

# Global Impact of Biotech Crops: Socio-Economic and Environmental Effects, 1996-2006

Graham Brookes and Peter Barfoot

PG Economics Ltd., Dorchester, UK

Genetically modified (GM) crops have been grown commercially on a substantial scale for eleven years. This paper updates the assessment of the impact this technology is having on global agriculture from both economic and environmental perspectives. It examines specific global economic impacts on farm income and environmental impacts associated with pesticide usage and greenhouse gas (GHG) emissions for each of the countries where GM crops have been grown since 1996. The analysis shows that there have been substantial net economic benefits at the farm level amounting to \$6.94 billion in 2006 and \$33.8 billion for the eleven-year period (in nominal terms). The technology has reduced pesticide spraying by 286 million kg and, as a result, decreased the environmental impact associated with herbicide and insecticide use on these crops by 15.4%. GM technology has also significantly reduced the release of GHG emissions from this cropping area, which, in 2006, was equivalent to removing 6.56 million cars from the roads.

**Key words:** yield, cost, income, environmental impact quotient, carbon sequestration, GM crops.

---

## Introduction

This article presents the findings of research into the global economic and environmental impact of GM crops since their commercial introduction in 1996. It updates the findings of earlier analyses presented by the authors in AgBioForum 8(2&3) and 9(3).<sup>1</sup>

The economic impact analysis concentrates on farm income effects because this is a primary driver of adoption amongst farmers (both large commercial and small-scale subsistence). The environmental impact analysis focuses on the environmental impacts associated with changes in the amount of insecticides and herbicides applied to the GM crops relative to conventionally grown alternatives. The analysis also examines the contribution of GM crops towards reducing global greenhouse gas (GHG) emissions. This arises from reduced tractor fuel consumption and additional soil sequestration (storage) associated with reduced/no-tillage cultivation<sup>2</sup> facilitated by the application of GM herbicide-tolerant (GM HT) technology.

---

1. Readers should note that some data presented in this article are not directly comparable with data presented in the previous two articles because the current article takes into account the availability of new data and analysis (including revisions to data for earlier years).

## Methodology

The report is based largely on extensive analysis of existing farm-level impact data from GM crops. Primary data for impacts of commercial cultivation were not available for every crop, in every year, or for each country, but all identified, representative, previous research has been utilized. The findings of this research have been used as the basis for the analysis presented,<sup>3</sup> although, where relevant, primary analysis has been undertaken from base data, most notably in relation to the environmental impacts.

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 vary widely, both between and within regions/countries. As a result, the impact of this technology and any new technology, GM

- 
2. *No-till farming means that the ground is not plowed 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.*
  3. *Where several pieces of research relevant to one subject (e.g., the impact of using a GM trait on the yield of a crop) have been identified, the findings used have been largely based on the most conservative finding.*

or otherwise, is subject to variation at the local level. Thus, the performance and impact should be considered on a case-by-case basis in terms of crop and trait combinations. This study examines the impact of the technology at the trait and crop level, including where stacked traits are available to farmers.

Agricultural production systems are dynamic and vary with time. This analysis seeks to address this issue, wherever possible, by comparing GM production systems with the most likely conventional alternative that could provide competitive levels of efficacy, if GM technology had not been available. This approach has been used by other researchers (e.g., Sankula, 2006; Sankula & Blumenthal, 2004).

## Farm Income Effects

### Methodology

The methodology used for assessing the farm-level income impact has been to review existing literature, from as many years of relevant comparable data as possible, and to use the findings as the basis for the impact estimates over the period examined. All values presented are nominal for the year shown. The base currency used is the US dollar and all financial impacts in other currencies have been converted to US dollars at prevailing annual average exchange rates for each year. The approach reflects 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 labor),<sup>4</sup> crop quality (e.g., 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 (e.g., second crop soybeans in Argentina following wheat that, in the absence of the GM HT seed, would most likely 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 GM crop adoption on global crop supply and world prices.

This approach may both overstate or understate the real impact of GM technology for some trait, crop, and country combinations. However, since impact data for every trait, crop, location, and year are not available, the authors have had to extrapolate available impact data to years for which no data are available. Therefore, the authors acknowledge that this represents a weakness of the research. However, the use of current prices does incorporate some dynamic degree into the analysis that would otherwise be missing if constant prices had been used. Where yield impacts have been identified for specific years, these have been used. 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.<sup>5</sup> Nevertheless, much of the reviewed literature only contains an analysis for one or a limited number of years. Where analysis is this limited, the impacts identified have been converted into a percentage change impact and applied to all other years on the basis of the prevailing average yield recorded. For example, if a study identified a yield gain of 5% in year one, this 5% yield increase was then applied to the average yield recorded in each other year. If more than one study identified different levels of yield impact, the more conservative yield impacts have been used. For example, in relation to the impact of GM insect resistant (GM IR) cotton in the United States, analysis by Sankula and Blumenthal (2004) put the average positive yield impact of the first generation of the trait (known by its trade name as Bollgard I) at +9%, while the average yield impact based on Marra, Pardey, and Alston (2002) is +11%; the yield impact used in this paper was +9%.<sup>6</sup> More specific examples of how this methodology has been applied are presented in Appendix 1. The key impact assumptions used for the analysis are summarized in Appendix 2.

4. Inclusion of the impact on these cost categories are, however, more limited than the impacts on seed and crop protection costs because only a few authors that we 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.

