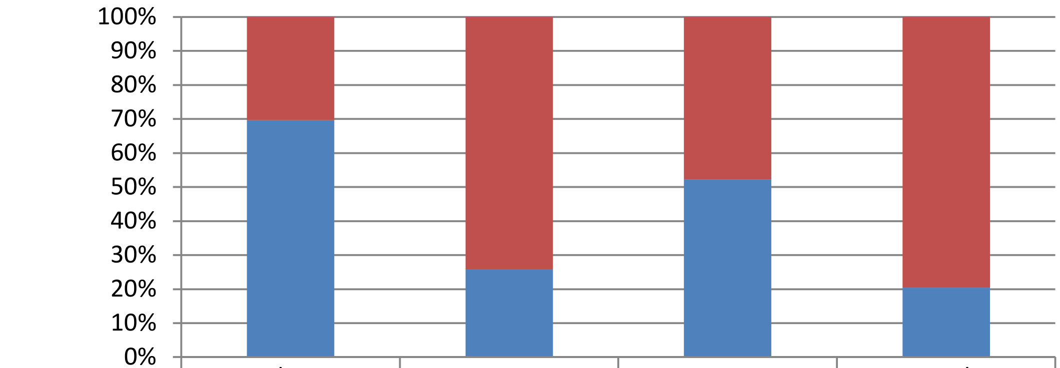


Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio, National Ministries of Agriculture (Mexico, Philippines, Spain), Grains South Africa

[19] In 2009 there were also additional GM crop plantings of papaya (410 hectares), squash (3,550 hectares) and sugar beet (432,000 ha) in the USA. There were also 4,500 hectares of papaya in China and 15,000 of sugar beet in Canada

In terms of the share of total global plantings to these four crops, biotech traits accounted for the majority of soybean plantings (70%) in 2010. For the other three main crops, the biotech shares in 2010 were 26% for corn, 52% for cotton and 20% for canola (Figure 4).

Figure 4: 2010's share of biotech crops in global plantings of key crops (ha)

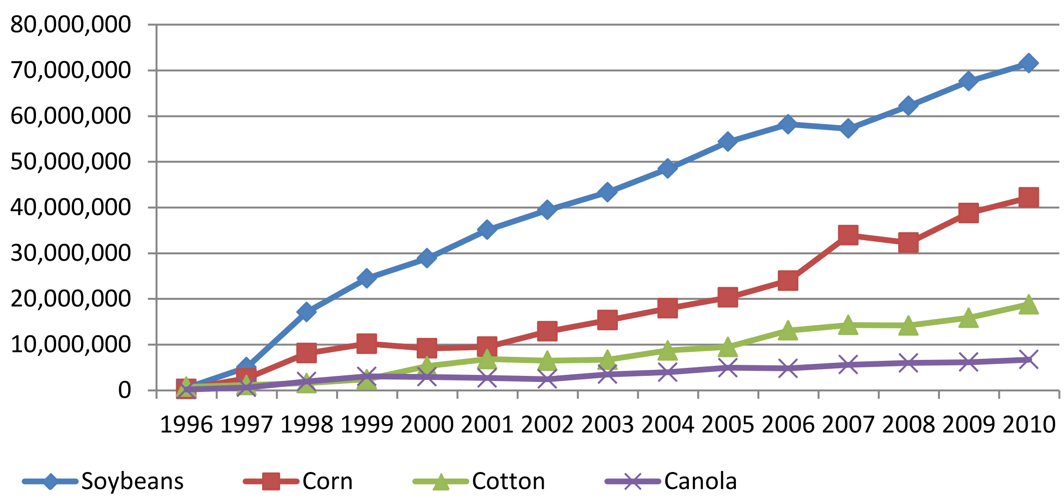


	Soybeans	Corn	Cotton	Canola
Conventional	31,131,071	120,893,831	17,248,105	26,122,356
Biotech area	71,578,929	42,206,169	18,821,895	6,707,644

Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio, National Ministries of Agriculture (Mexico, Philippines, Spain), Grains South Africa

The trend in plantings to biotech crops (by crop) since 1996 is shown in Figure 5.

Figure 5: Global biotech crop plantings by crop 1996-2010 (ha)

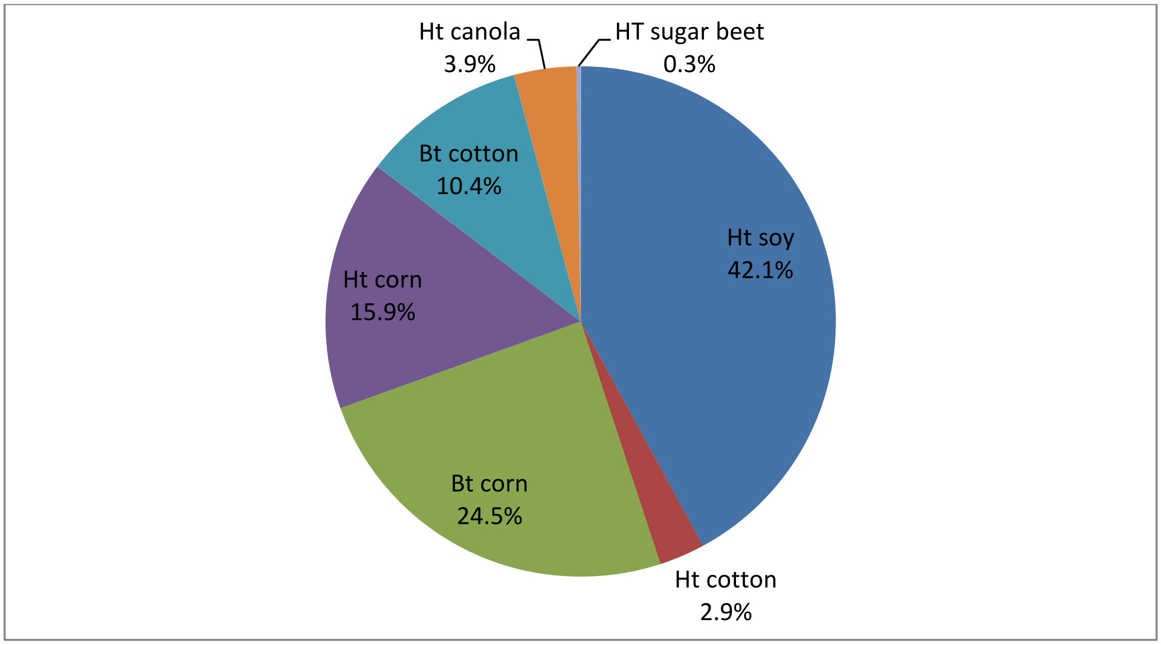


Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio, National Ministries of Agriculture (Mexico, Philippines, Spain), Grains South Africa

2.2.2 By trait

Figure 6 summarises the breakdown of the main biotech traits planted globally in 2010. Biotech herbicide tolerant soybeans dominate, accounting for 42% of the total, followed by insect resistant (largely Bt) corn, herbicide tolerant corn and insect resistant cotton with respective shares of 24%, 16% and 10%[20]. In total, herbicide tolerant crops account for 65%, and insect resistant crops account for 35% of global plantings.

Figure 6: Global biotech crop plantings by main trait and crop: 2010



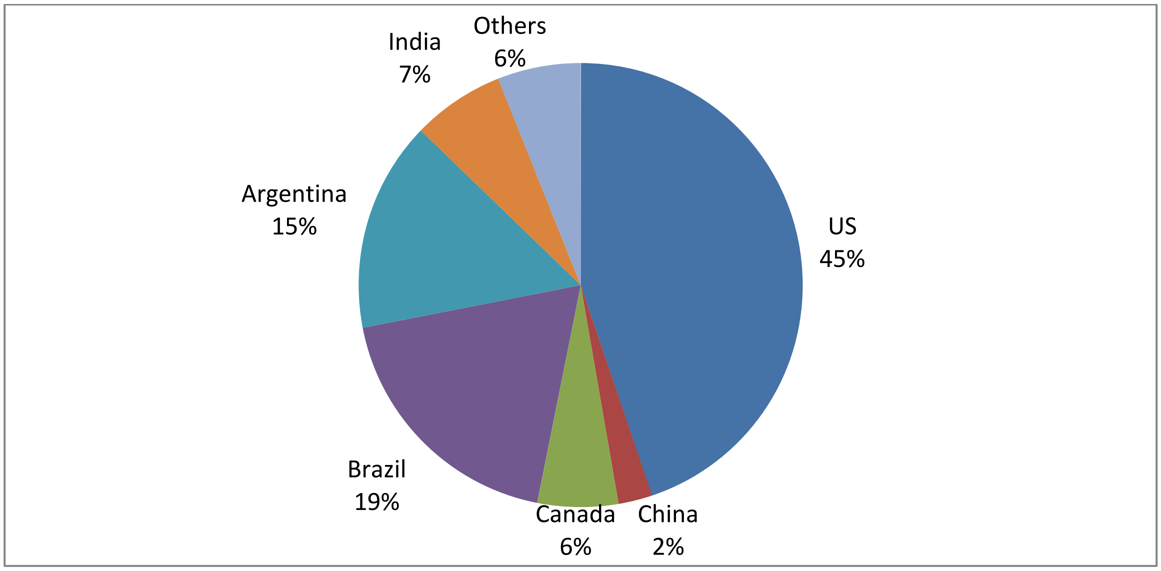
Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio, National Ministries of Agriculture (Mexico, Philippines, Spain), Grains South Africa

2.2.3 By country

The US had the largest share of global biotech crop plantings in 2010 (45%), followed by Brazil (19%). The other main countries planting biotech crops in 2010 were Argentina, India, Canada and China (Figure 7).

[20] The reader should note that the total plantings by trait produces a higher global planted area (162.4 million ha) than the global area by crop (129.4 million ha) because of the planting of some crops containing the stacked traits of herbicide tolerance and insect resistance

Figure 7: Global biotech crop plantings 2010 by country



Sources: Various including ISAAA, Canola Council of Canada, CropLife Canada, USDA, CSIRO, ArgenBio, National Ministries of Agriculture (Mexico, Philippines, Spain), Grains South Africa

In terms of the biotech share of production in the main adopting countries, Table 12 shows that, in 2010, the technology accounted for important shares of total production of the four main crops, in several countries. More specifically:

- *USA*: was one of the first countries to adopt the technology in 1996 for traits in soybeans, corn and cotton, and from 1999 in canola, hence the very high adoption levels that have been reached in 2010. Almost all of the US sugar beet crop (96%) also used GM herbicide tolerant technology in 2010, a level of almost total dominance of the crop achieved in three years (first available commercially to US farmers in 2008);
- *Canada and Argentina*: like the US were early adopters, with the technology now dominating production in the three crops of soybeans, corn and canola in Canada, and corn, cotton and soybeans in Argentina;
- *South Africa*: was the first, and remains the primary African country[21] to embrace the technology, which was first used commercially in 2000. The technology is widely used in the important crops of corn and soybeans, and now accounts (in 2010) for all of the small cotton crop (about 13,000 ha in 2010);
- *Australia:* was an early adopter of GM technology in cotton (1996), with GM traits now accounting for almost all cotton production. Extension of the technology to other crops did however, not occur until 2008 when herbicide tolerant canola was allowed in some Australian states;
- In *Asia*, three countries used GM crops in 2010. China was the first Asian country to use the technology commercially back in 1997 when GM insect resistant technology was first used. This technology rapidly expanded to about two thirds of the total crop within five years and has remained at this level ever since. GM virus resistant papaya has also been used in China since 2008. In India, insect resistant cotton was first adopted in 2002, and

[21] The only other African country where commercial GM crops were planted in 2010, was Burkina Faso. First used commercially in 2008, insect resistant cotton now accounts for two thirds (260,000 ha) of the total crop (2010)

its use increased rapidly in subsequent years, so that by 2010 this technology dominates total cotton production (85% of the total). Lastly in the Philippines, insect resistant corn was first used commercially in 2003, with herbicide tolerant corn also adopted from 2006;

- In *South America*, there are interesting country examples where the adoption of GM technology in one country resulted in a spread of the technology, initially illegally, across borders into countries which were first reluctant to legalise the use of the technology. Thus GM herbicide tolerant soybeans were first grown illegally in the southernmost states of Brazil in 1997, a year after legal adoption in Argentina. It was not until 2003 that the Brazilian government legalised the commercial growing of GM HT soybeans, when more than 10% of the country's soybean crop had been using the technology illegally (in 2002). Since then, GM technology use has extended to cotton in 2006 and corn in 2008. A similar process of widespread illegal adoption of GM HT soybeans occurred in Paraguay and Bolivia before the respective governments authorised the planting of soybean crops using this GM trait.

Table 12: GM share of crop plantings in 2010 by country (% of total plantings)

	Soybeans	Corn	Cotton	Canola
USA	93	86	93	88
Canada	70	94	N/a	93
Argentina	99	86	98	N/a
South Africa	85	69	100	N/a
Australia	N/a	N/a	99	8
China	N/a	N/a	67	N/a
Philippines	N/a	22	N/a	N/a
Paraguay	96	N/a	N/a	N/a
Brazil	76	55	27	N/a
Uruguay	94	95	N/a	N/a
India	N/a	N/a	85	N/a
Colombia	N/a	8	87	N/a
Mexico	24	N/a	47	N/a
Bolivia	79	N/a	N/a	N/a

Note: N/a = not applicable

3 The farm level economic impact of biotech crops 1996-2010

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.

The analysis is based on an extensive examination of existing farm level impact data for biotech crops. Whilst primary data for impacts of commercial cultivation were not available for every crop, in every year and for each country, a substantial body of representative research and analysis is available and this has been used as the basis for the analysis presented.

As the economic performance and impact of this technology at the farm level varies widely, both between, and within regions/countries (as applies to any technology used in agriculture), the measurement of performance and impact is considered on a case by case basis in terms of crop and trait combinations. The analysis presented is based on the average performance and impact recorded in different crops by the studies reviewed; the average performance being the most common way in which the identified literature has reported impact. Where several pieces of relevant research (eg, on the impact of using a GM trait on the yield of a crop in one country in a particular year) have been identified, the findings used have been largely based on the average of these findings.

This approach may both, overstate, or understate, the real impact of GM technology for some trait, crop and country combinations, especially in cases where the technology has provided yield enhancements. However, as impact data for every trait, crop, location and year is not available, the authors have had to extrapolate available impact data from identified studies for years for which no data are available. Therefore the authors acknowledge that this represents a weakness of the research. To reduce the possibilities of over/understating impact, the analysis:

- Directly applies impacts identified from the literature to the years that have been studied. As a result, the impacts used vary in many cases according to the findings of literature covering different years[22]. Hence, the analysis takes into account variation in the impact of the technology on yield according to its effectiveness in dealing with (annual) fluctuations in pest and weed infestation levels as identified by research;
- Uses current farm level crop prices and bases any yield impacts on (adjusted – see below) current average yields. In this way some degree of dynamic has been introduced into the

[22] Examples where such data is available include the impact of GM insect resistant (IR) cotton: in India (see Bennett et al (2004), IMRB (2006) and IMRB (2007)), in Mexico (see Traxler et al (2001) and Monsanto Mexico (annual reports to the Mexican government)) and in the US (see Sankala & Blumenthal (2003 and 2006), Mullins & Hudson (2004))

analysis that would, otherwise, be missing if constant prices and average yields identified in year-specific studies had been used;

- Includes some changes and updates to the impact assumptions identified in the literature based on consultation with local sources (analysts, industry representatives) so as to better reflect prevailing/changing conditions (eg, pest and weed pressure, cost of technology);
- Adjusts downwards the average base yield (in cases where GM technology has been identified as having delivered yield improvements) on which the yield enhancement has been applied. In this way, the impact on total production is not overstated (see Appendix 1 for examples).

Appendix 2 also provides details of the impacts, assumptions applied and sources.

Other aspects of the methodology used to estimate the impact on direct farm income are as follows:

- Impact is quantified at the trait and crop level, including where stacked traits are available to farmers. Where stacked traits have been used, the individual trait components were analysed separately to ensure estimates of all traits were calculated;
- All values presented are nominal for the year shown and the base currency used is the US dollar. All financial impacts in other currencies have been converted to US dollars at prevailing annual average exchange rates for each year;
- The analysis focuses on changes in farm income in each year arising from impact of GM technology on yields, key costs of production (notably seed cost and crop protection expenditure, but also impact on costs such as fuel and labour[23]), crop quality (eg, improvements in quality arising from less pest damage or lower levels of weed impurities which result in price premia being obtained from buyers) and the scope for facilitating the planting of a second crop in a season (eg, second crop soybeans in Argentina following wheat that would, in the absence of the GM herbicide tolerant (GM HT) seed, probably not have been planted). Thus, the farm income effect measured is essentially a gross margin impact (impact on gross revenue less variable costs of production) rather than a full net cost of production assessment. Through the inclusion of yield impacts and the application of actual (average) farm prices for each year, the analysis also indirectly takes into account the possible impact of biotech crop adoption on global crop supply and world prices.

The section also examines some of the more intangible (more difficult to quantify) economic impacts of GM technology. The literature in this area is much more limited and in terms of aiming to quantify these impacts, largely restricted to the US-specific studies. The findings of this research are summarised[24] and extrapolated to the cumulative biotech crop planted areas in the US over the period 1996-2010.

[23] Inclusion of impact on these categories of cost are, however, more limited than the impacts on seed and crop protection costs because only a few of the papers reviewed have included consideration of such costs in their analysis. Therefore in most cases the analysis relates to impact of crop protection and seed cost only

[24] Notably relating to the US - Marra and Piggott (2006)

Lastly, the paper includes estimates of the production impacts of GM technology at the crop level. These have been aggregated to provide the reader with a global perspective of the broader production impact of the technology. These impacts derive from the yield impacts (where identified), but also from the facilitation of additional cropping within a season (notably in relation to soybeans in South America).

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

First generation GM HT soybeans

In 2010, 93% (29.3 million ha) of the total US soybean crop was planted to genetically modified herbicide tolerant cultivars (GM HT). Of this, 26.9 million ha were first generation GM HT soybeans. The farm level impact of using this technology since 1996 is summarised in Table 13.

The key features are as follows:

- The primary impact has been to reduce the 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 been in the range of $30/ha and $85/ha (based on a comparison of conventional herbicide regimes in the early 2000s that would be required to deliver a comparable level of weed control to the GM HT soybean system). In recent years, the cost savings declined relative to earlier years, mainly because of the significant increase in the global price of glyphosate relative to increases in the price of other herbicides (commonly used on conventional soybeans). Overall, the main savings have come from lower herbicide costs[25] plus a $6/ha to $10/ha saving in labour and machinery costs;
- Against the background of underlying improvements in average yield levels over the 1996-2010 period (via improvements in plant breeding), the specific yield impact of the GM HT technology used up to 2010 has been neutral (excluding second generation GM HT soybeans: see below)[26];
- The annual total national farm income benefit from using the technology rose from $5 million in 1996 to $1.42 billion in 2007. In the last three years, the aggregate farm income gains have fluctuated, largely due to changes in herbicide prices, with the 2010 gain being $762 million. The cumulative farm income benefit over the 1996-2010 period (in nominal terms) was $11.91 billion;
- In added value terms, the recent increase in farm income has been equivalent to an annual increase in production of between +1% and +7%.

[25] 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 switched to using these generic alternatives (the price of Roundup also fell significantly post 2000)

[26] 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

Table 13: Farm level income impact of using GM HT soybeans (first generation) in the US 1996-2010

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	57.0	32.25	877.1	4.25
2007	85.2	60.48	1,417.2	6.01
2008	57.1	32.37	899.5	3.04
2009	54.7	15.90	437.2	1.38
2010	66.2	28.29	761.9	2.12

Sources and notes:

1. Impact data 1996-1997 based on Marra et al (2002), 1998-2000 based on Carpenter and Gianessi (1999) and 2001 onwards based on Sankala & Blumenthal (2003 & 2006) and Johnson and Strom (2008) plus updated 2008 onwards to reflect recent changes in herbicide prices and weed control programmes
2. Cost of technology: $14.82/ha 1996-2002, $17.3/ha 2003, $19.77/ha 2004, $24.71/ha 2005-2008, $38.79/ha 2009, $37.95/ha 2010
3. The higher values for the cost savings in 2001 onwards reflect the methodology used by Sankala & Blumenthal, 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 used elsewhere. In earlier years the cost savings were based on comparisons between GM HT soy growers and/or conventional herbicide regimes that were commonplace prior to commercialisation in the mid 1990s when conventional tillage systems were more important

Second generation GM HT soybeans

A second generation of GM HT soybeans became available to commercial soybean growers in the US in 2009. It was planted on 2.43 million ha in 2010. The technology offered the same tolerance to glyphosate as the first generation (and the same cost saving) but with higher yielding potential. Pre-launch trials of the technology suggested that average yields would increase by between +7% and +11%. In assessing the impact on yield of this new generation of GM HT soybeans in 2009, it is important to recognise that only limited seed was available for planting in 2009 and the trait was not available in many of the leading (best performing) varieties. As a result, reports of performance[27] were varied when compared with the first generation of GM HT soybeans (which was available in all leading varieties), with some farmers reporting no improvement in yield relative to first generation GM HT soybeans whilst others found significant

[27] The authors are not aware of any survey-based assessment of performance in 2009

improvements in yield, of up to +10%. In 2010, when the trait was available in many more of the leading varieties, farmer feedback to the seed/technology providers reports average yield improvements of about +5%. For the purposes of this analysis, we have applied a yield improvement assumption of +5%. Applying the same cost saving assumptions as applied to first generation GM HT soybeans, but with a seed premium of $65.21/ha for 2009 and $50.14/ha for 2010, the net impact on farm income in 2010, inclusive of yield gain, was +$72.87/ha. Aggregated to the national level this was equal to an improvement in farm income of $176.87 million in 2010 and over the two years the total farm income gain was $202.3 million. The technology also increased US soybean production by 446,000 tonnes over the two years.

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 14). 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/ha-$4/ha compared to $15/ha-$38/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. Estimates of the proportion of total soybean seed used that derives from a combination of declared saved seed and uncertified seed in 2010 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, although since 2008, savings fell back to $16/ha-$18/ha because of the significant increase in the price of glyphosate relative to other herbicides. Net income gains have been in the range of $21-$29/ha up to 2007[28] and $14/ha-$16/ha since 2008;
- The price received by farmers for GM HT soybeans in the early years of adoption 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 (not applied in the analysis in recent years);
- The net income gain from use of the GM HT technology at a national level was $284.6 million in 2010. Since 1996, the cumulative benefit (in nominal terms) has been $4.11 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

[28] 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

enabled many Argentine farmers to cultivate two crops (wheat followed by soybeans) in one season. As such, 24% of the total Argentine soybean crop was second crop in 2010[29], 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 $1.16 billion in 2010 and $7.1 billion cumulatively since 1996;

- The total farm income benefit inclusive of the second cropping was $1.45 billion in 2010 and $11.2 billion cumulatively between 1996 and 2010;
- 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 the last three years has been equivalent to an annual increase in production of between +2% and +7%. The additional production from second soybean cropping facilitated by the technology in 2010 was equal to 24% of total output.

Table 14: Farm level income impact of using GM HT soybeans in Argentina 1996-2010

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	429	1,134
2008	16.37	13.87	230	754
2009	16.60	14.10	256	759
2010	18.30	15.80	285	1,162

Sources and notes:

1. The primary source of information for impact on the costs of production is Qaim & Traxler (2002 & 2005). This has been updated in recent years to reflect changes in herbicide prices and weed control practices
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 and the Argentine Ministry of Agriculture
4. Additional information is available in Appendix 1

[29] The second crop share was 4.4 million ha in 2010

5. The net savings to costs understate the total gains in recent years because 70%-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 76% of the total crop in 2010[30].

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 savings arising from a combination of reduced herbicide use, fewer spray runs, labour and machinery savings, were between $30/ha and $81/ha in the period 2003 to 2010 (Table 15). The net cost saving after deduction of the technology fee (assumed to be about $19/ha in 2010) has been between $9/ha and $61/ha in recent years. At a national level, the adoption of GM HT soybeans increased farm income levels by $694 million in 2010. Cumulatively over the period 1997 to 2010, farm incomes have risen by $3.9 billion (in nominal terms).

In added value terms, the increase in farm income from the use of the GM HT technology in 2010 was equivalent to an annual increase in production of +2.2% (1.6 million tonnes).

Table 15: Farm level income impact of using GM HT soybeans in Brazil 1997-2010

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	29.85	8.74	116.3	0.68
2008	64.07	44.44	591.9	2.63
2009	47.93	27.68	448.4	1.73
2010	57.28	37.8	694.1	2.19

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 for the period to 2006. From 2007 based on Galvao (2009 & 2010)
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

[30] Until 2003 all plantings were technically illegal

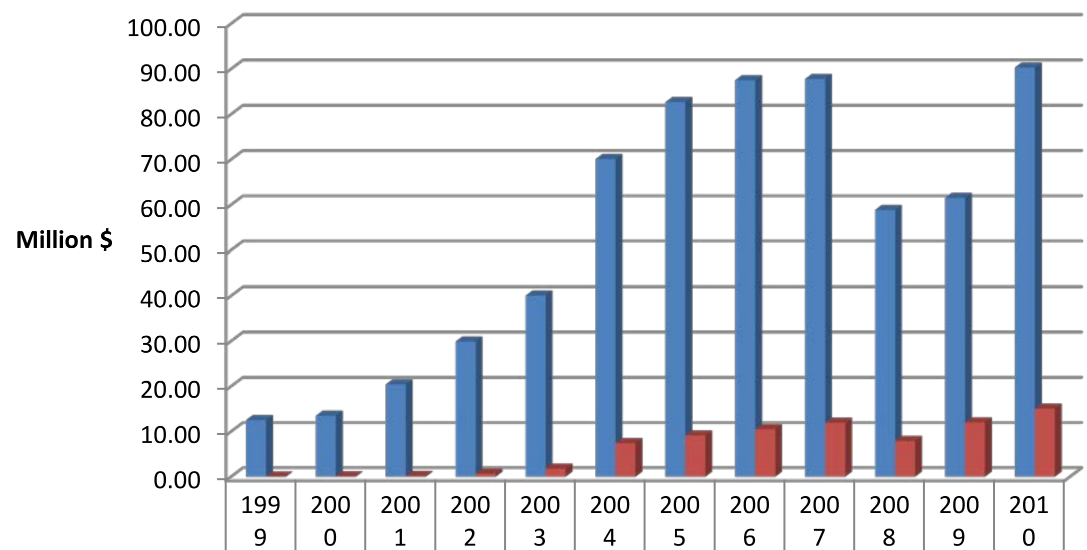
seed in Argentina (the source of the seed). This probably overstates the real cost of the technology and understates the cost savings

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. In 2010, they accounted for 95% of total soybean plantings in Paraguay and 94% of the soybean plantings in Uruguay[31]. Using the farm level impact data derived from Argentine research and applying this to production in these two countries[32], Figure 8 summarises the national farm level income benefits that have been derived from using the technology. In 2010, the respective national farm income gains were $90.3 million in Paraguay and $15 million in Uruguay.

Figure 8: National farm income benefit from using GM HT soybeans in Paraguay and Uruguay 1999-2010 (million $)



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Paraguay	12.50	13.48	20.42	29.91	40.04	70.06	82.65	87.52	87.80	58.84	61.51	90.32
Uruguay	0.00	0.06	0.13	0.59	1.80	7.42	9.11	10.49	11.89	7.89	12.00	15.01

3.1.5 Canada

First generation GM HT soybeans

GM HT soybeans were first planted in Canada in 1997. In 2010, the share of total plantings accounted for by first generation GM HT soybeans was 50% (0.74 million ha).

[31] As in Argentina, the majority of plantings are to farm saved or uncertified seed. For example, about two-thirds of plantings in Paraguay in 2010 were estimated to be uncertified seed

[32] Quam & Traxler (2002 & 2005). The authors are not aware of any specific impact research having been conducted and published in Paraguay or Uruguay. Cost of herbicide data for recent years has been updated to reflect price and weed control practice changes

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 $14/ha-$40/ha and the increase in farm income at the national level was $13.6 million in 2010 (Table 16). The cumulative increase in farm income since 1997 has been $142.6 million (in nominal terms). In added value terms, the increase in farm income from the use of the first generation GM HT technology in 2010 was equivalent to an annual increase in production of 0.7% (31,400 tonnes).

Table 16: Farm level income impact of using GM HT soybeans (first generation) in Canada 1997-2010

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
2008	56.59	14.33	12.61	1.03
2009	55.01	14.81	12.90	1.15
2010	43.93	18.38	13.57	0.72

Sources and notes:

1. Impact data based on George Morris Centre Report 2004 and updated in recent years to reflect changes in herbicide prices and weed control practices
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

Second generation GM HT soybeans

As in the US, 2009 was the first year of commercial availability of second generation GM HT soybeans. 295,000 ha were planted to this trait in 2010, equal to 20% of the total crop. In the absence of Canadian-specific impact data, we have applied the same cost of technology and yield impact assumption (+5%) as used in the analysis of impact in the US. On this basis, the net impact on farm income was +$60/ha in 2010, with an aggregate increase in farm income of +$18.6 million. Over the two years of use the total farm income gain has been $20.7 million.

3.1.6 South Africa

The first year GM HT soybeans were planted commercially in South Africa was 2001. In 2010, 355,000 hectares (85%) 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 17), although in 2008 and 2009, with the signficant increase in glyphosate prices relative to other herbicides, this fell back to $2/ha. At the national level, the increase in farm income was $2.5 million in 2010. Cumulatively the farm income gain since 2001 has been $7.2 million.

Table 17: Farm level income impact of using GM HT soybeans in South Africa 2001-2010

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
2008	25.38	1.77	0.32
2009	26.33	2.06	0.55
2010	33.64	7.03	2.50

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 2009, 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%[33] have been recorded. This yield gain has arisen from the substantial improvements in weed control[34]. In recent years, as fields have been cleaned of problem weeds, the average yield gains have decreased and were reported at +13% in 2006[35];
- 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

[33] Source: Brookes (2005)

[34] 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 subsequently been very difficult to control, until the GM HT soybean system became available (glyphosate has been the key to controlling difficult weeds like Johnson grass)

[35] Source: Farmer survey conducted in 2006 on behalf of Monsanto Romania

(less weed material in the beans sold to crushers which resulted in price premia being obtained[36]) and cost savings derived;

- The average net increase in gross margin in 2006 was $59/ha (an average of $105/ha over the eight years of commercial use: Table 18);
- At the national level, the increase in farm income amounted to $7.6 million in 2006. Cumulatively in the period 1999-2006 the increase in farm income was $44.6 million (in nominal terms);
- The yield gains in 2006 were equivalent to a 9% increase in national production[37] (the annual average increase in production over the eight years was equal to 10.1%);
- 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 9.3% (33,230 tonnes).

Table 18: 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	63.33	8.81	135.86	9.51	13.7
2005	64.54	9.10	76.16	6.69	12.2
2006	64.99	9.10	58.79	7.64	9.3

Sources and notes:

1. Impact data (sources: Brookes (2005) and Monsanto Romania (2008)). Average yield increase 31% applied to all years to 2003 and reduced to +25% 2004, +19% 2005 and +13% 2006. 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 from 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 2010, a continued 'trial area' of 20,810 ha (out of total plantings of 70,000 ha) were varieties containing the GM HT trait.

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

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

At the farm level, the main impacts of use have been a combination of yield increase (+9.1% in 2004 and 2005, +3.64% in 2006, +3.2% 2007, +2.4% 2008, +13% in 2009 and +4% in 2010) and (herbicide) cost savings. The average farm income benefit has been within a range of $9/ha-$89/ha (inclusive of yield gain, cost savings and after payment of the technology fee/seed premium ($9.3/ha in 2010)) and the increase in farm income at the national level was $0.19 million in 2010 (Table 19). The cumulative increase in farm income since 2004 has been $4.7 million (in nominal terms). In added value terms, the increase in farm income from the use of the GM HT technology in 2010 was equivalent to an annual increase in production of about 0.5%.

Table 19: Farm level income impact of using GM HT soybeans in Mexico 2004-2010

Year	Cost savings after inclusion of seed premium ($/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	49.44	82.34	1.18	3.07
2005	51.20	89.41	0.94	2.13
2006	51.20	72.98	0.51	1.05
2007	51.05	66.84	0.33	0.9
2008	33.05	54.13	0.54	0.7
2009	-12.79	59.55	1.01	2.3
2010	-12.84	9.29	0.19	0.5

Sources and notes:

1. Impact data based on Monsanto, 2005, 2007, 2008, 2009, 2010. Reportes 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 Bolivia

GM HT soybeans were officially permitted for planting in 2009, although 'illegal' plantings have occurred for several years. For the purposes of analysis in this section, impacts have been calculated back to 2005, when an estimated 0.3 million ha of soybeans used GM HT technology. In 2010, an estimated 777,000 ha (79% of total crop) used GM HT technology.

The main impacts of the technology[38] have been (Table 20):

- An increase in yield arising from improved yield control. The research work conducted by Fernandez et al (2009) estimated a 30% yield difference between GM HT and conventional soybeans, although some of the yield gain reflected the use of poor quality conventional seed by some farmers. In our analysis, we have used a more conservative yield gain of +15% (based on industry views);

[38] Based on Fernandez et al (2009)

- GM HT soybeans are assumed to trade at a price discount to conventional soybeans of 2.7%, reflecting the higher price set for conventional soybeans by the Bolivian government in 2010;
- The cost of the technology to farmers has been about $3.3/ha and the cost savings equal to about $9.3/ha, resulting in a net cost of production change of +$6/ha;
- Overall in 2010, the average farm income gain from using GM HT soybeans was about $103/ha, resulting in a total farm income gain of $80.1 million. Cumulatively since 2005, the total farm income gain is estimated at $223 million.

Table 20: Farm level income impact of using GM HT soybeans in Bolivia 2005-2010

Year	Cost savings excluding seed cost premium ($/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
2005	9.28	39.73	12.08	4.09
2006	9.28	36.60	15.55	6.35
2007	9.28	44.40	19.45	7.37
2008	9.28	79.97	36.27	7.24
2009	9.28	89.91	59.61	8.88
2010	9.28	103.13	80.15	8.86

Sources and notes:

1. Impact data based on Fernandez et al (2009). Average yield gain assumed +15%, cost of technology $3.32/ha

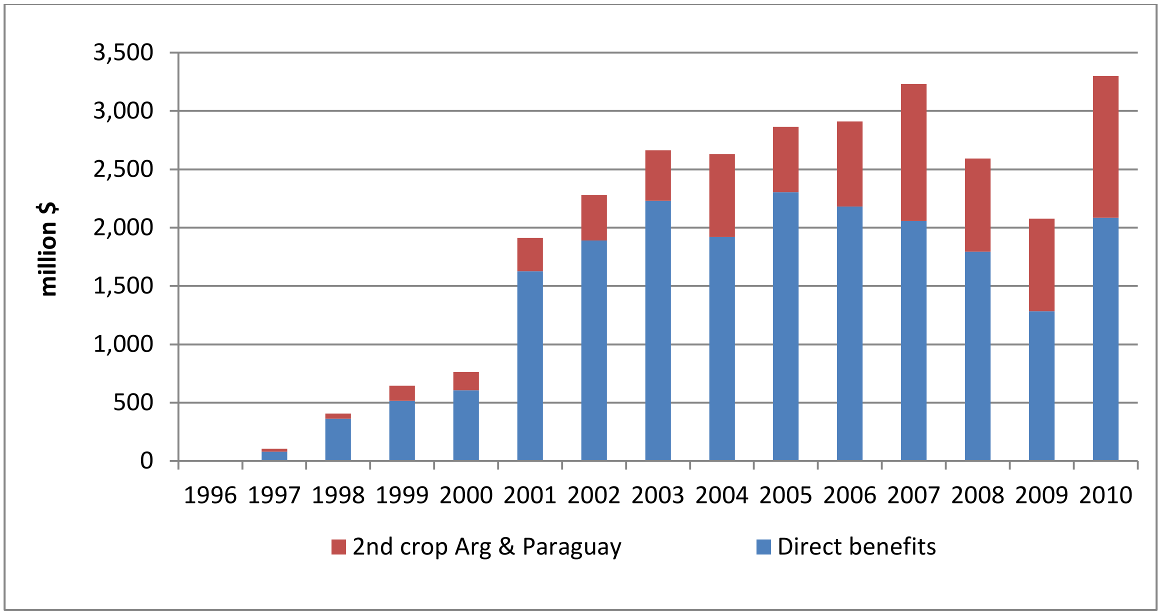
3.1.10 Summary of global economic impact

In global terms, the farm level impact of using GM HT technology in soybeans was $2.08 billion in 2010 (Figure 9). If the second crop benefits arising in Argentina are included this rises to $3.3 billion. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $20.95 billion ($28.4 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 2010, the additional farm income (inclusive of Argentine second crop gains) generated by the technology is equal to a value added equivalent of 3.5%. Relative to the value of global soybean production in 2010, the farm income benefit added the equivalent of 3.2%.

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 75% increase in the area planted in the leading soybean producing countries of the US, Brazil and Argentina).

Figure 9: Global farm level income benefits derived from using GM HT soybeans 1996-2010 (million $)



These economic benefits mostly derive from cost savings although farmers in Mexico, Bolivia and Romania also obtained yield gains (from significant improvements in weed control levels relative to levels applicable prior to the introduction of the technology). In addition, the availability of second generation GM HT soybeans in North America is also delivering yield gains since 2009. If it is also assumed that all of the second crop soybean gains are effectively additional production that would not otherwise have 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 soybeans, $7.99 billion (28%) is due to yield gains/second crop benefits and the balance, 72%, is due to cost savings.

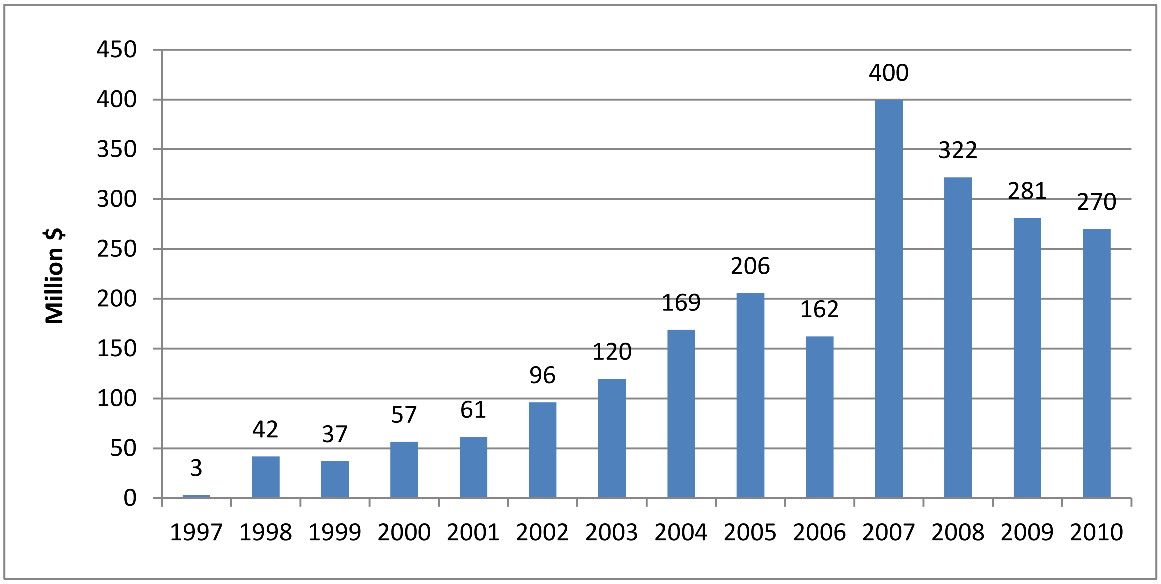
3.2 Herbicide tolerant maize

3.2.1 The US

Herbicide tolerant maize[39] has been used commercially in the US since 1997, and in 2010 was planted on 70% of the total US maize crop. The impact of using this technology at the farm level is summarised in Figure 10. 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 in most years, although since 2008 this has fallen to a range of $12/ha-$16/ha, largely due to the significant increase in glyphosate prices relative to other herbicides. The net gain to farm income in 2010 was $270 million and cumulatively, since 1997, the farm income benefit has been $2.2 billion. In added value terms, the effect of reduced costs of production on farm income in 2010 was equivalent to an annual increase in production of 0.51% (1.6 million tonnes).

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

Figure 10: National farm income impact of using GM HT maize in the US 1997-2010

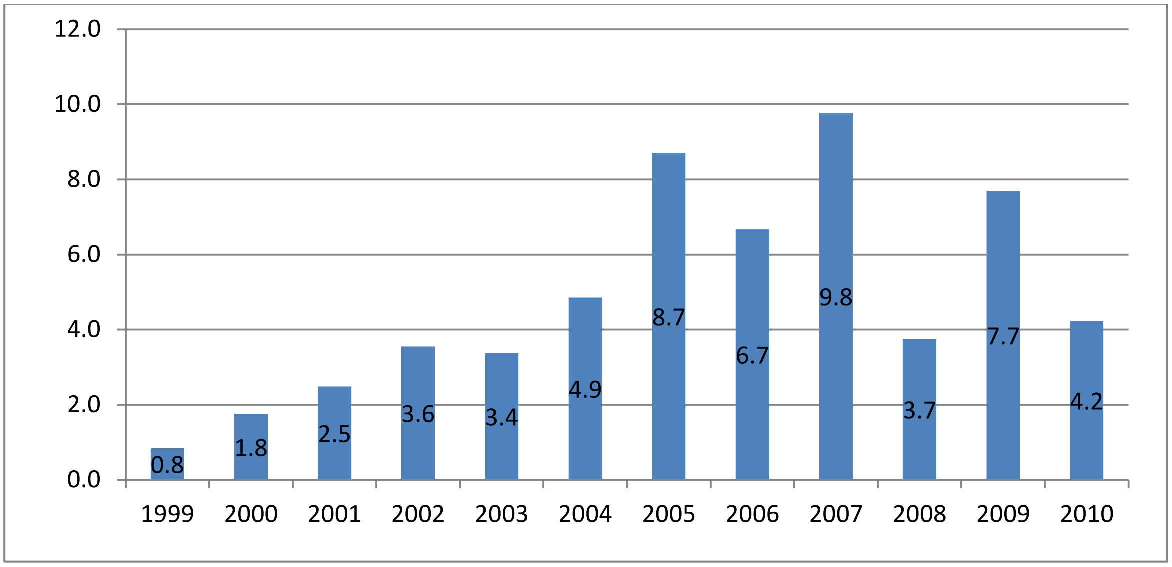


Source and notes: Impact analysis based on Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006), Johnson & Strom (2008) and updated from 2008 to reflect changes in herbicide prices and typical weed control programmes. Estimated cost of the technology $14.83/ha in years up to 2004, $17.3/ha in 2005, $24.71/ha 2006-2008, $26.35/ha in 2009 and $29.35/ha in 2010. Cost savings (mostly from lower herbicide use) $33.47/ha in 2004, $38.61/ha 2005, $29.27/ha 2006, $42.28/ha 2007, $39.29/ha 2008, $39.18 in 2009 and $41.12/ha in 2010

3.2.2 Canada

In Canada, GM HT maize was first planted commercially in 1999. In 2009, the proportion of total plantings accounted for by varieties containing a GM HT trait was 53%. 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 up to 2007, but fell from 2008 to under $10/ha ($6.6/ha in 2010) due mainly to the higher price increases for glyphosate relative to other herbicides. In 2010, the net increase in farm income was $4.2 million and cumulatively since 1999 the farm income benefit has been $57.7 million. In added value terms, the effect of reduced costs of production on farm income in 2010 was equivalent to an annual increase in production of 0.2% (18,400 tonnes: Figure 11).

Figure 11: National farm income impact of using GM HT maize in Canada 1999-2010 ($ million)



Source and notes: Impact analysis based on data supplied by Monsanto Canada. Estimated cost of the technology $18-$34/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, and in 2010 varieties containing a GM HT trait were planted on 1.5 million ha (47% of the total maize area). 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 traditionally been 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 either a GM HT or a 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 significant increase in the GM HT maize area in subsequent years. In 2010, stacked traited seed accounted for 85% of the total GM HT area.

In relation to impact on farm income this can be examined from two perspectives; as a single GM HT trait and as a stacked trait. This differential nature of impact largely reflects the locations in which the different (single or stacked traited seed) has tended to be used:

Single GM HT traited seed

- In all regions the cost of the technology (about $20/ha) has been broadly equal to the saving in herbicide costs, although since 2008, with the price increase of glyphosate relative to other herbicides, this became a net increase in costs of $2/ha-$5/ha ;
- In the 'Corn Belt' area, use of the single trait 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 2010, the additional farm income at a national level, from using single traited GM HT technology, has been +$23.1 million, and cumulatively since 2004, the income gain has been $111.2 million.

Stacked traited GM HT seed

- The average yield gain identified since adoption has been +15.75%[40]. Given the average yield impact identified for the early years of adoption of the single traited GM IR maize was +5.5% (see section 3.6), our analysis has applied this level of impact to the GM IR component of the study (section 3.6), with the balance attributed to the GM HT trait. Hence, for the purposes of this analysis, the assumed yield effect of the GM HT trait on the area planted to GM stacked maize seed is +10.25%;
- The cost of the technology (seed premium) applied to GM HT component was $41/ha, with the impact on costs of production (other than seed) assumed to be the same as for single traited seed;
- Based on these assumptions, the net impact on farm income in 2010 was +$78.5/ha, giving an aggregated national level farm income gain of $100.5 million. Cumulatively since 2007, the farm income gain has been $203 million.

3.2.4 South Africa

Herbicide tolerant maize has been grown commercially in South Africa since 2003, and in 2010 1 million hectares out of total plantings of 2.74 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), although in 2008 and 2009, due to the significant rise in the global price of glyphosate relative to other herbicides, the net farm income balance has been negative, at about -$2/ha. In 2010, as the price for glyphosate has fallen relative to others, the net impact of use of the technology was a small gain of $0.65/ha. At the national level, this is equivalent to a net gain of about $0.65 million. Since 2003, there has been a net cumulative income gain of $3.2 million. It should, however, be noted that about 50% of the maize planted with the GM HT trait was as a stack with the GM IR trait which has been delivering significant net farm income gains from higher yields (see section 3.6.4). Taken together, the net farm income gains from using the stacked traited seed has been about +$68/ha in 2010.

3.2.5 Philippines

GM HT maize was first grown commercially in 2006, and in 2010 was planted on 494,000 hectares. Information about the impact of the technology in the first two years of adoption was limited, although industry sources estimated that, on average farmers using it had 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 impacts on farm income in 2006 and 2007 were +$0.98 million and +$10.4 million respectively. More recent analysis by Gonsales et al (2009) identified an average yield gain of +5%, the same cost of technology of $24/ha-$27/ha and a cost saving (reduced weed

[40] Based on farm level feedback/surveys to the technology providers

control costs from reduced cost of herbicides and less hand weeding) of $35/ha-$41/ha. In 2010, this equated to a net farm income of +$44/ha, which at the national level was equal to +$21.9 million. Cumulatively, since 2006, the total farm income gain has been $54.6 million.

3.2.6 Brazil

2010 was the first year in which GM HT maize was planted in Brazil (on about 4% of the total crop: 404,000 ha). Based on analysis by Galvao (2010), the technology is estimated to be delivering a yield gain of about 2.5%, the technology (seed premium) costs just over $17/ha but this is largely offset by a net saving in herbicide expenditure of about $14/ha. In net farm income terms, the gain (inclusive of yield gain) was $44/ha. At the national level this is equal to a net farm income gain of nearly $17.8 million.

3.2.7 Colombia

GM HT maize was first planted in Colombia in 2009 and in 2010, just over 21,000 ha (4% of the total crop) used this technology (in the form of stacked traited seed, with GM IR technology). Analysis of its impact is limited, with a recent study by Mendez et al (2011) being the only publicly available material. This analysis focused only on a small area in one region of the country (San Juan valley) and therefore is unlikely to be fully representative of (potential) impact across the country. Nevertheless, as this represents the only available data, we have included it for illustrative purposes. The analysis identified a positive yield impact of +22% for the stacked traited seed (HT tolerance to glufosinate and IR resistance to corn boring pests) and for the purposes of our analysis, all of this yield gain has been included/attributed to the GM IR component of the technology, as presented in section 3.6.7. In terms of impact of costs of production, the GM HT part is estimated to have had a net positive impact on profitability of about $16/ha in 2010 (seed premium of about $23/ha, counterbalanced by weed control cost savings of nearly $39/ha). At the national level, the total income gain in 2010 was $0.34 million ($0.35 million for the two years 2009-10).

3.2.8 Summary of global economic impact

In global terms, the farm level economic impact of using GM HT technology in maize was $438.5 million in 2010 (62% of which was in the US). Cumulatively since 1997, the farm income benefit has been (in nominal terms) $2.67 billion. Of this, 86% has been due to cost savings and 14% 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 2010, the additional farm income generated by the technology is equal to a value added equivalent of 0.3% 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 2010 was planted on 78% of total cotton plantings[41].

The farm income impact of using GM HT cotton is summarised in Table 21. The primary benefit has been to reduce costs, and hence improve profitability levels, with annual average profitability increasing by between $21/ha and $49/ha[42] in the years up to 2004. Since then net income gains fell to between $3/ha and $7/ha (2005-2009), although in 2010, the net income gain was $13.6/ha. The relatively smaller positive impact on direct farm income in recent years reflects a combination of reasons, including the higher cost of the technology, significant price increases for glyphosate relative to price increases for other herbicides (although in 2010, the price of glyphosate tended to fall relative to most other herbicides) and changes in weed control practices (additional costs) for the management of weeds resistant to glyphosate (notably *Palmer Amaranth*). Overall, the net direct farm income impact in 2010 is estimated to be $46.7 million (this does not take into consideration any non pecuniary benefits associated with adoption of the technology: see section 3.9). Cumulatively since 1997 there has been a net farm income benefit from using the technology of $875.4 million.

Table 21: Farm level income impact of using GM HT cotton in the US 1997-2010

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
1997	34.12	21.28	12.56	0.2
1998	34.12	21.28	30.21	0.58
1999	34.12	21.28	53.91	1.29
2000	34.12	21.28	61.46	1.22
2001	65.59	45.27	161.46	4.75
2002	65.59	45.27	153.18	3.49
2003	65.59	45.27	129.75	2.33
2004	83.35	48.80	154.72	2.87
2005	71.12	2.89	9.57	0.18
2006	73.66	3.31	13.29	0.22
2007	76.01	5.40	16.56	0.27
2008	77.60	6.14	12.79	0.41
2009	83.69	7.49	18.96	0.40
2010	94.81	13.57	46.72	0.69

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

[42] The only published source that has examined the impact of HT cotton in the US is work by Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006) and Johnson & Strom (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. Revised analysis has, however, been conducted annually from 2008 to reflect changes in the costs of production (notably cost of the technology, in particular 'Roundup Ready Flex technology'), higher prices for glyphosate relative to other herbicides particularly in 2008 & 2009 and additional costs incurred to control weeds resistant to glyphosate in some regions

Source and notes:

1. Impact analysis based on Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006) and Johnson & Strom (2008) and own analysis from 2008
2. Estimated cost of the technology $12.85/ha (1997-2000) and $21.32/ha 2001-2003, $34.55 2004, $68.22/ha 2005, $70.35/ha 2006, $70.61/ha 2007, $71.56/ha 2008, $76.2/ha 2009 and $81.24/ha 2010

3.3.2 Other countries

Australia, Argentina, South Africa, Mexico, Colombia and Brazil are the other countries where GM HT cotton is grown commercially; from 2000 in Australia, 2001 in South Africa, 2002 in Argentina, 2005 in Mexico, 2006 in Colombia and 2010 in Brazil. In 2010, 99% (515,000 ha), 97% (608,500 ha), all (13,145 ha), 47% (51,230 ha), 87% (37,650 ha) and 17% (242,000 ha) respectively of the total Australian, Argentine, South African, Mexican, Colombian and Brazilian cotton crops were planted to GM HT cultivars.

We are not aware of any published research into the impact of GM HT cotton in South Africa, Argentina, Mexico or Colombia. In Australia, although research has been conducted into the impact of using GM HT cotton (eg, Doyle et al (2003)) this does not provide quantification of the impact[43]. Drawing on industry source estimates[44], the main impacts have been:

- *Australia*: no yield gain and cost of the technology in the range of $30/ha to $45/ha up to 2007. The cost of the technology increased with the availability of 'Roundup Ready Flex' and in 2010 was about $69/ha. The cost savings from the technology (after taking into consideration the cost of the technology) have delivered small net gains of $5/ha to $7/ha, although estimates relating to the net average benefits from Roundup Ready Flex since becoming widely adopted from 2008 are $25/ha plus ($36/ha in 2010). Overall, in 2010, the total farm income from using the technology was about $18.6 million and cumulatively, since 2000, the total gains have been $31.5 million;
- *Argentina*: no yield gain and a cost of technology in the range of $30/ha to $40/ha, although with the increasing availability of stacked traits in recent years, the 'cost' part of the HT technology has fallen to $20/ha. Net farm income gains (after deduction of the cost of the technology) have been $8/ha to $18/ha and in 2010 were $8/ha. Overall, in 2010, the total farm income from using GM HT cotton technology was about $23.6 million, and cumulatively since 2002, the farm income gain has been $68.6 million;
- *South Africa*: no yield gain and a cost of technology in the range of $15/ha to $25/ha. Net farm income gains from cost savings (after deduction of the cost of the technology) have been $30/ha to $65/ha. In 2010, the average net gain was $40.5/ha and the total farm income benefit of the technology was $0.53 million. Cumulatively since 2001, the total farm income gain from GM HT cotton has been $2.7million;
- *Mexico*: average yield gains of +3.6% from improved weed control have been reported[45] in the first three years of use, no yield gain was recorded in 2008 and yield gains of +5.1% in 2009 and +18.1% in 2010 (when Roundup Ready Flex technology was mainly used). The

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

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

[45] Annual reports of Monsanto Mexico to the Mexican government

average cost of the technology has been in the range of $50/ha to $66/ha. The typical net farm income gains were about $80/ha in the first two years of use, $16/ha in 2008 (when there was no yield gain), $90/ha in 2009 and $447/ha in 2010. Overall, in 2010 the total farm income gain from using GM HT cotton was $22.9 million and cumulatively since 2005, the total farm income gain has been $36.7 million;

- *Colombia*: average yield gain estimated at 4%, with a cost of technology at $177/ha in 2010 and herbicide cost savings of $204/ha. In 2010, this equates to a net increase in profitability of $84/ha, which aggregated to the national level is an increase in farm income of $3.2 million. Cumulatively since 2006, the total farm income gain has been $11.1 million.

In Brazil, estimates of impact are available from Galvao (2010). This estimated a positive yield effect of +2.35% and seed premium of $47/ha. There was a weed control cost saving of $137/ha, resulting in a net cost reduction of $90/ha. Inclusive of the yield gains, the net income gain was $135/ha in 2010. At the national level the total income gain in 2010 was $32.8 million ($36.4 million for the two years 2009-2010).

3.3.3 Summary of global economic impact

Across the seven countries using GM HT cotton in 2010, the total farm income impact derived from using GM HT cotton was +$148.3 million. Cumulatively since 1997, there have been net farm income gains of $1.06 billion (82% of this benefit has been in the US). Of this, 91% has been due to cost savings and 9% 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, and in 2010 was 93% of the total crop (6.06 million ha).

The farm level impact of using GM HT canola in Canada since 1996 is summarised in Table 22. 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[46] has been eroded. As a result, our analysis has applied the yield advantage of +10.7%, associated with the GM HT technology in its early years of adoption (source: Canola Council study of 2001), to 2003. From 2004 the yield gain has been based on differences between average annual variety

[46] The main one of which is 'Clearfield' conventionally derived herbicide tolerant varieties. Also hybrid canolas now account for the majority of plantings (including some GM hybrids) with the hybrid vigour delivered by conventional breeding techniques (even in the GM HT (to glyphosate) varieties)

trial results for 'Clearfield' (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, 2005, 2008 and 2010, +4% 2006 and 2007 and +1.67% 2009. For GM glufosinate tolerant varieties, the yield differences were +12% 2004 and 2008, +19% 2005, +10% 2006 and 2007, +11.8% 2009 and +10.9% 2010. 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) 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 $36/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 'Clearfield' HT canola (from 2004), there has been a net cost saving of about $16/ha and $17/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 'Clearfield' HT canola (from 2004), the net increase in profitability has been between $23/ha and $71/ha;
- The annual total national farm income benefit from using the technology has risen from $6 million in 1996 to $433 million in 2010. The cumulative farm income benefit over the 1996-2010 period (in nominal terms) was $2.42 billion;
- In added value terms, the increase in farm income in 2010 has been equivalent to an annual increase in production of 6.1%.

Table 22: Farm level income impact of using GM HT canola in Canada 1996-2010

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	-4.05	41.42	132.08	6.69
2004	21.42	+4.44	19.09	70.72	4.48
2005	23.11	+4.50	32.90	148.12	6.56
2006	34.02	+16.93	50.71	233.13	8.09
2007	35.44	+17.46	66.39	341.44	7.54
2008	35.53	+17.39	64.76	341.70	6.36
2009	35.31	+16.82	59.48	345.12	7.32
2010	33.96	+15.80	71.48	433.04	6.11

Sources and notes:

1. Impact data based on Canola Council study (2001) to 2003 and Gusta M et al (2009). 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 'Clearfield' 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, 2005, 2008 and 2010, +4% 2006 and 2007, +1.67% 2009. For GM glufosinate tolerant varieties, the yield differences were +12% 2004 and 2008, +19% 2005, +10% 2006 and 2007, +11.8% 2009, +10.9% 2010

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

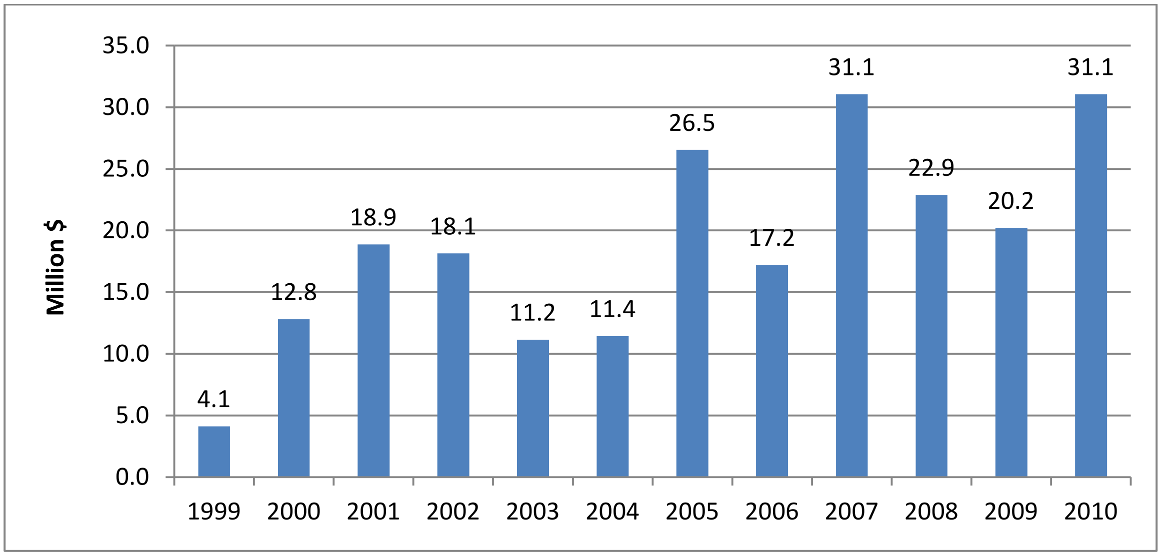
3.4.2 The US

GM HT canola has been planted on a commercial basis in the US since 1999. In 2010, 88% of the US canola crop was GM HT (515,950 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 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 $18/ha-$45/ha ($21/ha in 2010) for glufosinate tolerant canola and $40-$79/ha for glyphosate tolerant canola;
- The net impact on gross margins has been between +$22/ha and +$90/ha ($82/ha in 2010) for glufosinate tolerant canola, and between +$28/ha and +$61/ha for glyphosate tolerant canola ($48.9/ha in 2010);
- At the national level the total farm income benefit in 2010 was $31 million (Figure 12) and the cumulative benefit since 1999 has been $225.5 million;
- In added value terms, the increase in farm income in 2010 has been equivalent to an annual increase in production of about 7.3%.

Figure 12: National farm income impact of using GM HT canola in the US 1999-2010



Source and notes: Impact analysis based on Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006), Johnson & Strom (2008) and updated from 2008 to reflect changes in herbicide prices and weed control practices. 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 Australia

GM HT canola was first planted for commercial use in 2008. In 2010 GM HT canola was planted on 133,330 ha. 95% of these plantings had tolerance to the herbicide glyphosate and the balance were tolerant to glufosinate.

The main source of data on impact of this technology comes from a farm survey-based analysis of impact of the glyphosate tolerant canola commissioned by Monsanto amongst 92 of the 108 farmers using this technology in 2008/09. Key findings from this survey were as follows:

- The technology was made available in both open pollinated and hybrid varieties, with the open pollinated varieties representing the cheaper end of the seed market, where competition was mainly with open pollinated varieties containing herbicide tolerance (derived conventionally) to herbicides in the triazine (TT) group. The hybrid varieties containing glyphosate tolerance competed with non herbicide tolerant conventional hybrid varieties and herbicide tolerant 'Clearfield' hybrids (tolerant to the imidazolinone group of herbicides), although, where used in 2008, all of the 33 farmers in the survey using GM HT hybrids did so mainly in competition and comparison with 'Clearfield' varieties;
- The GM HT open pollinated varieties sold to farmers at a premium of about $Aus3/ha (about $2.5 US/ha) relative to the TT varieties. The GM HT hybrids sold at a seed premium of about $Aus 9/ha($7.55 US/ha) compared to 'Clearfield' hybrids. In addition, farmers using the GM HT technology paid a 'technology' fee in two parts; one part was a set fee of $Aus500 per farm plus a second part based on output - $Aus 10.2/tonne of output of canola. On the basis that there were 108 farmers using GM HT (glyphosate tolerant) technology in 2008, the average 'up front' fee paid for the technology was

$Aus5.62/ha. On the basis of average yields obtained for the two main types of GM HT seed used, those using open pollinated varieties paid Aus $11.83/ha (basis average yield of 1.16 tonnes/ha) and those using GM HT hybrids paid $Aus12.95/ha (basis: average yield of 1.27 tonnes/ha). Therefore, the total seed premium and technology fee paid by farmers for the GM HT technology in 2008/09 was $Aus20.45/ha ($17.16 US/ha) for open pollinated varieties and $Aus 27.57/ha ($23.13 US/ha) for hybrid varieties. After taking into consideration the seed premium/technology fees, the GM HT system was marginally more expensive by $Aus 3/ha ($2.5 US/ha) and Aus $4/ha (US $3.36/ha) respectively for weed control than the TT and 'Clearfield' varieties;

- The GM HT varieties delivered higher average yields than their conventional counterparts: +22.11% compared to the TT varieties and +4.96% compared to the 'Clearfield' varieties. In addition, the GM HT varieties produced higher oil contents of +2% and +1.8% respectively compared to TT and 'Clearfield' varieties;
- The average reduction in weed control costs from using the GM HT system (excluding seed premium/technology fee) was $Aus 17/ha for open pollinated varieties (competing with TT varieties) and $Aus 24/ha for hybrids (competing with 'Clearfield' varieties).

In the analysis summarised in Table 23, we have applied these research findings to the total GM HT crop area on a weighted basis in which the results of GM HT open pollinated varieties that compete with TT varieties were applied to 64% of the total area in 2009 and 32% in 2010 and the balance of area used the results from the GM HT hybrids competing with 'Clearfield' varieties. This weighting reflects the distribution of farms in the survey. The findings show an average farm income gain of over US $62.6/ha and a total farm income gain of $8.3 million in 2010. Cumulatively over the three years of use the total farm income gain has been $13.4 million.

Table 23: Farm level income impact of using GM HT canola in Australia 2008-2010 ($US)

Year	Average cost saving ($/ha)	Average cost savings (net after cost of technology: $/ha)	Average net increase in gross margins ($/ha)	Increase in farm income at a national level ('000 $)
2008	19.18	-20.76	96.87	978
2009	18.31	-19.18	99.37	4,094.2
2010	20.01	-9.25	62.59	8,345.3

Source derived from and based on Monsanto survey of licence holders 2008

Notes:

1. The average values shown are weighted averages
2. Other weighted average values derived include: yield +21.1% 2008, +20.9% 2009, +15.8% 2010 and quality (price) premium of 2.1% applied on the basis of this level of increase in average oil content. In 2010 because of a non GM canola price premia of 7%, the net impact on price was to apply a price discount of -4.9%

3.4.4 Summary of global economic impact

In global terms, the farm level impact of using GM HT technology in canola in Canada, the US and Australia was $472.4 million in 2010. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $2.66 billion. Within this, 77% has been due to yield gains and the balance (23%) has been from cost savings.

In terms of the total value of canola production in these three countries in 2010, the additional farm income generated by the technology is equal to a value added equivalent of 5.7%. Relative to the value of global canola production in 2010, the farm income benefit added the equivalent of 1.4%.

3.5 GM herbicide tolerant (GM HT) sugar beet

3.5.1 US

GM HT sugar beet was first grown commercially in the US in 2007. In 2009, 432,440 hectares of GM HT sugar beet were planted, equal to 93% of the total US crop.

Impact of the technology in 2007 and 2008 has been identified as follows:

a) *Yield*: analysis by Kniss (2008) covering a limited number of farms in Wyoming (2007) identified positive yield impacts of +8.8% in terms of additional root yield (from better weed control) and +12.6% in terms of sugar content relative to conventional crops (ie, the GM HT crop had about a 3.8% higher sugar content, which amounts to a 12.8% total sucrose gain relative to conventional sugar beet once the root yield gain was taken into consideration). In contrast, Khan (2008) found similar yields reported between conventional and GM HT sugar beet in the Red River Valley region (North Dakota) and Michigan. These contrasting results probably reflect a combination of factors including:

   - The sugar beet growing regions in Wyoming can probably be classified as high weed problem areas and, as such, are regions where obtaining effective weed control is difficult using conventional technology (timing of application is key to weed control in sugar beet, with optimal time for application being when weeds are small). Also some weeds (eg, Kochia) are resistant to some of the commonly used ALS inhibitor herbicides like chlorsulfuron. The availability of GM HT sugar beet with its greater flexibility on application timing has therefore potentially delivered important yield gains for such growers;
   - The GM HT trait was not available in all leading varieties suitable in all growing regions in 2008, hence the yield benefits referred to above from better weed control have to some extent been counterbalanced by only being available in poorer performing germplasm in states like Michigan and North Dakota (notably not being available in 2008 in leading varieties with rhizomania resistance). It should be noted that the authors of the research cited in this section both perceive that yield benefits from using GM HT sugar beet will be a common feature of the technology in most regions once the technology is available in leading varieties;
   - 2008 was reported to have been, in the leading sugar beet growing states, a reasonable year for controlling weeds through conventional technology (ie, it was possible to get good levels of weed control through timely applications), hence the similar performance reported between the two systems;
   - For 2009 and 2010 analysis, in the absence of any published yield impact data, we have applied the same assumptions used for 2008. This does, however, probably understate the overall yield benefit likely to have occurred in 2009 and 2010 because one of the features of the 2008 analysis was the limited availability of the trait in

leading varieties and hence limited positive yield impact relative to conventional alternatives. This feature did not apply in subsequent years.

b) *Costs of production*.
   - Kniss's work in Wyoming identified weed control costs (comprising herbicides, application, cultivation and hand labour) for conventional beet of $437/ha compared to $84/ha for the GM HT system. After taking into consideration the $131/ha seed premium/technology fee for the GM HT trait, the net cost differences between the two systems was $222/ha in favour of the GM HT system. Kniss did, however, acknowledge that the conventional costs associated with this sample were high relative to most producers (reflecting application of maximum dose rates for herbicides and use of hand labour), with a more typical range of conventional weed control costs being between $171/ha and $319/ha (average $245/ha);
   - Khan's analysis puts the typical weed control costs in the Red River region of North Dakota to be about $227/ha for conventional compared to $91/ha for GM HT sugar beet. After taking into consideration the seed premium/technology fee (assumed by Khan to be $158/ha[47]), the total weed control costs were $249/ha for the GM HT system, $22/ha higher than the conventional system. Despite this net increase in average costs of production, most growers in this region used (and planned to continue using), the GM HT system because of the convenience and weed control flexibility benefits associated with it (which research by Marra and Piggot (2006): see section 3.9) estimated in the corn, soybean and cotton sectors to be valued at between $12/ha and $25/ha to US farmers). It is also likely that Khan's analysis may understate the total cost savings from using the technology by not taking into account savings on application costs and labour for hand weeding.

For the purposes of our analysis we have drawn on both these pieces of work, as summarised in Table 24. This shows a net farm income gain in 2010 of $64.6 million to US sugar beet farmers (average gain per hectare of just under $145/ha). Cumulatively, the farm income gain since 2007 has been $131 million.

Table 24: Farm level income impact of using GM HT sugar beet in the US 2007-2010

Year	Average cost saving ($/ha)	Average cost savings (net after cost of technology: $/ha)	Average net increase in gross margins ($/ha)	Increase in farm income at a national level ('000 $)	Increase in national farm income as % of farm level value of national production
2007	353.35	222.39	584.00	473	0.03
2008	141.50	-10.66	75.48	19,471.4	1.51
2009	142.5	-8.69	108.09	46,740.9	2.68
2010	142.5	-8.69	145.03	64,566.4	2.82

Sources derived from and based on Kniss (2008) and Khan (2008)

Notes:

1. The yield gains identified by Kniss have been applied to the 2007 GM HT plantings in total and to the estimated GM HT plantings in the states of Idaho, Wyoming, Nebraska and Colorado, where

[47] Differences in the seed premium assumed by the different analysts reflects slightly different assumptions on seed rates used by farmers (the technology premium being charged per bag of seed)

penetration of plantings in 2008 was 85% (these states account for 26% of the total GM HT crop in 2008), and which are perceived to be regions of above average weed problems. For all other regions, no yield gain is assumed. For 2008 and 2009, this equates to a net average yield gain of +2.79% and +3.21% respectively (+3.21% also used for 2010)

2. The seed premium of $131/ha, average costs of weed control respectively for conventional and GM HT systems of $245/ha and $84/ha, from Kniss, were applied to the crop in Idaho, Wyoming, Nebraska and Colorado. The seed premium of $158/ha, weed control costs of $227/ha and $249/ha respectively for conventional and GM HT sugar beet, identified by Khan, were applied to all other regions using the technology. The resulting average values for seed premium/cost of technology was $152.16/ha in 2008 and $151.08/ha in 2009 (the latter also assumed for 2010). The average weed control cost savings associated with the GM HT system (before taking into consideration the seed premium) were $141.5/ha in 2008 and $142.5/ha in 2009 (the latter also assumed for 2010)

3.5.2 Canada

GM HT sugar beet has also been used in the small Canadian sugar beet sector since 2008. In 2010, 95% of the crop (about 20,000 ha) used this technology. We are not aware of any published analysis of the impact of GM HT sugar beet in Canada, but if the same assumptions used in the US are applied to Canada, the total farm income gain in 2010 was $2.69 million and cumulatively since 2008, the income gain has been $4.3 million.

3.6 GM insect resistant[48] (GM IR) maize

3.6.1 US

GM IR maize was first planted in the US in 1996 and in 2010, seed containing GM IR traits was planted on 63% (20.6 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 25:

- The primary impact has been increased average yields. Much of the analysis in early years of adoption (summarised for example in Marra et al (2002) and James (2002)) identified an average yield impact of about +5%. More comprehensive and recent work by Hutchison et al (2010) has examined impacts over the 1996-2009 period and considered the positive yield impact on non GM IR crops of 'area-wide' adoption of the technology. The key finding of this work puts the average yield impact at +7%. This revised analysis has been used as the basis for our analysis below. In 2010, this additional production is equal to an increase in total US maize production of +4.7%;
- 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). In the last three years however, with the rising cost of the technology[49], the net impact on costs has been an increase of $8/ha to $16/ha;
- The annual total national farm income benefit from using the technology has risen from $13.54 million in 1996 to $2.2 billion in 2010. The cumulative farm income benefit over the 1996-2010 period (in nominal terms) was $11.57 billion;

[48] Resistant to corn boring pests

[49] Which tends to be mostly purchased as stacked traited seed

- In added value terms, the increase in farm income in 2010 was equivalent to an annual increase in production of 4.1%.

Table 25: Farm level income impact of using GM IR maize in the US 1996-2010

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	45.53	13.54	0.05
1997	24.71	-9.21	39.38	96.0	0.40
1998	20.30	-4.8	35.31	225.0	1.13
1999	20.30	-4.8	33.05	265.7	1.47
2000	22.24	-6.74	32.71	207.9	1.07
2001	22.24	-6.74	35.68	202.7	1.02
2002	22.24	-6.74	40.13	306.5	1.34
2003	22.24	-6.74	41.37	391.5	1.67
2004	22.24	-6.36	44.90	536.7	2.11
2005	17.30	-1.42	44.49	512.1	2.20
2006	17.30	-1.42	67.13	901.3	2.71
2007	17.30	-1.42	78.69	1,607.6	3.47
2008	24.71	-8.83	95.00	1,990.5	3.94
2009	28.21	-12.33	84.62	2,076.1	4.35
2010	32.06	-16.18	92.65	2,234.6	4.10

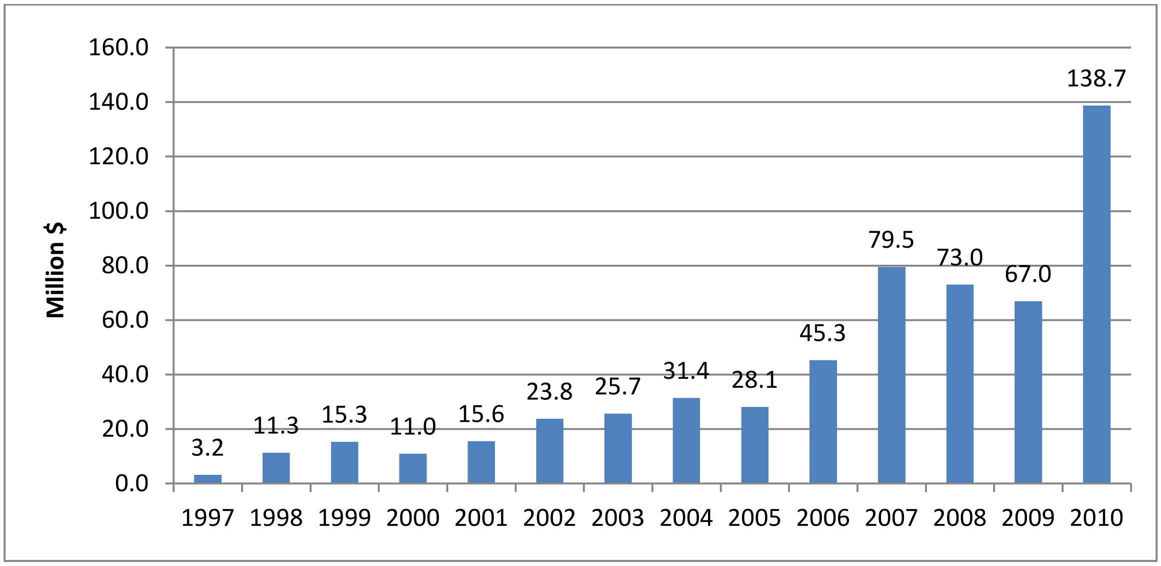
Sources and notes:

1. Impact data based on a combination of studies including the ISAAA (James) review (2002), Marra et al (2002), Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006), Johnson & Strom (2008) and Hutchison et al (2010)
2. Yield impact +7% based on Hutchison et al (2010)
3. Insecticide cost savings based on the above references
4. – (minus) value for net cost savings means the cost of the technology is greater than the other cost savings

3.6.2 Canada

GM IR maize has also been grown commercially in Canada since 1996. In 2010 it accounted for 78% of the total Canadian maize crop of 1.2 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, this equates to additional farm income generated from the use of GM IR maize of $138.7 million in 2010 (Figure 13) and cumulatively since 1996, additional farm income (in nominal terms) of $568.9 million.

Figure 13: National farm income impact of using GM IR maize in Canada 1996-2010



Notes:

1. Yield increase of 7% based on US analysis. Cost of technology and insecticide cost savings also based on US analysis
2. GM IR 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

3.6.3 Argentina

In 2010, GM IR maize traits were planted on 79% 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 increase 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 (see also note relating to yield impact of stacked traited seed in section 3.2.3: GM HT maize in Argentina).

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 increased by $20/ha-$22/ha (the cost of the technology) in years up to 2006. From 2007, with stacked traited seed becoming available and widely used, the additional cost of the technology relative to conventional seed has increased to about $30/ha-$33/ha.

The net impact on farm profit margins (inclusive of the yield gain) has, in recent years, been an increase of $3/ha to $23/ha. In 2010, the national level impact on profitability was an increase of $58.7 million (an added value equal to 1.73% of the total value of production). Cumulatively, the farm income gain since 1998 has been $309.5 million.

3.6.4 South Africa

GM IR maize has been grown commercially in South Africa since 2000. In 2010, 69% of the country's total maize crop of 2.74 million ha used GM IR cultivars.

The impact on farm profitability is summarised in Table 26. 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 2005-2007). In 2008 and 2009, the estimated yield impact was +10.6%[50]. The cost of the technology $8/ha to $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 2010 was $125.6 million and cumulatively since 2000 it has been $769 million. In terms of national maize production, the use of GM IR technology on 69% of the planted area has resulted in a net increase in national maize production of 7.3% in 2010. The value of the additional income generated was also equivalent to an annual increase in production of about 6.4%.

Table 26: Farm level income impact of using GM IR maize in South Africa 2000-2010

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	0.22	182.90	225.70
2008	11.74	-4.55	87.07	145.20
2009	12.07	-1.99	58.38	140.10
2010	13.23	-2.18	66.87	125.65

Sources and notes:

1. Impact data (sources: Gouse (2005 & 2006) and Van Der Weld (2009))
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

3.6.5 Spain

Spain has been commercially growing GM IR maize since 1998 and in 2010, 24% (76,575 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

[50] Van der Weld (2009)

from 2003, the reported average positive yield impact is about +10%[51]. There has also been a net annual average saving on cost of production (from lower insecticide use) of between $37/ha and $61/ha[52] (Table 27). At the national level, these yield gains and cost savings have resulted in farm income being boosted in 2010 by $20.4 million and cumulatively since 1998 the increase in farm income (in nominal terms) has been $113.9 million.

Relative to national maize production, the yield increases derived from GM IR maize were equivalent to a 2.4% increase in national production (2010). The value of the additional income generated from Bt maize was also equivalent to an annual increase in production of 2.2%.

Table 27: Farm level income impact of using GM IR maize in Spain 1998-2010

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
2008	61.49	10.25	225.36	17.86
2009	58.82	9.80	205.51	15.63
2010	55.26	9.21	265.96	20.37

Sources and notes:

1. Impact data (based on Brookes (2003) & 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

3.6.6 Other EU countries

A summary of the impact of GM IR technology in other countries of the EU is presented in Table 28. This shows that in 2010, the additional farm income derived from using GM IR technology in these six countries was about +$1 million, and cumulatively over the 2005-2010 period, the total income gain was $13.6 million.