5. Examples where such data is available include the impact of Bt cotton in India (see Asia-Pacific Consortium on Agricultural Biotechnology [APCoAB], 2006; Bennett, Ismael, Kamhampati, & Morse, 2004; IMRB International, 2007), in Mexico (see Monsanto Comercial Mexico, 2005, 2007; Traxler, Godoy-Avilla, Falck-Zepeda, & Espinoza-Arellano, 2001), and in the United States (see Mullins & Hudson, 2004; Sankula, 2006; Sankula & Blumenthal, 2004).

**Table 1. Global farm income benefits from growing GM crops, 1996-2006 (\$ million).**

Trait	Increase in farm income, 2006	Increase in farm income, 1996-2006	Farm income benefit in 2006 as % of total value of production of these crops in GM-adopting countries	Farm income benefit in 2006 as % of total value of global production of crop
<b>GM HT soybeans</b>	3,091	17,455	6.74%	5.58%
<b>GM HT maize</b>	296	1,111	0.64%	0.35%
<b>GM HT cotton</b>	21	814	0.13%	0.08%
<b>GM HT canola</b>	227	1,096	8.55%	1.49%
<b>GM IR maize</b>	1,131	3,634	2.47%	1.35%
<b>GM IR cotton</b>	2,149	9,567	13.15%	7.85%
<b>Others</b>	26	93	n/a	n/a
<b>Totals</b>	<b>6,941</b>	<b>33,770</b>	<b>6.20%</b>	<b>3.80%</b>

*Note. All values are nominal. n/a= Not applicable. Others = virus-resistant papaya and squash. Totals for the value shares exclude 'other crops' (i.e., relate to the four 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 (e.g., payment of seed premia, impact on crop protection expenditure).*

## Results

GM technology has had a very positive impact on farm income derived from a combination of enhanced productivity and efficiency gains (Table 1). In 2006, the direct global farm income benefit from GM crops was \$6.94 billion. This is equivalent to having added 3.8% to the value of global production of the four main crops of soybeans, maize, canola, and cotton. Since 1996, farm incomes have increased by \$33.8 billion.

The largest gains in farm income have arisen in the soybean sector, largely from cost savings. The \$3 billion additional income generated by GM HT soybeans in 2006 has been equivalent to adding 6.7% to the value of the crop in the GM-growing countries or adding the equivalent of 5.6% to the \$55 billion value of the global soybean crop in 2006. These economic benefits should, however, be placed within the context of a significant increase in the level of soybean production in the main GM-adopting countries. Since 1996, the soybean area in the leading soybean-producing countries of the United States, Brazil, and Argentina increased by 60%.

6. *The average base yield has been adjusted downwards (if necessary) to account for any positive yield impact of the technology. In this way, the impact on total production of any yield gains is not overstated. The authors do however, acknowledge that the use of this assumption may still over- or understate the yield effects in some years because yield impact findings from a limited number of years have been used as the basis for estimating impact in other years. However, in the absence of comprehensive yield impact analysis for each trait, country, and year, the authors consider this an appropriate approach to take in order to estimate cumulative impact.*

Substantial gains have also arisen in the cotton sector through a combination of higher yields and lower costs. In 2006, cotton farm income levels in the GM-adopting countries increased by \$2.15 billion and since 1996, the sector has benefited from an additional \$9.6 billion. The 2006 income gains are equivalent to adding 13.1% to the value of the cotton crop in these countries, or 7.8% to the \$27.3 billion value of total global cotton production. This is a substantial increase in value-added terms for two new cotton seed technologies.

Significant increases to farm incomes have also resulted in the maize and canola sectors. The combination of GM IR and GM HT technology in maize has boosted farm incomes by \$4.74 billion since 1996. In the North American canola sector, an additional \$1.1 billion has been generated.

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

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 2006, just over half of the farm income benefits (53%) 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.<sup>7</sup> Over the eleven years, 1996-2006, the

**Table 2. GM crop farm income benefits in selected countries, 1996-2006 (\$ million).**

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton	Total
<b>US</b>	8,730.0	1,052.0	779.0	128	3,094.0	2,065.0	<b>15,848.0</b>
<b>Argentina</b>	6,250.0	22.0	25.0	n/a	193.0	107.0	<b>6,597.0</b>
<b>Brazil</b>	1,912.0	n/a	n/a	n/a	n/a	17.0	<b>1,929.0</b>
<b>Paraguay</b>	349.0	n/a	n/a	n/a	n/a	n/a	<b>349.0</b>
<b>Canada</b>	87.0	32.0	n/a	968	145.0	n/a	<b>1,232.0</b>
<b>South Africa</b>	3.0	2.5	0.2	n/a	132.0	18.0	<b>155.7</b>
<b>China</b>	n/a	n/a	n/a	n/a	n/a	5,823.0	<b>5,823.0</b>
<b>India</b>	n/a	n/a	n/a	n/a	n/a	1,294.0	<b>1,294.0</b>
<b>Australia</b>	n/a	n/a	4.8	n/a	n/a	179.0	<b>183.8</b>
<b>Mexico</b>	5.1	n/a	6.0	n/a	n/a	59.7	<b>70.8</b>
<b>Philippines</b>	n/a	1.6	n/a	n/a	27.3	n/a	<b>28.9</b>
<b>Spain</b>	n/a	n/a	n/a	n/a	39.4	n/a	<b>39.4</b>

Note. 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 (e.g., payment of seed premia, impact on crop protection expenditure). n/a = not applicable.