Table 28: Farm level income impact of using GM IR maize in other EU countries 2005-2010

	Year first planted GM IR maize	Area 2010 (hectares)	Yield impact (%)	Cost of technology 2010 ($/ha)	Cost savings 2010 (before	Net increase in gross margin	Impact on farm income at a national

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

[52] Source: Brookes (2003) and Alcade (1999)

					deduction of cost of technology: $/ha)	**2010($/ha)**	**level 2010 (million $)**
France	2005	Nil	N/p	N/p	N/p	N/p	N/p
Germany	2005	Nil	N/p	N/p	N/p	N/p	N/p
Portugal	2005	4,868	+12.5	46.05	0	189.04	0.92
Czech Republic	2005	4,860	+10	46.05	23.68	121.56	0.57
Slovakia	2005	1,248	+12.3	46.05	0	110.35	0.14
Poland	2006	300	+12.5	46.05	0	172.20	0.05
Romania	2007	822	+7.1% 2007, +9.6% 2008, +4.8% 2009 and 2010	46.05	0	59.15	0.05
Total other EU (excluding Spain)		**12,098**					**1.73**

Source and notes:

1. Source: based on Brookes (2008) and industry sources for yields in 2008 and 2009 in Romania
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. N/p – planting not permitted in France and Germany in 2009 (and in France 2008)

3.6.7 Other countries

GM IR maize has been grown commercially in:

- *The Philippines* since 2003. In 2010, 458,500 hectares out of total plantings of 2.5 million (18%) 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%. The mid point of this range (+24.15%) was used for the years 2003-2007. For 2008 onwards a yield impact of +18% has been used based on Gonsales et al (2009). Based on the findings of these research papers, a small average annual insecticide cost saving of about $12/ha-$14/ha and average cost of the technology of $30/ha-$38/ha have been used. The net impact on farm profitability has been between $37/ha and $88/ha. In 2010, the national farm income benefit derived from using the technology was $40.7 million and cumulative farm income gain since 2003 has been $115.7 million;
- *Uruguay* since 2004, and in 2010, 100,000 ha (95% of the total crop) were GM IR. Using Argentine data as the basis for assessing impact, the cumulative farm income gain has been $8 million;
- *Brazil* since 2008. In 2010, 7.44 million ha of GM IR maize was planted (54% of the total crop). Based on analysis from Galvao (2009 & 2010), the average yield impact was +4.66% in 2008 and +7.3% in 2009, the cost of the technology was $21.6/ha in 2008 and $58.84 in 2009, insecticide cost savings were $42/ha in 2008 and $44/ha in 2009 and the average improvement to farm income equal to $66.4/ha in 2008 and $43.7/ha in 2009. For the purposes of this analysis, 2009 impact and cost data were used for estimating

impacts in 2010. As a result, the estimated increase in farm profitability associated with the adoption in 2010 was $414.7 million and cumulatively over the three years the total farm income gain has been $655.5 million;

- *Honduras*. Here farm level 'trials' have been permitted since 2003, and in 2010, an estimated 15,000 ha used GM IR traits. Evidence from Falck Zepeda et al (2009) indicated that the primary impact of the technology has been to increase average yields (in 2008 +24%). As insecticides have not traditionally been used by most farmers, no costs of production savings have arisen, coupled with no additional cost for use of the technology (which has been provided free of charge for the trials). In our analysis, we have, however, assumed a cost of the technology of $30/ha, and based on this, the estimated farm income benefit derived from the technology was $1.41 million in 2010 and cumulatively since 2003 the income gain has been $4.26 million;
- *Colombia*. GM IR maize has been grown on a 'trial basis' since 2007 in Colombia. In 2010, seed containing this technology was used on 7% of the crop (about 36,000 ha). Based on analysis from Mendez et al (2011) which explored impacts in one small region (San Juan valley), the average yield gain was +22%, the seed premium about $47/ha and the savings in insecticide use equal to about $53/ha (ie, a net cost saving of about $6/ha). Inclusive of the yield gain, the average farm income gain in 2010 was about $222/ha. If aggregated to the whole of the GM IR area in 2010, this equates to a net farm income gain of about $8 million. Cumulatively since 2007, the net farm income gain has been about $15.6 million.

3.6.8 Summary of economic impact

In global terms, the farm level impact of using GM IR maize was $3.04 billion in 2010. Cumulatively since 1996, the benefit has been (in nominal terms) $14.14 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 2010, the additional farm income generated by the technology is equal to a value added equivalent of 3.7%. Relative to the value of global maize production in 2008, the farm income benefit added the equivalent of 2.2%.

3.7 Insect resistant (Bt) cotton (GM IR)

3.7.1 The US

GM IR cotton has been grown commercially in the US since 1996, and in 2010 was used on 73% (3.2 million ha) of total cotton plantings.

The farm income impact of using GM IR cotton is summarised in Table 29. 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 for Bollgard I). 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 $146/ha in 2003-2010 with Bollgard II (containing two Bt genes and offering a broader spectrum of control). This resulted in a net gain to farm income in 2010 of $471 million. Cumulatively, since 1996 the farm income benefit has been $3.27 billion. In added value terms, the effect of the increased yields and reduced costs of production on farm income in 2010 was equivalent to an annual increase in production of 6.8% (278,000 tonnes).

Table 29: Farm level income impact of using GM IR cotton in the US 1996-2010

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	2.71	114.50	296.00	5.49
2008	2.71	98.22	189.50	5.89
2009	2.71	128.04	296.79	6.04
2010	2.71	146.37	471.73	6.76

Sources and notes:

1. Impact data based on Gianessi & Carpenter (1999), Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006), Johnson & Strom (2008), Marra et al (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/ha 2006, $25.7/ha 2007-2010
4. Insecticide cost savings $63.26/ha 1996-2002, $74.10/ha 2003-2005, $41.18/ha 2006, $28.4/ha 2007-2010

3.7.2 China

China first planted GM IR cotton in 1997, since when the area planted to GM IR varieties has increased to 67% of the total 5.25 million ha crop in 2010.

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-$200/ha and annual average profitability improved by $123/ha-$517/ha. In 2010, the net national gain to farm income was $1.78 billion (Table 30). Cumulatively since 1997 the farm income benefit has been $10.91 billion. In added value terms, the effect of the increased yields and reduced costs of production on farm income was equivalent to an annual increase in production of 9.1% (0.62 million tonnes) in 2010.

Table 30: Farm level income impact of using GM IR cotton in China 1997-2010

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
2008	167	244	933.7	18.64
2009	170	407	1,454.2	10.61
2010	172	516	1,782.4	9.14

Sources and notes:

1. Impact data based on Pray 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

3.7.3 Australia

Australia planted 91% of its 2010 cotton crop (total crop of 520,690 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 31). 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 savings 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 $241/ha;

- At the national level in 2010, the net farm income gain was $114.2 million and cumulatively since 1996 the gains have been $362.8 million;
- In added value terms, the effect of the reduced costs of production on farm income in 2010 was equivalent to an annual increase in production of 41.6% (335,720 tonnes).

Table 31: Farm level income impact of using GM IR cotton in Australia 1996-2010

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	40.90
2008	-264.26	199.86	24.23	37.40
2009	-234.49	211.31	33.73	38.00
2010	-266.97	240.58	114.24	41.60

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

3.7.4 Argentina

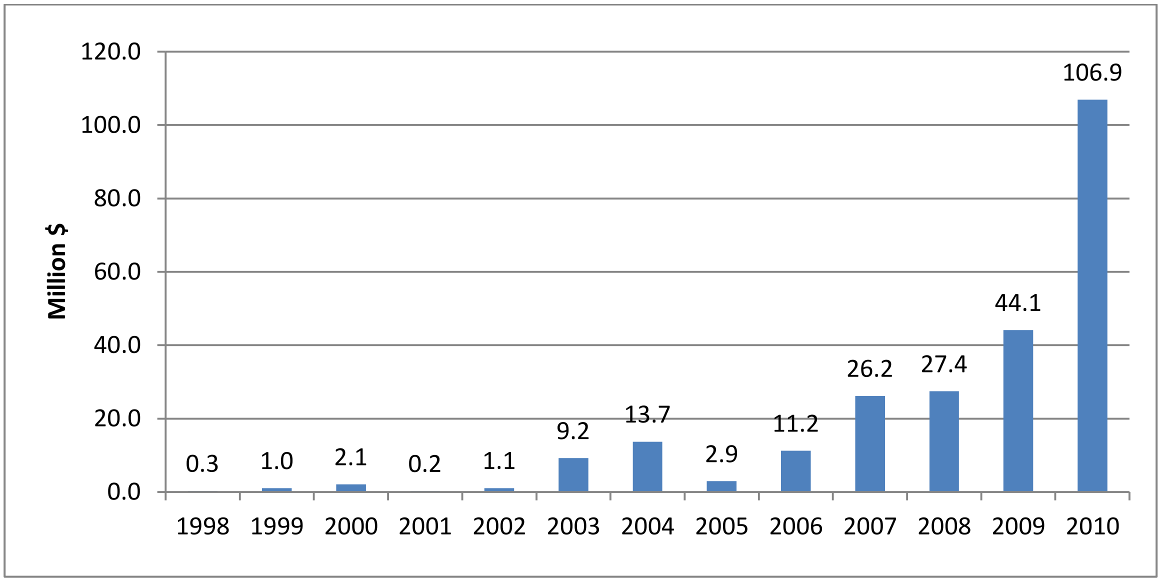
GM IR cotton has been planted in Argentina since 1998. In 2010, it accounted for 89% of total cotton plantings.

The main impact in Argentina has been yield gains of 30% (which has resulted in a net increase in total cotton production (2010) of 27%). This has more than offset the cost of using the technology[53]. In terms of gross margin, cotton farmers have gained between $25/ha and $249/ha annually during the period 1998-2010[54]. At the national level, the annual farm income gains in the last five years have been in the range of $11 million to $107 million (Figure 14). Cumulatively since 1998, the farm income gain from use of the technology has been $246.4 million. In added value terms, the effect of the yield increases (partially offset by higher costs of production) on farm income in 2010 was equivalent to an annual increase in production of 18.9%.

[53] The cost of the technology used in the years up to 2004 was $86/ha (source: Qaim & DeJanvry). From 2005, the cost has been 116 pesos/ha ($30/ha- $40/ha: source: Monsanto Argentina). The insecticide cost savings have been $13/ha-$17/ha

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

Figure 14: National farm income impact of using GM IR cotton in Argentina 1998-2010



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%, cost of technology $86/ha ($40/ha 2005), cost savings (reduced insecticide use) $13/ha-$17/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

3.7.5 Mexico

GM IR cotton has been planted commercially in Mexico since 1996. In 2010, GM IR cotton was planted on 48,930 ha (44% of total cotton plantings).

The main farm income impact of using the technology has been yield improvements of between 9% and 14% over the last five years. In addition, there have been important savings in the cost of production (lower insecticide costs)[55]. Overall, the annual net increase in farm profitability has been within the range of $104/ha and $354/ha between 1996 and 2010 (Table 32). At the national level, the farm income benefit in 2010 was $10.9 million and the impact on total cotton production was an increase of 4.6%. Cumulatively since 1996, the farm income benefit has been $95 million. In added value terms, the combined effect of the yield increases and lower cost of production on farm income in 2010 was equivalent to an annual increase in production of 3.5%.

Table 32: Farm level income impact of using GM IR cotton in Mexico 1996-2010

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

[55] Cost of technology has annually been between $48/ha and $70/ha up to 2008, $99.5/ha in 2009 and $39/ha based on estimated share of the trait largely sold as a stacked trait, insecticide cost savings between $88/ha and $121/ha to 2009 ($20/ha in 2010) and net impact on costs have been between -$39/ha and + $48/ha (derived from and based on Traxler et al (2001) and updated from industry sources)

				of national production
1996	58.1	354.5	0.3	0.1
1997	56.1	103.4	1.7	0.5
1998	38.4	316.4	11.3	2.7
1999	46.5	316.8	5.3	2.8
2000	47.0	262.4	6.8	5.8
2001	47.6	120.6	3.0	3.7
2002	46.1	120.8	1.8	3.8
2003	41.0	127.7	3.3	3.7
2004	39.3	130.4	6.2	4.5
2005	40.8	132.3	10.4	7.4
2006	20.4	124.4	6.4	4.4
2007	20.5	139.7	8.4	5.1
2008	19.9	150.4	10.5	6.8
2009	-21.0	254.3	7.7	5.0
2010	-39.2	222.34	10.88	3.5

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 +9.25%, 2006 +9%, 2007 & 2008 +9.28%, 2009 +14.2%, 2010 +10.3%
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

3.7.6 South Africa

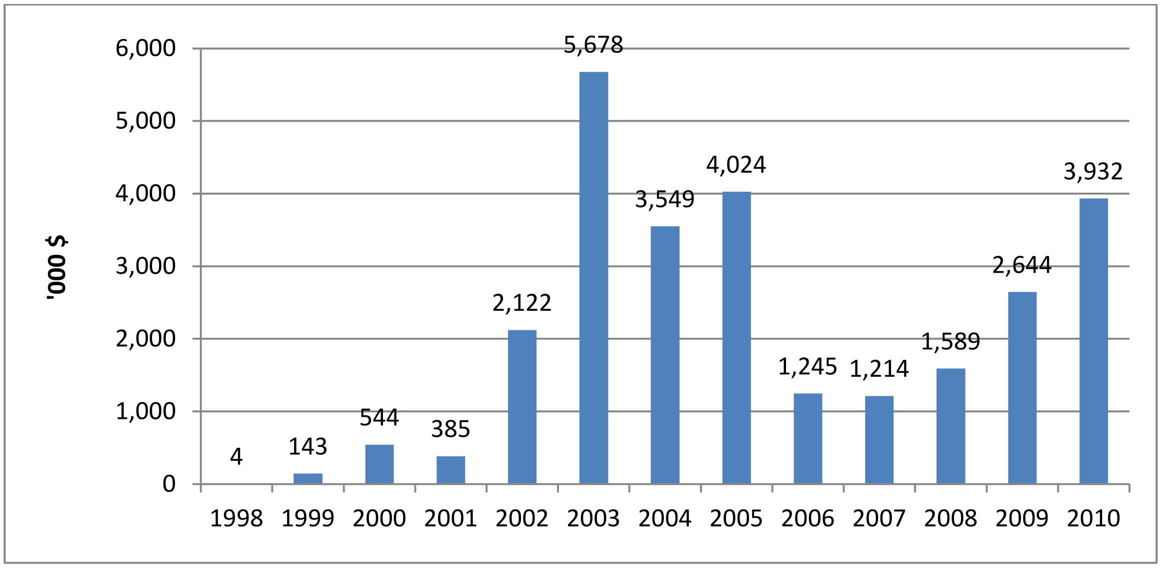
In 2010, GM IR cotton[56] was planted on 12,490 ha in South Africa (95% of the total crop).

The main impact on farm income 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 $40/ha to $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 $319/ha.

At the national level, farm incomes over the last five years have annually increased by between $1.2 million and $3.9 million (Figure 15). Cumulatively since 1998, the farm income benefit has been $27.1 million. The impact on total cotton production was an increase of 22.8% in 2010. In added value terms, the combined effect of the yield increases and lower costs of production on farm income in 2010 was equivalent to an annual increase in production of 16.8% (based on 2010 production levels).

[56] First planted commercially in 1998

Figure 15: National farm income impact of using GM IR cotton in South Africa 1998-2010



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)

3.7.7 India

GM IR cotton has been planted commercially in India since 2002. In 2010, 9.4 million ha were planted to GM IR cotton which is equal to 85% of total plantings.

The main impact of using GM IR cotton has been major increases in yield[57]. With respect to cost of production, the average cost of the technology (seed premium: $49/ha to $54/ha) up to 2006 was greater than the average insecticide cost savings of $31/ha-$58/ha resulting in a net increase in costs of production. Following the reduction in the seed premium in 2006 to $20/ha, farmers have made a net cost saving of $20/ha-$25/ha. Coupled with the yield gains, important net gains to levels of profitability have been achieved of between $82/ha and $356/ha. At the national level, the farm income gain in 2010 was $2.5 billion and cumulatively since 2002 the farm income gains have been $9.4 billion (Table 33).

[57] 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

Table 33: Farm level income impact of using GM IR cotton in India 2002-2010

Year	Cost savings (net after cost of technology: $/ha)	Net increase in gross margins ($/ha)	Increase in farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
2002	-12.42	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	26.41	356.85	2,093.97	22.84
2008	24.28	256.73	1,790.16	24.27
2009	22.19	211.17	1,754.96	23.47
2010	23.10	265.80	2,498.53	24.26

Sources and notes:

1. Impact data based on Bennett et al (2004) and IMRB (2005 & 2007). As 2008-2010 were reported to be years of below average pest pressure, the average yield gains used were reduced to +40% for 2008 and to +35% for 2009 and 2010
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 29.9% in 2010. In added value terms, the combined effect of the yield increases and higher costs of production on farm income was equivalent to an annual increase in production of 24% (based on the 2010 production level that is inclusive of the GM IR related yield gains).

3.7.8 Brazil

GM IR cotton was planted commercially in Brazil for the first time in 2006, and in 2010 was planted on 240,000 ha (17% of the total crop). The area planted to GM IR cotton in Brazil has fluctuated (eg, 358,000 ha in 2007 and 116,000 ha in 2009) largely due to the performance of the seed containing the GM IR trait compared to leading conventional varieties. In 2006, on the basis of industry estimates of impact of GM IR cotton relative to similar varieties (average yield gain of +6% and a net cost saving (reduced expenditure on insecticides after deduction of the premium paid for using the technology) of about +$25/ha)), a net farm income gain of about $125/ha was realised. Since then, however, improved conventional varieties in which the GM IR trait is not present have dominated production because of their superior yields. As a result, varieties containing the GM IR trait have delivered inferior yields (despite offering effective control against bollworm pests) relative to the leading conventional varieties. In addition, boll weevil is a major pest in many cotton growing areas, a pest that the GM IR technology does not target. Analysis by Galvao (2009 & 2010) estimated that the yield performance of the varieties containing GM IR traits was lower (by –2.7% to -3.8%) than the leading conventional alternatives available in 2007-2009. As a result, the average impact on farm income (after taking into consideration insecticide cost savings and the seed premium) has been negative (-$34.5/ha in 2007, a small net gain of about $2/ha in 2008 and a net loss of -$44/ha in 2009). Not surprisingly, at the country level, this resulted in net aggregate losses in 2007 and 2009 from using the technology (eg, -$5 million in 2009). In 2010, stacked traits (containing GM HT and GM IR traits) became available in some of the leading varieties for the first time and this has contributed to the increase in plantings during 2010. Early estimates of the impact of this technology relative to the leading conventional varieties (Galveo (2010)) suggest a small net yield increase of between 2% and 2.5%. For the purposes of the analysis presented in this report, all of this yield gain has been attributed to the GM HT component and therefore included in the analysis presented in section 3.3.2. Therefore the 'residual' yield assumption used for the impact of the GM IR cotton technology in this section has been zero (ie, the technology delivers neither yield gain or loss). Based on this assumption together with estimates from Galvao (2010) of the seed premium ($42.54/ha) and insecticide cost savings of $58.94/ha, the net impact from using the GM IR technology was +16.4/ha in 2010. At the national level this equates to a net income gain of $3.94 million. Cumulatively, since 2006 GM IR technology has delivered a net farm income gain of $3.8 million.

3.7.9 Other countries

- *Colombia*. GM IR cotton has been grown commercially in Colombia since 2002 (34,300 ha planted in 2010 out of a total cotton crop of 43,085 ha). Drawing on recent analysis of impact by Zambrano et al (2009), this shows the main impact has been a significant improvement in yield (+32%). On the cost side, this analysis shows that GM IR cotton farmers tend to have substantially higher expenditures on pest control than their conventional counterparts which, when taking into consideration the approximate $70/ha cost of the technology, results in a net addition to costs of between $200/ha and $280/ha (relative to typical expenditures by conventional cotton growers). Nevertheless, after taking into consideration the positive yield effects, the net impact on profitability has been positive. In 2008, the average improvement in profitability was about $90/ha and the total net gain from using the technology was $1.8 million[58]. Since the Zambrano work, the use of GM IR cotton has seen problems with reduced yield benefits in 2009 due mainly to heavy rains in the planting season delaying planting, followed by lack of rain in the growing season and the increasing availability of stacked traited seed. For the purposes of this analysis, the 2010 estimates of impact are based on industry source data which were an estimated net yield benefit of +10%, seed premium of $166/ha and insecticide cost savings of $84/ha. As a result, the net farm income benefit in 2010 was estimated to be +$42.6/ha. At the national level, this equated to a net farm income gain of $1.5 million. Cumulatively, since 2002 the net farm income gain was + $11.4 million;

- *Burkina Faso*: GM IR cotton was first grown commercially in 2008. In 2010, GM IR cotton accounted for 65% (260,000 ha) of total plantings. Based on analysis by Vitale et al (2006, 2008 and 2009), the main impact of the technology is improved yields (by +18% to +20%) and savings in insecticide expenditure of about $62/ha. Based on a cost of technology of $51/ha, the net cost savings are small ($1-$2/ha), but inclusive of the yield gains, the net income gain in 2010 was $138.8/ha. The total aggregate farm income gain in 2010 was $36.1 million and cumulatively, since 2008, it has been $51.7 million.

3.7.10 Summary of global impact

In global terms, the farm level impact of using GM IR cotton was $5 billion in 2010. Cumulatively since 1996, the farm income benefit has been (in nominal terms) $24.4 billion. Within this, 69% of

[58] Given that the Zambrano et al work identified important differences between the baseline level of insecticide use by GM IR cotton users and conventional cotton farmers (pre-adoption of the technology), this probably understates the cost savings associated with the technology. A more representative assessment of the impact would compare the costs (post adoption) of GM IR technology users with the likely costs of reverting back to conventional technology on these farms

the farm income gain has derived from yield gains (less pest damage) and the balance (31%) 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 2010, the additional farm income generated by the technology is equal to a value added equivalent of 14% (based on the 2010 production level inclusive of the GM IR related yield gains). Relative to the value of global cotton production in 2010, the farm income benefit added the equivalent of 11.9%.

3.8 Other biotech crops

3.8.1 Maize/corn rootworm resistance

GM rootworm resistant (CRW) maize has been planted commercially in the US since 2003. In 2010, there were 17.3 million ha of CRW maize (53% of the total US crop).

The main farm income impact[59] has been higher yields of about 5% relative to conventional corn. The impact on average costs of production has been +$2/ha to +$12/ha (based on an average cost of the technology of $25/ha-$42/ha and an insecticide cost saving of $32/ha-$37/ha). As a result, the net impact on farm profitability has been +$24/ha to +$87/ha.

At the national level, farm incomes increased by $4 million in 2003, rising to $1.43 billion in 2010. Cumulatively since 2003, the total farm income gain from the use of CRW technology in the US maize crop has been +$4.76 billion.

CRW cultivars were also planted commercially for the first time in 2004 in Canada. In 2010, the area planted to CRW resistant varieties was 0.35 million ha. Based on US costs, insecticide cost savings and yield impacts, this has resulted in additional income at the national level of $38.7 million in 2010 (cumulative total since 2004 of $68.9 million).

At the global level, the extra farm income derived from biotech CRW maize use since 2003 has been $4.83 billion.

3.8.2 Virus resistant papaya

Ringspot resistant papaya has been commercially grown in the US (State of Hawaii) since 1999, and in 2010, 75% of the state's papaya crop was GM virus resistant (410 ha of fruit bearing trees).

The main farm income impact of this technology 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% (19% in 2010). At a state level, this is equivalent to a 14% increase in total papaya production in 2010.

In terms of profitability[60], the net annual impact has been an improvement of between $2,700/ha and $11,400/ha, and in 2010, this amounted to a net farm income gain of $3,078/ha and an

[59] Impact data based on Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006), Johnson and Strom (2008) and Rice (2004)

[60] Impact data based on Carpenter & Gianessi (2002), Sankala & Blumenthal (2003 & 2006) and Johnson and Strom (2008)

aggregate benefit across the state of $1.3 million. Cumulatively, the farm income benefit since 1999 has been $22 million.

Virus resistant papaya are also reported to have been grown in China in 2010, on 4,500 ha. No impact data on this technology has been identified.

3.8.3 Virus resistant squash

Biotech virus resistant squash has also been grown in some states of the US since 2004. It is estimated to have been planted on 2,000 ha in 2010[61] (11% of the total crop in the US).

Based on analysis from Johnson & Strom (2008), the primary farm income impact of using biotech virus resistant squash has been derived from higher yields which in 2010, added a net gain to users of $21.6 million. Cumulatively, the farm income benefit since 2004 has been $166.8 million.

3.8.4 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 (Carpenter & Gianessi (2002).

3.9 Indirect (non pecuniary) farm level economic impacts

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

Many of the studies[62] 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 after the weeds and crop are established. As a result, the crop may suffer 'knock-back' to its

[61] Mostly found in Georgia and Florida

[62] 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)

growth from the effects of the herbicide. In the GM HT crop, this problem is avoided because the crop is tolerant to the herbicide;

- 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);
- 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 a switch to more environmentally benign 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. Piloted in 2008 and more widely operational from 2009, US farmers using stacked corn traits (containing insect resistant and herbicide tolerant traits) are being offered discounts on crop insurance premiums (for crop losses) equal to $12.97/ha in 2010. Over the three years, this has applied to 12.7 million ha, resulting in insurance premia savings of $137.8 million;
- A 'convenience' benefit derived from having to devote less time to crop walking and/or applying insecticides;
- Savings in energy use – mainly associated with less use of aerial spraying;
- Savings in machinery use (for spraying and possibly reduced harvesting times);
- 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[63]. Also some Indian cotton growers

[63] Notably maize in India

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, Yorobe J (2004): see above). 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 GM technology, and in some cases farmers have been willing to adopt for these reasons alone, even when the measurable impacts on yield and direct costs of production suggest marginal or no direct economic gain.

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[64] to obtain farmers valuations of non pecuniary benefits. A summary of these findings is shown in Table 34.

Table 34: Values of non pecuniary benefits associated with biotech crops in the US

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[65]	12.35 (relative to first generation HT cotton)

Source: Marra & Piggot (2006)[11] and (2007)[21]

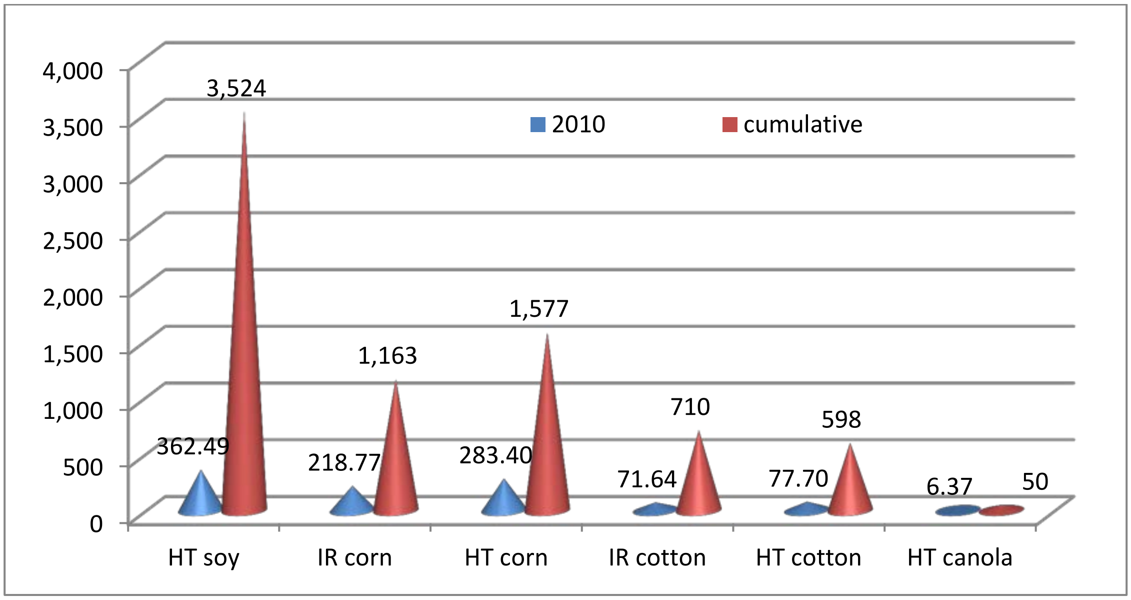
Aggregating the impact to US crops 1996-2010

The approach used to estimate the non pecuniary benefits derived by US farmers from biotech crops over the period 1996-2010 has been to draw on the values identified by Marra and Piggot (2006 & 2007: Table 34) and to apply these to the biotech crop planted areas during this 15 year period. Figure 16 summarises the values for non pecuniary benefits derived from biotech crops in the US (1996-2010) and shows an estimated (nominal value) benefit of $1,020 million in 2010 and a cumulative total benefit (1996-2010) of $7.62 billion. Relative to the value of direct farm income benefits presented above, the non pecuniary benefits were equal to 18.5% of the total direct income benefits in 2010 and 21.6% of the total cumulative (1996-2010) 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).

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

[65] 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 16: Non pecuniary benefits derived by US farmers 1996-2010 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 these 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.

3.10 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 not, however, take into consideration 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 (2003) identified that in Spain the average size of farm 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 farm using the technology;

- Brookes (2005) also identified in Romania that the average size of farm adopting HT soybeans was not related to farm size;
- Pray et al (2002). This research into GM IR cotton adoption in China illustrated that adoption has been mostly by 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 farm (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 (2008)).

Overall, the findings from most studies examining size of adopting farms 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 2010, 15.4 million farmers were using the technology globally, 90% of which were resource-poor farmers in developing countries.

3.11 Production effects of the technology

Based on the yield assumptions used in the direct farm income benefit calculations presented above (see Appendix 1) and taking into account the second soybean crop facilitation in South America, biotech crops have added important volumes to global production of corn, cotton, canola and soybeans (Table 35).

Table 35: Additional crop production arising from positive yield effects of biotech crops

	1996-2010 additional production (million tonnes)	2010 additional production (million tonnes)
Soybeans	97.5	13.08
Corn	159.4	28.29
Cotton	12.5	2.05
Canola	6.1	0.65

The biotech IR traits, used in the corn and cotton sectors, have accounted for 98% of the additional corn production and 99.4% 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[66]) when compared to average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). The average yield impact across the total area planted to these traits over the 15 year period since 1996 has been +9.6% for corn traits and +14.4% for cotton traits (Figure 17).

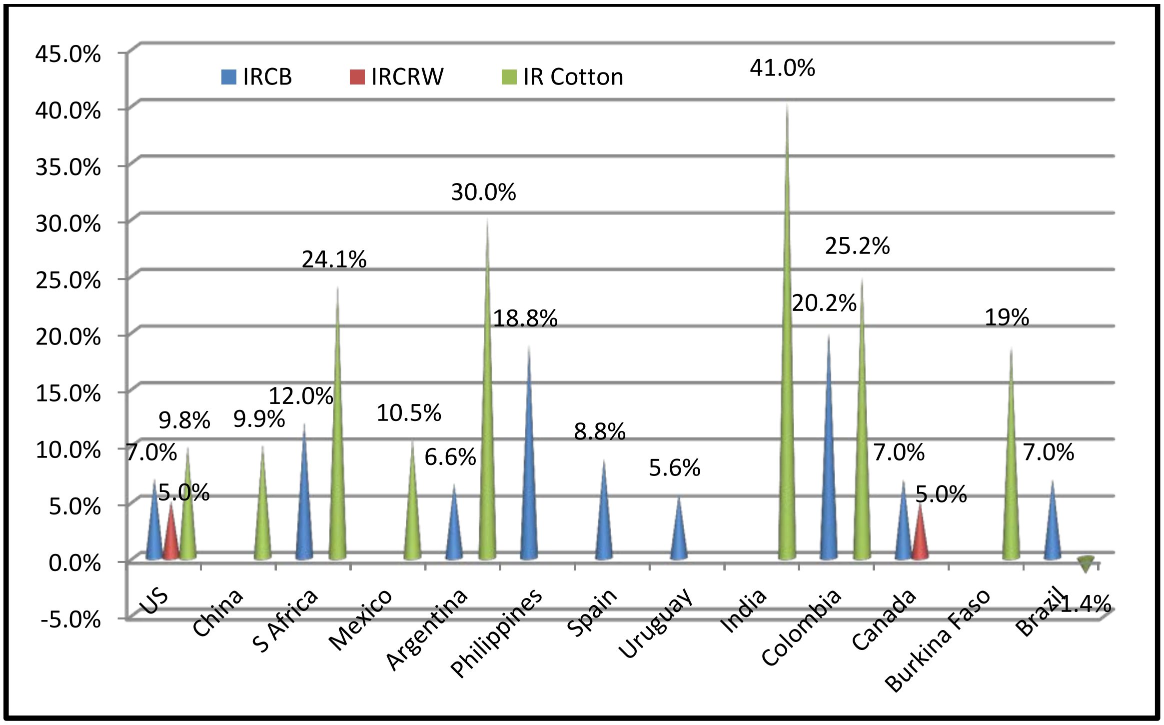
Although the primary impact of biotech HT technology has been to provide more cost effective (less expensive) and easier weed control versus improving yields from better weed control (relative to weed control obtained from conventional technology), improved weed control has, nevertheless, occurred delivering higher yields in some countries (eg, HT soybeans in Romania, Bolivia and Mexico, HT corn in Argentina and the Philippines: see Appendix 2).

[66] 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

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 96.1 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2010 (accounting for 98.5% of the total biotech-related additional soybean production).

Using the same sensitivity analysis as applied to the farm income estimates presented above to the production impacts (one scenario of consistent lower than average pest/weed pressure and one of consistent higher than average pest/weed pressure), Table 36 shows the range of production impacts.

Figure 17: Average yield impact of biotech IR traits 1996-2010 by country and trait



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

Table 36: Additional crop production arising from positive yield effects of biotech crops 1996-2010 under different pest/weed pressure assumptions and impacts of the technology (million tonnes)

Crop	Consistent below average pest/weed pressure	Average pest/weed pressure (main study analysis)	Consistent above average pest/weed pressure
Soybeans	97.0	97.5	98.0
Corn	137.2	159.4	197.7
Cotton	8.8	12.5	18.2
Canola	4.6	6.1	6.5

Note: No significant change to soybean production under all three scenarios as 99% of production gain due to second cropping facilitation of the technology

3.12 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 37 and Table 38) show the following:

- *Soybeans*: in 2010/11, 35% of global production was exported and 98% 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)[67], about 3.3% of global trade in soybeans is probably 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 95%. A similar pattern occurs in soymeal, where 85% of globally traded meal probably contains biotech material;
- *Maize*: 11% of global production was internationally traded in 2010/11[68]. Within the leading exporting nations, the biotech maize growers of the US, Argentina, Brazil, South Africa and Canada are important players (83% 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 79%;
- *Cotton*: in 2010/11, 31% of global production was traded internationally. Of the leading exporting nations, the biotech cotton growing countries of the US, Australia, India, Brazil and Burkina Faso are prominent exporters accounting for 72% of global trade. Given that the market for certified conventional cotton is very small, virtually all of this share 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[69]. In terms of cottonseed meal the biotech share of global trade is 47%;
- *Canola*: 17% of global canola production in 2010/11 was exported, with Canada being the main global trading country. The share of global canola exports accounted for by the three biotech canola producing countries (Canada, the US and Australia) was 82% in 2010/11. 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 82% of global trade. For canola/rapemeal, the biotech share of global trade is about 58%.

[67] Brookes (2008b) and updated from industry sources and own research

[68] 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

[69] 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

Table 37: Share of global crop trade accounted for biotech production 2010/11 (million tonnes)

	Soybeans	Maize	Cotton	Canola
Global production	264.2	828.0	25.1	60.2
Global trade (exports)	93.45	91.3	7.75	10.34
Share of global trade from biotech producers	91.66 (98.1%)	76.5 (83.7%)	5.56 (71.7%)	8.46 (81.8%)
Estimated size of market requiring certified conventional (in countries that have import requirements)	3.1	4.5	Negligible	Negligible
Estimated share of global trade that may contain biotech (ie, not required to be segregated)	88.56	72.0	5.56	8.46
Share of global trade that may be biotech	94.8%	78.9%	71.7%	81.8%

Sources: derived from and updated - USDA & Oil World statistics, Brookes (2008b)
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 satisfied 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 2.1 million tonnes bean equivalents, Japan and South Korea 1 million tonnes.

Table 38: Share of global crop derivative (meal) trade accounted for biotech production 2010/11 (million tonnes)

	Soymeal	Cottonseed meal	Canola/rape meal
Global production	177.8	19.7	33.6
Global trade (exports)	60.0	0.5	4.8
Share of global trade from biotech producers	53.6 (89.3%)	0.236 (47.2%)	2.8 (58.3%)
Estimated size of market requiring certified conventional (in countries that have import requirements)	2.5	Negligible	Negligible
Estimated share of global trade that may contain biotech (ie, not required to be segregated)	51.1	0.236	2.8
Share of global trade that may be biotech	85.2%	47.2%	58.3%

Sources: derived from and updated - USDA & Oil World statistics, Brookes (2008b)
Notes: Estimated size of certified conventional market for soymeal: EU 2.25 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 that for a crop such as soybeans, 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, $3.3 billion in 2010) 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 probably also 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 soybean real 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 (2010) 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)[70], as the base for imputing into 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[71]. 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%

[70] 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

[71] 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

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%.

4 The environmental impact of biotech crops

This section examines the environmental impact of using biotech crops over the last fifteen 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

Assessment of the impact of biotech crops on insecticide and herbicide use requires comparisons of the respective weed and pest control measures used on biotech versus the 'conventional alternative' form of production. This presents a number of challenges relating to data availability and representativeness. Comparison data ideally derives from farm level surveys which collect usage data on the different forms of production. A search of literature on biotech crop impact on insecticide or herbicide use at the trait, local, regional or national level shows that the number of studies exploring these issues is limited (eg, Qaim & Traxler (2002), Qaim & De Janvry (2005) and Pray et al (2002) with even fewer (eg, Brookes (2003 & 2005), providing data to the pesticide (active ingredient) level. Secondly, national level pesticide usage survey data is also extremely limited; in fact there are no published annual pesticide usage surveys conducted by national authorities in any of the countries currently growing biotech traits. The only country in which pesticide usage data is collected (by private market research companies) on an annual basis and which allows a comparison between biotech and conventional crops to be made is the US[72]. Unfortunately, even where national survey data is available on usage, the data on conventional crop usage may fail to be reasonably representative of what herbicides and insecticides might be expected to be used in the absence of biotechnology. When biotech traits dominate total production (eg, for soybeans, corn, cotton and canola in the US since the early 2000s), the conventional cropping dataset used to identify pesticide use relates to a relatively small share of total crop area and therefore is likely to under estimate what usage would probably be in the absence of biotechnology. The reasons why this conventional cropping dataset is unrepresentative of the levels of pesticide use that might reasonably be expected to be used in the absence of biotechnology include:

- Whilst the levels of pest and weed problems/damage vary by year, region and within region, farmers who continue to farm conventionally are often those with relatively low levels of pest or weed problems, and hence see little if any economic benefit from using the biotech traits targeted at these agronomic problems. Their pesticide usage levels therefore tend to be below the levels that would reasonably be expected to be used to control these weeds and pests on an average farm. A good example to illustrate this relates to the US cotton crop where, for example, in 2010, nearly half of the conventional cotton crop was located in Texas. Here levels of bollworm pests (the main target of biotech insect resistant cotton) tend to be consistently low and cotton farming systems are

[72] The US Department of Agriculture also conducts pesticide usage surveys but these are not conducted on an annual basis (eg, corn has been covered in 2005 and then not again until 2010) and do not disaggregate usage by production type (biotech versus conventional)

traditionally of an extensive, low input nature (eg, the average cotton yield in Texas was about 58% of the US average in 2010);

- The widespread adoption of GM insect resistant technology has resulted in 'area-wide' suppression of target pests such as the European corn borer in maize crops. As a result, conventional farmers (eg, maize in the US) have benefited from this lower level of pest infestation and the associated reduced need to conduct insecticide treatments (Hutchison et al (2010));
- Some of the farms continuing to use conventional (non biotech) seed traditionally use extensive, low intensive production methods (including organic) in which limited (below average) use of pesticides is a feature (see, for example, the Texas cotton example above). The usage pattern of this sub-set of growers is therefore likely to understate usage for the majority of farmers if all crops were conventional;
- Many of the farmers using biotech traits have experienced improvements in pest and weed control from using this technology relative to the conventional control methods previously used. If these farmers were now to switch back to using conventional techniques, based wholly on pesticides, it is likely that most would wish to maintain the levels of pest/weed control delivered with use of biotech traits and therefore would use higher levels of pesticide than they did in the pre-biotech crop days.

To overcome these problems in the analysis of pesticide use changes arising from the adoption of biotech crops (ie, where biotech traits account for the majority of total planting), presented in this paper[73], actual recorded usage levels for the biotech crops are used (based on survey data), with the conventional alternative (counterfactual situation) identified based on opinion from extension advisors and industry specialists as to what farmers might reasonably be expected to use in terms of crop protection practices and usage levels of pesticide[74]. This methodology has been used by others, for example Johnson & Strom (2008). Details of how this methodology has been applied to the 2010 calculations, sources used for each trait/country combination examined and examples of typical conventional versus biotech pesticide applications are provided in Appendix 3.

The most common way in which changes in pesticide use with biotech crops has been presented in the literature has been in terms of the volume (quantity) of pesticide applied. Whilst comparisons of total pesticide volume used in biotech and conventional crop production systems are a useful indicator of associated environmental impacts, amount of active ingredient used is an imperfect measure because it does not account for differences in the specific pest control programmes used in biotech and conventional cropping systems. For example, different specific products used in biotech versus conventional crop systems, differences in the rate of pesticides used for efficacy and differences in the environmental characteristics (mobility, persistence, etc) are masked in general comparisons of total pesticide volumes used.

In this section, the pesticide related environmental impact changes associated with biotech crop adoption are examined in terms of changes in the volume (amount) of active ingredient applied, but supplemented by the use of an alternative indicator, developed at Cornell University in the

[73] And earlier work: AgbioForum 8 (2&3) 187-196 of 2005, 9 (3) 1-13 of 2006, 11 (1), 21-38 of 2008 and 13 (1) 76-94, also GM Crops 2011, vol 12, issue 1, 34-49

[74] In other words Brookes & Barfoot draw on the findings of work by Carpenter & Gianessi (1999), Sankala & Blumenthal (2003 & 2006) and Johnson & Strom (2008) – see www.ncfap.org. This work consults with in excess of 50 extension advisors in almost all of the states growing corn, cotton and soybeans and therefore provides a reasonably representative perspective on likely usage patterns

1990s, the environmental impact quotient (EIQ). The EIQ indicator, developed by Kovach et al (1992) and updated annually, effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare'. 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 15.33. By using this rating multiplied by the amount of glyphosate used per hectare (eg, a hypothetical example of 1.1 kg applied per ha), the field EIQ value for glyphosate would be equivalent to 16.86/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 impact 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 conventional). The use of environmental indicators is commonly used by researchers and the EIQ indicator has been, for example, cited by Brimner et al (2004) in a study comparing the environmental impacts of biotech and conventional canola and by Kleiter et al (2005).

The EIQ indicator provides an improved assessment of the impact of biotech crops on the environment when compared to only examining changes in volume of active ingredient applied, because it draws on some of the key toxicity and environmental exposure data related to individual products, as applicable to impacts on farm workers, consumers and ecology. Readers should, however, note that the EIQ is an indicator only and does not take into account all environmental issues and impacts. It is therefore not a comprehensive indicator. Detailed examples of the relevant amounts of active ingredient used and their associated field EIQ values for biotech versus conventional crops for the year 2010 are presented in Appendix 3. Additional information about the EIQ indicator is presented in Appendix 4.

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 GfK Kynetec. Based on these sources of information, the main features relating to herbicide usage on US soybeans over the last fifteen years have been (Table 39 and Table 40):

- The amount of herbicide active ingredient (ai) used per hectare on the US soybean crop has been fairly stable for most of the period, although there has been an increase in average usage over the last few years;
- The average field EIQ/ha load has also been fairly consistent, with a small rise in recent years;
- A comparison of conventionally grown soybeans (per ha) with GM HT soybeans (Table 40) 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. In the last few years, however, the average amount of ai use on GM HT soybeans has increased to about 1.6 to 1.7 kg/ha. This marginally higher average usage level for GM HT soybeans partly reflects the

changes in cultivation practices in favour of low/no tillage[75], which accounted for 73.7% of soybean production in 1996 and 80% in 2010 (low/no tillage systems tend to favour the use of glyphosate as the main burn-down treatment between crops (see section 4.2)). It also partly reflects the increasing adoption of both reactive and proactive weed management practices designed to address the issue of weed resistance to glyphosate (see section 4.1.8 for more detailed discussion);

- A comparison of average field EIQs/ha also shows fairly stable values for both conventional and GM HT soybeans for most of the period and small increases in recent years. The average load rating for GM HT soybeans has been lower than the average load rating for conventional soybeans for most of the period, 2008-2010 excepted, despite the continued shift to no/low tillage production systems that rely much more on herbicide-based weed control than conventional tillage systems and the adoption of reactive and proactive weed resistance management programmes;
- At the macro level, the adoption of both reactive and proactive weed management programmes in GM HT soybeans has begun to influence the mix, total amount and overall environmental profile of herbicides applied to GM HT soybeans. Thus, in the US GM HT soybean crop (2010), just over a third of the crop received an additional herbicide treatment of one of the following active ingredients[76] 2 4 D, chlorimuron, clethodim and flumioxazin. This compares with 13% of the GM HT soybean crop receiving a treatment of one of these four herbicide active ingredients in 2006. As a result, the average amount of herbicide active ingredient applied to GM HT soybeans in the US (per hectare) has increased by about a third over the last five years (the associated EIQ value has increased by about 27%). This compares with the average amount of herbicide active ingredient applied to the conventional (non GM) soybean alternative which increased by 15% over the same period (the associated EIQ value for conventional soybeans increased by 27%). The increase in the use of herbicides on conventional soybeans in the US can also be partly attributed to the ongoing development of weed resistance to herbicides commonly used and highlights that the development of weed resistance to herbicides is a problem faced by all farmers, regardless of production method.

Table 39: Herbicide usage on soybeans in the US 1996-2010

Year	Average ai use (kg/ha): NASS data	Average ai use: GfK Kynetec data: index 1998=100	Average field EIQ/ha: NASS data	Average field EIQ/ha: based on GfK Kynetec data
1996	1.02	N/a	22.0	N/a
1997	1.22	N/a	26.2	N/a
1998	1.09	100	21.5	25.8
1999	1.05	94.9	19.6	23.2
2000	1.09	96.0	20.2	23.1
2001	0.73	100.1	13.4	23.5
2002	1.23	97.8	21.4	21.6
2003	N/a	104.7	N/a	22.6
2004	1.29	106.1	15.2	22.6
2005	1.23	106.3	20.2	22.6

[75] 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)

[76] The four most used herbicide active ingredients used on soybeans after glyphosate (source: derived from GfK Kynetec)

2006	1.53	100.8	16.9	21.4
2007	N/a	113.0	N/a	23.6
2008	N/a	125.1	N/a	26.1
2009	N/a	125.7	N/a	26.6
2010	N/a	135.0	N/a	28.8

Sources: NASS data no collection of data in 2003, 2007-2010. GfK Kynetec 1998-2010, N/A = not available. Average ai/ha figures derived from GfK dataset are not permitted by GfK to be published

Table 40: Herbicide usage on GM HT and conventional soybeans in the US 1996-2010

Year	Average ai use (kg/ha) index 1998=100: conventional	Average ai use (kg/ha) index 1998=100: 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	100	100	28.1	22.2
1999	89.8	97.0	25.7	21.5
2000	86.7	99.7	24.5	22.3
2001	91.4	101.2	25.9	22.7
2002	85.2	98.3	24.1	21.1
2003	83.6	105.0	23.6	22.5
2004	84.4	105.9	23.7	22.5
2005	85.9	105.8	23.8	22.5
2006	79.8	100.3	21.4	21.4
2007	90.6	111.3	24.6	23.5
2008	95.1	123.2	25.4	26.1
2009	94.7	124.3	25.6	26.7
2010	97.3	133.5	26.4	28.9

Source: derived from GfK 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. Average ai/ha figures derived from GfK dataset are not permitted by GFK to be published

- The comparison data between the GM HT crop and the conventional alternative presented in section 4.1 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 adoption has increased (see section 4.1 for reasons). In addition, 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 had all growers still been using conventional technology. The approach used to address this deficiency has been to make comparisons between typical weed control programmes for GM HT soybeans (designed to both reactively and proactively address weed resistance issues) and recorded (average) herbicide treatment regimes for GM HT soybeans), with typical herbicide treatment regimes 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 a methodology used by others, for example, Sankala & Blumenthal (2003 & 2006) and Johnson & Strom (2008). Based on this approach, information collected by these analysts[77] and updated as part of this research for 2009 and 2010, the respective values for conventional soybeans in the last five years are shown in Table 41. These usage levels were then compared to typical and recommended weed control regimes for GM HT soybeans and recorded usage levels on the GM HT crop (which accounted for over 90% of the total crop since 2007), using the dataset from GfK Kynetec.

Table 41: Average ai use and field EIQs for conventional soybeans 2006-2010 to deliver equal efficacy to GM HT soybeans

Year	Ai use (kg/ha)	Field eiq/ha
2006	1.48	36.2
2007	1.60	33.1
2008	1.62	36.2
2009	1.66	42.7
2010	1.77	46.1

Sources: based on Sankala & Blumenthal (2006), Johnson & Strom (2008) and updated for this research for 2009 and 2010

Through this (most representative) comparison of conventional versus GM HT soybean herbicide usage, the estimated national level changes in herbicide use and the environmental impact associated with the adoption of GM HT soybeans[78] (Table 42) shows:

- In 2010, there was a small net decrease in herbicide ai use of 3.6% (1.9 million kg). The EIQ load was, however, significantly lower by 35% 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, there have been savings in both active ingredient use and the associated environmental impact (as measured by the EIQ indicator) of 4.5% (-30.3 million kg) in active ingredient usage and -27% for the field EIQ load.

Table 42: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in the US 1996-2010

Year	ai decrease (kg)	eiq saving (units)	% decrease in ai	% eiq saving
1996	67,989	7,171,927	0.18	0.8
1997	447,542	47,215,219	1.06	4.5
1998	1,648,725	172,426,896	3.8	16.0
1999	2,294,618	252,068,358	5.16	22.9
2000	2,549,575	265,573,278	5.68	23.9
2001	3.104,816	315,700,504	6.95	28.5
2002	3,399,433	382,497,959	7.72	35.1
2003	3,603,399	370,162,816	8.14	33.8

[77] That is based on consultations with extension advisors in over 50 US states

[78] 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

2004	3,807,365	391,729,950	8.44	35.1
2005	4,170,010	386,371,129	9.72	36.3
2006	4,221,167	402,416,739	9.30	36.4
2007	2,812,022	224,342,547	6.83	26.3
2008	-277,900 (increase)	279,295,234	-0.57 (increase)	25.6
2009	403,677	449,901,608	0.78	34.1
2010	-1,937,220	504,225,844	-3.6	34.7

b) Canada

The analysis of impact in Canada is based on comparisons 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[79]. Details of these are presented in Appendix 3. Overall, this identifies:

- Up to 2006, an average ai/ha and field EIQ value/ha for GM HT soybeans of 0.9 kg/ha and 13.8/ha respectively, compared to conventional soybeans with 1.43 kg/ha of ai and a field EIQ/ha of 34.2;
- Post 2006, the same values for conventional with 1.32 kg/ai and a field EIQ/ha of 20.88 for GM HT soybeans.

Based on these values, at the national level[80], in 2010, there was a net decrease in the volume of active ingredient used of 5.4% (-113,730 kg) and a 27% decrease in associated environmental impact (as measured by the EIQ indicator: Table 43). Cumulatively since 1997, there has been a 8.8% saving in active ingredient use (2.1 million kg) and a 20.9% saving in field EIQ/ha indicator value.

Table 43: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Canada 1997-2010

Year	ai saving (kg)	eiq saving (units)	% decrease in ai (- = increase)	% eiq saving
1997	530	20,408	0.03	
1998	25,973	1,000,094	1.85	0.06
1999	106,424	4,097,926	7.41	2.98
2000	112,434	4,329,353	7.41	11.93
2001	169,955	6,544,233	11.12	17.90
2002	230,611	8,879,827	15.75	25.36
2003	276,740	10,656,037	18.53	29.83
2004	351,170	13,522,035	20.38	32.82
2005	373,968	14,399,885	22.24	35.80
2006	84,130	10,191,227	4.85	24.54
2007	75,860	9,167,500	4.49	22.71
2008	96,800	11,726,000	5.63	28.52
2009	103,374	12,521,832	5.23	26.49
2010	113,729	13,776,201	5.38	27.27

[79] Sources: George Morris Center (2004) and the (periodically) updated Ontario Weed Control Guide

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

c) Brazil

Drawing on herbicide usage data for the periods 2001-2003 and 2007-2009[81] and information from industry and extension advisers, the annual average use of herbicide active ingredient per ha in the early years of GM HT adoption was estimated to be a difference of 0.22kg/ha (ie, GM HT soybeans used 0.22 kg/ha less of herbicide active ingredient) and resulted in a net saving of 15.62 field EIQ/ha units. More recent data analysis for 2007-2009, however, suggests a change in herbicide regimes used in both systems, partly due to changes in herbicides available and increasing adoption of reduced/no tillage production practices (in both conventional and GM HT soybeans). As a result, estimated values for the respective systems in 2010 (see Appendix 3) were:

- An average active ingredient use of 2.37 kg/ha for GM HT soybeans compared to 1.96 kg/ha for conventional soybeans;
- The average field EIQ/ha value for the two production systems were 36.34/ha for GM HT soybeans compared to 30.71/ha for conventional soybeans[82].

Based on the above herbicide usage data, (Table 44):

- In 2010, the total herbicide active ingredient use and total field EIQ/ha values were respectively 20% and 10% higher than the conventional counterparts;
- Cumulatively since 1997, there has been a 2.7% increase in herbicide active ingredient use (17.9 million kg) and a 3.4% reduction in the environmental impact (332 million field EIQ/ha units).

Table 44: National level changes in herbicide ai use and field EIQ values for GM HT soybeans in Brazil 1997-2010

Year	ai saving (kg negative sign denotes increase in ai use)	eiq saving (units)	% decrease in ai (- = increase)	% eiq saving
1997	22,333	1,561,667	0.1	0.3
1998	111,667	7,808,333	0.3	1.4
1999	263,533	18,427,667	0.7	3.3
2000	290,333	20,301,667	0.7	3.4
2001	292,790	20,473,450	0.7	3.4
2002	389,145	27,211,105	0.8	3.8
2003	670,000	46,850,000	1.2	5.9
2004	1,116,667	78,083,333	1.7	8.4
2005	2,010,000	140,550,000	2.9	14.4
2006	2,546,000	178,030,000	4.0	19.8
2007	-5,808,563	-45,847,926	-8.8	-4.9
2008	-5,704,705	-45,028,156	-17.6	-8.2
2009	-6,642,000	-54,763,974	-18.7	-9.1
2010	-7,529,650	-62,082,740	-20.0	-10.0

[81] Sources: AMIS Global & Kleffmann

[82] Inclusive of herbicides (mostly glyphosate) used in no/low tillage production systems for burndown. Readers should note that this data is based on recorded usage for the two production systems and does not indicate if equal efficacy to the GM HT system is achieved in the conventional system

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[83]);
- In 2010, the area planted to soybeans had increased 18.4 million ha. Almost all of this (99%) was planted to varieties containing the GM HT trait, and 90% plus of this area used no/reduced tillage systems that rely more on herbicide-based weed control programmes than conventional tillage systems. Twenty four per cent of the total crop was also 'second crop soybeans' in 2010/11, which followed on immediately behind a wheat crop in the same season.

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 2010, the estimated average herbicide ai use was 2.64kg/ha and the average field EIQ was 36.88/ha[84]. Given 99% of the total crop is GM HT, these values effectively represent the typical values of use and impact for GM HT soybeans in Argentina.

These changes should, however, be assessed within the context of the fundamental changes in tillage systems that have occurred over the 1996-2010 period (some of which may possibly have taken place in the absence of the GM HT technology[85]). 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 15 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.

To make a representative comparison of usage of the GM HT crop, with what might reasonably be expected if all of the GM HT crop reverted to conventional soybean production, requires identification of typical herbicide treatment regimes for conventional soybeans that would deliver similar levels of weed control (in a no tillage production system) as achieved in the GM HT system. To do this, we identified a number of alternative conventional treatments in the mid 2000s and again more recently in 2010/11 (see Appendix 3). Based on these, the current GM HT, largely no tillage production system, has a slightly higher volume of herbicide ai use (2.64 kg/ha compared to 2.53 kg/ha) than its conventional no tillage alternative. However, in terms of associated environmental impact, as measured by the EIQ methodology, the GM HT system delivers a 15% improvement (GM HT field EIQ of 36.88/ha compared to 43.64/ha for conventional no/low tillage soybeans).

[83] Derived from GFK Kynetec herbicide usage data

[84] Source: AMIS Global (national herbicide usage data based on farm surveys)

[85] 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

At the national level these reductions in herbicide use[86] are equivalent to:

- In 2010, a 3.5% increase in the volume of herbicide ai used (2 million kg) but a net 12% reduction in the associated environmental impact, as measured by the EIQ indicator (122 million EIQ/ha units);
- Cumulatively since 1996, there has been a net reduction in herbicide ai use (due to estimates of earlier comparisons of GM HT versus conventional soybean herbicide usage for the late 1990s and early 2000s) of 2.6% (-16.2 million kg) and the field EIQ load is 12% lower (10,649 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

The analysis presented below for Paraguay is based on AMIS Global usage data for the soybean crop and estimates of conventional alternative equivalents. Based on this, the respective differences for herbicide ai use and field EIQ values for GM HT and conventional soybeans in 2010 were:

- Conventional soybeans: average volume of herbicide used 0.99 kg/ha and a field EIQ/ha value of 20.05/ha;
- GM HT soybeans: average volume of herbicide used 1.16 kg/ha and a field EIQ/ha value of 18.8/ha.

Using these values, the level of herbicide ai use and the total EIQ load in 2010 were respectively 16.3% higher in terms of active ingredient use (+0.46 million kg), but lower by 5.9% in terms of associated environmental impact as measured by the EIQ indicator (-3.4 million EIQ/ha units). Cumulatively, since 1999, herbicide ai use has been 5.4% higher (1.25 million kg[87]) whilst the associated environmental impact, as measured by the EIQ indicator, was 9.6% lower.

f) Uruguay

Analysis for Uruguay also draws on AMIS Global data and estimates of the herbicide regime on conventional alternatives that would deliver a level of weed control with equal efficacy to GM HT soybeans. Based on this, the respective values for 2010 were:

- Conventional soybeans: average volume of herbicide used 1.11 kg/ha and a field EIQ/ha value of 20.90/ha;
- GM HT soybeans: average volume of herbicide used 1.22 kg/ha and a field EIQ/ha value of 14.14/ha.

Using these values, the level of herbicide ai use and the total EIQ load in 2010 were respectively 4.2% higher in terms of active ingredient use (+108,000 kg), but lower by 14.6% in terms of associated environmental impact as measured by the EIQ indicator (-6.4 million EIQ/ha units).

[86] 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

[87] Up to 2006, estimated ai use was slightly higher for conventional relative to GM HT soybeans by 0.03 kg/ha

Cumulatively, since 1999, herbicide ai use has been 2.7% higher (286,000 kg[88]) whilst the associated environmental impact, as measured by the EIQ indicator, was 9.9% lower.

g) Bolivia

As no data on herbicide use in Bolivia has been identified, usage values and assumptions for differences in the adjacent country of Paraguay have been used. On this basis, the impact values are as follows:

- In 2010, a 13.5% increase in the volume of herbicide ai used (132,000 kg) but a net 4.9% reduction in the associated environmental impact, as measured by the EIQ indicator;
- Cumulatively since 2005, there has been a net increase in herbicide ai use of 7% (+331,000 kg) but a net reduction in the field EIQ load of 7%.

h) 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 45). More specifically:

- The average volume of herbicide ai applied has increased by 0.09 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[89] 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 45: 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 in use: kg)	eiq saving (units)	% decrease in ai (- = increase)	% eiq saving
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

[88] Up to 2006, estimated ai use was slightly higher for conventional relative to GM HT soybeans by 0.03 kg/ha

[89] 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

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%.

i) South Africa

GM HT soybeans have been grown in South Africa since 2000 (335,00 ha in 2010). 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 11.6% higher (equal to about 388,000 kg of ai) than the level of use if the crop had been conventional (in 2010 usage was 18% higher);
- The field EIQ load has fallen by 8% (equal to 5.4 million field EIQ/ha units) since 1999 (in 2010 the EIQ load was 8.2% lower).

j) Summary of impact

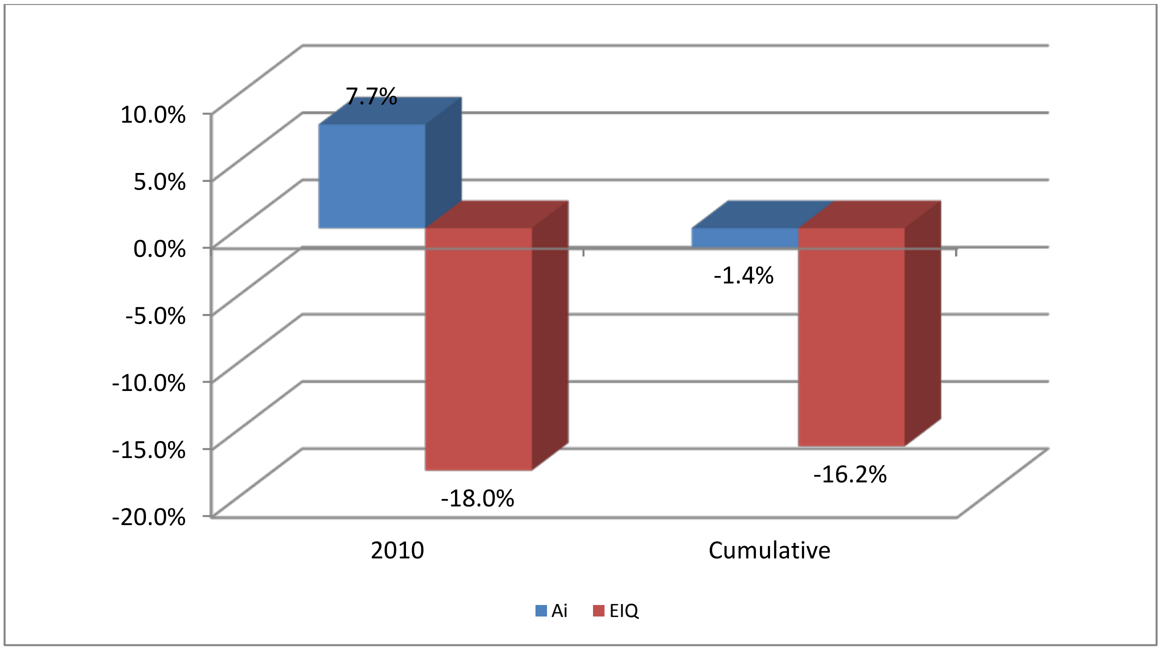
Across all of the countries that have adopted GM HT soybeans since 1996, the net impact on herbicide use and the associated environmental impact[90] has been (Figure 18):

- In 2010, a 7.7% increase in the total volume of herbicide ai applied (12.2 million kg) but an 18% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 1.4% less herbicide ai has been used (28.8 million kg) and the environmental impact applied to the soybean crop has fallen by 16.2%.

It should be noted that this analysis takes into consideration changes in herbicide use, in recent years, on GM HT soybeans, that have occurred to specifically address the issue of weed resistance to glyphosate in some regions. Whilst such actions have resulted in some farmers using additional herbicides to glyphosate with GM HT crops (that were not used in the early years of GM HT (to glyphosate) crop adoption), the net environmental impact associated with the herbicides used on GM HT crops continues to represent an improvement relative to purely conventional alternative form of production.

[90] 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 18: Reduction in herbicide use and the environmental load from using GM HT soybeans in all adopting countries 1996-2010



4.1.2 GM Herbicide tolerant (GM HT) maize

a) The USA

Drawing on the two main statistical sources of pesticide usage data (USDA and GfK Kynetec), Table 46 and Table 47 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 been about 0.6 to 0.7 kg/ha lower than the average usage on the residual conventional crop, although in the last three years, this differential has been about 0.1-0.2 kg/ha;
- The average field EIQ/ha used on a GM HT crop has been about 20/ha units lower than the conventional crop, although in the last four years the difference has narrowed;
- The recent increase in ai use and the associated field EIQ/ha for GM HT maize mainly reflects the increasing adoption of both reactive and proactive weed management practices designed to address the issue of weed resistance to glyphosate (see section 4.1.8 for more detailed discussion) .

Table 46: Herbicide usage on maize in the US 1996-2010

Year	Average ai use (kg/ha): NASS data	Average ai use (kg/ha) index 1998=100: GfK data	Average field EIQ/ha: NASS data	Average field EIQ/ha: GfK data
1996	2.64	N/a	54.4	N/a
1997	2.30	N/a	48.2	N/a
1998	2.47	100	51.3	62.0
1999	2.19	88.1	45.6	55.7
2000	2.15	87.8	46.2	54.5

2001	2.30	86.8	48.8	53.8
2002	2.06	82.4	43.4	51.1
2003	2.29	83.0	47.5	51.2
2004	N/a	80.0	N/a	48.9
2005	2.1	80.7	51.1	48.7
2006	N/a	79.3	N/a	47.7
2007	N/a	85.1	N/a	49.8
2008	N/a	88.8	N/a	50.9
2009	N/a	86.9	N/a	49.7
2010	2.36	90.5	49.2	51.4

Sources and notes: derived from NASS pesticide usage data 1996-2003 and 2010 (no data collected in 2004, 2006-2009), GfK Kynetec data from 1998-2010. N/a = not available. Average ai/ha figures derived from GfK dataset are not permitted by GfK to be published.

Table 47: Average US maize herbicide usage and environmental load 1997-2010: conventional and GM HT

Year	Average ai/ha (kg) index 1998=100: conventional	Average ai/ha index 1998=100 (kg): GMHT	Average field EIQ: conventional	Average field EIQ: GMHT
1997	92.3	98.9	57.0	36.02
1998	100	100	63.2	36.9
1999	87.9	99.5	55.9	36.8
2000	89.3	98.3	56.5	35.7
2001	87.9	105.9	56.2	38.4
2002	85.3	99.9	54.6	35.6
2003	87.3	100	55.6	34.9
2004	85.3	101.5	54.7	35.3
2005	87.9	109.1	56.2	38.5
2006	87.9	112.2	56.5	40.1
2007	92.8	128.2	59.4	45.9
2008	87.9	140.3	56.2	50.1
2009	88.8	136.9	56.1	48.9
2010	90.2	142.7	57.9	50.7

Sources and notes: derived from GfK Kynetec. 1998 and 1997 based on the average of the years 1997-1999. Average ai/ha figures derived from GfK dataset are not permitted by GfK to be published

The comparison data between the GM HT crop and the conventional alternative presented above, is, as indicated in section 4.1, however, not a reasonable representation of average herbicide usage on the average conventional alternative for recent years. It probably understates the herbicide usage for an average conventional maize grower, as the level of GM HT maize adoption has increased (70% of the total crop in 2010). The approach used to address this deficiency has been to make comparisons between typical herbicide treatment regimes for GM HT maize (including more recently the use of proactive and reactive weed management systems to address weed resistance issues), actual recorded usage of herbicides on the GM HT crop and typical herbicide treatment regime for an average conventional maize grower that would deliver a similar level of weed control to the level delivered in the GM HT system. This approach for identifying the 'conventional alternative' draws on the work of Sankala & Blumenthal (2003 & 2006) and Johnson & Strom (2008), but has been updated for 2009 and 2010. It compared typical herbicide treatment regimes for GM HT and average conventional maize crops (that would deliver similar levels of weed control in a conventional crop to the level delivered in the GM HT systems). For 2010, average values for conventional maize were 3.88 kg herbicide ai/ha and a field EIQ rating of 81.46/ha (regimes using a mix of herbicides such as acetochlor, atrazine, mesotrione, dicamba and difluenzopyr). This compares with GM glyphosate tolerant maize (2.55 kg herbicide ai/ha and a field EIQ rating of 48.94/ha (use of glyphosate plus half doses of acetochlor and atrazine relative to conventional crops)) and GM glufosinate tolerant maize (2.04 kg herbicide ai/ha and a field EIQ/ha rating of 44.76/ha).

At the national level (Table 48), in 2010, there has been an annual saving in the volume of herbicide active ingredient use of 22.1% (28.1 million kg). The annual field EIQ load on the US maize crop has also fallen by 26.5% in 2010 (equal to 907 million field EIQ/ha units). The cumulative decrease in active ingredient use since 1997 has been 10.6% (162 million kg), and the cumulative reduction in the field EIQ load has been 12%.

Table 48: National level changes in herbicide ai use and field EIQ values for GM HT maize in the US 1997-2010

Year	ai decrease (kg)	eiq saving (units)	% decrease in ai	% eiq saving
1997	150,669	3,289,024	0.15	0.16
1998	2,035,698	45,547,351	2.03	2.13
1999	1,691,777	39,635,149	1.75	1.92
2000	2,637,395	61,022,158	2.65	2.88
2001	2,733,427	65,572,295	2.88	3.25
2002	4,227,123	102,237,216	4.28	4.86
2003	5,226,766	127,103,738	5.31	6.06
2004	7,918,178	194,961,239	6.52	7.56
2005	7,658,532	223,957,285	6.39	8.39
2006	16,289,458	384,122,360	14.75	15.71
2007	28,117,185	663,032,455	21.31	22.69
2008	28,539,264	680,940,318	25.74	27.73
2009	27,087,280	657,124,206	22.25	25.90
2010	28,165,979	907,496,668	22.15	26.49

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[91] 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 36/ha and 39/ha compared to 61/ha for conventional maize;

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

- At the national level in 2010 (based on the plantings of the different production systems), the reductions in herbicide ai use and the total field EIQ load were respectively 17.9% (584,000 kg) and 21.1% (15.6 million: Table 49);
- Cumulatively since 1997, total national herbicide ai use has fallen by 11.2% (4.6 million kg) and the total EIQ load has fallen by 13% (120.6 million field EIQ units).

Table 49: Change in herbicide use and environmental load from using GM HT maize in Canada 1999-2010

Year	Total ai saving (kg)	Total field EIQ reductions (in units per hectare)
1999	59,324	1,439,924
2000	121,985	2,991,494
2001	177,902	4,461,172
2002	255,305	6,377,468
2003	209,556	5,334,283
2004	203,320	5,234,173
2005	467,088	11,963,706
2006	501,479	13,110,306
2007	697,961	18,379,776
2008	565,770	14,979,769
2009	776,103	20,837,313
2010	584,446	15,557,562

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 (1.03 million ha in 2010) has been:

- On a per hectare basis in 2010 there has been a 0.35 kg decrease in the amount of herbicide active ingredient used and an improvement in the average field EIQ of 19.7/ha;
- In 2010, at the national level, the amount of herbicide used was 360,000 kgs (-4.3%) 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 11.2% lower;
- Cumulatively since 2003, total national herbicide ai use has fallen by 1.6% (1.1 million kg) and the total EIQ load has fallen by 4.3%.

d) Argentina

Average use of herbicides across the total crop (based on AMIS Global data) puts the average ai/ha usage over the period 2006-2009 at between 2.7 kg/ha and 3 kg/ha, with the associated field EIQ/ha value in the range of 52/ha and 61/ha. The AMIS Global dataset does, however, not allow for dissagregation between GM HT and conventional maize, hence in order to assess differences between the two production systems, we have drawn on industry estimates of typical herbicide regimes for the two different systems (see Appendix 3). Based on this analysis, 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:

- The average volume of herbicide ai applied to GM HT maize is estimated to typically be 2.36g/ha compared to 2.77 kg/ha for conventional maize, in 2010;

- The average field EIQ/ha load for GM HT maize is significantly lower than the conventional counterpart (43.8/ha for GM HT maize, 57.8/ha for conventional maize);
- The reduction in the volume of herbicide used was 616,000 kg (-6.7%) in 2010. Since 2004, the cumulative reduction in usage has been 3.3% (- 1.8 million kg);
- In terms of the field EIQ load, the reduction in 2010 was 11.4% (-21.1 million field/ha units) and over the period 2004-2010, the load factor fell by 5.4%.

e) *Other countries*

GM HT maize was also grown commercially in the Philippines, for the first time in 2006 and 494,000 ha used this technology in 2010. 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.

GM HT maize was also grown commercially for the first time in 2010 in Brazil (404,000 ha) and Colombia (21,400 ha). Analysis of the environmental impact associated with changes in herbicide use on these crops has not been possible due to a lack of data.

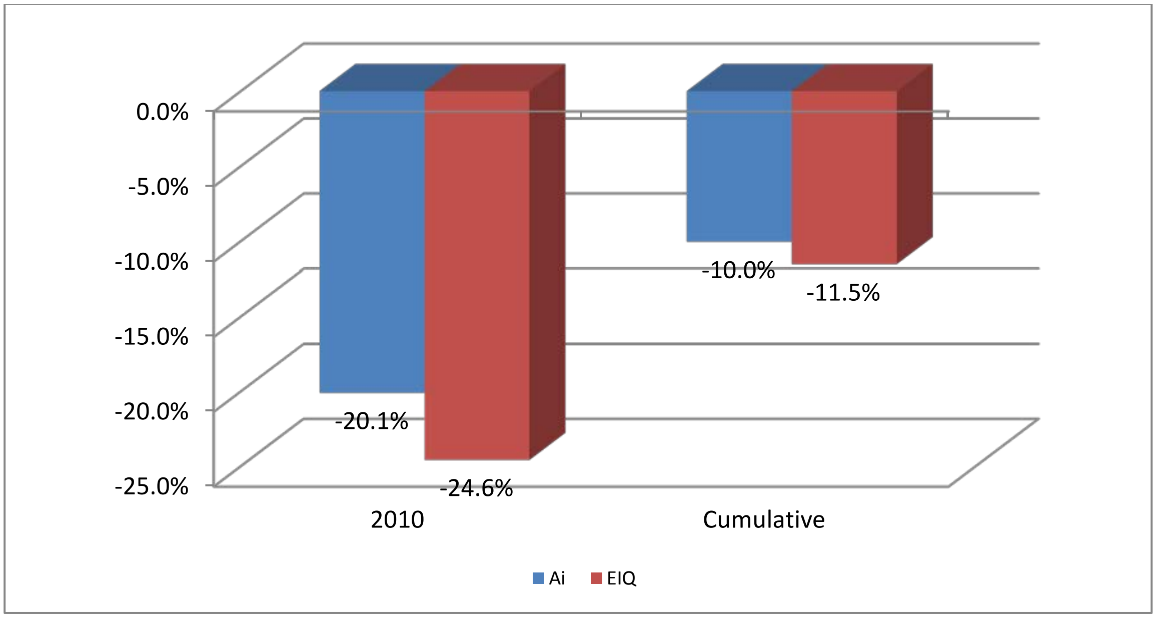
f) Summary of impact

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 19). More specifically:

- In 2010, total herbicide ai use was 20.1% lower (29.7 million kg) than the level of use if the total crop had been planted to conventional varieties. The EIQ load was also lower by 24.6%;
- Cumulatively since 1997, the volume of herbicide ai applied is 10% lower than its conventional equivalent (a saving of 170 million kg). The EIQ load has been reduced by 11.5%.

This analysis takes into consideration changes in herbicide use, in recent years, on GM HT maize that has specifically addressed the issue of weed resistance to glyphosate in some regions. Whilst such actions have resulted in some farmers using additional herbicides to glyphosate with GM HT crops (that were not used in the early years of GM HT (to glyphosate) crop adoption), the net environmental impact associated with the herbicides used on GM HT crops continues to represent an improvement relative to purely conventional alternative forms of production.

Figure 19: Reduction in herbicide use and the environmental load from using GM HT maize in adopting countries 1997-2010



4.1.3 GM HT Herbicide tolerant (GM HT) cotton

a) The USA

Drawing on the herbicide usage data from the USDA and GfK 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 fifeteen years, although there has been a rise in usage in the last few years (Table 50).

Table 50: Herbicide usage on cotton in the US 1996-2010

Year	Average ai use (kg/ha): NASS data	Average ai use (index 1998=100): GfK data	Average field EIQ/ha: NASS data	Average field EIQ/ha: based on GfK data
1996	1.98	N/a	53.19	N/a
1997	2.43	N/a	42.50	N/a
1998	2.14	100	35.60	45.4
1999	2.18	89.2	36.20	40.1
2000	2.18	95.4	35.20	42.5
2001	1.89	97.1	27.50	42.9
2002	N/a	97.1	N/a	42.3
2003	2.27	95.4	33.90	41.4
2004	N/a	103.3	N/a	44.5
2005	N/p	107.9	N/p	46.4
2006	N/a	105.0	N/a	45.8
2007	2.7	107.3	47.40	45.5
2008	N/a	113.3	N/a	48.8
2009	N/a	122.5	N/a	53.1
2010	2.5	142.0	53.11	61.5

Sources and notes: derived from NASS pesticide usage data 1996-2003 and 2010 (no data collected in 2002, 2004, 2006, 2008 & 2009), GfK Kynetec data from 1998-2010. N/p = Not presented - 2005 results based on NASS data are significantly different and inconsistent with previous trends and GfK data. These results have therefore not been presented. Average ai/ha figures derived from GfK dataset are not permitted by GfK to be published

Looking at a comparison of average usage data for GM HT versus conventional cotton, the GfK Kynetec dataset[92] 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 GfK dataset suggests that there has been a marginally lower average field EIQ rating for GM HT cotton in the first few years of adoption, but since then, the average field EIQ/ha rating has been lower for conventional cotton (Table 51).

Table 51: Herbicide usage and its associated environmental load: GM HT and conventional cotton in the US 1997-2010

Year	Average ai use (index 1998=100): conventional cotton	Average ai use (index 1998=100): GM HT cotton	Average field EIQ/ha: conventional cotton	Average field EIQ/ha: GM HT cotton
1997	109.4	104.8	48.2	46.1
1998	100	100	43.5	46.3
1999	84.6	90.0	37.1	37.8
2000	93.2	92.8	41.3	36.0
2001	85.2	99.5	38.0	44.5
2002	82.3	99.3	37.7	43.1
2003	72.9	100.2	33.1	40.1
2004	70.9	107.4	32.9	47.4
2005	70.4	110.6	33.5	48.7
2006	76.7	106.6	35.2	47.9
2007	75.6	107.4	33.7	47.1
2008	86.9	112.4	37.5	50.3
2009	75.6	123.6	35.4	55.4
2010	97.7	140.3	42.7	63.2

Sources and notes: derived from GfK 1998-2010. 1997 based on the average of the years 1997-1999. Average ai/ha figures derived from GfK dataset are not permitted by GfK to be published

The comparison data between the GM HT crop and the conventional alternative presented above, is, as indicated in section 4.1, not a reasonable representation of average herbicide usage on the average conventional alternative for recent years. The approach used to address this deficiency has been to make comparisons between typical herbicide treatment regimes for GM HT cotton (including more recently the use of proactive and reactive weed management systems to address weed resistance issues), actual recorded usage of herbicides on the GM HT crop and typical herbicide treatment regimes for an average conventional cotton grower that would deliver a similar level of weed control to the level delivered in the GM HT system. The approach for identifying the 'conventional alternative' draws on the work of Sankala & Blumenthal (2003 & 2006) and Johnson & Strom (2008), and has been updated for 2008 onwards. It compared typical herbicide treatment regimes for GM HT and average conventional cotton crops that would

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

deliver similar levels of weed control to that level delivered in the GM HT systems. Based on this methodology, the respective values for conventional cotton in the last five years are shown in Table 52. These usage levels were then compared to typical weed treatment regimes for GM HT cotton and recorded usage levels on the GM HT crop (which accounted for 78% of the total crop in 2010), using the dataset from GfK Kynetec.

Table 52: Average ai use and field EIQs for conventional cotton 2006-2010 to deliver equal efficacy to GM HT cotton

Year	ai use (kg/ha)	Field eiq/ha
2006	2.61	49.34
2007	2.98	52.14
2008	3.26	60.08
2009	3.59	64.59
2010	4.07	73.62

Sources: based on Sankala & Blumenthal (2006), Johnson & Strom (2008) and updated to reflect changes in weed resistance management practices

Using this basis for herbicide regimes for conventional cotton and comparing with typical weed control regimes for GM HT cotton and recorded usage for GM HT cotton (from the GfK Kynetec dataset), at the national level (Table 53), the impact of using the GM HT technology in 2010 resulted in a 10.2% decrease in the amount of herbicide use (1.84 million kg) and an 11% decrease in the associated environmental impact, as measured by the EIQ indicator. Cumulatively since 1997, there have been savings in herbicide use of 4.2% for ai use (8.7 million kg) and a 6.9% reduction in the associated environmental impact, as measured by the EIQ indicator.

Table 53: National level changes in herbicide ai use and field EIQ values for GM HT cotton in the US 1997-2010

Year	ai decrease (kg: + sign denotes increase in usage)	eiq saving (units)	% decrease in ai	% eiq saving
1997	194,126	2,428,514	1.3	0.8
1998	268,015	5,612,708	1.8	+0.5
1999	1,111,761	31,351,903	6.8	8.0
2000	1,065,210	40,941,518	6.3	7.8
2001	710,162	20,555,753	4.1	7.4
2002	706,310	24,032,871	4.5	7.2
2003	512,302	28,841,339	3.9	7.4
2004	+4,001	8,599,710	0.0	3.8
2005	+268,966	4,840,670	+1.8	1.8
2006	+314,796	5,367,442	+2.0	1.9
2007	831,195	14,492,231	6.4	6.4
2008	895,615	18,599,640	9.0	10.1
2009	1,192,270	23,265,816	9.3	10.1
2010	1,840,035	35,897,072	10.2	11.0

b) Australia

Drawing on information from the University of New England study from 2003[93], analysis of the typical herbicide treatment regimes for GM HT and conventional cotton and more recent industry assessments of conventional versus the newer 'Roundup Ready Flex' cotton that is widely used in Australia (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). Under the Roundup Ready Flex versus conventional equivalent[94], the conventional ai/ha load is 0.47 kg/ai more;
- The average field EIQ/ha value for GM HT cotton has been 51/ha, compared to 66/ha for conventional cotton. Under the Roundup Ready Flex versus conventional equivalent, the conventional cotton has a higher field EIQ/ha load of 4.5/ha;
- Based on the above data, at the national level (Table 54), in 2010, herbicide ai use has been 10.6% lower than the level expected if the whole crop had been planted to conventional cotton cultivars. The total field EIQ load was 6.5% lower;
- Cumulatively since 2000, total national herbicide ai use fell by 2.6% (385,440 kg) and the total EIQ load decreased by 3.7%.