**Table 3. GM crop farm income benefits in developing versus developed countries, 2006 (\$ million).**

Crop	Developed	Developing
<b>GM HT soybeans</b>	1,263	1,828
<b>GM IR maize</b>	992	139
<b>GM HT maize</b>	274	22
<b>GM IR cotton</b>	434	1,715
<b>GM HT cotton</b>	12	9
<b>GM HT canola</b>	227	0
<b>GM virus-resistant papaya and squash</b>	26	0
<b>Total</b>	<b>3,228</b>	<b>3,713</b>

Note. Developing countries are all countries in South America, Mexico, India, China, the Philippines, and South Africa.

cumulative farm income gain derived by developing country farmers was \$16.4 billion (48.5% of the total).

Examining the cost farmers pay for accessing GM technology, Table 4 shows that across the four main GM crops, the total cost in 2006 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).<sup>8</sup>

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

8. 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.

For farmers in developing countries the total cost was equal to about 17% of total technology gains, while it was equal to 38% for farmers in developed countries. While 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.

In addition to these quantifiable direct impacts on farm profitability, there have been other important, indirect impacts that are more difficult to quantify (e.g., facilitation of adoption of reduced/no-tillage systems, reduced production risk, convenience, reduced exposure of farmers and farm workers to pesticides, improved crop quality). These less tangible benefits have often been cited by GM adopting farmers as having been important influences for adoption of the technology, although studies that have examined and attempted to quantify these impacts have, to date, been few in number. As such, this category of impact has not been analyzed in this paper and therefore represents a limitation of the methodology. It does, however, suggest that the farm income benefits quantified are conservative.

## Environmental Impacts from Insecticide and Herbicide Use Changes

### Methodology

The most common way in which changes in pesticide use with GM crops have been presented is in terms of the volume (quantity) of pesticide applied. While com-

**Table 4. Cost of accessing GM technology relative to the total farm income benefits, 2006 (\$ million).**

	Cost of technology: All farmers	Farm income gain: All farmers	Total benefit of technology to farmers and seed supply chain	Cost of technology: Developing countries	Farm income gain: Developing countries	Total benefit of technology to farmers and seed supply chain: Developing countries
<b>GM HT soybeans</b>	1,000	3,091	4,091	284	1,828	2,112
<b>GM IR maize</b>	436	1,131	1,567	61	139	200
<b>GM HT maize</b>	223	296	519	10	22	32
<b>GM IR cotton</b>	576	2,149	2,725	375	1,715	2,090
<b>GM HT cotton</b>	290	21	311	12	9	21
<b>GM HT canola</b>	162	227	389	0	0	0
<b>Total</b>	<b>2,687</b>	<b>6,915</b>	<b>9,602</b>	<b>742</b>	<b>3,713</b>	<b>4,455</b>

*Note.* Cost of accessing the technology is based on the seed premia paid by farmers for using GM technology relative to its conventional equivalents. Total farm income gain excludes \$26 million associated with virus-resistant crops in the United States.

parisons of total pesticide volume used in GM and non-GM crop production systems can be a useful indicator of environmental impacts, it is an imperfect measure because it does not account for differences in the specific pest control programs used in GM and non-GM cropping systems. For example, different specific products used in GM 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.

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

The EIQ value is multiplied by the amount of pesticide active ingredient (ai) used per hectare to produce a field EIQ value. For example, the EIQ rating for glyphosate is 15.3. By using this rating multiplied by the amount of glyphosate used per hectare (e.g., a hypothet-

ical example of 1.1 kg applied per ha), the field EIQ value for glyphosate would be equivalent to 16.83/ha.

The EIQ indicator used is therefore a comparison of the field EIQ/ha for conventional versus GM crop-production systems, with the total environmental impact or load of each system a direct function of respective field EIQ/ha values and the area planted to each type of production (GM versus non-GM). The use of environmental indicators is commonly used by researchers, and the EIQ indicator has been, for example, cited by Brimmer, Gallivan, and Stephenson (2004) in a study comparing the environmental impacts of GM and non-GM canola and by Kleiter et al. (2005).

The EIQ methodology was used to calculate and compare typical EIQ values for conventional and GM crops and then aggregate these values to a national level. The level of pesticide use on the respective areas planted to conventional and GM crops in each year was compared with the level of pesticide use that would otherwise have probably occurred if the whole crop, in each year, had been produced using conventional technology. This is based on the approach used by Sankula and Blumenthal (2004) and Sankula (2006)<sup>9</sup> that identifies and utilizes typical herbicide or insecticide treatment regimes for conventional and GM crops provided by extension and research advisors in each sector/country. This approach was selected to address gaps in the availability of herbicide or insecticide usage data in most countries that differentiate between GM and conventional crops. Additionally, this allows reasonably representative comparisons to be made between GM and non GM cropping systems when GM accounts for a large proportion of the total crop-planted area. For example,