Table 54: National level changes in herbicide ai use and field EIQ values for GM HT cotton in Australia 2000-2010

Year	ai decrease (kg: + sign denotes increase in usage)	eiq saving (units)	% change in ai	% eiq saving
2000	-1,290	106,030	-0.1	0.4
2001	-8,051	661,743	-0.8	3.6
2002	-9,756	801,898	-1.5	6.5
2003	-9,028	742,052	-1.7	7.2
2004	-17,624	1,448,593	-2.0	9.0
2005	-24,235	1,991,945	-2.9	12.1
2006	48,910	471,405	7.4	4.5
2007	23,718	228,602	8.4	5.2
2008	57,591	555,084	9.0	5.5
2009	83,111	801,049	10.3	6.3
2010	242,096	2,333,389	10.6	6.5

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:

- In 2010, there has been an average 0.1 kg decrease in the amount of herbicide active ingredient used and a 13% decrease in the environmental impact, as measured by the EIQ indicator (-4.3 field EIQ/ha units);

[93] Doyle et al (2003)

[94] Designed to deliver equal efficacy

- At the national level, the amount of herbicide used in 2010 was 131 kg (0.6%) 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, however, 13.4% lower;
- Cumulatively since 2001, total national herbicide ai use increased by 1.3% (5,600 kg), whilst the total EIQ load fell by 6.9%. 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 2010, there were 608,500 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 2010, the national level reduction in the amount of herbicide applied to the cotton crop was 1 million kg (-47%) lower than would otherwise have occurred if the whole crop had been planted to conventional varieties. The associated EIQ load was 57% lower;
- Cumulatively, since 2002, the amount of herbicide active ingredient applied had fallen 28% (-3.2 million kg). The field EIQ rating associated with herbicide use on the Argentine cotton crop fell 34% over the same period.

e) Other countries

Cotton farmers in Mexico, Colombia and Brazil have also been using GM HT technology since 2005, 2006 and 2009 respectively. No analysis is presented for the impact of using this technology in these countries because of the limited availability of herbicide usage data.

f) Summary of impact

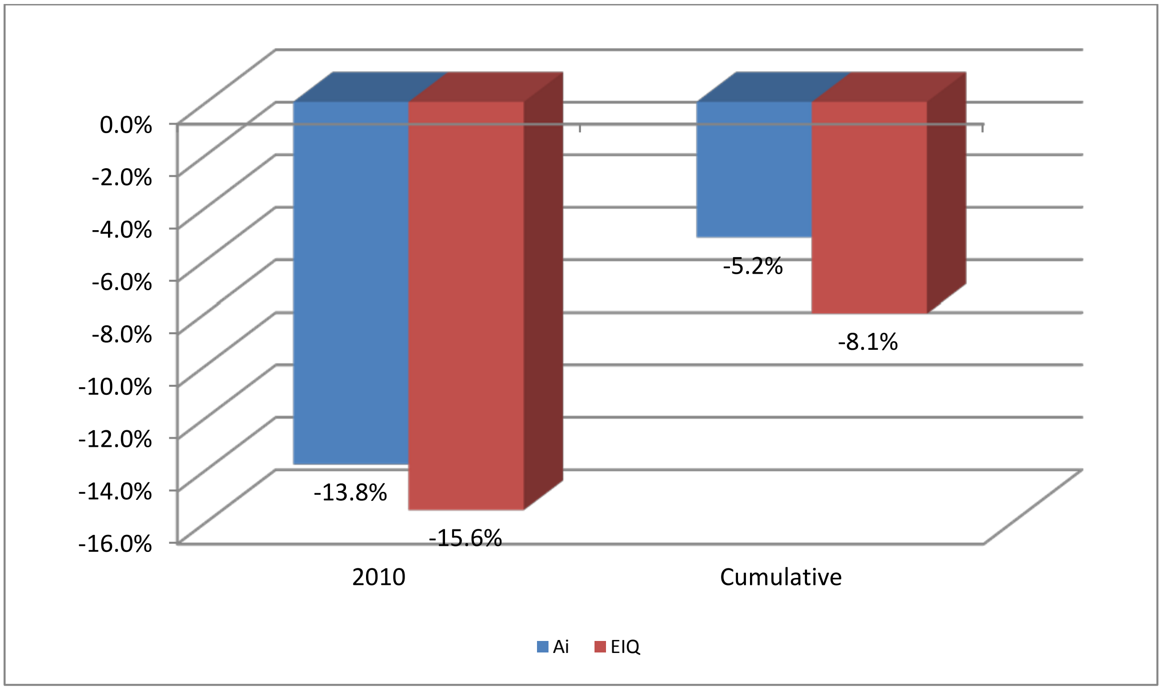
In 2010, the overall effect of using GM HT cotton technology (Figure 20) in the adopting countries has been a reduction in herbicide ai use[95] of 13.8% and a decrease in the total environmental impact of 15.6%. Cumulatively since 1997, herbicide ai use fell by 5.2% (-12.1 million kg) and the associated environmental impact fell by 8.1%.

As with the analysis of herbicide use changes on GM HT soybeans and maize, this analysis takes into consideration changes in herbicide use, in recent years, on GM HT cotton that has occurred to specifically address the issue of weed resistance to glyphosate in some regions (notably the US). Such actions have resulted in a significant number of (US) cotton farmers using additional herbicides to glyphosate with GM HT cotton (that were not used in the early years of GM HT (to glyphosate) crop adoption) and can be seen in the increase in the average amounts of herbicide active ingredient applied per ha. Nevertheless, the net environmental impact associated with the herbicides used on GM HT crops in 2010 continues to represent an improvement relative to the

[95] 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

environmental profile of herbicides that would likely be used if the crop reverted to using conventional (non GM) technology.

Figure 20: Reduction in herbicide use and the environmental load from using GM HT cotton in the US, Australia, Argentina and South Africa 1997-2010



4.1.4 GM Herbicide tolerant (GM HT) canola

a) The USA

Based on analysis of typical herbicide treatments for conventional, GM glyphosate tolerant and GM glufosinate tolerant canola identified in Sankala and Blumenthal (2003 & 2006), Johnson and Strom (2008), updates for 2010 undertaken as part of this research and data from the GfK Kynetec dataset (see Appendix 3), the changes in herbicide use and resulting environmental impact arising from adoption of GM HT canola in the US since 1999[96] are summarised in Table 55. This shows consistent savings in terms of both the amount of herbicide active ingredient applied and the EIQ value for both glyphosate and glufosinate tolerant canola relative to conventional canola.

Table 55: Active ingredient and field EIQ differences conventional versus GM HT canola US 1999-2010

Year	ai saving GM HT (to glyphosate: kg/ha)	ai saving GM HT (to glufosinate: kg/ha)	eiq saving GM HT (to glyphosate: field eiq/ha)	eiqsaving GM HT (to glufosinate: field eiq/ha)
1999	0.68	0.75	14.8	18.4
2000	0.68	0.75	14.8	18.4
2001	0.68	0.75	14.8	18.4

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

2002	0.57	0.75	17.7	18.4
2003	0.57	0.75	17.7	18.4
2004	0.79	0.83	21.2	19.8
2005	0.79	0.83	21.2	19.8
2006	0.7	0.78	19.8	18.8
2007	0.47	0.74	15.8	17.9
2008	0.47	0.74	15.8	17.9
2009	0.11	0.72	10.2	17.6
2010	0.09	0.57	9.9	14.6

Sources: derived from Sankala & Blumenthal (2003 & 2006), Johnson & Strom (2008) and updates of this work, GfK Kynetec

The reduction in the volume of herbicides used was equal to 131,000 kg of active ingredient (-20%) in 2010. In terms of the EIQ load, this had fallen by 5.9 million field EIQ units (-40%) compared to the load that would otherwise have been applied if the entire crop had been planted to conventional varieties. Cumulatively, since 1999, the amount of active ingredient use has fallen by 37%, and the EIQ load reduced by 47%.

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 0.65 kg/ha (GM glyphosate tolerant) and 0.39 kg/ha (GM glufosinate tolerant), compared to 1.13 kg/ha for conventional canola. This analysis has been applied to the years to 2004. From 2005, the conventional 'alternative' used as the basis for comparison is 'Clearfield' canola, which makes up the vast majority of conventional plantings[97]. In terms of active ingredient use, GM HT canola tolerant to glyphosate uses more (+0.137 kg/ha) but GM HT to glufosinate uses less (-0.21 kg/ha) active ingredient than 'Clearfield' canola;
- The average field EIQ/ha load for GM HT canola has been significantly lower than the conventional counterpart (10/ha for GM glyphosate tolerant canola, 7.9/ha for GM glufosinate tolerant canola, 26.2/ha for conventional canola). In relation to comparisons with 'Clearfield' canola (used from 2005 as the comparison) in terms of EIQ field ratings, the typical GM HT to glyphosate canola results in a saving of 0.84/ha and GM HT to glufosinate canola results in a saving of 4.45/ha;
- On the basis of comparisons with 'Clearfield' canola, the reduction in the volume of herbicide used was 0.22 million kg (a reduction of 5.9%) in 2010. Since 1996, the cumulative reduction in usage has been 18% (11.9 million kg);
- In terms of the field EIQ load, the reduction in 2010 was 21.2% (15.9 million) and over the period 1996-2010, the load factor fell by 28%.

c) Australia

Australia first allowed commercial planting of GM HT canola in 2008. Based on analysis of Fischer & Tozer (2009: see Appendix 3) which examined the use of GM HT (to glyphosate) canola relative to triazine tolerant (non GM) and 'Clearfield' canola, the average savings from adoption of the GM HT system were 0.4 kg/ha of active ingredient use and a reduction in the average field EIQ/ha of 2.74/ha (when applied to the 2010 crop weighted by type of conventional canola the

[97] Herbicide tolerant by a non GM process, tolerant to the imidazolinone group of herbicides

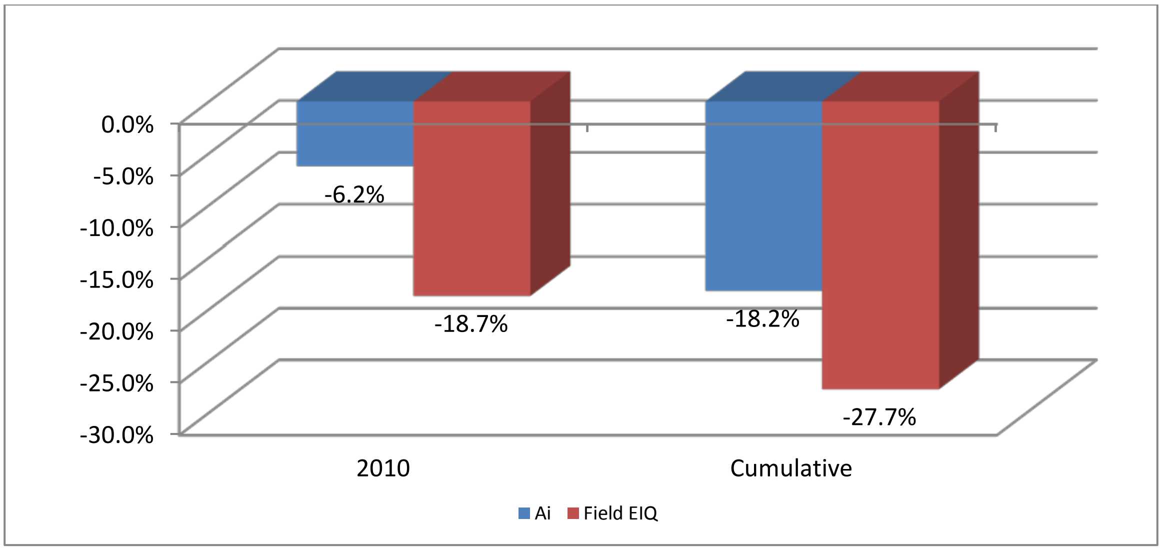
GM HT replaced (ie, triazine tolerant or 'Clearfields')). At the national level in 2010, this resulted in a net saving of just over 53,810 kgs of active ingredient (2.5% saving across the total canola crop) and a 1.3% reduction in the associated environmental impact of herbicide use (as measured by the EIQ indicator) on the Australian canola crop.

d) Summary of impact

In the 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 21). More specifically:

- In 2010, total herbicide ai use was 6.2% lower (0.4 million kg) than the level of use if the total crop had been planted to conventional non GM varieties. The EIQ load was also lower by 18.7%;
- Cumulatively since 1996, the volume of herbicide ai applied was 18.2% lower than its conventional equivalent (a saving of 14.4 million kg). The EIQ load had been reduced by 27.7%.

Figure 21: Reduction in herbicide use and the environmental load from using GM HT canola in the US, Canada and Australia 1996-2010



4.1.5 GM HT sugar beet

The USA

GM HT sugar beet was first planted on a small area in the US in 2007, and in 2010 accounted for 96% (445,160 ha) of the total US sugar beet crop. In terms of weed control, the use of this technology has resulted in a switch in use from a number of selective herbicides to glyphosate. Drawing on evidence from a combination of industry observers and the GfK Kynetec dataset on pesticide use, the analysis below summarises the environmental impact (see appendix 3 for details of the typical conventional versus GM HT sugar beet treatment).

The switch to GM HT sugar beet has resulted in a net increase in the amount of herbicide active ingredient used (about +0.39 kg/ha 2007-2009 and +0.62 kg/ha in 2010), but a decrease in the field EIQ/ha value of about 4/ha 2007-2009 and 0.4/ha in 2010. As a result, the 2010 impact of use of the technology was an increase in the volume of herbicide ai applied of 276,000 kg (+39%) but a decrease in the associated environmental load, as measured by the EIQ indicator of 1.1%. Cumulatively, since 2007 there has been additional use of 0.54 million kg of ai but a 5% improvement in the associated environmental impact of herbicides used on the US sugar beet crop (as measured by the EIQ indicator).

GM HT sugar beet is also planted on a small area (about 20,000 ha) in Canada. Due to the lack of publicly available data on sugar beet herbicide use in Canada, no environmental impact analysis is presented. The impact is likely to be similar to the impact in the US.

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 56). Whilst levels of insecticide ai use have fallen on both conventional and GM IR maize, usage by GM IR growers has consistently been lower than their conventional counterparts (with the exception of 2008). A similar pattern has occurred in respect of the average field EIQ value. This data therefore suggests both that insecticide use *per se* has fallen on the US maize crops over the last fifteen years and that usage on GM IR crops has fallen by a greater amount. However, examining the impact of GM IR traits on insecticide use is more complex because:

- There are a number of pests for the maize crop. These vary in incidence and damage by region and year and typically affect only a proportion of the total crop. In the case of GM IR maize, this comprises two main traits that target corn boring pests and the corn rootworm. In the US, typically, a maximum of about 10% of the crop was treated with insecticides for corn boring pests each year and about 30% of the US corn area treated with insecticides for corn rootworm. This means that assessing the impact of the GM IR technology requires disaggregation of insecticide usage specifically targeted at these pests and limiting the maximum impact area to the areas that would otherwise require insecticide treatment, rather than necessarily applying insecticide savings to the entire area planted to seed containing GM IR traits targeting these pests;
- Typically, the first users of the GM IR technology will be those farmers who regularly experience economic levels of damage from the GM IR target pests. This means that once the level of adoption (in terms of areas planted to the GM IR traits) is in excess of the areas normally treated with insecticide sprays for these pests, it is likely that additional areas planted to the traits are largely for insurance purposes and no additional insecticide savings would arise (if assumed across all of the GM IR area). Secondly, comparing the level of insecticide use on the residual conventional crop with insecticide use on the GM IR area would probably understate the insecticide savings, because the residual conventional farmers tend to be those who do not suffer the pest problems that are the target of the GM IR technology and hence do not spray their crops with appropriate insecticide treatments;

- The widespread adoption of GM IR maize technology has resulted in 'area-wide' suppression of target pests such as the European Corn Borer in maize crops. As a result, conventional farmers have benefited from this lower level of pest infestation and the associated reduced need to conduct insecticide treatments (Huchison et al (2010)).

In order to address these issues, our approach has been to first identify the insecticides typically used to treat the corn boring and corn rootworm pests and their usage rates from the GfK Kynetec database and relevant literature (eg, Carpenter & Gianessi (1999)). These sources identified average usage of insecticides for the control of corn boring pests and corn rootworm at 0.6 kg/ha and 0.216 kg/ha respectively. The corresponding field EIQ/ha values are 20/ha for corn boring pests and 7.63/ha for corn rootworm.

These active ingredient and field EIQ savings were then applied to the maximum of the area historically receiving insecticide spray treatments for corn boring pests and corn rootworm (10% and 30% respectively of the US maize crop) or the GM IR area targeting these pests, whichever was the smallest of the two areas.

Based on this approach, at the national level, the use of GM IR maize has resulted in an annual saving in the volume of insecticide ai use of 83.8% (of the total usage of insecticides typically targeted at both corn boring pests and corn rootworm) in 2010 (4.1 million kg) and the annual field EIQ load fell by 82.3% in 2010 (equal to 141 million field EIQ/ha units). Since 1996, the cumulative decrease in insecticide ai use has been 40% (36.6 million kg), and the cumulative reduction in the field EIQ load has been 34% (Table 57).

Table 56: Average US maize insecticide usage and its environmental load 1996-2010: 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	0.66	0.61	19.3	18.1
1997	0.65	0.59	19.0	17.7
1998	0.71	0.63	20.3	18.4
1999	0.63	0.61	18.4	18.3
2000	0.62	0.54	18.2	16.4
2001	0.51	0.49	15.5	14.4
2002	0.48	0.30	15.0	10.5
2003	0.55	0.41	16.0	12.5
2004	0.57	0.30	16.7	10.3
2005	0.43	0.33	12.8	11.2
2006	0.53	0.34	15.4	10.5
2007	0.39	0.24	11.9	7.9
2008	0.31	0.27	9.6	8.3
2009	0.26	0.21	8.7	7.0
2010	0.51	0.4	17.1	14.0

Sources: derived from GfK Kynetec (excludes seed treatments for which there is no significant difference in the pattern of usage between conventional and GM IR maize) and Carpenter & Gianessi (1999).

Table 57: National level changes in insecticide ai use and field EIQ values for GM IR maize in the US 1996-2010 (targeted at cornboring and rootworm pests)

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% eiq saving
1996	180,000	6,000,000	2.8	1.9
1997	1,467,773	48,925,760	19.1	14.0
1998	1,946,520	64,884,000	22.6	17.7
1999	1,879,080	62,636,000	25.9	20.3
2000	1,931,640	64,388,000	25.7	21.6
2001	1,838,160	61,272,000	30.1	25.1
2002	1,915,680	63,856,000	29.2	24.1
2003	1,943,603	64,855,127	31.4	26.8
2004	2,105,594	70,494,074	36.3	32.0
2005	2,344,543	78,852,057	51.4	47.8
2006	2,776,990	94,275,192	65.9	64.4
2007	4,176,915	142,948,919	72.9	68.2
2008	3,972,994	136,462,730	76.8	72.7
2009	4,038,767	138,738,515	78.3	74.7
2010	4,113,864	141,321,293	83.8	82.3

Note: 2003 was the first year of commercial use of GM IR targeting corn rootworm

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[98], 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 targeted at corn boring pests has been 520,000 kg (-94%). In terms of environmental load, the total EIQ/ha load has fallen by 17.5 million units (-82%)[99].

c) Spain

Analysis for Spain draws on insecticide usage data from the early years of GM IR trait adoption when the areas planted with this trait were fairly low (1999-2001 – from Brookes (2002)) and restricts the estimation of insecticide savings to a maximum of 10% of the total maize crop area, which may have otherwise received insecticide treatments for corn boring pests. The difference in the data presented for Spain relative to the other countries is that the changes identified in insecticide usage relate to total insecticide use rather than insecticides typically used to target corn boring pests. The analysis of changes in insecticide usage as a result of the adoption of GM IR maize is a net decrease in both the volume of insecticide used and the field EIQ/ha load[100]. More specifically:

[98] And limiting the national impact to 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

[99] This relates to the total insecticide usage that would otherwise have probably been used on the Canadian maize crop to combat corn boring pests

[100] The average volume of all insecticide ai used is 0.96 kg/ha with an average field EIQ of 26/ha

- The volume of total maize insecticide ai use was 35% lower than the level would probably have been if the entire crop had been conventional in 2010 (-31,000 kg). Since 1998 the cumulative saving (relative to the level of use if all of the crop had been conventional) was 389,280 kg of insecticide ai (a 34% decrease);
- The field EIQ/ha load has fallen by 19% since 1999 (-10.5 million units). In 2010, the field EIQ load was 19.9% 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:

- 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 6.11/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 3.06/ha;
- The first 200,000 ha to adopt GM IR technology is assumed to be irrigated crops.

Based on these assumptions:

- In 2010, the adoption of GM IR maize resulted in a net reduction in the volume of insecticides used of 165,310 kg (relative to the volume that would probably have been used if 1.768 million ha had been treated with insecticides targeted at corn boring pests). The EIQ load (in respect of insecticide use targeted at corn boring pests) was almost 100% 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 57% (1.03 million kg ai).

f) Brazil

The GM IR maize area in Brazil, in 2010, was 7.44 million ha (first planted commercially in 2008). Corn boring pests (notably the Fall Armyworm (*Spodoptera)*) are a major pest problem for maize crops in Brazil, and approximately 50% of the total annual crop has regularly been treated with insecticides targeting this pest (typically five spray treatments/crop).

The availability of GM IR maize has allowed users to decrease the number of insecticide spray runs from about five to two and significantly reduce the use of insecticides such as methomyl, lufenuron, triflumuron, sponosad and thiodicarb. As a result, the typical average saving in active ingredient use has been 0.356 kg/ha and the field EIQ/ha saving has been 21.5/ha[101]. Applying these savings to the national level (constrained to a maximum of 48% of the total maize crop that has been the historic average annual area receiving insecticide treatments for corn boring pests), this resulted in 2.34 million kg of insecticide active ingredient saving in 2010. This represents a 100% reduction in the environmental impact associated with insecticide use targeted at corn boring pests. Cumulatively, over the three years of use, the ai and field EIQ savings have been 66% lower than they would otherwise have been if this technology had not been used (a saving of 4.55 million kg of ai).

g) Colombia

The GM IR area in Colombia in 2010 was about 36,200 ha (first grown in 2009). Based on analysis by Mendez et al (2011), this estimates that conventional maize growers (in the San Juan valley) typically use 0.56 kg/ai of insecticide to control corn boring pests, with an average field EIQ of 15.89/ha. Applying these savings to the areas planted in 2009 and 2010 to GM IR maize shows a saving in insecticide active ingredient use of 12,460 kgs. In terms of both active ingredient use and EIQ rating, this represents about a 20% reduction.

h) Other countries

GM IR maize has also been grown on significant areas in the Philippines (since 2003: 458,500 ha planted in 2010), in Uruguay (since 2004: 100,000 ha in 2010) and in Honduras (on a trial basis: since 2003: 15,000 ha in 2010). Due to limited availability on insecticide use on maize crops (targeting corn boring pests)[102], it has not been possible to analyse the impact of reduced insecticide use and the associated environmental impact in these countries.

i) 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 22):

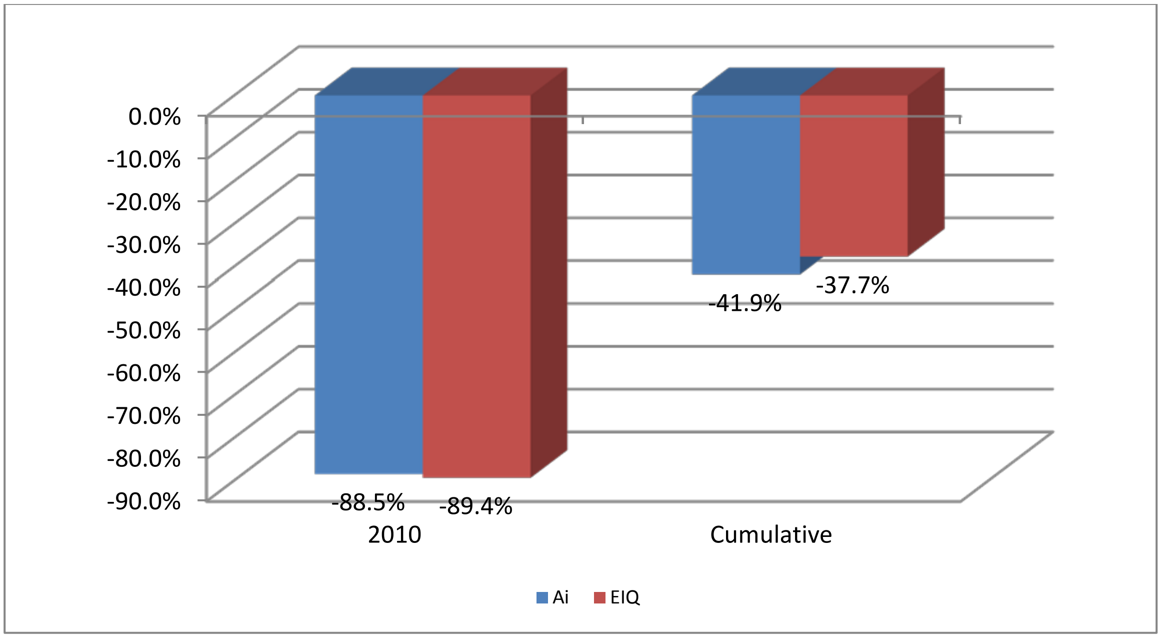
- In 2010, a 88.5% decrease in the total volume of insecticide ai applied (6.7 million kg) and a 89.4% reduction in the environmental impact (measured in terms of the field EIQ/ha load[103]);
- Since 1996, 41.9% less insecticide ai has been used (42.9 million kg) and the environmental impact from insecticides applied to the maize crop has fallen by 37.7%.

[101] Based on AMIS Global data for the 2006-2009 period

[102] 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

[103] Readers should note that these estimates relate to usage of insecticides targeted at corn boring and rootworm pests. Some of the active ingredients traditionally used to control these pests may still be used with GM IR maize for the control of some other pests that the GM IR technology does not target

Figure 22: Reduction in insecticide use and the environmental load from using GM IR maize in adopting countries 1996-2010



4.1.7 GM insect resistant (GM IR) cotton

a) The USA

Whilst the annual average volume of insecticides used on the US cotton crop has fluctuated (as to be expected according to variations in regional and yearly pest pressures), there has been an underlying decrease in usage (Table 58). Applications on GM IR crops and the associated environmental impact have also been consistently lower for most years until 2007. Drawing conclusions from the usage data for the conventional versus GM IR cotton alone should, however, be treated with caution for a number of reasons (see also section 4.1.6):

- There are a number of pests for the cotton crop. These vary in incidence and damage by region and year and may affect only a proportion of the total crop. In the case of GM IR cotton, this comprises traits that target various *Heliothis* pests (eg, budworm and bollworm). These are major pests of cotton crops in all cotton growing regions of the world (including the US) and can devastate crops, causing substantial reductions in yield, unless crop protection practices are employed. In the US, all of the crop may typically be treated with insecticides for *Heliothis* pests each year although in some regions, notably Texas, the incidence and frequency of pest pressure tends to be much more limited than in other regions. In addition, there are pests such as boll weevil that may be commonplace but which are not targeted by current GM IR traits and crops receive insecticide treatments for these pests. This means that assessing the impact of the GM IR cotton technology requires disaggregation of insecticide usage specifically targeted at the *Heliothis* pests, and possibly limiting the maximum impact area to the areas that would otherwise require insecticide treatment rather than necessarily applying insecticide savings to the entire area planted to seed containing GM IR traits targeting these pests;

- The widespread adoption of GM insect resistant technology has resulted in 'area-wide' suppression of target pests such as some *Heliothis* pests in cotton crops. As a result, some conventional farmers have benefited from this lower level of pest infestation and the associated reduced need to conduct insecticide treatments (Wu et al (2008));
- Typically, the first users of the GM IR technology will be those farmers who regularly experience economic levels of damage from the GM IR target pests. This means that once the levels of adoption (in terms of areas planted to the GM IR traits) become significant (above 50% of the US crop from 2005, and 73% in 2010), it is likely that the residual conventional crop tends to be found in regions where the pest pressure and damage from *Heliothis* pests is lower than would otherwise be the case in the regions where GM IR traits have been adopted. Hence, using data based on the average insecticide use on this residual conventional crop as an indicator of insecticide use savings relating to the adoption of GM IR traits probably understates the insecticide savings.

In order to address these issues, our approach has been to first identify the insecticides typically used to treat the *Heliothis* pests and their usage rates from the GfK Kynetec database and relevant literature (eg, Carpenter & Gianessi (1999), Sankala & Blumenthal (2003 & 2006)). This identified average usage of a number of insecticides commonly used for the control of *Heliothis* pests in terms of amount of active ingredient applied, field eiq/ha values and the proportion of the total crop receiving each active ingredient in a baseline period of 1996-2000. As most of these insecticide active ingredients are still in use in 2010 (for control of some other pests than those targeted by the GM IR trait), we have calculated the potential maximum usage of each insecticide for each year under the assumption of no GM IR technology was used (using the baseline 1996-2000 adoption rates) and then compared these levels of use with actual recorded usage in each year. The differences between these two values represents the savings in insecticide usage attributed to the GM IR technology. Thus the annual savings estimated have been between 0.21 kg/ha and 0.405 kg/ha of active ingredient use and the field EIQ savings have been between 7.76/ha and 14.9/ha. In 2010, the savings were 0.369 kg/ai/ha and the field eiq saving was 13.54/ha. These active ingredient and field EIQ savings were then applied to the GM IR area targeting these pests.

At the national level, the use of GM IR cotton has resulted in an annual saving in the volume of insecticide ai use of 23% in 2010 (1.19 million kg) and the annual field EIQ load on the US cotton crop also fell by 25.7% in 2010 (equal to 43.6 million field EIQ/ha units). Since 1996, the cumulative decrease in insecticide ai use has been 9.7% (8.67 million kg), and the cumulative reduction in the field EIQ load has been 9.9% (Table 59).

Table 58: Average US cotton insecticide usage and environmental impact 1996-2010: conventional versus biotech

Year	Average ai/ha (kg) index 1998=100: conventional	Average ai/ha (kg) index 1998=100: GM IR	Average field EIQ: conventional	Average field EIQ: GM IR
1996	82.7	80.1	40.1	32.4
1997	118.7	118.2	53.0	44.0
1998	100	100	53.6	43.7
1999	82.0	44.0	45.3	41.1
2000	87.4	53.5	47.6	45.1

2001	88.3	41.7	47.8	32.9
2002	57.7	42.5	29.2	33.5
2003	100.4	36.6	50.3	28.5
2004	56.4	44.6	28.0	34.0
2005	32.8	38.3	14.6	20.4
2006	95.0	39.9	42.3	28.8
2007	60.4	47.9	29.9	35.1
2008	44.4	40.3	20.8	29.1
2009	39.3	35.4	18.3	26.0
2010	67.5	38.3	30.7	27.7

Sources: derived from GfK Kynetec

Table 59: National level changes in insecticide ai use and field EIQ values for GM IR cotton in the US 1996-2010

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% eiq saving
1996	213,371	7,708,736	3.1	3.2
1997	219,217	7,919,934	2.3	2.7
1998	236,617	8,548,572	2.8	2.7
1999	410,076	15,070,341	5.9	5.4
2000	564,221	19,685,752	6.9	6.3
2001	136,502	27,049,342	9.3	9.2
2002	511,015	18,226,708	9.2	9.2
2003	560,624	20,236,059	9.1	9.2
2004	649,509	23,980,157	11.6	12.9
2005	1,143,628	42,105,057	26.9	24.2
2006	1,193,080	43,623,825	15.1	16.0
2007	929,047	34,274,333	17.7	18.7
2008	613,891	22,331,832	19.9	21.9
2009	689,965	25,161,611	21.2	23.3
2010	1,187,626	43,639,636	23.2	25.7

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 in the earlier years of adoption was about 1.35 kg/ha, compared to 6.02 kg/ha for conventionally grown cotton (a 77% decrease)[104]. In terms of an average field EIQ load/ha the GM IR cotton insecticide load was 61/ha compared to 292/ha for conventional cotton. More recent assessments of these comparisons (see Appendix 3) put the average conventional treatment at 2.75 kg/ha, with a field EIQ/ha of 124.38/ha, compared to 1.86 kg/ha and a field EIQ/Ha of 82.74/ha for GM IR cotton.

Based on these differences, the amount of insecticide ai used and its environmental load impact were respectively 22.5% and 21.7% lower in 2010 (Table 60) 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 30.6% (105.2 million kg ai) and the field EIQ load has fallen by 31.4% (5.1 billion field EIQ/ha units).

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

Table 60: National level changes in insecticide ai use and field EIQ values for GM IR cotton in China 1997-2010

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% eiq saving
1997	158,780	7,843,630	0.6	0.6
1998	1,218,870	60,211,395	4.5	4.6
1999	3,054,180	150,874,530	13.6	13.9
2000	5,678,720	280,525,120	24.8	25.3
2001	10,152,580	501,530,930	35.0	35.7
2002	9,807,000	484,459,500	38.8	39.5
2003	13,076,000	645,946,000	42.5	42.5
2004	17,279,000	853,571,500	50.3	50.3
2005	15,411,000	761,293,500	50.2	50.2
2006	16,335,660	806,971,110	51.2	51.2
2007	3,382,000	158,236,180	20.5	19.8
2008	3,406,920	159,402,131	21.5	20.8
2009	3,177,300	148,658,727	22.8	22.0
2010	3,070,500	143,661,795	22.5	21.7

Note: Change of basis in comparison data conventional versus GM IR cotton in 2007: see appendix 3

c) Australia

Using a combination of data from industry sources and CSIRO[105], 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 61);
- 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 62) has been respectively 73% (2.9 million kg) and 75% lower in 2010 than the levels that would have occurred if only conventional cotton had been planted;
- Cumulatively, since 1996 the volume of insecticide use is 31.8% lower (16.2 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 25.7%.

Table 61: 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 (7.7)	4.3	2.2 (1.54)
Field EIQ value/ha	220 (154)	97	39 (27.3)

[105] 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

Sources and notes: derived from industry sources and CSIRO 2005. Ingard cotton grown from 1996, Bollgard from 2003/04, bracketed figures = values updated/revised for 2010)

Table 62: National level changes in insecticide ai use and field EIQ values for GM IR cotton in Australia 1996-2010

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% eiq saving
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
2008	1,066,894	21,944,078	66.5	68.4
2009	1,403,591	28,869,319	69.9	71.9
2010	2,925,150	60,165,015	73.0	75.0

d) Argentina

Adoption of GM IR cotton in Argentina has also resulted in important reductions in insecticide use[106]:

- The average volume of insecticide ai used by GM IR cotton growers is 44% lower than the average of 0.736 kg/ha for conventional cotton growers in 2010;
- The average field EIQ/ha is also significantly lower for GM IR cotton growers (38.2/ha for conventional growers compared to 15.1/ha for GM IR growers);
- The total amount of ai used and its environmental impact (Table 63) have been respectively 39.4% (182,780 kg) and 53.7% lower (12.9 million field EIQ/ha units in 2010) than the levels that would have occurred if only conventional cotton had been planted;
- Cumulatively since 1998, the volume of insecticide use is 12.5% lower (0.59 million kg) and the EIQ/ha load 17.5% lower (38.4 million field EIQ/ha units) than the amount that would have been used if GM IR technology had not been adopted.

Table 63: National level changes in insecticide ai use and field EIQ values for GM IR cotton in Argentina 1998-2010

Year	ai decrease (kg)	eiq saving (units)	%decrease in ai	% eiq saving
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

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

2001	5,100	320,000	1.1	1.6
2002	10,200	640,000	5.4	7.4
2003	23,664	1,484,800	17.6	23.9
2004	22,400	1,408,000	6.0	8.2
2005	9,180	576,000	3.2	4.4
2006	35,904	2,252,800	9.6	13.1
2007	66,218	4,154,880	21.8	29.7
2008	86,904	5,452,800	31.6	43.1
2009	126,194	7,918,080	31.2	42.4
2010	182,784	12,902,400	39.4	53.7

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 2006 and 2009). The respective differences for ai use (see appendix 3) and field EIQ values for GM IR and conventional cotton used in 2009 are:

- Conventional cotton: average volume of insecticide used was 1.86 kg/ha and a field EIQ/ha value of 70.1/ha;
- GM IR cotton: average volume of insecticide used was 1.06 kg/ha and a field EIQ/ha value of 34.4/ha.

Based on these values the level of insecticide ai use and the total EIQ load in 2010 were respectively 36.7% (7.5 million kg) and 43.5% (335 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 16.2% lower (38.6 million kg) and the total EIQ load 20.4% lower (1.78 billion EIQ/ha units).

f) Brazil

GM IR cotton was first planted commercially in 2006 (in 2010, on 240,000 ha, 17% 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 0.736 kg/ha and a field EIQ/ha value of 38.2/ha;
- GM IR cotton: average volume of insecticide used 0.41 kg/ha and a field EIQ/ha value of 15.1/ha.

Based on these values the level of insecticide ai use and the total EIQ load in 2010 were respectively 8% (78,240 kg) and 10% (5.5 million EIQ/ha units) lower than would have been expected if the total crop had been conventional cotton. Cumulatively since 2006, the total active ingredient saving has been 0.4 million kg (8%) and the EIQ/ha load factor has fallen by 11%.

g) Mexico

GM IR cotton has been grown in Mexico since 1996, and in 2010, 48,930 ha (44% 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 32% improvement on conventional cotton (a field EIQ/ha value of 56.6/ha compared to 137/ha for conventional cotton);
- In 2010, at a national level, there had been a 13.8% saving in the amount of insecticide active ingredient use (79,370 kg) applied relative to usage if the whole crop had been planted to conventional varieties. The field EIQ load was 13.7% lower;
- Cumulatively since 1996, the amount of insecticide active ingredient applied was 8.8% (0.9 million kg) lower relative to usage if the Mexican cotton crop had been planted to only conventional varieties over this period. The field EIQ load was 8.7% lower than it would otherwise have been if the whole crop had been using conventional varieties.

h) Other countries

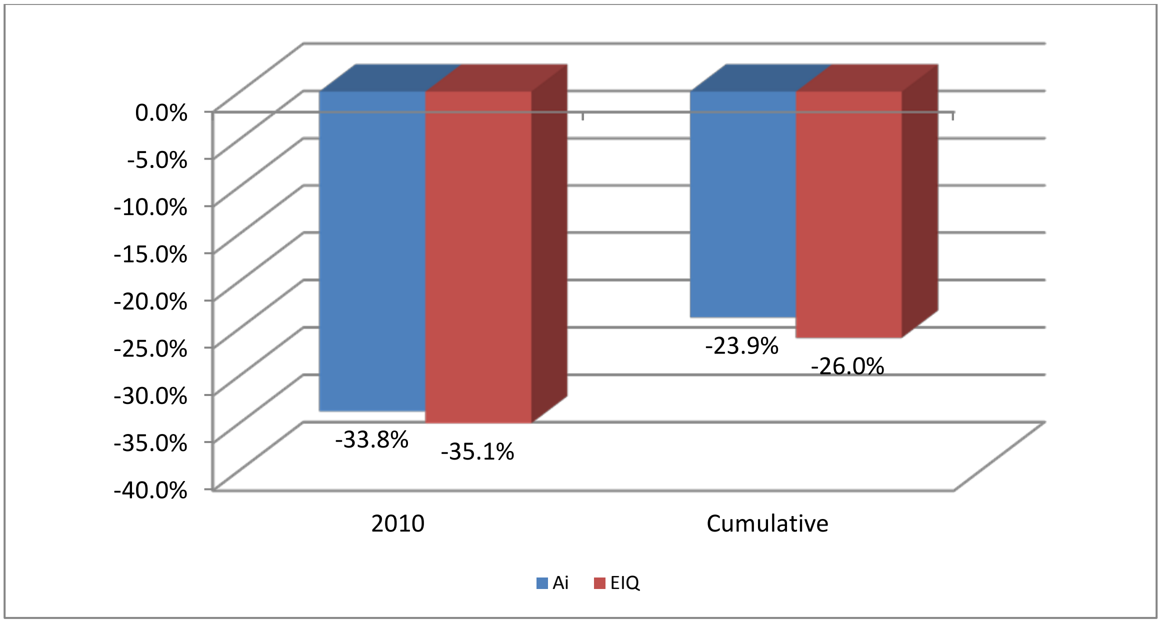
Cotton farmers in South Africa, Colombia and Burkina Faso have also been using GM IR technology in recent years (respectively since 1998, 2002 and 2008). In 2010, the respective plantings were 12,490 ha, 34,300 ha and 260,000 ha. Analysis of the impact on insecticide use and the associated environmental 'foot print' are not presented for these crops because of the lack of publicly available insecticide usage data.

i) 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 23):

- In 2010, a 33.8% decrease in the total volume of insecticide ai applied (15 million kg) and a 35.1% reduction in the environmental impact (measured in terms of the field EIQ/ha load);
- Since 1996, 23.9% less insecticide ai has been used (170.5 million kg) and the environmental impact from insecticides applied to the cotton crop has fallen by 26%.