9. Also applied by others, e.g., Kleiter et al. (2005).

**Table 5. Impact of changes in the use of herbicides and insecticides from growing GM crops globally, 1996-2006.**

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 GM crops	% change in environmental impact associated with herbicide & insecticide use on GM crops
GM HT soybeans	-62.4	-5,536	-4.4	-20.4
GM HT maize	-46.7	-1,172	-3.9	-4.6
GM HT cotton	-32.1	-616	-14.3	-14.5
GM HT canola	-7.9	-372	-12.6	-24.2
GM IR maize	-8.2	-452	-5.0	-5.3
GM IR cotton	-128.4	-5,628	-22.9	-24.6
<b>Totals</b>	<b>-285.7</b>	<b>-13,776</b>	<b>-7.9</b>	<b>-15.4</b>

in the case of soybeans in several countries, more than 60% of the total soybean crop-planted area is GM. A comparison of the production practices of these two groups would, however, not produce a reasonably representative comparison of the GM versus conventional alternative because the remaining non-adopters are likely to be farmers in a region characterized by lower than average weed or pest pressures or with a tradition of less-intensive production systems. Hence, their levels of pesticide use are likely to be lower than the average pesticide-use level that would otherwise occur if the entire crop was planted to conventional cultivars (i.e., the GM crop area reverted back to conventional cultivars).

### Results

GM crops have contributed to a significant reduction in the environmental impact of production agriculture on the areas devoted to GM crops (Table 5). Since 1996, the use of pesticides on the GM crop area was reduced by 286 million kg of active ingredient, a 7.9% reduction, and the overall environmental impact associated with herbicide and insecticide use on these crops was reduced by 15.4%. In absolute terms, the largest environmental gain has been associated with the adoption of GM HT soybeans and reflects the large share of global soybean plantings accounted for by GM soybeans. The volume of herbicides used in GM soybean crops decreased by 62.4 million kg (1996-2006), a 4.4% reduction, and, the overall environmental impact associated with herbicide use on these crops decreased by 20.4% (relative to the volume that would have probably been used if this cropping area had been planted to conventional soybeans). It should be noted that in some countries, such as in South America, the adoption of GM HT soybeans coincided with increases in the volume of herbicides used relative to historic levels. This largely reflects the facilitating role of the GM HT tech-

nology in accelerating and maintaining the switch away from conventional tillage to no/low-tillage production systems with their inherent other environmental benefits (notably reductions in GHG emissions—see next section—and reduced soil erosion). Despite this net increase in the volume of herbicides used in some countries, the associated environmental impact (as measured by the EIQ methodology) still fell as farmers switched to herbicides with a more environmentally benign profile.

Major environmental gains have also been derived from the adoption of GM IR cotton. These gains were the largest of any crop on a per-hectare basis. Since 1996, farmers have used 128.4 million kg less insecticide in GM IR cotton crops (a 22.9% reduction), and this has reduced the associated environmental impact of insecticide use on this crop area by 24.6%. Important environmental gains have also arisen in the maize and canola sectors. In the maize sector, herbicide and insecticide use decreased by 54.9 million kg and the associated environmental impact of pesticide use on this crop area decreased due to a combination of reduced insecticide use (5.3%) and a switch to more environmentally benign herbicides (4.6%). In the canola sector, farmers reduced herbicide use by 7.9 million kg (a 12.6% reduction) and the associated environmental impact of herbicide use on this crop area fell by 24% (due to a switch to more environmentally benign herbicides).

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

In terms of the division of the environmental benefits associated with less insecticide and herbicide use for farmers in developing countries relative to farmers in developed countries, Table 7 shows that just over half of the environmental benefits (1996-2006) associated with lower insecticide and herbicide use have been in developing countries (52%). The vast majority of these envi-

**Table 6. Changes in the 'environmental impact' from changes in pesticide use associated with GM crop adoption in selected countries, 1996-2006 (% reduction in field EIQ values).**

Country	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton
US	-28	-5	-15	-41	-5	-20
Argentina	-21	-1	-20	n/a	0	-5
Brazil	-7	n/a	n/a	n/a	n/a	-8
Paraguay	-14	n/a	n/a	n/a	n/a	n/a
Canada	-10	-8	n/a	-23	-60	n/a
South Africa	-8	-2	-7	n/a	-26	NDA
China	n/a	n/a	n/a	n/a	n/a	-33
India	n/a	n/a	n/a	n/a	n/a	-6
Australia	n/a	n/a	-4	n/a	n/a	-24
Mexico	n/a	n/a	n/a	n/a	n/a	-7
Spain	n/a	n/a	n/a	n/a	-33	n/a

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

**Table 7. GM crop environmental benefits from lower insecticide and herbicide use in developing versus developed countries, 1996-2006.**

	Change in field EIQ impact (in terms of million field EIQ/ha units): Developed countries	Change in field EIQ impact (in terms of million field EIQ/ha units): Developing countries
GM HT soybeans	-3,318	-2,218
GM IR maize	-444	-8
GM HT maize	-1,162	-10
GM IR cotton	-716	-4,912
GM HT cotton	-598	-18
GM HT canola	-372	n/a
<b>Total</b>	<b>6,610</b>	<b>-7,166</b>

ronmental gains have been from the use of GM IR cotton and GM HT soybeans.

## Impact on Greenhouse Gas Emissions

### Methodology

Reductions in the level of GHG emissions from GM crops derive from two principle sources (Conservation Technology Information Center [CTIC], 2002; Fabrizio, Morón, & García, 2003; Jasa, 2002; Johnson et al., 2005; Lazarus & Selley, 2005; Liebig et al., 2005; Reicosky, 1995; Robertson, Paul, & Harwood, 2000; West & Post, 2002). First, GM crops contribute to a reduction in fuel use due to less-frequent herbicide or insecticide applications and a reduction in the energy use in soil cultivation. For example, Lazarus and Selley (2005) estimated that one pesticide spray application

uses 1.045 liters of fuel, which is equivalent to 2.87 kg/ha of carbon dioxide emissions. In this analysis we used the conservative assumption that only GM IR crops reduced spray applications and, ultimately, GHG emissions.