Figure 23: Reduction in insecticide use and the environmental load from using GM IR cotton in adopting countries 1996-2010



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

These 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.

Context

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 21 weed species that are currently[107] resistant to glyphosate, compared to 107 weed species resistant to ALS herbicides and 69 weed species resistant to triazine herbicides, such as atrazine.

Several of the confirmed glyphosate resistant weed species have also been found in areas where no GM HT crops have been grown. For example, there are currently eleven weeds recognized in the US as exhibiting resistance to glyphosate, of which two are not associated with glyphosate

[107] Accessed December 2011

tolerant crops. It should, however, be noted that where GM HT crops have been widely grown, some farmers have relied too much on the use of single herbicides like glyphosate to manage weeds in GM HT crops and this has contributed to the development of weed resistance. In addition, the adoption of GM HT technology has played a major role in facilitating the adoption of no and reduced tillage production techniques in North and South America (see section 4.2). This has also probably contributed 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. A few of the glyphosate resistant species, such as marestail (*Conyza Canadensis*) and palmer pigweed (*Amaranthus Palmeri*) are now reasonably widespread in the US, especially marestail, where there are several million acres infested, and palmer pigweed, in southern states, where over a million acres are estimated to exhibit such resistance. In Argentina, development of resistance to glyphosate in weeds such as Johnson Grass (*Sorghum halepense*) is also reported.

Control and implications

Where farmers are faced with the existence of weeds resistant to glyphosate, there is a need to adopt reactive weed management strategies incorporating the use of a mix of herbicides (ie, the same way as control of other herbicide resistant weeds). In recent years, there has also been a growing consensus among weed scientists of a need for changes in the weed management programmes in GM HT crops, because of the evolution of these weed populations that are resistant to glyphosate. While the overall level of weed resistance in areas planted to GM HT crops is still low (equal to between 5% and 10% of the total US cropping annually planted to GM HT crops), growers of GM HT crops are increasingly being advised to be more proactive and include other herbicides (with different and complementary modes of action) in combination with glyphosate in their weed management systems, even where instances of weed resistance to glyphosate have not been found. This proactive approach to weed management is therefore the principle strategy for avoiding the emergence of herbicide resistant weeds in GM HT crops. A proactive weed management programme also generally requires less herbicide, has a better environmental profile and is more economical than a reactive weed management programme (see Appendix 3 for examples in the soybean sector).

At the macro level, the adoption of both reactive and proactive weed management programmes in GM HT crops has already begun to influence the mix, total amount and overall environmental profile of herbicides applied to GM HT soybeans, cotton, maize and canola. This is shown in the analysis presented in earlier sub-sections within section 4.1, where for example, the usage and mix of herbicides on GM HT crops in the US has increased in recent years. Relative to the conventional alternative, however, the overall environmental profile and economic impact of the GM HT crops continues to offer advantages[108] (see Appendix 3). It should also be noted that, as indicated in section 4.1.1, whilst the amount of herbicide applied to GM HT crops in some countries like the US has increased in recent years, so has the amount of herbicide applied to conventional alternatives. The increase in the use of herbicides on conventional alternatives for crops like soybeans in the US also reflects the ongoing development of weed resistance to herbicides commonly used and highlights that the development of weed resistance to herbicides is a problem faced by all farmers, regardless of production method.

[108] Also, many of the herbicides used in conventional production systems had significant resistance issues themselves; this was, for example, one of the reasons why glyphosate tolerant soybeans were rapidly adopted, since glyphosate provided good control of these weeds

In addition, 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).

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'[109] 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[110].

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 mouldboard 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, notably NT systems which are facilitated by the availability of GM herbicide tolerant crops, we have reviewed reports and data from a number of sources, of which the main ones of relevance were: 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), Reeder (2010), Illinois University (2006) and USDA (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

[109] 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

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

energy savings between conventional tillage (CT) and alternative tillage systems. The quantity of tractor fuel used for seed-bed preparation, herbicide spraying and planting in each of these systems is illustrated for soybeans planted in Illinois - see Table 64 below. Conventional tillage requires 49.01 litres/ha, ridge till 33.58 litres/ha and no-till 23.01 litres/ha.

Table 64: USA soybean: tractor fuel consumption by tillage method (litres per ha)

Year 1 – Illinois	Conventional tillage	Ridge-till	No-till
Sprayer, kill crop	0.00	1.22	1.22
Plough, mouldboard	17.49	0.00	0.00
Disk, tandem light finishing	3.74	0.00	0.00
Cultivator, field 6-12 in sweeps	6.92	0.00	0.00
Planter, double disk operation	4.12	4.12	0.00
Planter, double disk operation w/fluted coulter	0.00	0.00	5.05
Cultivator, row - 1st pass ridge till	0.00	5.80	0.00
Cultivator, row - 2nd pass ridge till	0.00	6.92	0.00
Sprayer, post emergence	1.22	0.00	1.22
Sprayer, insecticide post emergence	1.22	1.22	1.22
Harvest, killing crop 50pct standing stubble	14.31	14.31	14.31
Total fuel use:	**49.01**	**33.58**	**23.01**
Saving on Conventional tillage:		***15.43***	***26.00***

Source: USDA Energy Estimator 2011

- The fuel saving obtained by a switch from conventional tillage to mulch-till, ridge-till and no-till for corn and soybeans across the three most important crop management zones (CMZ's) is illustrated in Table 65. The adoption of no-till in corn results in a 24.41 litre/ha saving compared with conventional tillage and in the case of soybeans, the no-till saving is 27.22 litre/ha[111].

Table 65: Total farm diesel fuel consumption estimate (litres per ha)

Crop (crop management zones)	Conventional tillage	Mulch-till	Ridge-till	No-till
Corn (Minnesota, Iowa & Illinois)				
Total fuel use	54.50	46.98	36.39	30.09
Potential fuel savings over conventional tillage		*7.52*	*18.11*	*24.41*
Saving		13.8%	33.2%	44.8%
Soybeans (Iowa, Illinois & Nebraska)				
Total fuel use	49.01	40.87	32.36	21.79
Potential fuel savings over conventional tillage		*8.14*	*16.65*	*27.22*
Saving		16.6%	34.0%	55.5%

Source: USDA Energy Estimator 2011

[111] These figures differ from ones presented in last year's report because the USDA Energy Estimator has been updated

- 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 University 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 36.01 litres/ha compared to the strip-till and no-till systems used 22.92 litres/ha – a reduction of 13.09 litres/ha.
- Reeder (2010) estimates that ridge-till or no-till typically uses 19 to 38 litres/ha less diesel fuel than conventional tillage.
- 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 mouldboard 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 litres/ha - a reduction of 36.01 litres/ha compared to intensive tillage.
- Other analyses have suggested similar savings in fuel from no-till. For example, the USDA 2007 Farm Bill Theme Paper 'Energy and Agriculture' states: *'During the past couple of decades, the Natural Resources Conservation Service (NRCS) has helped farmers adopt no-till practices on about 25 million hectares of cropland. Assuming an average saving of 33.13 litres/ha in diesel fuel, this amounts to savings of 821 million litres of diesel fuel per year with cost savings to farmers of about $500 million per year.'*

In our analysis[112] presented below, it is assumed that the adoption of NT farming systems in soybean production reduces cultivation and seedbed preparation fuel usage by 27.22 litres/ha compared with traditional conventional tillage and in the case of RT cultivation by 9.56 litres/ha (this reduction in fuel use is a weighted average between mulch till and ridge till taking into consideration the greater relative importance of mulch-till). These are conservative estimates and are 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 for USA soybeans is shown in (Table 66).

Table 66: USA soybean: tractor fuel consumption by tillage method (litre/ha)

Tillage system	litre/ha
Intensive tillage: traditional cultivation: mouldboard plough, disc and seed planting etc	49.01
Reduced tillage (RT): chisel plough, disc and seed planting	39.45
No-till (NT): fertiliser knife, seed planting plus 2 sprays: pre-plant burn down and post-emergent	21.79

Source: Adapted from USDA Fuel Estimator 2011

[112] In previous editions of this report the authors have applied a saving of 32.3 litres/ha for NT and 12.97 litres/ha for RT compared to CT.

In terms of GHG, each litre of tractor diesel consumed contributes an estimated 2.67[113] 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 72.68 kg/ha and 25.53 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 USA, a typical method of application is with a self-propelled boom sprayer which consumes approximately 1.31 litres/ha[114] (Lazarus (2011)). One less spray application therefore reduces carbon dioxide emissions by 3.5 kg/ha[115].

The conversion of one hectare of conventional tillage to no-till equates to a saving of approximately 485 km travelled by a standard family car[116] and one less spray pass is equal to a saving of nearly 23.3 km travelled.

4.2.2 Soil carbon sequestration

Soil organic carbon has been depleted through:

- the long-term use of extractive farming practices; and
- the conversion of natural ecosystems (such as forest lands, prairie lands and steppes) into croplands and grazing lands.

Such a conversion depletes the soil organic carbon pool by increasing the rate of conversion of soil organic matter to carbon dioxide, thereby reducing the input of biomass carbon and accentuating losses by erosion. Most agricultural soils have lost 30 to 40 tonnes/ha of carbon, and their current reserves of soil organic carbon are much lower than their potential capacity.

Soil carbon sequestration involves adding the maximum amount of carbon possible to the soil. The technical potential for this process is higher in degraded/desertified soils and soils that have been managed with extractive farming practices than it is in good-quality soils, that have been managed according to recommended management practices (RMPs). Thus, converting degraded/desertified soils into restorative land and adopting RMPs can increase the soil carbon pool. The rate of soil carbon sequestration through the adoption of RMPs on degraded soils ranges from 100 kg/ha per year in warm and dry regions to 1,500 kg/ha per year in cool and temperate regions.

A recent estimate of the technical potential of soil organic carbon sequestration through adoption of RMPs for world cropland soils (1.5 billion ha) is 0.6 billion to 1.2 billion tonnes of carbon per

[113] In previous editions of this report the authors have applied a co-efficent of 2.75 to convert 1 litre of diesel to kgs of carbon dioxide. This report uses the updated figure of 2.6676 rounded to 2.67

[114] In previous editions of this report the authors have used 1.045 litres/ha (Lazarus & Selley (2005))

[115] 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

[116] Assumed standard family car carbon dioxide emission rating = 150 grams/km. Therefore 72.68 kg of carbon dioxide divided by 150g/km = 485 km

year and about 3 billion tonnes of carbon per year in soils of all ecosystems (eg, cropland, grazing land, forest lands, degraded lands and wetlands: Lal R (2010)).

Examples of soil and crop management technologies that increase soil carbon sequestration include:

- no-till (NT) farming with residue mulch and cover cropping;
- integrated nutrient management (INM), which balances nutrient application with use of organic manures and inorganic fertilizers;
- various crop rotations (including agroforestry);
- use of soil amendments (such as zeolites, biochar, or compost); and
- improved pastures with recommended stocking rates and controlled fire as a rejuvenate method (Lal (2009)).

The most effective natural method of achieving soil carbon sequestration is by the absorption of atmospheric carbon dioxide in plants by photosynthesis, where plants convert carbon dioxide into plant tissue (lignin and carbohydrates). When a plant dies, a portion of the stored carbon is left behind in the soil by decomposing plant residue (eg, roots, stalks) 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[117] (billion tonnes) of carbon. This is approximately half of the total carbon emissions from fossil fuels (270 +/- 30 Pg (billion tonnes)), with soil cultivation accounting for 78 +/- 12 Pg and soil erosion 26 +/- 9 Pg of carbon emissions. Lal also estimates that the potential of carbon sequestration in soil, biota and terrestrial ecosystems 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 alternative energy strategies.

[117] 1 Pg of soil carbon pool equates to 0.47 parts per million of atmospheric carbon dioxide

- Bernacchi *et al* (2005) estimate that if the total area of corn/soybeans in the USA converted to no-till, 21.7 Tg C (21.7 million tonnes) would be sequestered annually (approximately 350 kg/C/ha/yr), an offset of about 2% of annual USA carbon emissions.

A number of researchers have examined issues relating to carbon sequestration and different tillage systems. The following are of note:

- 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[118].
- Johnson *et al* (2005) summarised how alternative tillage and cropping systems interact to sequester soil organic carbon (SOC) and impact on GHG emissions from the main agricultural area in central USA. This analysis estimated that the rate of SOC storage in NT compared to CT has been significant, but variable, averaging 400 +/- 61 kg/carbon/ha/yr (Table 67).
- Calegari *et al* (2008) conducted a 19 year experiment comparing CT and NT management systems with various winter cover crop treatments in Brazil. The research identified that the NT system led to 64.6% more carbon being retained in the upper soil layer than in the CT system. It also found that using NT with winter cover crops resulted in soil properties that most closely resembled an undisturbed forest (ie, best suited for greenhouse gas storage). In addition, both maize and soybean yields were found to be respectively 6% and 5% higher, under NT, than CT production systems.
- IPCC estimates put 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 2.0 tool[119] for the three key production states and assuming the adoption of NT from CT for non-irrigated corn in the major corn producing states results in a projected 269 to 514 kg carbon per year being sequestered (Table 67).

Table 67: Summary of the potential of NT cultivation systems (kg of carbon/ha/yr)

	Low	High	Average
West and Post (2002)	310	1,490	900
Johnson *et al* (2005)	339	461	400
Liebig (2005)	80	460	270

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

[119] COMET-VR 2.0 is a web-based tool that provides estimates of carbon sequestration and net greenhouse gas emissions from soils and biomass for US farms. It links databases containing information on soils, climate and management practices to run an ecosystem simulation model as well as empirical models for soil N_2O emissions and CO_2 from fuel usage for field operations. In 2011, an updated version was released - http://www.comet2.colostate.edu/.

IPCC	50	1,300	300
COMET-VR V2[120] (NT from CT in corn)			
Illinois	*269*	*456*	*359*
Minnesota	*303*	*504*	*399*
Nebraska	*316*	*514*	*412*

- The adoption of NT systems has also had an impact on other GHG emissions such as methane and nitrous oxide which are respectively 21 and 310 times more potent than carbon dioxide. Robertson (2002) and Sexstone *et al* (1985) suggested that the adoption of NT (sequestering SOC) could do so at the expense of increased nitrous oxide production if growers were to increase the use of nitrogen fertiliser in NT 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. They found that the net GWP was highest for conventional tillage systems at 114 grams of carbon dioxide equivalents/ha/year compared with 41 grams/ha/year for an organic system with legumes cover and 14 grams/ha/year for a no-till system (with liming) and minus 20 grams/ha/year 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 carbon dioxide equivalents m^{-2} $year^{-1}$ compared with 16 grams in conventional tillage and 19 grams for organic tillage. The release of nitrous oxide in terms of carbon dioxide was equivalent in the organic and NT systems due to the availability of nitrogen under the organic system compared with the targeted use of nitrogen fertiliser under the NT systems.
- The importance of nitrogen fixing legume grain crops has also been investigated by Almaraz *et al* (2009). They studied the GHG emission associated with N_2 fixing soybean grown under CT and NT tillage systems. Their findings suggest that using NT in N-fixing legume crops may reduce both carbon dioxide and N_2O emissions in comparison to CT, because in the CT system, harvest residue is incorporated into the soil during ploughing (increasing N_2O emissions).
- Omonode *et al* (2011) assessed N_2O emissions in corn following three decades of different tillage and rotation systems. Seasonal cumulative N_2O emissions were significantly lower by 40%-57% under NT compared to long term chisel and mouldboard plough tillage systems due to soil organic C decomposition associated with higher levels of soil residue mixing and higher soil temperatures.
- 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.
- Baker *et al* (2007) expressed caution with the premise that NT results in positive carbon sequestration compared with CT. Their analysis identified 37 out of 45 studies (from 17 experiments) with sampling depth <30 cm at which NT treatments (82%) reported more

[120] In previous editions of this report the authors have applied data obtained from COMET-VR version 1 which has been updated in version 2.

SOC than in the CT control with a mean annual SOC gain of 0.38 +/- 0.72 t ha^{-1} yr^{-1}. In contrast, in 35 of 51 studies (from 5 experiments) with sampling depths >30 cm, the NT treatments registered less SOC relative to CT with a mean annual loss of -0.23 +/- 0.97 t ha^{-1} yr^{-1}. In both cases, however, the standard error associated with the estimates was so large that the mean (impact of tillage) was not considered to be significant.

- Research by Angers and Eriksen-Hamel (2008) and Blanco-Canqui and Lal (2008) found that the majority of SOC increase under NT is in the top 10 to 15 cm of soil with insignificant changes (or even decreases) in SOC relative to CT at depths over 15 cm. Hence, newly sequestered carbon in a NT system is accumulated where it is most vulnerable to environmental and management pressures. This makes any permanent increase in SOC associated with NT systems vulnerable to changes in environmental pressures and soil management practices.
- Angers and Eriksen-Hamel's (2008) work also compared NT and full-inversion tillage (FIT) trials and found that while there was a statistically significant increase in total SOC stocks under NT (100.3 versus 95.4 Mg C ha^{-1} for NT and FIT respectively in the upper 10 cm), to the 21-25 cm soil depth (which corresponds to the mean ploughing depth (23 cm)), the average SOC content was significantly greater under FIT than NT. It was also greater under FIT just below the average depth of ploughing (26-35 cm). However, overall there was significantly more SOC (4.9 Mg ha^{-1}) under NT than FIT across all depths and this difference in favour of NT increased weakly with the duration of the experiment.

The discussion above illustrates the difficulty in estimating the contribution NT systems can make to soil carbon sequestration. The modelling of soil carbon sequestration is also made more difficult by the dynamic nature of soils, climate, cropping types and patterns. 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 a continuous NT system which itself tends to be highly dependent upon effective herbicide-based weed control systems.

In sum, drawing on the various discussed literature, the analysis presented in the following sub-sections assumes[121] the following:

USA: soil carbon sequestered by tillage system for corn and soybeans in continuous rotation:

- NT systems store 375 kg of carbon/ha/year;
- RT systems store 175 kg of carbon/ha/year; and
- CT systems <u>release</u> 25 kg of carbon/ha/year).

Argentina and Brazil: soil carbon retention is 175 kg carbon/ha/year for NT soybean cropping and CT systems <u>release</u> 25 kg carbon/ha/year.

[121] In previous editions of this report the authors have assumed NT systems store 300 kg of carbon/ha/yr, RT systems store 100 kg of carbon/ha/yr and CT systems release 100 kg of carbon/ha/yr. The changes adopted in this report reflect recent research referred to above. The reader should also note that the relative difference has remained unchanged at +400 kg and +200 kg of carbon/ha/yr respectively. Similarly, for Argentina, the authors applied a carbon sequestration rate of 100 kg of carbon/ha/yr for RT/NT systems and a carbon release of 100 kg of carbon/ha/yr for CT systems, the difference between the systems has remained at 200 kg of carbon/ha/yr in both the old and current analysis

Where the use of biotech crops has resulted in a reduction in the number of spray passes or the use of less intensive cultivation practices (ie, less ploughing) this has provided (and continues to provide) 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 effect 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[122]. Before the introduction of GM HT soybean cultivars, NT systems were practised by some farmers with varying degrees of success using a number of herbicides. 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 and cost advantages have contributed to the rapid adoption of GM HT cultivars and the near doubling of the NT soybean area in the USA (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 USA

Over the 1996-2010 period the area of soybeans cultivated in the USA increased rapidly from 26 million ha to 31.6 million ha. Over the same period, the area planted using conventional tillage is estimated to have fallen by 17.2% (from 7.5 million ha to 6.2 million ha), whilst the area planted using reduced-till has increased by 14.5% (from 10.8 million ha to 12.3 million ha) and the area planted using no-till has increased by 68.8% (from 7.7 million ha to 13.0 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 99% of total NT soybeans by 2010). This compares with conventional tillage systems for soybeans where GM HT cultivars may account for up to 84% of total conventional tillage soybean plantings (Table 68).

[122] See for example, CTIC 2002

Table 68: USA soybean: tillage practices and the adoption of GM HT cultivars 1996-2010 (million ha)

	Total area	No-till	Reduced till	Conventional till	Total biotech area	Total conventional area	No till biotech area	Reduced till biotech area	Conventional tillage biotech area
1996	25.98	7.72	10.75	7.51	0.49	25.49	0.23	0.16	0.10
1997	28.33	8.72	12.03	7.58	3.20	25.13	1.92	1.20	0.08
1998	29.14	9.28	12.69	7.17	11.77	17.37	4.92	4.82	2.03
1999	29.84	9.65	12.78	7.41	16.39	13.45	6.08	7.03	3.28
2000	30.15	9.90	12.69	7.56	18.21	11.94	6.93	7.61	3.67
2001	29.99	10.16	12.53	7.30	22.18	7.81	8.63	9.02	4.53
2002	29.55	10.31	12.26	6.98	24.29	5.26	9.38	10.41	4.50
2003	29.71	10.92	12.30	6.49	25.74	3.97	10.37	11.07	4.26
2004	30.28	11.69	12.51	6.08	27.20	3.08	11.40	11.28	4.52
2005	28.88	11.40	11.65	5.83	26.87	2.01	11.29	11.06	4.52
2006	30.57	12.34	12.03	6.20	27.21	3.36	12.09	10.44	4.68
2007	25.75	10.69	10.03	5.03	23.43	2.32	10.42	9.10	3.91
2008	30.20	12.47	11.78	5.95	27.78	2.42	12.35	10.72	4.71
2009	30.91	12.76	12.06	6.09	28.13	2.78	12.63	10.97	4.53
2010	31.56	13.03	12.31	6.22	29.35	2.21	12.90	11.20	5.25

Source: Adapted from Conservation Tillage and Plant Biotechnology (CTIC) 1998, 2000, 2002, 2006, 2007 and 2008
Reduced tillage includes mulch till and ridge till

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, the total consumption of tractor fuel has increased by only 11.9% (114 million litres) from 960.3 to 1,074.3 million litres (1996 to 2010: Table 69) while the area planted increased by 21%, some 5.58 million ha. Over the same period, the average fuel usage fell 8.1% (from 37 litres/ha to 34 litres/ha: Table 69). A comparison of biotech versus conventional production systems shows that in 2010, the average tillage fuel consumption on the biotech planted area was 33.4 litres/ha compared to 43.1 litres/ha for the conventional crop (primarily because of differences in the share of NT plantings).

Table 69: USA soybean: consumption of tractor fuel used for tillage (1996-2010)

	Total fuel consumption (million litres)	Average (litre/ha)	Conventional average (litre/ha)	Biotech average (litres/ha)
1996	960.3	37.0	37.1	31.1
1997	1036.1	36.6	37.5	29.1
1998	1054.5	36.2	37.8	33.8
1999	1077.5	36.1	37.8	34.8
2000	1086.8	36.0	38.0	34.8
2001	1073.6	35.8	39.4	34.5
2002	1050.0	35.5	40.7	34.4
2003	1041.2	35.0	42.5	33.9
2004	1046.1	34.6	42.9	33.6
2005	993.6	34.4	45.4	33.6
2006	1047.0	34.3	42.8	33.2
2007	875.2	34.0	41.8	33.2
2008	1028.3	34.0	43.8	33.2
2009	1052.1	34.0	44.3	33.0
2010	1074.3	34.0	43.1	33.4

The cumulative permanent reduction in tillage fuel use in USA soybeans is summarised in Table 70. This amounted to a reduction in tillage fuel usage of 797.65 million litres which equates to a reduction in carbon dioxide emission of 2,130 million kg.

Table 70: USA soybeans: permanent reduction in tractor fuel consumption and reduction in carbon dioxide emissions (1996-2010)

	Annual reduction based on 1996 average (litres/ha)	Crop area (million ha)	Total fuel saving (million litres)	Carbon dioxide (million kg)
1996	0.00	25.98	0.00	0.00
1997	0.39	28.33	11.13	29.72
1998	0.79	29.15	22.91	61.17
1999	0.85	29.84	25.38	67.76
2000	0.91	30.15	27.58	73.64
2001	1.17	29.99	34.96	93.34
2002	1.42	29.54	41.85	111.73
2003	1.91	29.71	56.84	151.76
2004	2.41	30.28	72.98	194.86
2005	2.56	28.88	73.87	197.23
2006	2.71	30.56	82.68	220.75
2007	2.98	25.75	76.67	204.70
2008	2.92	30.21	88.27	235.68
2009	2.92	30.91	90.31	241.13
2010	2.92	31.56	92.22	246.23
Total			**797.65**	**2,129.70**

Assumption: baseline fuel usage is the 1996 level of 37 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 375 kg of carbon/ha/year, the RT system assumed to store 175 kg carbon/ha/year and the CT system assumed to release 25 kg carbon/ha/year)[123], our estimates of total soil carbon sequestered are (Table 71):

- An increase of 2,297 million kg carbon/year (from 4,589 million kg in 1996 to 6,886 million kg carbon/year in 2010 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 23.5% (41.5 kg carbon/ha/year) from 176.7 to 218.2 kg carbon/ha/year.

Table 71: USA soybeans: potential soil carbon sequestration (1996 to 2010)

	Total carbon sequestered (million kg)	Average (kg carbon/ha/yr)
1996	4,589.38	176.7
1997	5,186.81	183.1
1998	5,523.56	189.5
1999	5,669.55	190.0
2000	5,743.85	190.5
2001	5,819.00	194.0
2002	5,835.35	197.5
2003	6,083.49	204.8
2004	6,419.49	212.0
2005	6,169.18	213.6
2006	6,577.32	215.2
2007	5,638.74	219.0
2008	6,590.66	218.2
2009	6,743.58	218.2
2010	6,886.10	218.2

Cumulatively, since 1996 the increase in soil carbon due to the increase in RT and NT in USA soybean production systems has been 11,601 million kg of carbon which, in terms of carbon dioxide emissions, equates to a saving of 42,577 million kg of carbon dioxide that would otherwise have been released into the atmosphere (Table 72). This estimate does not take into consideration the potential loss in carbon sequestration that might arise from a return to conventional tillage.

Table 72: USA soybeans: potential additional soil carbon sequestration (1996 to 2010)

	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	0.00	0.00

[123] 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

1997	6.4	28.3	181.93	667.69
1998	12.8	29.1	374.36	1,373.89
1999	13.4	29.8	398.45	1,462.32
2000	13.9	30.1	417.99	1,534.01
2001	17.4	30.0	521.04	1,912.23
2002	20.9	29.5	616.89	2,264.00
2003	28.1	29.7	835.71	3,067.05
2004	35.4	30.3	1,071.19	3,931.26
2005	37.0	28.9	1,067.48	3,917.65
2006	38.5	30.6	1,178.08	4,323.56
2007	42.3	25.8	1,089.61	3,998.88
2008	41.5	30.2	1,254.47	4,603.90
2009	41.5	30.9	1,283.58	4,710.72
2010	41.5	31.6	1,310.70	4,810.28
Total			**11,601.48**	**42,577.44**

Assumption: carbon sequestration remains at the 1996 level of 176.7 kg carbon/ha/year

4.2.4.2 Argentina

Since 1996, the area planted to soybeans in Argentina has increased by 208% (from 5.91 to 18.2 million ha). Over the same period, the area planted using NT practices also increased by an estimated 636%, from 2.15 to 15.83 million ha, whilst the area planted using conventional tillage decreased 37%, from 3.76 to 2.37 million ha (Table 73).

As in the USA, a key driver for the growth in NT soybean production has been the availability of GM HT soybean cultivars, which in 2010 accounted for 99% of the total Argentine soybean area. The most important reasons for the adoption of GM HT soybean cultivars in Argentina have been analysed by Finger *et al* (2009) following a survey of Argentine soybean growers. This analysis concluded that the combination of herbicide tolerance and no-till have been the key drivers to adoption of GM HT soybeans to facilitate easier crop management and reduced herbicide costs. 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 2010 the share of soybean plantings accounted for by second crop soybeans had risen to 24% of total plantings (4.4 million ha).

Table 73: Argentine soybeans: tillage practices and the adoption of biotech cultivars 1996-2010 (million ha)

	Total area	**No-till** (NT)	**Conventional till (CT)**	**Total biotech area**	**Total conventional area**	**NT biotech area**	**CT biotech area**
1996	5.91	2.15	3.76	0.04	5.87	0.04	0.00
1997	6.39	2.87	3.52	1.76	4.63	1.76	0.00
1998	6.95	3.32	3.63	4.80	2.15	3.32	1.48
1999	8.18	3.78	4.40	6.64	1.54	3.78	2.86
2000	10.59	5.02	5.57	9.00	1.59	5.02	3.98
2001	11.50	6.66	4.84	10.93	0.57	6.66	4.27
2002	12.96	8.67	4.29	12.45	0.51	8.67	3.78
2003	13.50	9.78	3.72	13.23	0.27	9.78	3.45

2004	14.34	11.39	2.95	14.06	0.28	11.39	2.67
2005	15.20	11.54	3.66	15.20	0.00	11.54	3.66
2006	16.15	12.41	3.74	15.84	0.31	12.41	3.43
2007	16.59	13.56	3.03	16.42	0.17	13.56	2.86
2008	16.77	14.59	2.18	16.60	0.17	14.59	2.01
2009	18.60	15.83	2.77	18.18	0.42	15.83	2.35
2010	18.20	15.83	2.37	18.02	0.18	15.83	2.19

Adapted from Benbrook, Trigo and AAPRESID (2009)

a) Fuel consumption

Between 1996 and 2010 total fuel consumption associated with soybean cultivation doubled from 231.3 to 461.1 million litres/year. However, during this period the average quantity of fuel used per ha fell 35.2% from 39.1 to 25.3 litres/ha, due predominantly to the widespread use of GM HT soybean cultivars and NT systems. If the proportion of NT soybeans in 2010 (applicable to the total 2010 area planted) had remained at the 1996 level, an additional 1,841 million litres of fuel would have been used. At this level of fuel usage, an additional 4,916 million kg of carbon dioxide would have otherwise been released into the atmosphere (Table 74).

Table 74: Argentine soybeans: permanent reduction in tractor fuel consumption and reduction in carbon dioxide emissions (1996-2010)

	Annual reduction based on 1996 average of 39.1 (litres/ha)	Crop area (million ha)	Total fuel saving (million litres)	Carbon dioxide (million kg)
1996	0.0	5.9	0.0	0.00
1997	2.3	6.4	14.7	39.32
1998	3.1	7.0	21.6	57.61
1999	2.7	8.2	22.0	58.75
2000	3.0	10.6	31.7	84.77
2001	5.9	11.5	67.4	180.07
2002	8.3	13.0	107.7	287.62
2003	9.8	13.5	132.7	354.20
2004	11.7	14.3	168.0	448.67
2005	10.8	15.2	163.6	436.79
2006	11.0	16.2	178.1	475.49
2007	12.4	16.6	204.9	547.16
2008	13.8	16.8	231.2	617.40
2009	13.3	18.6	246.8	658.95
2010	13.8	18.2	250.8	669.52
Total			**1,841.2**	**4,916.32**

Note: based on 21.79 litres/ha for NT and 49.01 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[124]) 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 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 175 kg/carbon/ha/yr for NT and a release of 25 kg/carbon/ha/yr for soybean cropping in Argentina, a cumulative total of 13,529 million kg of carbon, which equates to a saving of 49,652 million kg of carbon dioxide. has been retained in the soil that would otherwise have been released into the atmosphere (Table 75).

Table 75: Argentine soybeans: potential additional soil carbon sequestration (1996 to 2010)

	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	0.00	0.00
1997	16.9	6.4	108.17	396.98
1998	22.8	7.0	158.52	581.78
1999	19.8	8.2	161.68	593.38
2000	22.0	10.6	233.27	856.09
2001	43.1	11.5	495.53	1,818.58
2002	61.1	13.0	791.51	2,904.83
2003	72.2	13.5	974.71	3,577.19
2004	86.1	14.3	1,234.69	4,531.31
2005	79.1	15.2	1,202.00	4,411.35
2006	81.0	16.2	1,308.48	4,802.13
2007	90.8	16.6	1,505.72	5,526.00
2008	101.3	16.8	1,699.00	6,235.34
2009	97.5	18.6	1,813.37	6,655.06
2010	101.2	18.2	1,842.45	6,761.81
Total			**13,529.10**	**49,651.82**

Assumption: NT = +175 kg carbon/ha/yr, CT = -25 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.

[124] 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 Brazil

In previous reports we have excluded Brazil from the analysis of carbon savings associated with the facilitating role of GM HT soybeans on the adoption of NT/RT systems in the Brazilian soybean sector, largely because NT/RT systems were commonplace in the sector before the legal availability of GM HT soybeans in 2003. However, after consultation with several analysts in Brazil who have examined the factors influencing the adoption of NT/RT systems in Brazil, we now partially include some of the Brazilian GM HT soybean area in the calculations of carbon savings. Thus, our analysis now includes the area devoted to GM HT soybeans in the southern states of Paraná and Rio Grande de Sol where the agricultural conditions are similar to those in Argentina and where the availability of GM HT soybean technology is considered to have played an important role in allowing farmers to remain in NT/RT systems.

From 1997 when GM HT soybeans were first planted in Brazil (illegally), the total area of GM HT soybeans has increased from 0.1 million ha to 18.4 million ha in 2010, of which these southern states accounted for 41.8% (7.67 million ha) in 2010. The vast majority of the soybean production in these states is using NT systems (85%: 7.76 million ha), with virtually all of the NT area being GM HT soybeans (7.67 million ha: 99%: Table 76).

Table 76: Southern Brazil (Parana and Rio Grande de Sol states) soybeans: tillage practices and the adoption of biotech cultivars 1997-2010 (million ha)

	Total area	No-till	Conventional tillage	Total biotech area	Total conventional area	NT biotech area	NT non-biotech
1997	6.19	1.86	4.33	0.10	6.09	0.10	1.76
1998	6.12	2.14	3.98	0.50	5.62	0.50	1.64
1999	6.05	2.42	3.63	1.18	4.87	1.18	1.24
2000	5.98	2.69	3.29	1.30	4.68	1.30	1.39
2001	6.84	3.42	3.42	1.31	5.53	1.31	2.11
2002	7.49	4.12	3.37	1.74	5.74	1.74	2.38
2003	8.21	4.93	3.28	2.87	5.34	2.87	2.06
2004	8.59	5.58	3.01	3.01	5.58	3.01	2.57
2005	8.30	5.81	2.49	3.32	4.98	3.32	2.49
2006	8.25	6.19	2.06	5.36	2.89	5.36	0.83
2007	8.19	6.14	2.05	5.98	2.21	5.98	0.16
2008	8.23	6.58	1.65	6.09	2.14	6.09	0.49
2009	8.90	7.39	1.51	7.03	1.87	7.03	0.36
2010	9.13	7.76	1.37	7.67	1.46	7.67	0.09

Adapted from FEBRAPDP, AMIS Global and personal communications (November 2011)
NT = No-till

a) Fuel consumption

The Brazilian Federation of 'direct planting' (FEBRAPDP) and the Brazilian Agricultural Research Corporation (Embrapa) estimate that the conversion from CT to NT results in fuel savings of between 60-70% (Plataforma Plantio Direto (2006)). This compares with findings from the US, used in earlier sub-sections, of 55% (reductions). In our analysis presented below (Table 77) we adopt a conservative approach and apply the fuel consumption rates used in the USA (21.79 litres/ha for NT and 49.01 litres/ha for CT - a reduction of 55% for NT relative to CT) to the GM HT soybean area planted in the two southern Brazilian states.

As a result of the use of GM HT soybeans and their facilitating role in allowing farmers to remain in NT, total fuel consumption associated with soybean cultivation (1997-2010) decreased by 6.5% from 252.8 to 236.3 million litres/year. During this period the average quantity of fuel used per ha also fell 36.6% from 40.8 to 25.9 litres/ha. If the proportion of NT soybeans in 2010 (applicable to the total 2010 area planted in the two southern states) had remained at the 1997 level, an additional 952 million litres of fuel would have been used. At this level of fuel usage, an additional 2,542 million kg of carbon dioxide would have otherwise been released into the atmosphere (Table 77)

Table 77: Brazil (2 southernmost states) soybeans: permanent reduction in tractor fuel consumption and reduction in carbon dioxide emissions (1997-2010)

	Annual reduction based on 1997 average of 40.8 (litres/ha)	Crop area (million ha)	Total fuel saving (million litres)	Carbon dioxide (million kg)
1997	-0.03	6.19	-0.17	-0.45
1998	1.33	6.12	8.16	21.79
1999	2.69	6.05	16.30	43.52
2000	4.06	5.98	24.27	64.80
2001	5.42	6.84	37.04	98.89
2002	6.78	7.49	50.74	135.49
2003	8.14	8.21	66.85	178.49
2004	9.50	8.59	81.58	217.83
2005	10.86	8.30	90.09	240.54
2006	12.22	8.25	100.79	269.12
2007	12.22	8.19	100.03	267.09
2008	13.58	8.23	111.74	298.36
2009	14.40	8.90	128.17	342.21
2010	14.94	9.13	136.48	346.40
Total			**952.09**	**2,542.08**

Note: based on 21.79 litres/ha for NT and RT and 49.01 litres/ha for CT

b) Soil carbon sequestration

The rate of carbon sequestration in Brazil has been researched by several leading groups over the last 15 years. Bayer *et al* (2006) estimated the mean rate of carbon sequestration in NT Brazilian tropical soils to be 0.35 t/ha/year, similar to the 0.34 t/ha/year reported for soils from temperate regions, but lower than the 0.48 t/ha/year estimated for southern Brazilian sub-tropical soils. Amado and Bayer (2008) estimated an average carbon sequestration rate of 0.17 t/ha/year (0.0 – 0.44 t/ha/year) for NT soils in the south (sub-tropical) and middle-west (tropical) regions of Brazil. The highest level of carbon sequestration (0.36 to 0.42 t/ha/year) occurs in intensive cropping systems because of relatively high crop residue levels in the maize/soybean rotation or where winter and summer cover crops are used.

Applying a soil carbon retention of 175 kg of carbon/ha/yr for NT soybean cropping in Brazil (as applied in Argentina), a cumulative total of 6,996 million kg of carbon (equal to a saving of 25,674 million kg of carbon dioxide) has been retained in the soil that would otherwise have been released into the atmosphere (Table 78).

Table 78: Brazil (2 southernmost states) soybeans: potential additional soil carbon sequestration (1997 to 2010)

	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)
1997	-0.2	6.2	-1.24	-4.56
1998	9.8	6.1	59.96	220.06
1999	19.8	6.0	119.77	439.54
2000	29.8	6.0	178.32	654.43
2001	39.8	6.8	272.15	998.78
2002	49.8	7.5	372.85	1,368.35
2003	59.8	8.2	491.19	1,802.67
2004	69.8	8.6	599.44	2,199.93
2005	79.8	8.3	661.94	2,429.30
2006	89.8	8.2	740.58	2,717.91
2007	89.8	8.2	735.01	2,697.48
2008	99.8	8.2	821.05	3,013.25
2009	105.8	8.9	941.72	3,456.11
2010	109.8	9.1	1,002.80	3,680.27
Total			**6,995.58**	**25,673.52**

Assumption: NT/RT = +175 kg carbon/ha/yr, CT = -25 kg carbon/ha/yr

4.2.4.4 Bolivia, Paraguay and Uruguay

NT systems have also become important in soybean production in Bolivia, Paraguay and Uruguay, where the majority of production in these countries use NT systems. Across the three countries, the area planted to soybeans has increased from 1.3 million ha to 4.88 million ha between 1996 and 2010 (Paraguay 0.833 to 2.85 million ha, Uruguay 0.008 million ha to 1.04 million ha and Bolivia 0.463 to 0.99 million ha).

a) Fuel consumption

Using the findings and assumptions applied to Argentina[125] (see above), the savings in fuel consumption for soybean production between 1996 and 2010 (associated with changes in no/reduced tillage systems, the adoption of GM HT technology and comparing the proportion of NT soybeans in 2010 with the 1996 level) has been 438 million litres. At this level of fuel saving, the reduction in the level of carbon dioxide released into the atmosphere has been 1,170 million kg.

b) Soil carbon sequestration

Applying the same rate of soil carbon retention for NT soybeans as Argentina, the cumulative increase in soil carbon since 1996, due to the increase in NT in Bolivia, Paraguay and Uruguay,

[125] We are not aware of any country-specific studies into NT/RT systems in these three countries. However, analysts consulted in each country have confirmed that the availability of GM HT technology in soybeans has been an important driver behind the use of NT/RT production systems. We have applied carbon change assumptions in these countries based on findings from Argentina because this represents the only available data from a neigbouring country. We acknowledge this represents a weakness to the analysis and the findings should be treated with caution

soybean production systems, has been 3,221 million kg of carbon. In terms of carbon dioxide emission this equates to a saving of 11,821 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 USA GM HT canola crop as the area devoted to canola in the USA is relatively small by comparison to the area in Canada (0.59 million ha in the USA in 2010 compared to 6.5 million ha in Canada).