In addition to the reduction in the number of herbicide applications, there has been a shift from conventional tillage to reduced/no till. This has had a marked impact 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.<sup>10</sup> Before the introduction of GM HT soybean cultivars, no-tillage (NT) systems were practiced by some farmers using a number of herbicides and with varying degrees of success. The opportunity for growers to control weeds with a non-residual foliar herbicide as a "burndown" pre-seeding treatment followed by a post-emergent treatment when the soybean crop became established has made the NT system more reliable, technically viable, and commercially attractive. These technical advantages, combined with the cost advantages, have contributed to the rapid adoption of GM HT cultivars and the near doubling of the NT soybean area in the United States (also more than a five-fold increase in Argentina). In both countries, GM HT soybeans are estimated to account for more than 95% of the NT soybean crop area.

10. See, for example, CTIC (2002, 2007).

**Table 8. Impact of GM crops on carbon sequestration impact, 2006 (car equivalents).**

Crop/trait/country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the permanent fuel savings	Potential additional soil carbon sequestration savings (million kg of carbon dioxide)	Average family car equivalents removed from the road for a year from the potential additional soil carbon sequestration
<b>US: GM HT soybeans</b>	245	108,877	4,064	1,806,345
<b>Argentina: GM HT soybeans</b>	659	293,094	6,994	3,108,408
<b>Other countries: GM HT soybeans</b>	77	34,091	813	361,547
<b>Canada: GM HT canola</b>	136	60,541	1,677	745,304
<b>Global GM IR cotton</b>	98	43,582	0	0
<b>Total</b>	<b>1,215</b>	<b>540,185</b>	<b>13,548</b>	<b>6,021,604</b>

Note. 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.

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

The fuel savings we used resulting from changes in tillage systems are drawn from estimates from studies by Jasa (2002) and CTIC (2002). The adoption of NT farming systems is estimated to reduce cultivation fuel usage by 32.52 liters/ha compared with traditional conventional tillage and 14.7 liters/ha compared with (the average of) reduced tillage cultivation. In turn, this results in reductions of carbon dioxide emissions of 89.44 kg/ha and 40.43 kg/ha, respectively.

Secondly, the use of *NT* and *reduced-till* farming systems that utilize less plowing increase the amount of organic carbon in the form of crop residue that is stored or sequestered in the soil. This carbon sequestration reduces carbon dioxide emissions to the environment. Rates of carbon sequestration have been calculated for cropping systems using normal tillage and reduced tillage and these were incorporated in our analysis on how GM crop adoption has played an important facilitative role in increasing carbon sequestration, and ultimately, on reducing the release of carbon dioxide into the atmosphere. Of course, the amount of carbon sequestered varies by soil type, cropping system, and eco-region. In North America, the International Panel on Climate Change estimates that the conversion from conventional-tillage to no tillage (NT) systems stores between

50 kg carbon/ha<sup>-1</sup> yr and 1,300 kg carbon/ha<sup>-1</sup> yr (average 300 kg carbon/ha<sup>-1</sup> yr). In the analysis presented below, a conservative saving of 300 kg carbon/ha<sup>-1</sup> yr was applied to all NT agriculture and 100 kg carbon/ha<sup>-1</sup> yr was applied to reduced-tillage agriculture. Where some countries aggregate their no- and reduced-till data the reduced-tillage saving value of 100 kg carbon/ha<sup>-1</sup> yr was used. One kg of carbon sequestered is equivalent to 3.67 kg of carbon dioxide. These assumptions were applied to the reduced pesticide spray applications data on GM IR crops, derived from the farm-income literature review, and the GM HT crop areas using no/reduced tillage (limited to the GM HT soybean crops in North and South America and GM HT canola crop in Canada).<sup>11</sup>

## Results

Table 8 summarizes the impact on GHG emissions associated with the planting of GM crops between 1996 and 2006. In 2006, the permanent carbon dioxide savings from reduced fuel use associated with GM crops was 1.2

11. Due to the likely small-scale impact and/or lack of tillage-specific data relating to GM HT maize and cotton crops (and the US GM HT canola crop), analysis of possible GHG emission reductions in these crops have not been included. The no/reduced-tillage areas to which these soil carbon reductions were applied were limited to the increase in the area planted to no/reduced tillage in each country since GM HT technology has been commercially available. In this way, the authors have tried to avoid attributing no/reduced-tillage soil carbon sequestration gains to GM HT technology on cropping areas that were using no/reduced-tillage cultivation techniques before GM HT technology became available.

billion kg. This is equivalent to removing 540,000 cars from the road for a year.

The additional soil carbon sequestration gains resulting from reduced tillage with GM crops accounted for a reduction in 13.5 billion kg of carbon dioxide emissions in 2006. This is equivalent to removing 6 million cars from the roads for a year. In total, the carbon savings from reduced fuel use and soil carbon sequestration in 2006 were equal to removing 6.56 million cars from the road (equal to 25% of all registered private cars in the United Kingdom).

### Concluding Comments

This article quantified the cumulative global impact of GM technology on farm income, pesticide usage, and GHG emissions from 1996 to 2006. The analysis shows that there have been substantial economic benefits at the farm level, amounting to a cumulative total of \$33.8 billion. Just over half of this has been derived by farmers in developing countries. GM technology has also resulted in 286 million kg less pesticide use by growers and a 15.4% reduction in the environmental impact associated with insecticide and herbicide use on the GM crop area. GM crops have also made a significant contribution to facilitating a reduction in GHG emissions, equal to a 14.76 billion kg of carbon dioxide in 2006. This is the equivalent of removing 6.56 million cars from the roads for a year.

The impacts identified are, however, probably conservative, reflecting the limitations of the methodologies used to estimate each of the three main categories of impact, and the limited availability of relevant data. As such, subsequent research at the trait and country level might usefully extend the analysis to incorporate more sophisticated consideration of dynamic economic impacts and some of the less tangible economic impacts (e.g., on labor savings). Further useful analysis of the environmental impact might also include additional environmental indicators, such as impact on soil erosion.

### References

- Asia-Pacific Consortium on Agricultural Biotechnology (APCoAB). (2006). *Bt cotton in India: A status report*. New Delhi, India: ICRSTAT.
- Bennett, R.M., Ismael, Y., Kambhampati, U., & Morse, S. (2004). Economic impact of genetically modified cotton in India. *AgBioForum*, 7(3), 96-100. Available on the World Wide Web: <http://www.agbioforum.org>.
- Brimner, T.A., Gallivan, G.J., & Stephenson, G.R. (2004). Influence of herbicide-resistant canola on the environmental impact of weed management. *Pest Management Science*, 61(1), 47-52.
- Brookes, G. (2003, July). *The farm level impact of using Bt maize in Spain*. Paper presented at the 6<sup>th</sup> International Consortium on Agricultural Biotechnology Research (ICABR) Conference, Ravello, Italy. Available on the World Wide Web: [http://www.pgeconomics.co.uk/pdf/bt\\_maize\\_in\\_spain.pdf](http://www.pgeconomics.co.uk/pdf/bt_maize_in_spain.pdf).
- Brookes, G. (2005). The farm-level impact of herbicide-tolerant soybeans in Romania. *AgBioForum*, 8(4), 235-241. Available on the World Wide Web: [www.agbioforum.org](http://www.agbioforum.org).
- Brookes, G. (2008). The impact of using GM insect resistant maize in Europe since 1998. *International Journal of Biotechnology*, 10(2&3), 148-166.
- Canola Council of Canada. (2001). *An agronomic & economic assessment of transgenic canola*. Winnipeg: Author. Available on the World Wide Web: [http://www.canola-council.org/research\\_transgenic.aspx](http://www.canola-council.org/research_transgenic.aspx).
- Carpenter, J., & Gianessi, L. (2001). *Agricultural biotechnology: Updated benefit estimates*. Washington, DC: National Center for Food and Agriculture Policy (NCFAP). Available on the World Wide Web: <http://www.ncfap.org/reports/biotech/updatedbenefits.pdf>.
- Conservation Technology Information Center (CTIC). (2002). *Conservation tillage and plant biotechnology: How new technologies can improve the environment by reducing the need to plow*. West Lafayette, IN: CTIC. Available on the World Wide Web: <http://www.ctic.purdue.edu/CTIC/BiotechPaper.pdf>.
- CTIC. (2007). *2006 crop residue management survey: A survey of tillage usage by crop and acres planted*. West Lafayette, IN: Author. Available on the World Wide Web: <http://www.conservationinformation.org/pdf/2006CRMSurveySummaryLoRes.pdf>.
- Commonwealth Scientific and Industrial Research Organisation (CSIRO). (2005). *The cotton consultants Australia 2005 Bollgard II comparison report*. Collingwood, Australia: Author.
- Doyle, B. (2005). *The performance of Ingard and Bollgard II cotton in Australia during the 2002/2003 and 2003/2004 seasons*. Armidale, Australia: University of New England.
- Doyle, B., et al. (2003). *The performance of roundup ready cotton 2001-2002 in the Australian cotton sector*. Armidale, Australia: University of New England.
- Fabrizzi, K.P., Morón, A., & García, F.O. (2003). Soil carbon and nitrogen organic fractions in degraded vs non-degraded mollisols in Argentina. *Soil Science Society of America Journal*, 67, 1831-41.
- George Morris Centre. (2004). *Economic & environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario* (unpublished report). Guelph, Ontario: Author.
- Gianessi, L., & Carpenter, J. (1999). *Agricultural biotechnology: Insect control benefits*. Washington, DC: NCFAP. Available