Smyth *et al* (2011) surveyed nearly 600 canola farmers in the three prairie provinces of Western Canada over a three year period 2007-2009 to evaluate the environmental impacts of the adoption of HT canola. As well as a reduction in the total number of herbicide applications (resulting in a decrease of herbicide active ingredient being applied), there were fewer tillage passes, improving moisture conservation, decreasing soil erosion and a substantial contribution to carbon sequestration in annual cropland. This research estimated that, by 2009, approximately 1 million tonnes of carbon (3.67 million tonnes of carbon dioxide) had either been sequestered or no longer released under land management systems facilitated by HT canola production, as compared to 1995.

a) Fuel consumption

Our estimate for the cumulative, permanent reduction in tillage fuel use in Canadian canola for the period 1996-2010 is 301.7 million litres, which equates to a reduction in carbon dioxide emissions of 806 million kg (Table 79). Readers should note that these values are lower than the values presented in last year's report because of revisions (updates) to fuel usage assumptions (see section 4.2.1) and to the estimated area of Canadian canola that uses NT systems.

Table 79: Canadian canola: permanent reduction in tractor fuel consumption and reduction in carbon dioxide emissions (1996-2010)

	Annual reduction based on 1996 average 44.4 (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	0.9	4.9	4.5	11.96
1998	0.9	5.4	5.0	13.33
1999	0.9	5.6	5.1	13.66
2000	0.9	4.9	4.5	11.93
2001	1.8	3.8	7.0	18.59
2002	2.8	3.3	9.0	24.02
2003	3.7	4.7	17.2	46.05
2004	4.6	4.9	22.7	60.63
2005	5.5	5.5	30.3	80.88
2006	6.4	5.2	33.7	90.02
2007	6.4	5.9	38.0	101.58
2008	6.4	6.5	41.8	111.61
2009	6.4	6.4	41.0	109.57
2010	6.4	6.5	41.9	111.95
Total			**301.7**	**805.78**

Notes: fuel usage NT/RT = 30.62 litres/ha CT = 49.01 litres/ha *b) Soil carbon sequestration*

Our analysis of soil carbon sequestration levels associated with GM HT canola in Canada is based on the carbon sequestration co-efficients/assumptions derived by McConkey *et al* (2007). Table 80 summarises this analysis and shows a cumulative increase in soil carbon storage associated with the increase in RT and NT in Canadian canola production between 1996 and 2010 of 1,067 million kg of carbon, which in terms of carbon dioxide emissions, equates to a saving of 3,915 million kg of carbon dioxide that would otherwise have been released into the atmosphere. Readers should note these estimates are lower than the values presented in last year's report because of changes in the soil sequestration assumptions used - the carbon sequestration rate of 0.055 t/ha/year used (based on McConkey et al (2007) is significantly lower than the rate used in the USA for soybeans (0.375 t/ha/year) due to a combination of lower temperatures and different soil types in the Canadian canola growing regions compared to the US soybean production belt.

Table 80: Canadian canola: potential additional soil carbon sequestration (1996 to 2010)

	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	0.00	0.00
1997	3.3	4.9	15.83	58.09
1998	3.3	5.4	17.64	64.75
1999	3.3	5.6	18.08	66.37
2000	3.3	4.9	15.79	57.96
2001	6.5	3.8	24.60	90.30
2002	9.8	3.3	31.80	116.71
2003	13.0	4.7	60.96	223.72
2004	16.3	4.9	80.26	294.55
2005	19.5	5.5	107.07	392.96
2006	22.8	5.2	119.17	437.36
2007	22.8	5.9	134.47	493.52
2008	22.8	6.5	147.75	542.25
2009	22.8	6.4	145.05	532.34
2010	22.8	6.5	148.20	543.90
Total			**1,066.67**	**3,914.78**

Notes: NT/RT = +55 kg of carbon/ha/yr CT = -10 kg of 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 USA, it still only represented 17.5% of the total cotton crop in 2008[126]. Therefore, no analysis has been undertaken relating to possible fuel usage and soil carbon sequestration savings associated with the adoption of GM HT cotton in the USA. However, the importance of GM HT cotton in facilitating NT cotton tillage has been

[126] 2008 is the latest year for which no tillage data in cotton is available

confirmed by Doane Marketing Research (2002) 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 a small proportion of total maize plantings (eg, in the USA, NT maize accounted for 16.8% of total plantings in 1996 and by 2008 its share rose to 21%). The total area of conservation tillage (NT and RT) used in US maize production has remained at about 40% over the 1997-2010 period, even though during the same period the area of GM HT maize increased from zero to 69% of the maize area;
- 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 USA;
- as the soybean:maize rotation system is common place in the USA, 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. Between 1996 and 2010, the global cotton area planted with GM IR cultivars increased from 0.77 million ha to 18.8 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 Burkina Faso, China and India[127]) of GM IR cotton over the period 1996-2010, suggests that there has been a reduction of 150.2 million ha of cotton being sprayed. The cumulative saving in tractor fuel consumption has been 196.8 million litres. This represents a permanent reduction in carbon dioxide emissions of 525 million kg (Table 81).

Table 81: Permanent reduction in global tractor fuel consumption and carbon dioxide emissions resulting from the cultivation of GM IR cotton (1996-2010)

	Total cotton area in GM IR growing countries excluding Burkina Faso, India and China (million ha)	GM IR area (million ha) excluding Burkina Faso, 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	4.52	12.06
1997	7.09	0.92	3.67	4.81	12.85
1998	7.11	1.05	4.20	5.51	14.70
1999	7.15	2.11	8.44	11.05	29.51
2000	7.42	2.43	9.72	12.74	34.01
2001	7.07	2.55	10.18	13.34	35.62
2002	6.36	2.17	8.69	11.39	30.40
2003	5.34	2.17	8.70	11.39	30.41
2004	6.18	2.79	11.17	14.63	39.06
2005	6.28	3.21	12.84	16.81	44.89

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

2006	7.90	3.94	15.75	20.63	55.09
2007	6.07	3.25	12.99	17.02	45.45
2008	4.99	2.55	10.19	13.35	35.64
2009	5.33	2.96	11.83	15.50	41.39
2010	7.13	4.59	18.37	24.07	64.27
Total			**150.20**	**196.76**	**525.36**

Notes: assumptions: 4 tractor passes per ha, 1.31 litres/ha of fuel per insecticide application

4.2.8 Insect resistant maize

Limited 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 (CRW) 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 practised (eg, the USA), 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. The main exception to this has been in Brazil (see below);
- nominal application savings have occurred in relation to the adoption of GM CRW maize where over 17.38 million ha were planted in 2010. The adoption of the GM CRW may become increasingly important with wider adoption of no-till cultivation systems due to the potential increase in soil-borne pests.

In respect of the impact of using GM IR maize in Brazil (since 2008), in general, farmers using the technology have reduced the average number of insecticide spray runs by three (from five to two). This has resulted in a reduction of 40.95 million ha of maize being sprayed (for the three years 2008-2010), with a cumulative saving in tractor fuel of 53.64 million litres. This is equivalent to a permanent reduction in carbon dioxide emissions of 143 million kg.

4.2.9 Summary of carbon sequestration impact

A summary of the carbon sequestration impact is presented in Table 82. This shows the following key points:

- The permanent savings in carbon dioxide emissions (arising from reduced fuel use of 4,582 million litres of fuel) since 1996 have been about 12,232 million kg;
- The additional amount of soil carbon sequestered since 1996 has been equivalent to 133,639 million tonnes of carbon dioxide that has not been released into the global atmosphere[128]. The reader should note that these soil carbon savings are based on savings arising from the rapid adoption of NT/RT farming systems in North and South America (Argentina and Southern Brazil), for which the availability of GM HT

[128] 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

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. Cumulatively, the amount of carbon sequestered may be higher than these estimates due to year-on-year benefits to soil quality, however it is equally likely that the total cumulative soil sequestration gains have been lower because only a proportion of the crop area will have remained in NT/RT. For example, NT/RT data from the US shows that about 80% of the soybean crop is typically using NT/RT, whilst only 40% of the corn crop derives from NT/RT. Given that the soybean:corn rotation is a common system in the US (though not the only system of production for either crop), this suggests that an important area in RT/NT one year (whilst planted to soybeans) is subsequently reverted to CT the next year for a following corn crop. It is, nevertheless, not possible to confidently estimate cumulative soil sequestration gains that take into account reversions to conventional tillage because of a lack of data across countries and regions. Consequently, the estimate provided above of 133,639 million tonnes of carbon dioxide not released into the atmosphere should be treated with caution. It is a maximum potential, with the actual level of carbon dioxide savings occuring likely to be at a lower level.

Table 82: Summary of carbon sequestration impact 1996-2010

Crop/trait/country	Permanent fuel saving (million litres)	Potential additional carbon dioxide saving from fuel saving (million kg)	Potential additional carbon dioxide saving from soil carbon sequestration (million kg)
USA: GM HT soybeans	798	2,130	42,577
Argentina: GM HT soybeans	1,841	4,916	49,652
Brazil: GM HT eans	952	2,542	25,674
Bolivia, Paraguay, Uruguay: GM HT soybeans	438	1,170	11,821
Canada: GM HT canola	302	806	3,915
Global: GM IR cotton	197	525	0
Brazil: GM IR corn	54	143	0
Total	**4,582**	**12,232**	**133,639**

Examining further the context of the carbon sequestration benefits, Table 83 measures the carbon dioxide equivalent savings associated with planting of biotech crops for the latest year (2010), in terms of the number of car use equivalents. This shows that in 2010, the permanent carbon dioxide savings from reduced fuel use (1,715 million kg carbon dioxide) was the equivalent of removing 0.76 million cars from the road for a year and the additional soil carbon sequestration gains (17,634 million kg carbon dioxide) were equivalent to removing 7.84 million cars from the roads. In total, biotech crop-related carbon dioxide emission savings in 2010 were equal to the removal from the roads of 8.6 million cars, equal to 27.7% of all registered cars in the UK.

Table 83: Context of carbon sequestration impact 2010: car equivalents

Crop/trait/country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Permanent fuel savings: as average family car equivalents removed from the road for a year ('000s)	Potential additional soil carbon sequestration savings (million kg of carbon dioxide)	Soil carbon sequestration savings: as average family car equivalents removed from the road for a year ('000s)
USA: GM HT soybeans	246	109	4,810	2,138
Argentina: GM HT soybeans	670	298	6,762	3,005
Brazil: GM HT soybeans	364	162	3,680	1,636
Bolivia, Paraguay, Uruguay: GM HT soybeans	183	81	1,850	822
Canada: GM HT canola	110	49	532	237
Global: GM IR cotton	64	29	0	0
Brazil: GM IR corn	78	35	0	0
Total	**1,715**	**763**	**17,634**	**7,838**

Due to the limitations referred to above, no estimates of cumulative (1996-2010) carbon dioxide savings as car-equivalents have been provided.

Appendix 1: 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 (2010)

Country	Average yield across all forms of production (t/ha)	Total cotton area ('000 ha)	Total production ('000 tonnes)	GM IR area ('000 ha)	Conventional area ('000 ha)	Assumed yield effect of GM IR technology	Adjusted base yield for conventional cotton (t/ha)	GM IR production ('000 tonnes)	Conventional production ('000 tonnes)
US	0.91	4,415	4,017	3,222.3	1,192	+10%	0.848	3,006	1.011
China	1.289	5,140	6,625	3,450	1,690	+10%	1.208	4,584	2,041

Note: Figures subject to rounding

Appendix 2: Impacts, assumptions, rationale and sources for all trait/country combinations

IR corn (resistant to corn boring pests)

Country	Yield impact assumption used	Rationale	Yield references	Sensitivity analysis applied to yield assumptions	Cost of technology data/assumptions	Cost savings (excluding impact of seed premium) assumptions	Costs references
GM IR corn: resistant to corn boring pests							
US & Canada	+7% all years	Broad average of impact identified from	Carpenter & Gianessi (2002) found yield impacts of +9.4% 1997, +3% 1998, +2.5% 1999	+3% to +9%	$25 1996 & 1997 $20 1998 & 1999 $22 2000-	$15.5 all years to 2004 $15.9	The same reference sources as yield were used.

		several studies/papers and latest review/analysis covering 1996-2010 period	Marra et al (2002) average impact of +5.04% 1997-2000 based a review of five studies, James (2003) average impact of +5.2% 1996-2002, Sankala & Blumenthal (2003 & 2006) range of +3.1% to +9.9%. Hutchison et al (2010) +7% examining impact over the period 1996-2010. Canada - no studies identified – as US - impacts qualitatively confirmed by industry sources (personal communications 2005, 2007, 2008 & 2010)		2004 $17 2005-2007 $24.71 2008 $28.2, 2009 $34.06 2010	2005 onwards	Industry sources also confirmed costs of technology and estimated cost saving values for Canada 2008 onwards. Seed premia based on weighted cost of seed sold as single and stacked traits
Argentina	+9% all years to 2004, +5.5% 2005 onwards	Average of reported impacts in first seven years, later revised downwards for more recent years to reflect professional opinion	James (2003) cites two unpublished industry survey reports; one for 1996-1999 showing an average yield gain of +10% and one for 2000-2003 showing a yield gain of +8%, Trigo (2002) Trigo & Cap (2006) +10%, Trigo (2007 & 2008) personal communication estimates average yield impact since 2005 to be lower at between +5% and +6%	+5% to +9%	As US to 2005 then 61 pesos 2006 onwards	None as maize crops not traditionally treated with insecticides for corn boring pest damage	Cost of technology drawn from Trigo (2002) and Trigo & Cap (2006), ie, costed/priced at same level as US Trigo personal communications 2007, 2009 & 2010
Philippines	+24.6% to 2006, 2007-10 +18%	Average of three studies used all years to 2006. Thereafter	Gonzales (2005) found average yield impact of +23% dry season crops & +20% wet season crops; Yorobe (2004) +38%	+14% to +34% all years	$1,673 Pesos all years	651 Pesos all years	Based on Gonzales (2005) & Gonzales et al (2009) – the only sources to

		based on Gonzales et al (2009)	dry season crops & +35% wet season crops; Ramon (2005) found +15.3% dry season crops & +13.3% wet season crops. Gonzales et al (2009) +18%				break down these costs
South Africa	+11% 2000 & 2001 +32% 2002 +16% 2003 +5% 2004 +15% 2005-2007, +10.6% 2008 onwards	Reported average impacts used for years available (2000-2004), 2005-2007 based on average of other years. 2008 onwards based on Van der Welt (2009)	Gouse et al (2005), Gouse et al (2006 a & b) reported yield impacts as shown (range of +11% to +32%), Van der Wald (2010)	+5% to +32% all years	84 Rand 2000 & 2001 90 Rand 2002 94 Rand 2004 & 2005 113 Rand 2006 onwards	97 Rand all years	Based on the same papers as used for yield, plus confirmation in 2006-2010 that these are representativ e values from industry sources
Spain	+6.3% 1998-2004 +10% 2005 onwards	Impact based on authors own detailed, representat ive analysis for period 1998-2002 then updated to reflect improved technology based on industry analysis	Brookes (2003) identified an average of +6.3% using the Bt 176 trait mainly used in the period 1998-2004 (range +1% to +40% for the period 1998-2002). From 2005, 10% used based on Brookes (2008) which derived from industry (unpublished sources) commercial scale trials and monitoring of impact of the newer, dominant trait Mon 810 in the period 2003-2007. Gomez Barbero & Rodriguez-Corejo (2006) reported an average impact of	+3% to +15% all years	30 Euros 1998 & 1999 28 Euros 2000 18.5 Euros 2001-2005 35 Euros 2006 onwards	42 Euros all years	Based on Brookes (2003) the only source to break down these costs. The more recent cost of technology costs derive from industry sources (reflecting the use of Mon 810 technology). Industry sources also confirm value for insecticide cost savings as being representativ e

			+5% for Bt 176 used in 2002-2004				
Other EU	France +10%, Germany +4%, Portugal +12.5%, Czech Republic +10%, Slovakia +12.3%, Poland +12.5%, Romania +7.1% 2007, +9.6% 2008 & +4.8% 2009 & 2010	Impacts based on average of available impact data in each country	Based on Brookes (2008) which drew on a number of sources. For France 4 sources with average yield impacts of +5% to +17%, for Germany the sole source had average annual impacts of +3.5% and +9.5% over a two year period, for Czech Republic three studies identified average impacts in 2005 of an average of 10% and a range of +5% to +20%; for Portugal, commercial trial and plot monitoring reported +12% in 2005 and between +8% and +17% in 2006; in Slovakia based on trials for 2003-2007 and 2006/07 plantings with yield gains averaging between +10% and +14.7%; in Poland based on variety trial tests 2005 and commercial trials 2006 which had a range of +2% to +26%; Romania based on reported impact by industry sources	Not applied in context of total study due to very small scale of production (ie, would produce an insignificant impact range in the context of the whole study)	France & Germany 40 euros, Portugal, Czech & Slovak Republics, Poland 35 euros, Romania 32 euros	France & Germany 50 euros, Portugal, Slovakia, Poland & Romania nil, Czech Republic 18 euros	Data derived from the same source(s) referred to for yield
Uruguay	As Argentina	As Argentina	No country-specific studies identified, so impact analysis from nearest country of relevance (Argentina) applied	As Argentina: +5% to +9%	As Argentina	As Argentina	As Argentina
Brazil	+4.66%	Farmer	Galveo A (2009 &	+3% to +9%	$21.59	$41.98	Data derived

	2008, +7.3% 2009 & 2010	surveys	2010[38])		2008, $58.84 2009 $ 53.99 2010	2008, $44.21 2009 $48.60 2010	from Galveo A (2009 & 2010). Seed premium based on weighted average of seed sales
Honduras	+13% 2003-2006 +24% 2007-2010	Trials results 2002 and farmer survey findings in 2007	James (2003) cited trials results for 2002 with a 13% yield increase (it should be noted all of Honduras's crop is effectively trials) Falk Zepeda J et al (2009) undertook a farmer survey in 2007 – finding average yield differences with non GM corn of +24%	+10% to +30%	$30 based on average of rates in S Africa & the Philippines (seed provided to farmers in farm level trials are largely provided free to date)	Nil – no insecticide assumed to be used on conventional crops	As indicated
Colombia	+22%	Mendez et al (2011)	Mendez et al (2011) farm survey from 2009	+15% to +28%	88,850 pesos/ha	299,050 pesos/ha savings	Mendez et al (2011)
GM IR corn (resistant to corn rootworm)	**Yield impact assumption used**	**Rationale**	**Yield references**	**Sensitivity analysis applied to yield assumptions**	**Cost of technology data/assumptions**	**Cost savings (excluding impact of seed premium) assumptions**	**Costs references**
US & Canada	+5% all years	Based on the impact used by the references cited	Sankala & Blumenthal (2003 & 2006) used +5% in analysis citing this as conservative, themselves having cited impacts of +12%-+19% in 2005 in Iowa, +26% in Illinois in 2005 and +4%-+8% in Illinois in 2004. Johnson S & Strom S (2008) used the same basis as Sankala &	+3% to +9%	$42 2003 and 2004 $35 2005-2007. 2008 $24.71, 2009 $28.21, 2010 $32.06	$32 2003 $37 2004 onwards	Data derived from Sankala & Blumenthal (2005) and Johnson S & Strom S (2008). Seed costs 2008 onwards based on weighted seed sales of single and stacked traits

			Blumenthal Rice (2004) range of +1.4% to +4.5% (based on trials) Canada - no studies identified – as US - impacts qualitatively confirmed by industry sources (personal communications 2005, 2007 & 2010)				Canada - no studies identified – as US - impacts qualitatively confirmed by industry sources (personal communications 2005-2010)
IR cotton	**Yield impact assumption used**	**Rationale**	**Yield references**	**Sensitivity analysis applied to yield assumptions**	**Cost of technology data/assumptions**	**Cost savings (excluding impact of seed premium) assumptions**	**Costs references**
US	+9% 1996-2002 +11% 2003 & 2004 +10% 2005 onwards	Based on the (conservative) impact used by the references cited	Sankala & Blumenthal (2003) & (2006[9]) drew on earlier work from Carpenter and Gianessi (2002) in which they estimated the average yield benefit in the 1996-2000 period was +9%. Marra et al (2002) examined the findings of over 40 state-specific studies covering the period 1996 up to 2000, the approximate average yield impact was +11%. The lower of these two values was used for the period to 2002. The higher values applied from 2003 reflect values used by Sankala & Blumenthal (2006)	+5% to +15%	$58.27 1996-2002 $68.32 2003 & 2004 $49.6 2005 & 2006, $25.7 2007 onwards	$63.26 1996-2002 $74.1 2003-2005 $41.18 2006, $28.4/ha 2007 onwards	Data derived from the same sources referred to for yield

			and Johnson & Strom (2008) that take into account the increasing use of Bollgard II technology, and draws on work by Mullins & Hudson (2004) that identified a yield gain of +12% relative to conventional cotton. The values applied 2005 onwards were adjusted downwards to reflect the fact that some of the GM IR cotton area has still been planted to Bollgard I				
China	+8% 1997-2001 +10% 2002 onwards	Average of studies used to 2001. Increase to 10% on basis of industry assessments of impact and reporting of unpublished work by Schuchan	Pray et al (2002) surveyed farm level impact for the years 1999-2001 and identified yield impacts of +5.8% in 1999, +8% in 2000 and +10.9% in 2001 Monsanto China personal communications (2007-2010)	+6% to +12%	$46.3 all years to 2005 366 Yuan 2006 onwards	$261 2000 $438 2001 average of these used all other years to 2004 1,530 Yuan 2005 onwards	Data derived from the same sources referred to for yield
Australia	None	Studies have usually identified no significant average yield gain	Fitt (2001) Doyle (2005) James (2002) CSIRO (2005)	None applied	$Aus 245 1996 & 1997 $Aus 155 1998 $Aus 138 1999 $Aus 138 2000-2001 $ Aus 155 2002, $Aus 167 2003 $Aus 190 2004 $Aus	$Aus 151 1996 $Aus 157 1997 $Aus 188 1998 $Aus 172 1999 $Aus 267 2000-	Data derived from the same sources referred to for yield covering earlier years of adoption, then CSIRO[45] for later years. For 2006-2009 cost of technology values

					250 2005-2007 $Aus300 2008 $Aus 315, 2009 & 2010 $Aus 291	2002 $Aus 598 2003 $Aus 509 2004 $Aus 553 2005 onwards	confirmed by personal communication from Monsanto Australia
Argentina	+30% all years	More conservative of the two pieces of research used	Qaim & De Janvry (2002[46] & 2005[47]) analysis based on farm level analysis in 1999/00 and 2000/01 +35% yield gain, Trigo & Cap (2006[27]) used an average gain of +30% based on work by Elena (2001[48])	+25% to +35%	$86 all years to 2004 116 pesos 2005 onwards	51 pesos all years	Data derived from the same sources referred to for yield. Cost of technology in 2006-2008 also confirmed from industry sources
South Africa	+24% all years	Lower end of estimates applied	Ismael et al (2002) identified yield gain of +24% for the years 1998/99 & 1999/2000. Kirsten et al (2002) for 2000/01 season found a range of +14% (dry crops/large farms) to +49% (small farmers) James (2002) also cited a range of impact between +27% and +48% during the years 1999-2001	+15% to +40%	149 Rand all years to 2005 345 Rand 2006 onwards	127 Rand all years	Data derived from the same sources referred to for yield. Values for cost of technology and cost of insecticide cost savings also provided/confirmed from industry sources
Mexico	+37% 1996 +3% 1997 +20% 1998 +27% 1999 +17% 2000 +9% 2001	Recorded yield impact data used as available for almost all years	The yield impact data for 1997 and 1998 is drawn from the findings of farm level survey work by Traxler et al (2001). For all other years the data is based on the commercial crop	None applied as almost all years are crop-specific estimates	540 pesos all years to 2005 760 Pesos 2006-2008, 2009 1,319 pesos, 2010 1,250 pesos	985 pesos all years	Data derived from the same sources referred to for yield. 2009 seed cost based on weighted average of single and

	+6.7% 2002 +6.4% 2003 +7.6% 2004 +9.25% 2005 +9% 2006 +9.28 2007 & 2008, +14.2% 2009, +10.9% 2010 (based on av of last 3 yrs)		monitoring reports required to be submitted to the Mexican government (source: Monsanto Mexico (various years)				stacked traited seed sales
India	+45% 2002 +63% 2003 +54% 2004 +64% 2005 +50% 2006 & 2007 +40% 2008, +35% 2009 & 2010	Recorded yield impact used for years where available	Yield impact data 2002 and 2003 is drawn from Bennett et al (2004[3]), for 2004 the average of 2002 and 2003 was used. 2005 and 2006 are derived from IMRB (2006 & 2007). 2007 impact data based on lower end of range of impacts identified in previous 3 years (2007 being a year of similar pest pressure to 2006). 2008 onwards based on them being years of fairly low average pest pressure & industry estimates	45% to 65% all years	2,636 Rupees 2002 2,512 Rupees 2003 2,521 Rupees 2004 2,307 Rupees 2005 2,211 Rupees 2006 801 Rupees 2007 onwards	2,032 Rupees 2002 1,767 Rupees 2003 1,900 Rupees 2004 1,362 Rupees 2005 2,308 Rupees 2006 1,857 Rupees 2007 onwards	Data derived from the same sources referred to for yield. 2007 onwards cost of technology confirmed from industry sources and cost savings for 2007 onwards taken as average of past 3 years
Brazil	+6.23% 2006 -3.6% 2007 -2.7% 2008, -3.8% 2009, 2010 nil	Recorded yield impacts for each year	2006 unpublished farm survey data – source: Monsanto (2008[0]) 2007- 2010 farm survey data from Galveo (2009 & 2010))	-4% to +8% all years	Real 87 2006 Real 67.1 2007 Real 79.4 2008, Real 83 2009 & 2010	Real 141 2006 Real 134 2007 Real 161 2008, Real 115	Data derived from the same sources referred to for yield

						2009 & 2010	
Colombia	+30% all years except 2009 +15%, 2010 +10%	Farm survey 2007 comparing performance of GM IR versus conventional growers. 2009 onwards based on trade estimates	Based on Zambrano P et al (2009) and trade estimates (2009 & 2011)	+5% to +30%	Assumed as Mexico – no breakdown of seed premium provided in Zambrano et al (2009). From 2008 based on weighted cost of seed sold as single and stacked traits $111.72 2008, $101.88 2009, $165.77 2010	423,912 pesos all years to 2009, 160,000 pesos 2010	Data derived from Zambrano P et al (2009). Cost savings exc seed premium derived from Zambrano as total cost savings less assumed seed premium. 2010 seed premium & cost savings from industry sources
Burkina Faso	+20 2008, +18.9% 2009 & 2010	Trials 2008, farm survey 2009	Vitale J et al (2008) & Vitale J et al (2010)	+15% to +25%	$42 2008 Assumed as S Africa as no premium available from trials	$62 all years	Based on Vitale J et al (2008 & 2010)
GM HT soybeans	**Yield impact assumption used**	**Rationale**	**Yield references**	**Sensitivity analysis applied to yield assumptions**	**Cost of technology data/assumptions**	**Cost savings (excluding impact of seed premium) assumptions**	**Costs references**
US: 1st generation	Nil	Not relevant	Not relevant	Not relevant	$14.82 1996-2002 $17.3 2003 $19.77 2004 $24.71 2005-2008. $38.79 2009,	$25.2 1996-97 $33.9 1998-2002 $73.4 2003 $60.1	Marra et al (2002) Gianessi & Carpenter (1999) Carpenter & Gianessi (2002)

					$37.95 2010	2004 $69.4 2005 $57.06 2006 $85.2 2007 $57.12 2008, $54.72 2009, $66.20 2010	Sankala & Blumenthal (2003 & 2006) Johnson S & Strom S (2008) & updated post 2008 to reflect herbicide price and common product usage
Canada: 1st generation	Nil	Not relevant	Not relevant	Not relevant	32 Can $ 1997-2002 48 Can $ 2003 45 Can $ 2004 & 2005 41 Can $ 2006-22-9, Can $ 26.31 2010 onwards	Range of 66 to 89 Can $ 1997-2007, Can 60 $ 2008, Can $ 60.38 2009, Can $45.25 2010	George Morris Center (2004) & updated for 2008 to reflect herbicide price changes
US & Canada: 2nd generation	+5%	Reported findings	Farm level monitoring and farmer feedback to seed companies	+3% to +7%	$65.21 2009 $50.14 2010 & Can $43.54	as 1st generation	As 1st generation
Argentina	Nil but second crop benefits	Not relevant except 2nd crop – see separate table	Not relevant	Not relevant	$3-$4 all years to 2001 $1.2 2002-2005 (reflecting all use of farm saved seed) $2.5 2006 onwards (Monsanto royalty rate)	$24-$30: varies each year to 2007 according to exchange rate. $13.87 2008, $16.42 2009, $18.13 2010	Qaim & Traxler (2002 & 2005[56]), Trigo & CAP (2006) & updated from 2008 to reflect herbicide price changes
Brazil	Nil	Not relevant	Not relevant	Not relevant	As Argentina to 2002 (illegal plantings)	$88 in 2004 applied to all other	Data from the Parana Department of Agriculture

					$9 2003 $15 2004 $16 2005 $19.8 2006 $21.11 2007 $19.63 2008, $20.26 2009, $19.49 2010	years to 2006 at prevailing exchange rate. $29.83 2007 $64.07 2008, $47.93 2009, $50.28 2010	(2004). Also agreed royalty rates from 2004 applied to all years to 2006. 2007 onwards based on Galveo (2009 & 2010)
Paraguay	Nil but second crop benefits	Not relevant except 2nd crop	Not relevant	Not relevant	As Argentina to 2004 2005 $4.86 2006 $3.09 2007 &2008 $9.64, $4.4 2009 onwards	As Argentina	As Argentina: no country-specific analysis identified. Impacts confirmed from industry sources (personal communications 2006, 2008 & 2009). Seed cost based on royalty rate since 2007
South Africa	Nil	Not relevant	Not relevant	Not relevant	170 Rand all years to 2005 195 Rand 2006 onwards	230 Rand each year to 2007, 2008 210 Rand, 2009 212 Rand, 2010 247 Rand	No studies identified - based on Monsanto S Africa (personal communications 2005, 2007, 2008, 2009 & 2011)
Uruguay	Nil	Not relevant	Not relevant	Not relevant	As Argentina	As Argentina	As Argentina: no country-specific analysis identified.

							Impacts confirmed from industry sources (personal communications 2006, 2008, 2009 & 2011)
Mexico	+9.1% 2004 &2005 +3.64% 2006 +3.2% 2007 +2.4% 2008 +13% 2009, +4% 2010	Recorded yield impact from studies	From Monsanto (various years) – annual monitoring reports submitted to government (of crop which are all technically trials)	None applied – small scale (effectively trial)plantings all years	212 pesos all years to 2008, 310 pesos 2009	770 pesos 2004-2007 580 pesos 2008, 150pesos 2009 onwards	No published studies identified based on Monsanto annual monitoring reports
Romania	+31%	Based on only available study covering 1999-2003 (note not grown in 2007)	For previous year – based on Brookes (2005) – the only published source identified	+20% to +40%	$160 1999-2000 $148 2001 $135 2002 $130 2003 & 2004 $121 2005 $100 2006 Not permitted for use in EU 2007 All years includes 4 litres of herbicide	$150-$192 1999-2006 depending on Euro to $ exchange rate 2007 not applicable – trait not permitted for growing in EU	Brookes (2005)
Bolivia	+15%	Based on survey in 2007-08	Fernandez W et al (2009) farm survey of GM HT versus conventional growers	+10% to +20%	$3.32 all years	$9.28 all years	Fernandez W et al (2009)
GM HT corn	**Yield impact assumption used**	**Rationale**	**Yield references**	**Sensitivity analysis applied to yield assumptions**	**Cost of technology data/assumptions**	**Cost savings (excluding impact of seed**	**Costs references**

						premium) assumptions	
US	Nil	Not relevant	Not relevant	Not relevant	$14.8 all years to 2004 $17.3 2005 $24.71 2006-2008 $26.35 2009, $29.35 2010	$39.9 all years to 2003 $38.47 2004 $38.61 2005 $ 29.27 2006 $42.28 2007 $39.29 2008 $39.18 2009, $41.12 2010	Carpenter & Gianessi (2002) Sankala & Blumenthal (2003 & 2006) Johnson S & Strom S (2008). 2008 and 2009 updated to reflect changes in common treatments and prices. Seed cost based on weighted seed sales (sold as single and stacked traits)
Canada	Nil	Not relevant	Not relevant	Not relevant	$ Can 27 1999-2005 $ Can 35 2006 onwards	$Can 48.75 all years to 2007 $ Can 41.12 2008, $44.67 2009, $41.44 2010	No studies identified – based on personal communications with industry sources, including Monsanto Canada. 2008 & 2009 updated to reflect herbicide price changes
Argentina: sold as single trait	+3% corn belt +22% marginal areas	Based on only available analysis - Corn Belt = 70% of	No studies identified – based on personal communications with industry sources in 2007 and	+1% to +5% corn belt, +15% to +30% marginal areas	61 pesos all years to 2008. 72 pesos 2009 & 2010	61 pesos all years to 2007. 43.4	No studies identified - based on Monsanto Argentina & Grupo CEO

		plantings, marginal areas 30% - industry analysis (note no significant plantings until 2006)	2008 Monsanto Argentina & Grupo CEO (personal communications 2007, 2008 & 2011)			pesos 2008, 53.66 pesos 2009, 64.15 pesos 2010	(personal communications 2007 & 2008). 2008 & 2009 updated to reflect herbicide price changes
Argentina: sold as stacked trait	+10.25%	Farmer level feedback to seed suppliers	Unpublished farm level survey feedback to Monsanto: +15.75% yield impact overall – for purposes of this analysis, 5.5% allocated to IR trait and balance to HT trait	+5% to +15%	2007 125 peso, 2008 130 peso, 2009 & 2010 153 peso	As single trait	As single trait
South Africa	Nil	Not relevant	Not relevant	Not relevant	80 Rand 2003-2005 120 Rand 2006 onwards	162 Rand all years to 2007. 101.6 Rand 2008, 106.5 Rand 2009, 124.8 Rand 2010	No studies identified - based on Monsanto S Africa (personal communications 2005, 2007 & 2008). 2008 onwards updated to reflect herbicide price changes
Philippines	+15% 2006 and 2007, +5% 2008 & 2009	Farm survey	Based on unpublished industry analysis for 2006 &2007, thereafter Gonsales L et al (2009)	+3% to +18% all years	1,232 pesos all years	Not known originally so conservative assumption of zero used to 2007 2008 & 2009 1,644 pesos, 2010 1,834	Monsanto Philippines (personal communications 2007 & 2008). Gonsales L et al (2009). 2010 updated to reflect changes in herbicide costs

						pesos	
Brazil	+2.5% 2010	Farm survey	Galveo (2010))	Zero to +5% all years	Real 31 2010	Real 71 2010	Data derived from the same sources referred to for yield
Colombia	Zero	Mendez et al (2011)	Mendez et al (2011) farm survey from 2009	Zero	43,335 pesos	221,050 pesos savings	Mendez et al (2011)
GM HT Cotton	**Yield impact assumption used**	**Rationale**	**Yield references**	**Sensitivity analysis applied to yield assumptions**	**Cost of technology data/assumptions**	**Cost savings (excluding impact of seed premium) assumptions**	**Costs references**
US	Nil	Not relevant	Not relevant	Not relevant	$12.85 1996-2000 $21.32 2001-2003 $34.55 2004 $68.22 2005 $70.35 2006 $70.61 2007 $71.56 2008 $76.2 2009, $81.24 2010	$34.12 1996-2000 $66.59 2001-2003 $83.35 2004 $71.12 2005 $73.66 2006 $76.01 2007 $77.7 2008 $83.69 2009, $94.81 2010	Carpenter & Gianessi (2002) Sankala & Blumenthal (2003 & 2006) Johnson S & Strom S (2008[41]) and updated from 2008 to reflect changes in weed control practices and prices of herbicides. Seed costs 2008 onwards weighted by single, stack Roundup Ready and Roundup Ready Flex seed sales
Australia	Nil	Not relevant	Not relevant	Not relevant	$ Aus 50 all years to 2007 $ Aus 75 2008	+$ Aus 60 all years to 2007 +$ Aus	Doyle et al (2003) Monsanto Australia (personal

					$ Aus 79 2009, $ Aus 75 2010	104.5 2008, $ Aus 113 2009, $ Aus 114.4 2010	communications 2005, 2007, 2009 & 2010)
South Africa	Nil	Not relevant	Not relevant	Not relevant	133 Rand 2001-2004 101 Rand 2005 165 Rand 2006 and 2007 182.5 Rand, 2008 onwards	160 Rand all years to 2004 485 Rand 2005 513 Rand 2006 & 2007 555 Rand 2008 460 Rand, 449 Rand 2009, 479 Rand 2010	No studies identified - based on Monsanto S Africa (personal communications 2005, 2007, 2008 & 2010)
Argentina	Nil on area using farm saved seed, +9.3% on area using certified seed	Based on only available data – company monitoring of commercial plots	No studies identified – based on personal communications with Grupo CEO and Monsanto Argentina (2007 & 2008)	+10% to +20% on certified seed area which equalled 30% of total plantings 2008	122 pesos all years to 2007, 75 pesos 2008 onwards	68 pesos all years to 2007, 106 pesos 2008 onwards	No published studies identified – based on personal communications with Grupo CEO and Monsanto Argentina (2007, 2008 & 2010)
Mexico	+3.6% all years to 2007 0% 2008, +5.11% 2009 & 2010	Based on only available data – company monitoring of	Same as source for cost data	Zero to +5% all years	720 pesos all years to 2007 758 pesos 2008, 385 pesos 2009 & 2010	1,150 pesos all years to 2007 961 pesos	No published studies identified - based on personal communicati

		commercial 'trial' plots & annual reporting to government				2008, 230 pesos 2009 & 2010	ons with Monsanto Mexico and their annual reporting of the trials to government (annually)
Colombia	+4%	Based on only available data – company monitoring of commercial plots	As cost data	+2% to +6%	$95.8 all years to 2009, $177 2010	$88.2 all years to 2009, $205 2010	No published studies identified – based on personal communications with Monsanto Colombia (2010)
Brazil	+2.35% 2010	Farm survey	Galveo (2010[51]))	Zero to +5% all years	Real 83 2010	Real 242 2010	Data derived from the same sources referred to for yield
GM HT canola	**Yield impact assumption used**	**Rationale**	**Yield references**	**Sensitivity analysis applied to yield assumptions**	**Cost of technology data/assumptions**	**Cost savings (excluding impact of seed premium) assumptions**	**Costs references**
US	+6% all years to 2004. Post 2004 based on Canada – see below	Based on the only identified impact analysis – post 2004 based on Canadian impacts as same alternative (conventional HT) technology to Canada available	Same as for cost data	+3% to +9% all years	$29.5 1999-2001 $33 2002-2004 $12 2005 onwards for glyphosate tolerant $ 17.3 all years for glufosinate tolerant to 2004 $12 2005-2007 $17.3 2008 onwards	*glyphosate tolerant* $60.75 1999-2001 $67 2002 & 2003 $69 2004 $49 2005 $40 2006 $64 2007 $60.4	Sankala & Blumenthal (2003 & 2006)) Johnson S & Strom S (2008). These are the only studies identified that examine GM HT canola in the US. Updated for 2008 & 2009 based on changes in

						2008 $62.2 2009, $66.2 2010 *glufosinate tolerant* $44.89 all years to 2003 $44 2004 $40 2005 $ 34.6 2006 $ 18.2 2007 $20.2 2008 $20.7 2009, $21.3 2010	herbicide prices
Canada	+10.7% all years to 2004. Post 2004; for GM glyphosate tolerant varieties no yield difference 2004, 2005, 2008, +4% 2006 and 2007, +1.67% 2009. For GM glufosinate tolerant varieties: +12% 2004, +19%	After 2004 based on differences between average annual variety trial results for Clearfields (non GM herbicide tolerant varieties) and GM alternatives. GM alternatives differentiated into glyphosate tolerant and glufosinate tolerant	Same as for cost data	+4% to +12% all years	$ Can 44.63 all years to 2003 2004 onwards based on difference seed premium and technology fee relative to Clearfields HT canola; zero for GM glufosinate tolerance & $ Can 37 for glyphosate tolerance	Glyphosate tolerant $ Can 39 all years to 2003 $ Can 40 2004 & 2005 $ Can 53.46 2006 $ Can 53.5 2007 $ Can 36.56 2008 $Can 37.7 2009, Can $34.89 2010 Glufosinate	Based on Canola Council (2001) to 2003 then adjusted to reflect main current non GM (HT) alternative of 'Clearfields' – data derived from personal communications with the Canola Council (2008) plus Gusta M et al (2009) which includes spillover benefits of $ Can13.49 to follow on

	2005, +10% 2006 & 2007 +12% 2008 +11.8% 2009					tolerant $ Can 39 all years to 2003 $ Can 10 2004 & 2005 $ Can 22.17 2006 $Can 21.81 2007 $ Can 11.1 2008 $ Can 11.37 2009, Can $7.8 2010	crops – applied to 2006-2008 only
Australia	+21.08% 2008 average across comparisons with hybrids and open pollinated varieties. 2009 onwards yield gains identified in original survey weighted according to sales of open pollinated and hybrid varieties	Survey based	Based on survey of licence holders by Monsanto Australia	+15% to +25% all years	$Aus 47.02 2208, $ Aus 46.52 2009, $ Aus 31.9 2010	$ Aus 22.87 2008, $ Aus 22.72 2009, $ Aus 21.8 2010	Monsanto Australia survey of licence holders (2009). Subsequent years weighted by seed sales
GM HT sugar beet							
US &	+12.58%	Farm	Kniss (2008)	+2% to +10%	$130.96	$353.35	Kniss A

Canada	2007 +2.8% 2008 +3.3% 2009 & 2010	survey & extension service analysis	Khan (2008)	all years	2007 $131.08 2008 onwards	2007 $142.5 2008 onwards	(2008) Khan M (2008)
GM VR crops US							
Papaya	between +15% and +77% 1999-2009 – relative to base yield of 22.86 t/ha	Based on average yield in 3 years before first use	Draws on only published source disaggregating to this aspect of impact	+15% all years to +50% all years	Nil 1999 to 2003 $42 2004 $148 2005-2007 $494 2008 &2009	Nil – no effective conventional method of protection	Sankala & Blumenthal (2003 & 2006), Johnson S & Strom S (2008) and updating of these from 2008 and 2009
Squash	+100% on area planted	assumes virus otherwise destroys crop on planted area	Draws on only published source disaggregating to this aspect of impact	+50% all years	$398 2004 & 2005 $376 2006 $736 2007 onwards	Nil – no effective conventional method of treatment	Sankala & Blumenthal (2003 & 2006), Johnson S & Strom S (2008) and updating of these from 2008

Readers should note that the assumptions are drawn from the references cited supplemented and updated by industry sources (where the authors have not been able to identify specific studies). This has been particularly of relevance for some of the herbicide tolerant traits more recently adopted in several developing countries. Accordingly, the authors are grateful to industry sources which have provided information on impact, (notably on cost of the technology and impact on costs of crop protection). Whilst this information does not derive from detailed studies, the authors are confident that it is reasonably representative of average impacts; in fact in a number of cases, information provided from industry sources via personal communications has suggested levels of average impact that are lower than that identified in independent studies. Where this has occurred, the more conservative (industry source) data has been used.