- on the World Wide Web: <http://www.ncfap.org/reports/biotech/insectcontrolbenefits.pdf>.
- Gonzales, L.A. (2005). *Harnessing the benefits of biotechnology: The case of Bt corn in the Philippines*. Laguna, Philippines: Strive Foundation.
- Gouse, M., Piesse, J., & Thirtle, C. (2006). Output & labour effect of GM maize and minimum tillage in a communal area of Kwazulu-Natal. *Journal of Development Perspectives*, 2(2), 71-86.
- Gouse, M., Pray, C., Kirsten, J.F., & Schimmelpfennig, D. (2005). A GM subsistence crop in Africa: The case of Bt white maize in South Africa. *International Journal of Biotechnology*, 7(1/2/3), 84-94.
- Gouse, M., Pray, C., Schimmelpfennig, D., & Kirsten, J. (2006). Three seasons of subsistence insect-resistant maize in South Africa: Have smallholders benefited? *AgBioForum*, 9(1), 15-22. Available on the World Wide Web: <http://www.agbioforum.org>.
- IMRB International. (2007). Socio-economic benefits of Bollgard and product satisfaction in India. Mumbai, India: Author.
- Ismael, Y., Bennett, R., Morse, S., & Buthelezi, T.J. (2002, July). *Bt Cotton and pesticides. A case study of smallholder farmers in Makhathini Flats South Africa*. Paper presented at the International ICABR Conference, Ravello, Italy.
- James, C. (2002). *Global review of commercialized transgenic crops 2001: Feature Bt cotton* (ISAAA Issue Brief No. 26). Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications (ISAAA).
- James, C. (2003). *Global review of commercialized transgenic crops 2002: Feature Bt maize* (ISAAA Issue Brief No. 29). Ithaca, NY: ISAAA.
- James, C. (2007). *Global status of commercialised biotech/GM crops: 2006* (ISAAA Issue Brief No. 35). Ithaca, NY: ISAAA.
- Jasa, P. (2002). *Conservation tillage systems*. Lincoln, NE: University of Nebraska. Available on the World Wide Web: <http://agecon.okstate.edu/isct/labranza/jasa/tillagesys.doc>.
- Johnson, J.M.F., Reicosky, D.C., Allmaras, R.R., Sauer, T.J., Venterea, R.T., & Dell, C.J. (2005). Greenhouse gas contributions and mitigation potential of agriculture in the central USA. *Soil Tillage Research*, 83(1), 73-94.
- Kirsten, J., Gouse, M., & Jenkins, L. (2002, July). Bt cotton in South Africa: Adoption and the impact on farm incomes amongst small-scale and large-scale farmers. Paper presented at the 6<sup>th</sup> International ICABR Conference, Ravello, Italy.
- 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*. Wageningen, Netherlands: RIKILT, Institute of Food Safety.
- Kovach, J., Petzoldt, C., Degni, J., & Tette, J. (1992). *A method to measure the environmental impact of pesticides*. New York's Food and Life Sciences Bulletin. Geneva, NY: NYS Agricultural Experiment Station, Cornell University.
- Available on the World Wide Web: <http://www.nysipm.cornell.edu/publications/EIQ.html>.
- Lazarus, W., & Selley, R. (2005). *Farm machinery economic cost estimates for late 2005*. St. Paul, MN: University of Minnesota Extension Service. Available on the World Wide Web: <http://www.apec.umn.edu/faculty/wlazarus/mf2005late.pdf>.
- Liebig, M.A., Morgan, J.A., Reeder, J.D., Ellert, B.H., Gollany, H.T., & Schuman, G.E. (2005). Greenhouse gas contributions and mitigation potential of agriculture practices in northwestern USA and western Canada. *Soil Tillage Research*, 83(1), 25-52.
- Marra, M., Pardey, P., & Alston, J. (2002). *The payoffs of agricultural biotechnology: An assessment of the evidence*. Washington, DC: International Food Policy Research Institute (IFPRI).
- Monsanto Brazil. (2008). *Farm survey of conventional and Bt cotton growers in Brazil 2007* (unpublished).
- Monsanto Comercial Mexico. (2004). *Official report to Mexican Ministry of Agriculture* (unpublished).
- Monsanto Comercial Mexico. (2005). *Official report to Mexican Ministry of Agriculture* (unpublished).
- Monsanto Comercial Mexico. (2007). *Official report to Mexican Ministry of Agriculture* (unpublished).
- Morse, S., Bennett, R., & Ismael, Y. (2004). Why Bt cotton pays for small-scale producers in South Africa. *Nature Biotechnology*, 22(4), 379-380.
- Mullins, W., & Hudson, J. (2004, Jan.). *Bollgard II versus Bollgard sister line economic comparisons, 2004*. Paper presented at the Beltwide cotton conferences, San Antonio, TX.
- Parana Department of Agriculture. (2004). *Cost of production comparison: Biotech and conventional soybeans* (USDA GAIN Report BR4629). Washington, DC: Author. Available on the World Wide Web: <http://www.fas.usad.gov/gainfiles/200411/146118108.pdf>.
- Pray, C., Huang, J., Hu, R., & Rozelle, S. (2002). Five years of Bt cotton in China: The benefits continue. *The Plant Journal*, 31(4), 423-430.
- Qaim, M., & De Janvry, A. (2002, July). *Bt cotton in Argentina: Analysing adoption and farmers' willingness to pay*. Paper presented at the American Agricultural Economics Association annual meeting, Long Beach, CA.
- Qaim, M., & De Janvry, A. (2005). Bt cotton and pesticide use in Argentina: Economic and environmental effects. *Environment and Development Economics*, 10, 179-200. Available on the World Wide Web: [http://are.berkeley.edu/~sadoulet/papers/Argentina\\_EDE.pdf](http://are.berkeley.edu/~sadoulet/papers/Argentina_EDE.pdf).
- Qaim, M., & Traxler, G. (2002, July). *Roundup Ready soybeans in Argentina: Farm level, environmental, and welfare effects*. Paper presented at the 6<sup>th</sup> International 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.
- Ramon, G. (2005). *Acceptability survey on the 80-20 bag in a bag insect resistance management strategy for Bt corn*. Quezon City, Philippines: Biotechnology Coalition of the Philippines.
- Reicosky, D.C. (1995). *Conservation tillage and carbon cycling: Soil as a source or sink for carbon*. Davis, CA: University of California. Available on the World Wide Web: <http://vric.ucdavis.edu/issues/bulletinboard/soilconf/contill.pdf>.
- Rice, M.E. (2004). Transgenic rootworm corn: Assessing potential agronomic, economic, and environmental benefits. *Plant Health Progress*. Available on the World Wide Web: <http://www.plantmanagementnetwork.org/pub/php/review/2004/rootworm/>.
- Robertson, G.P., Paul, E.A., & Harwood, R.R. (2000). Greenhouse gases in intensive agriculture: Contributions of individual gases to the radioactive forces of the atmosphere. *Science*, 289, 1922-25.
- Sankula, S. (2006). *A 2006 update of impacts on US agriculture of biotechnology-derived crops planted in 2005*. Washington, DC: NCFAP. Available on the World Wide Web: <http://www.ncfap.org/whatwedo/pdf/2005biotechimpacts-finalversion.pdf>.
- Sankula, S., & Blumenthal, E. (2004). *Impacts on US agriculture of biotechnology-derived crops planted in 2003: An update of eleven case studies*. Washington, DC: NCFAP. Available on the World Wide Web: <http://www.ncfap.org/whatwedo/pdf/2004finalreport.pdf>.
- Traxler, G., Godoy-Avilla, S., Falck-Zepeda, J., & Espinoza-Arellano, J.J. (2001, June). *Transgenic cotton in Mexico: Economic and environmental impacts*. Paper presented at the 5th International Conference on Biotechnology, Science and Modern Agriculture: A new industry at the dawn of the century, Ravello, Italy.
- Trigo, E., Chudnovsky, D., Cap, E., & Lopez, A. (2002). Genetically modified crops in Argentine agriculture: An open ended story. Buenos Aires, Argentina: Libros del Zorzal.
- United States Department of Agriculture Foreign Agriculture Service (USDA FAS). (n.d.). Market and trade reports database: Estadistica Ministerio de Agricultura.
- USDA FAS, & FAOSTAT (n.d.). Market and trade reports database.
- West, T.O., & Post, W.M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation: A global analysis. *Soil Science Society of American Journal*, 66, 930-1046.
- Yorobe, J. (2004, October). Economics impact of Bt corn in the Philippines. Paper presented to the 45<sup>th</sup> PAEDA Convention, Quezon City, Philippines.