Farm level income impact of using GM HT soybeans in Argentina 1996-2010 (2): second crop soybeans

Year	Second crop area (million ha)	Average gross margin/ha for second crop soybeans ($/ha)	Increase in income linked to GM HT system (million $)
1996	0.45	128.78	Negligible
1997	0.65	127.20	25.4
1998	0.8	125.24	43.8
1999	1.4	122.76	116.6
2000	1.6	125.38	144.2

2001	2.4	124.00	272.8
2002	2.7	143.32	372.6
2003	2.8	151.33	416.1
2004	3.0	226.04	678.1
2005	2.3	228.99	526.7
2006	3.2	218.40	698.9
2007	4.94	229.36	1,133.6
2008	3.35	224.87	754.1
2009	3.55	213.86	759.2
2010	4.40	264.10	1,162.1

Source & notes:

1. Crop areas and gross margin data based on data supplied by Grupo CEO and the Argentine Ministry of Agriculture (2009 & 2010). No data available before 2000, hence 2001 data applied to earlier years but adjusted, based on GDP deflator rates
2. 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)

Appendix 3: Additional information relating to the environmental impact

US Soybeans: typical herbicide regimes for conventional production systems

	Active ingredient (kg/ha)	Field EIQ/ha value
Option 1		
Pendimethalin	1.109	33.45
Flumioxazin	0.066	1.58
Chlorimuron	0.022	0.34
Total	**1.197**	**35.37**
Option 2		
Pendimethalin	1.109	33.45
Flumioxazin	0.066	1.58
Cloransulam	0.215	3.3
Total	**1.39**	**38.33**
Option 3		
S Metalochlor	1.13	24.86
Metribuzin	0.436	12.37
Bentazon	0.56	10.45
Acifloren	0.28	6.60
Total	**2.406**	**54.28**
Average all conventional options	**1.664**	**42.66**

US Soybeans: typical herbicide regimes for GM HT soybeans: reactive for addressing weed resistance

	Active ingredient (kg/ha)	Field EIQ/ha value
Option 1		
Glyphosate	1.06	16.25
Flumioxazin	0.066	1.58
Chlorimuron	0.022	0.34

Fomesafen	0.008	0.19
Total	**1.156**	**18.36**
Option 2		
Glyphosate	1.06	16.25
Flumioxazin	0.11	1.69
Cloransulam	0.215	3.29
Total	**1.385**	**21.23**
Option 3		
Glyphosate	1.06	16.25
Bentazon	0.56	10.45
Acifloren	0.25	6.60
Total	**1.87**	**33.30**
Average all options	**1.47**	**24.30**

US Soybeans: typical herbicide regimes for GM HT soybeans: proactive for addressing weed resistance

	Active ingredient (kg/ha)	**Field EIQ/ha value**
Option 1		
Glyphosate	1.06	16.25
Flumioxazin	0.066	1.58
Chlorimuron	0.022	0.34
Total	**1.148**	**18.36**
Option 2		
Glyphosate	1.06	16.25
Flumioxazin	0.067	1.61
Cloransulam	0.036	0.55
Total	**1.163**	**18.41**
Option 3		
Glyphosate	1.06	16.25
Metribuzin	0.436	12.37
Total	**1.496**	**28.62**
Average all options	**1.269**	**21.80**

US Soybeans: GM HT soybeans: glyphosate only option

	Active ingredient (kg/ha)	**Field EIQ/ha value**
Glyphosate	**1.6**	**24.53**

US Soybeans: no till burndown: applicable to about two thirds of GM HT soybeans and 45% of conventional soybeans

	Active ingredient (kg/ha)	**Field EIQ/ha value**
Glyphosate	1.06	16.25
2 4 D	0.56	7.66
Total	**1.62**	**23.91**

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	2.64	36.88

Source: AMIS Global dataset on pesticde use 2006-2010		
Conventional soybeans		
Option 1		
Glyphosate	0.864	13.25
Metsulfuron	0.03	0.50
2 4 D	0.3	6.21
Imazethapyr	0.08	1.57
Diflufenican	0.05	0.88
Clethodim	0.144	2.45
Total	**1.468**	**24.85**
Option 2		
Glyphosate	1.35	20.70
Dicamba	0.0576	1.46
Acetochlor	1.08	21.49
Haloxifop	0.096	2.13
Sulfentrazone	0.0875	1.02
Total	**2.67**	**46.80**
Option 3		
Glyphosate	1.62	24.83
Atrazine	0.384	8.79
Bentazon	0.6	11.22
2 4 D ester	0.04	0.61
Imazaquin	0.024	0.37
Total	**2.67**	**45.83**
Option 4		
Glyphosate	1.8	27.59
2 4 D amine	0.384	7.95
Flumetsulam	0.06	0.94
Fomesafen	0.25	0.13
Chlorimuron	0.015	0.29
Fluazifop	0.12	3.44
Total	**2.63**	**46.34**
Option 5		
Glyphosate	1.8	27.59
Metsulfuron	0.05	0.84
2 4 D amine	0.75	15.53
Imazethapyr	0.1	1.96
Haloxifop	0.096	2.13
Total	**2.80**	**48.05**
Option 6		
Glyphosate	1.8	27.59
Metsulfuron	0.05	0.84
2 4 D amine	0.75	15.53
Imazethapyr	0.1	1.96
Clethodim	0.24	4.08
Total	**2.94**	**49.99**
Average all six conventional options	**2.53**	**43.64**

Sources: AAPRESID and Monsanto Argentina

GM HT versus conventional maize Argentina 2010

	Active ingredient (kg/ha)	Field eiq/ha value
Conventional		
Option 1		
Acetochlor	1.68	33.43
Atrazine	1.0	22.90
Misotrione	0.14	2.52
Total	**2.82**	**58.85**
Option 2		
Acetochlor	1.68	33.43
Atrazine	1.0	22.90
Foramsulam	0.03	0.46
Total	**2.71**	**56.79**
Average conventional	**2.77**	**57.82**
GM HT corn		
Acetochlor	0.84	16.72
Atrazine	0.5	11.45
Glyphosate	1.02	15.64
Total	**2.36**	**43.80**

Sources: AMIS Global and Monsanto Argentina

Typical herbicide regimes for GM HT cotton in Argentina

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional cotton		
Glyphosate	1.8	27.59
Acetochlor	0.6	11.94
Diuron	1.034	27.40
Quizalofop	0.05	1.10
Total	**3.484**	**68.04**
GM HTcotton		
Glyphosate	**1.8**	**27.59**

Source: Monsanto Argentina

Typical herbicide regimes for GM HT soybeans Brazil 2010

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Burndown (applicable to conventional and GM HT)	1.27	19.51
GM HT over the top	1.10	16.83
GM HT total	**2.37**	**36.34**
Conventional over the top	0.67	13.45
Conventional total	**1.96**	**30.71**

Source: derived from Kleffmann & AMIS Global

Typical herbicide regimes for GM HT soybeans in South Africa

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional soybeans		
Option one		
Alachlor	1.536	27.49

Chlorimuron	0.01	0.19
Total	**1.546**	**27.69**
Option two		
S Metolachlor	1.536	33.79
Imazethapyr	0.07	0.78
Total	**1.576**	**34.58**
Option 3		
S Metolachlor	1.536	33.79
Chlorimuron	0.01	0.78
Total	**1.546**	**34.58**
Average	**1.556**	**32.08**
GM HT soybeans		
Glyphosate	**1.89**	**28.97**

Source: Monsanto South Africa

Typical herbicide regimes for GM HT maize in South Africa

Active ingredient	**Amount (kg/ha of crop)**	**Field EIQ/ha**
Conventional maize		
Acetochlor	1.728	34.39
Atrazine	1.375	31.49
Total	**3.103**	**65.87**
GM HT maize		
Acetochlor	0.864	17.89
Glyphosate	1.89	28.97
Total	**2.754**	**46.17**

Source: Monsanto South Africa

Typical herbicide regimes for GM HT cotton in South Africa

Active ingredient	**Amount (kg/ha of crop)**	**Field EIQ/ha**
Conventional cotton		
Option one		
Trifluralin	1.12	21.06
Total	**1.12**	**21.06**
Option two		
S Metolachlor	0.96	20.9
Flumeturon	0.4	5.72
Prometryn	0.5	7.70
Total	**1.85**	**34.48**
Option 3		
Trifluralin	1.12	21.06
Cyanazine	0.85	11.56
Total	**1.97**	**32.62**
Option 4		
Trifluralin	1.12	21.06
Flumeturon	0.4	5.72
Prometryn	0.5	7.70
Acetochlor	0.32	6.37
Atrazine	0.128	2.93
Total	**2.093**	**43.77**
Option 5		
Trifluralin	0.75	14.10
Flumeturon	0.4	5.72

Prometryn	0.5	7.70
Total	**1.65**	**27.52**
Average conventional	**1.81**	**31.86**
GM HT cotton		
Glyphosate	**1.8**	**27.59**

Source: Monsanto South Africa

Typical herbicide regimes for GM HT maize in Canada

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional maize		
Metolachlor	1.3566	29.84
Atrazine	1.1912	27.28
Primsulfuron	0.0244	0.41
Dicamba	0.14	3.54
Total	**2.7122**	**61.07**
GM glyphosate tolerant maize		
Metolachlor	0.678	14.92
Atrazine	0.594	13.60
Glyphosate	0.56	8.58
Total	**1.832**	**37.10**
GM glufosinate tolerant maize		
Metolachlor	0.678	14.92
Atrazine	0.594	13.60
Glufosinate	0.37	7.49
Total	**1.642**	**36.01**

Sources: Weed Control Guide Ontario, industry

Typical insecticide regimes for cotton in India 2010

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional cotton		
Option 1		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Triazophos	0.5	17.80
Profenfos	0.625	37.19
Acephate	0.6	14.94
Spinosad	0.384	5.53
Metaflumizone	0.025	0.82
Flubendiamide	0.048	0.93
Total	**2.42**	**84.15**
Option 2		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Profenfos	0.625	37.19
Chloripyrifos	0.4	10.76
Metaflumizone	0.025	0.82

Emamectin	0.011	0.29
Total	**1.30**	**56.00**
Average conventional	**1.86**	**70.07**
GM IR cotton		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Triazophos	0.5	17.80
Profenfos	0.625	37.19
Total	**1.36**	**61.92**
Option 2		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Total	**0.24**	**6.94**
Average GM IR cotton	**1.06**	**34.43**

Source: Monsanto India

Typical insecticide regimes for cotton in China 2010

Active ingredient	**Amount (kg/ha of crop)**	**Field EIQ/ha**
Conventional cotton		
Imidacloprid	0.65	23.86
Abamectin	0.03	1.04
Chlorpyrifos	1.10	29.54
Cypermethrin	0.21	7.65
Fipronil	0.68	60.01
Acetamiprid	0.08	2.30
Total	**2.75**	**124.40**
GM IR cotton		
Imidacloprid	0.41	15.05
Abamectin	0.05	1.73
Chlorpyrifos	0.77	20.67
Cypermethrin	0.13	4.74
Fipronil	0.44	38.83
Acetamiprid	0.06	1.72
Total	**1.86**	**82.74**

Sources: Monsanto China & Plant Protection Institute of the Chinese Academy of Agricultural Sciences

Typical herbicide regimes for canola in the US, Canada & Australia 2010
USA

Active ingredient	**Amount (kg/ha of crop)**	**Field EIQ/ha**
Conventional canola		
Ethafluralin	1.0	23.3
Quizalofop	0.06	1.33
Ethametsulfuron	0.05	0.9
Total	**1.11**	**25.53**
GM glyphosate tolerant canola		

Glyphosate	**1.02**	**15.64**
GM glufosinate tolerant canola		
Glufosinate	0.51	10.30
Quizalofop	0.03	0.66
Total	**0.54**	**10.97**

Based on Johnson & Strom (2008) and updated

Canada

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional canola (Clearfields)		
Imazamox	0.03	0.58
Imazapethayr	0.03	0.59
2 4 D	0.5	10.35
Total	**0.56**	**11.52**
GM glyphosate tolerant canola		
Glyphosate	**0.697**	**10.68**
GM glufosinate tolerant canola		
Glufosinate	0.322	6.50
Quizalofop	0.03	0.57
Total	**0.35**	**7.07**

Australia

	Active ingredient (kg/ha)	Field EIQ/ha value
Conventional triazine tolerant		
Option 1		
Atrazine	0.66	15.11
Simazine	1.8	38.70
Clethodim	0.047	0.78
Total	**2.507**	**54.59**
Option 2		
Atrazine	0.66	15.11
Clethodim	0.046	0.78
Total	**0.706**	**15.89**
Option 3		
Trefluralin	0.48	9.02
Atrazine	0.66	15.11
Simazine	1.8	38.70
Total	**2.94**	**62.83**
Average all options	**2.05**	**44.44**
Weighted average	**1.85**	**40.35**
Conventional Clearfield		
Option 1		
Glyphosate	0.621	9.52
Clethodim	0.046	0.78
Imazamox	0.013	0.26
Imazethapyr	0.006	0.13
Total	**0.6858**	**10.69**
Option 2		

Trefluralin	0.48	9.02
Clethodim	0.0456	0.78
Imazamox	0.0132	0.26
Imazethapyr	0.006	0.13
Total	**0.5448**	**10.19**
Option 3		
Trefluralin	0.48	9.02
Imazamox	0.0132	0.26
Imazethapyr	0.006	0.13
Glyphosate	**0.621**	**9.52**
Total	**1.1202**	**18.94**
Average	**0.7836**	**13.27**
Weighted average	**0.87**	**14.69**
GM HT canola		
Option 1		
Glyphosate	0.621	9.52
Option 2		
Glyphosate	1.242	19.04
Option 3		
Glyphosate	0.621	9.52
Trefluralin	0.48	9.02
Total	**1.101**	**18.54**
Average	**0.988**	**15.70**
Weighted average	**0.94**	**15.03**

Source:

Notes: Weighting on usage: TT canola, option 1: 45%, option 2: 40%, option 3: 15%, Clearfield canola, option 1: 25%, option 2: 25%, option 3: 50% GM HT canola, option 1: 40%, option 2: 40%, option 3: 20%

2010 crop weighting 40% of GMHT versus TT canola and 60% GMHT versus Clearfields canola giving an average all conventional usage of 1.34kg/ha and a field EIQ/ha of 17.78

Typical herbicide regimes for GM HT versus conventional sugar beet: USA 2010

	Active ingredient (kg/ha)	Field EIQ/ha value
Conventional		
Phenmedipham	0.16	2.62
Desmedipham	0.19	3.36
Ethofumesate	0.81	20.90
Clopyralid	0.18	3.26
Triflusulfuron	0.03	0.57
Clethodim	0.15	2.55
Total	**1.52**	**29.13**
GM HT sugar beet		
Glyphosate	**1.90**	**29.13**

Sources: GFK Kynetec and Monsanto US

Typical herbicide regimes for GM HT soybeans in Mexico

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional soybeans		
Metribuzin	0.376	10.68
Imazethapyr	0.1	1.96

Paraquat	0.3	7.41
Quizalafop	0.042	0.93
Fluazafop	0.1875	5.38
Linuron	0.75	14.67
Total	**1.7655**	**41.03**
GM HT soybeans		
Glyphosate	**1.62**	**24.79**

Source: Monsanto Mexico

Typical herbicide regimes for GM HT cotton Australia 2010

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional cotton		
Trifluralin	1.15	21.62
Flumeturon	2.25	32.18
Prometryn	1.00	15.40
Total	**4.40**	**69.20**
GM HT cotton		
Pendimethalin	0.33	9.97
Fluometuron	0.50	7.15
Glyphosate	3.102	47.55
Total	**3.932**	**64.67**

Source: Monsanto Australia

Typical insecticide regimes for cotton in Mexico

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional cotton		
Lambda cyhalothrin	0.04	1.89
Cypermethrin	0.16	5.82
Monocrotophos	0.6	22.08
Methidathion	0.622	20.34
Triazophos	0.6	21.36
Methomyl	0.225	4.95
Chlorpyrifos	0.96	25.82
Chlorfenapyr	0.12	5.53
Endosulfan	1.08	41.69
Azinphos methyl	0.315	14.52
Parathion methyl	0.5	13.0
Total	**5.222**	**177.00**
GM IR cotton		
Lambda cyhalothrin	0.02	0.94
Cypermethrin	0.08	2.91
Monocrotophos	0.3	11.04
Methomyl	0.225	4.95
Chlorpyrifos	0.96	25.82
Chlorfenapyr	0.12	5.53
Endosulfan	1.08	41.69
Azinphos methyl	0.315	14.52
Parathion methyl	0.5	13.0
Total	**3.60**	**120.41**

Typical conventional insecticide regime for maize (targeting corn boring pests) in Colombia

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha

Luferon	0.0225	0.37
Chlorifluzanon	0.05	1.82
Chlorpyrifos	0.325	8.73
Mathavin	0.162	4.97
Total	**0.56**	**15.89**

Source: Mendez et al (2011)
Note: GM IR maize replaces the above treatment

Appendix 4: 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.

References

Alcade E (1999) Estimated losses from the European Corn Borer, Symposium de Sanidad Vegetal, Seveilla, Spain, cited in Brookes (2002)

Alston J et al (2003) An ex-ante analysis of the benefits from adoption of corn rootworm resistant, transgenic corn technology, AgBioforum vol 5, No 3, article 1

Almaraz J J (2009) Greenhouse gas fluxes associated with soybean production under two tillage systems in south western Quebec, Soil & Tillage Research 104, 134-139

American Soybean Association Conservation Tillage Study (2001). http://www.soygrowers.com/ctstudy/ctstudy_files/frame.htm

Angers DA, Eriksen-Hamel NS (2008) Full-inversion tillage and organic carbon distribution in soil profiles: a meta-analysis. Soil Science Society of America Journal 72, 1370-1374

Asia-Pacific Consortium on Agricultural Biotechnology (APCoAB) (2006) Bt cotton in India: a status report, ICRASTAT, New Delhi, India

Baker, J.M et al (2007) Tillage and soil carbon sequestration—What do we really know? Agriculture, Ecosystems and Environment 118:1–5

Benbrook C (2005) Rust, resistance, run down soils and rising costs – problems facing soybean producers in Argentina, Ag Biotech Infonet, paper No 8

Bennett R, Ismael Y, Kambhampati U, and Morse S (2004) Economic Impact of Genetically Modified Cotton in India, Agbioforum Vol 7, No 3, Article 1

Blanco-Canqui H and Lal R (2007) No-tillage and soil-profile carbon sequestration: an on-farm assessment, Soil Science Society of America Journal 2008 72:693-701

Brimner T A et al (2004) Influence of herbicide-resistant canola on the environmental impact of weed management. Pest Management Science

Brookes G (2001) GM crop market dynamics, the case of soybeans, European Federation of Biotechnology, Briefing Paper 12

Brookes G (2003) The farm level impact of using Bt maize in Spain, ICABR conference paper 2003, Ravello, Italy. Also on www.pgeconomics.co.uk

Brookes G (2005) The farm level impact of using Roundup Ready soybeans in Romania. Agbioforum Vol 8, No 4. Also available on www.pgeconomics.co.uk

Brookes G (2008) The benefits of adopting GM insect resistant (Bt) maize in the EU: first results from 1998-2006. www.pgeconomics.co.uk. Also in the International Journal of Biotechnology (2008) vol 10, 2/3, pages 148-166

Brookes G (2008b) Economic impact of low level presence of not yet approved GMOs on the EU food sector, GBC Ltd, for CIAA, Brussels

Brookes G et al (2010) The production and price impact of biotech crops, Working Paper 10.WP 503, Centre for Agriculture and Rural Development, Iowa State University. www.card.iastate.edu. Also in Agbioforum 13 (1) 2010. www.agbioforum.org

Brookes G, Barfoot P. (2006). Global impact of biotech crops: socio-economic and environmental effects 1996-2004, AgbioForum 8 (2&3) 187-196, Available on the World Wide Web: http://www.agbioforum.org

Brookes G, Barfoot P (2007). Global impact of biotech crops: socio-economic and environmental effects 1996-2005, Agbioforum 9 (3) 1-13. Available on the World Wide Web: http://www.agbioforum.org

Brookes G, Barfoot P (2008). Global impact of biotech crops: socio-economic and environmental effects 1996-2006, Agbioforum 11(1), 21-38. Available on the World Wide Web: http://www.agbioforum.org

Brookes G. Barfoot P (2011). Global impact of biotech crops: socio-economic effects 1996-2009, Journal of Biotechnology, vol 12, Nos 1-2, 1-49

Brookes G, Barfoot P (2011). Global impact of biotech crops: environmental effects 1996-2008, AgBioforum 13(1), 76-94. Available on the World Wide Web: http://www.agbioforum.org

Brookes G, Barfoot P (2011). Global impact of biotech crops: environmental effects 1996-2009, GM Crops, vol 2, issue 1, 34-49

Canola Council of Canada (2001) An agronomic & economic assessment of transgenic canola, Canola Council, Canada. www.canola-council.org

Canola Council (2005) Herbicide tolerant volunteer canola management in subsequent crops, www.canolacouncil.org

Calegari A et al (2008) Impact of Long-Term No-Tillage and Cropping System Management on Soil Organic Carbon in an Oxisil: A Model for Sustainability, Agron Journal 100:1013-1019

Carpenter J & Gianessi L (1999) Herbicide tolerant soybeans: Why growers are adopting Roundup ready varieties, Ag Bioforum, Vol 2 1999, 65-72

Carpenter J (2001) Comparing Roundup ready and conventional soybean yields 1999, National Centre for Food & Agriculture Policy, Washington

Carpenter et al (2002) Comparative environmental impacts of biotech-derived and traditional soybeans, corn and cotton crops, Council for Agricultural Science and Technology (CAST), USA

Carpenter J & Gianessi L (2002) Agricultural Biotechnology: updated benefit estimates, National Centre for Food and Agricultural Policy (NCFAP), Washington, USA

Council for Biotechnology Information Canada (2002) Agronomic, economic and environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario

Conservation Tillage and Plant Biotechnology (CTIC: 2002) How new technologies can improve the environment by reducing the need to plough. http://www.ctic.purdue.edu/CTIC/Biotech.html

Crossan A & Kennedy I (2004) A snapshot of Roundup Ready cotton in Australia: are there environmental benefits from the rapid adoption of RR cotton, University of Sydney

CSIRO (2005) The cotton consultants Australia 2005 Bollgard II comparison report, CSIRO, Australia

CTIC (2007) 2006 Crop residue management survey: a survey of tillage systems usage by crop and acreas planted

Doyle B et al (2003) The Performance of Roundup Ready cotton 2001-2002 in the Australian cotton sector, University of New England, Armidale, Australia

Doyle B (2005) The Performance of Ingard and Bollgard II Cotton in Australia during the 2002/2003 and 2003/2004 seasons, University of New England, Armidale, Australia

Elena M (2001) Economic advantages of transgenic cotton in Argentina, INTA, cited in Trigo & Cap (2006)

Falck Zepeda J et al (2009) Small 'resource poor' countries taking advantage of the new bio-economy and innovation: the case of insect protected and herbicide tolerant corn in Honduras, paper presented to the 13th ICABR conference, Ravello, Italy, June 2009

Fabrizzi et al (2003**).** Soil Carbon and Nitrogen Organic Fractions in Degraded VS Non-Degraded Mollisols in Argentina. Soil Sci. Soc. Am. J. 67:1831-1841

Fernandez W et al (2009) GM soybeans in Bolivia, paper presented to the 13th ICABR conference, Ravello, Italy, June 2009

Fernandez-Cornejo J & Klotz-Ingram C (1998) Economic, environmental and policy impacts of

using GE crops for pest management. Presented to 1998 NE Agricultural & Resource Economics Association, Itthaca, USA. Cited in Fernandez-Cornejo J & McBride W (2000)
Fernandez-Cornejo J & McBride W (2002) Adoption of bio-engineered crops, USDA, ERS Agricultural Economics Report No 810
Fernandez-Cornejo J, Heimlich R & McBride W (2000) Genetically engineered crops: has adoption reduced pesticide use, USDA Outlook August 2000
Fernandez-Cornejo J & McBride W (2000) Genetically engineered crops for pest management in US agriculture, USDA Economic Research Service report 786
Finger R et al (2009) Adoption patterns of herbicde-tolerant soybeans in Argentina AgBioForum, 12 (3&4): 404-411
Fischer J & Tozer P (2009) Evaluation of the environmental and economic impact of Roundup Ready canola in the Western Australian crop production system, Curtin Univeristy of Technology Technical Report 11/2009
Fitt G (2001) Deployment and impact of transgenic Bt cotton in Australia, reported in James C (2001), Global review of commercialised transgenic crops: 2001 feature: Bt cotton, ISAAA
Galvao A (2009 & 2010) Farm survey findings of impact of insect resistant corn in Brazil, Celeres, Brazil. www.celeres.co.br
Galveo A (2009 & 2010) Farm survey findings of impact of herbicide tolerant soybeans and insect resistant cotton in Brazil, Celeres, Brazil. www.celeres.co.br
George Morris Centre (2004) Economic & environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario, unpublished report for Monsanto Canada
Gianessi L & Carpenter J (1999) Agricultural biotechnology insect control benefits, NCFAP, Washington, USA
Gomez-Barbero and Rodriguez-Cereozo (2006) The adoption of GM insect-resistant Bt maize in Spain: an empirical approach, 10th ICABR conference on agricultural biotechnology, Ravello, Italy, July 2006.
Gonsales L (2005) Harnessing the benefits of biotechnology: the case of Bt corn in the Philippines. .ISBN 971-91904-6-9. Strive Foundation, Laguna, Philippines
Gonsales L et al (2009) Modern Biotechnology and Agriculture: a history of the commercialisation of biotechnology maize in the Philippines, Strive Foundation, Los Banos, Philippines, ISBN 978-971-91904-8-6
Gouse M et al (2006a) Output & labour effect of GM maize and minimum tillage in a communal area of Kwazulu-Natal, Journal of Development Perspectives 2:2
Gouse M et al (2005) A GM subsistence crop in Africa: the case of Bt white maize in S Africa, Int Journal Biotechnology, Vol 7, No1/2/3 2005
Gouse et al (2006b) Three seasons of insect resistant maize in South Africa: have small farmers benefited, AgBioforum 9 (1) 15-22
Gusta M et al (2009) Economic benefits of GMHT canola for producers, University of Saskatchewan, College of Biotechnology Working Paper
Heap I (2007) International Survey of Herbicide Resistant Weeds. Database. http://www.weedscience.org/in.asp.
Huang J et al (2003) Biotechnology as a alternative to chemical pesticides: a case study of Bt cotton in China, Agricultural Economics 25, 55-67
Intergovernmental Panel on Climate Change (2006) Chapter 2: Generic Methodologies Applicable to Multiple Land-Use Categories. Guidelines for National Greenhouse Gas Inventories Volume 4. Agriculture, Forestry and Other Land Use. (http://www.ipcc-

nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf).
Hutchison W et al (2010) Area-wide suppression of European Corn Borer with Bt maize reaps savings to non-bt maize growers, Science, Vol 330, October 2010,, 222-225. www.sciencemag.org
IMRB (2006) Socio-economic benefits of Bollgard and product satisfaction (in India), IMRB International, Mumbai, India
IMRB (2007) Socio-economic benefits of Bollgard and product satisfaction (in India), IMRB International, Mumbai, India
Ismael Y et al (2002) A case study of smallholder farmers in the Mahathini flats, South Africa, ICABR conference, Ravello Italy 2002
James C (2002) Global review of commercialized transgenic crops 2001: feature Bt cotton, ISAAA No 26
James C (2006) Global status of Transgenic crops, various global review briefs from 1996 to 2006, ISAAA
James C (2003) Global review of commercialized transgenic crops 2002: feature Bt maize, ISAAA No 29
James C (2006) Global status of commercialised biotech/GM crops: 2006, ISAAA brief No 35. www.isaaa.org
James C (2007) Global status of commercialised biotech/GM crops: 2006 ISAAA Brief No 35
James C (2008) Global status of commercialised biotech/GM crops: 2008 ISAAA Brief No 39
Jasa P (2002) Conservation Tillage Systems, Extension Engineer, University of Nebraska
Johnson et al (2005) Greenhouse gas contributions and mitigation potential of agriculture in the central USA. Soil Tillage Research 83 (2005) 73-94
Johnson S & Strom S (2008) Quantification of the impacts on US agriculture of biotechnology-derived crops planted in 2006, NCFAP, Washington. www.ncfap.org
Khan M (2008) Roundup Ready sugar beet in America. British Sugar Beet Review Winter 2008 vol 76, no 4, p16-19
Kirsten J et al (2002) Bt cotton in South Africa: adoption and the impact on farm incomes amongst small-scale and large-scale farmers, ICABR conference, Ravello, Italy 2002
Kleiter G et al (2005) The effect of the cultivation of GM crops on the use of pesticides and the impact thereof on the environment, RIKILT, Institute of Food Safety, Wageningen, Netherlands
Kniss A (2009) Farm scale analysis of glyphosate resistant sugar beet in the year of commercial introduction in Wyoming, University of Wyoming
Kovach, J. C. Petzoldt, J. Degni and J. Tette (1992). A method to measure the environmental impact of pesticides. New York's Food and Life Sciences Bulletin. NYS Agricul. Exp. Sta. Cornell University, Geneva, NY, 139. 8 pp. Annually updated http://www.nysipm.cornell.edu/publications/EIQ.html
Lal et al (1998) The Potential for US Cropland to sequester Carbon and Mitigate the Greenhouse Effect. Ann Arbor Press, Chelsea. MI.
Lal et al (1999) Managing US Crop Land to sequester carbon in soil. Journal of Soil Water Conservation, Vol 54: 374-81
Lal R (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science. 304: 5677: 1623-1627.
Lal R. (2005). Enhancing Crop Yields in the Developing Countries through Restoration of the Soil Organic Carbon Pool in Agricultural Lands. Land Degradation and Development. 17: 2: 197-209.
Lal R (2009) Agriculture and climate change: an agenda for negotiation in Copenhagen for food, agriculture, and the environment the potential for soil carbon sequestration
Focus 16, Brief 5, May 2009

Lal R. 2010). Beyond Copenhagen: mitigating climate change and achieving food security through soil carbon sequestration, Food Security, 2 (2) 169-177

Lazarus W F (2011) Machinery Cost Estimates May 2011, University of Minnesota Extension Service

Lazarus & Selley (2005) Farm Machinery Economic Cost Estimates for 2005, University of Minnesota Extension Service

Leibig et al (2005) Greenhouse gas contributions and mitigation potential of agriculture practices in northwestern USA and western Canada. Soil Tillage Research 83 (2005) 25-52

Manjunath T (2008) Bt cotton in India: remarkable adoption and benefits, Foundation for Biotech Awareness and Education, India. www.fbae.org

Marra M, Pardey P & Alston J (2002) The pay-offs of agricultural biotechnology: an assessment of the evidence, International Food Policy Research Institute, Washington, USA

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

Marra M & Piggott N (2007) The net gains to cotton farmers of a national refuge plan for Bollgard II cotton, Agbioforum 10, 1, 1-10. www.agbioforum.org

Martinez-Carillo J & Diaz-Lopez N (2005) Nine years of transgenic cotton in Mexico: adoption and resistance management, Proceedings Beltwide Cotton Conference, Memphis, USA, June 2005

McClelland et al (2000) Rou, Arkansas Agricultural Experiment Station

McConkey et al (2007). Canadian Agricultural Greenhouse Gas Monitoring Accounting and Reporting System: Methodology and greenhouse gas estimates for agricultural land in the LULUCF sector for NIR, Agriculture and Agri-Food Canada, Ottawa, Ontario

Mendez K et al (2011) Production cost analysis and use of pesticides in the transgenic and conventional crop in the valley of San Juan (Colombia), GM Crops, vol 2, issue 3, June-Dec 2011, pp 163-168

Monsanto Comercial Mexico (2005) Official report to Mexican Ministry of Agriculture, unpublished

Monsanto Comercial Mexico (2007) Official report to Mexican Ministry of Agriculture of the 2006 crop, unpublished

Monsanto Brazil (2008) Farm survey of conventional and Bt cotton growers in Brazil 2007, unpublished

Monsanto Comercial Mexico (2008) Official report to Mexican Ministry of Agriculture of the 2008 cotton crop, unpublished

Monsanto Australia (2009) Survey of herbicide tolerant canola licence holders 2008

Monsanto Romania (2007) Roundup Ready soybeans: Survey growers crops in 2006 and intentions for 2007

Morse S et al (2004) Why Bt cotton pays for small-scale producers in South Africa, Nature Biotechnology 22 (4) 379-380

Moschini G, Lapan H & Sobolevsky A (2000) Roundup ready soybeans and welfare effects in the soybean complex, Iowa State University, Agribusiness vol 16: 33-55

Mullins W & Hudson J (2004) Bollgard II versus Bollgard sister line economic comparisons, 2004 Beltwide cotton conferences, San Antonio, USA, Jan 2004

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

PG Economics (2003) Consultancy support for the analysis of the impact of GM crops on UK farm profitability, www.pgeconomics.co.uk

Pray C et al (2001) Impact of Bt cotton in China, World Development, 29(5) 1-34

Pray C et al (2002) Five years of Bt cotton in China – the benefits continue, The Plant Journal 2002, 31 (4) 423-430
Phipps R & Park J (2001) Environmental benefits of GM crops: global & European perspectives on their ability to reduce pesticide use, Journal of Animal Sciences, 11, 2002, 1-18
Qaim M & De Janvry A (2002) Bt cotton in Argentina: analysing adoption and farmers willingness to pay, American Agricultural Economics Association Annual Meeting, California,
Qaim M & De Janvry A (2005) Bt cotton and pesticide use in Argentina: economic and environmental effects, Environment and Development Economics 10: 179-200
Qaim M & Traxler G (2002) Roundup Ready soybeans in Argentina: farm level, environmental and welfare effects, 6th ICABR conference, Ravello, Italy
Qaim M & Traxler G (2005) Roundup Ready soybeans in Argentina: farm level & aggregate welfare effects, Agricultural Economics 32 (1) 73-86
Qaim M & Matuschke J (2006) Impact of GM crops in developing countries: a survey, Quarterly Journal of International Agriculture 44 (3) 207-227
Ramon G (2005) Acceptability survey on the 80-20 bag in a bag insect resistance management strategy for Bt corn, Biotechnology Coalition of the Philippines (BCP)
Reeder R (2010) No-till benefits add up with diesel fuel savings http://www.thelandonline.com/currentedition/x1897235554/No-till-benefits-add-up-with-diesel-fuel-savings
Reicosky D C (1995) Conservation tillage and carbon cycling:soil as a source or sink for carbon. University of Davis
Rice M (2004) Transgenic rootworm corn: assessing potential agronomic, economic and environmental benefits, Plant Health Progress 10, `094/php-2001-0301-01-RV
Robertson et al (2000) Greenhouse Gases in Intensive Agriculture: Contributions of Individual Gases to the Radioactive Forces of the Atmosphere. Science Vol 289 September 15 2000 1922-1925
Runge Ford C & Ryan B (2004) The global diffusion of plant biotechnology: international adoption and research in 2004, University of Minnesota, USA
Sankala S & Blumenthal E (2003) Impacts on US agriculture of biotechnology-derived crops planted in 2003- an update of eleven case studies, NCFAP, Washington. www.ncfap.org
Sankala S & Blumenthal E (2006) Impacts on US agriculture of biotechnology-derived crops planted in 2005- an update of eleven case studies, NCFAP, Washington. www.ncfap.org
Sexstone et al (1985) Temporal response of soil denitrification rates to rainfall and irrigation. Soil Sci. Soc. Am. J. 49: 99-103.
Smyth S & Gusta M (2008) Environmental benefits from GM HT canola production, 12th International ICABR conference on biotechnology, Ravello, Italy, June 2008
Steinbach H S & Alvarez R (2006) Changes in Soil Organic Carbon Contents and Nitrous Oxide Emissions after the Introduction of No-Till in Pampean Agroecosystems. Journal Environmental Qual 35:3-13
Taylor I (2003) Cotton CRC annual report, UNE, Armidale, Cotton Research Institute, Narrabri, Australia
Traxler G et al (2001) Transgenic cotton in Mexico: economic and environmental impacts, ICABR conference, Ravello, Italy
Trigo et al (2002) Genetically Modified Crops in Argentina agriculture: an opened story. Libros del Zorzal, Buenos Aires, Argentina
Trigo E & Cap E (2006) Ten years of GM crops in Argentine Agriculture, ArgenBio
University of Illinois (2006) Costs and fuel use for alternative tillage systems.www.farmdoc.uiuc.edu/manage/newsletters/fefo06 07/fefo06 07.html

USDA (1999) Farm level effects of adopting genetically engineered crops, preliminary evidence from the US experience, Economic issues in agricultural biotechnology
USDA (1999) Farm level effects of adopting genetically engineered crops, preliminary evidence from the US experience, Economic Issues in Agricultural Biotechnology
USDA - The Voluntary Reporting of Greenhouse Gases-CarbOn Management Evaluation Tool (COMET-VR)
http://www.cometvr.colostate.edu/
USDA Energy Estimator: tillage. 2011 http://ecat.sc.egov.usda.gov .
Van der Weld W (2009) Final report on the adoption of GM maize in South Africa for the 2008/09 season, South African Maize Trust
Vitale, J et al (2006) The Bollgard II Field Trials in Burkina Faso: Measuring How Bt Cotton Benefits West African Farmers. Paper presented at the 10th ICABR Conference, Ravello, Italy
Vitale J et al (2008) The economic impact of 2nd generation Bt cotton in West Africa: empirical evidence from Burkina Faso, International Journal of Biotechnology vol 10, 2/3 p 167-183
West T.O. and Post W.M. (2002) Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Analysis. Soil Science Society of American Journal. Vol 66 November/December: 930-1046
Wu K et al (2008) Suppression of cotton bollworm in multiple crops in China in areas with Bt toxin containing cotton, Science 321, 1676-1678
Yorobe J (2004) Economics impact of Bt corn in the Philippines. Paper presented to the 45th PAEDA Convention, Querzon City
Zambrano P et al (2009) Insect resistant cotton in Colombia: impact on farmers, paper presented to the 13th ICABR conference, Ravello, Italy, June 2009