**See next page for Appendix.**

## Appendix 1. Examples of Farm Income Methodology Application

**Table A1. Farm-level income impact of using GM IR maize in the United States, 1996-2006.**

Year	Farm-level price of maize (\$/ton)	Base yield (tons/ha)	Insecticide cost saving*	Cost savings (net after cost of technology)*	Net increase in farm gross margin income*	Area of GM IR maize (million ha)	Increase in farm income at a national level (\$ millions)
1996	107.0	7.18	24.71	-9.21	29.20	0.300	8.76
1997	96.0	7.52	24.71	-9.21	28.81	2.446	70.47
1998	76.0	8.38	20.30	-4.80	27.04	6.196	167.58
1999	72.0	8.42	20.30	-4.80	25.51	8.111	206.94
2000	73.0	8.51	22.24	-6.74	24.32	6.117	148.77
2001	78.0	8.59	22.24	-6.74	26.76	5.821	155.87
2002	93.0	8.06	22.24	-6.74	30.74	7.822	240.45
2003	87.0	8.80	22.24	-6.74	31.54	9.225	291.00
2004	81.1	9.91	15.88	-6.36	33.82	10.714	363.41
2005	78.7	9.13	15.88	-1.42	34.52	11.584	399.91
2006	119.3	9.59	15.88	-1.42	55.78	12.679	707.23

Note. \*\$/ha. Farm-level prices (USDA FAS & FAOSTAT, n.d.) and average base yields (derived from USDA FAS & FAOSTAT, n.d.). Impact data based on references cited in Appendix 2. Yield impact +5% applied to all years based on average of reference findings (see Appendix 2). Insecticide cost savings based on Sankula and Blumenthal (2004) and Sankula (2006). A negative value for net cost savings means the cost of the technology is greater than the other cost savings.

**Table A2. Farm-level income impact of using GM IR cotton in India, 2002-2006.**

Year	Exchange rate to \$US	Farm-level price of cotton lint (\$/ton)	Base yield (tons/ha)	Yield impact	Crop protection cost saving*	Cost savings (net after cost of technology)*	Net increase in farm gross margin income*	Area of GM IR cotton (million ha)	Increase in farm income at a national level (\$ millions)
2002	48.612	1,106.27	0.191	+45%	41.80	-12.42	82.66	0.04	3.69
2003	46.542	1,168.77	0.317	+63%	37.96	-16.20	209.85	0.10	20.98
2004	45.813	1,204.96	0.318	+54%	41.47	-13.56	193.36	0.50	96.68
2005	44.100	1,278.53	0.340	+64%	30.06	-22.25	255.96	1.30	332.74
2006	45.307	1,372.24	0.317	+50%	52.34	3.52	221.02	3.80	839.89

Note. \*\$/ha. Yield impact data based on references cited in Appendix 2. Cost of technology: 2002=2,636 rupees/ha; 2003 & 2004=2,521 rupees/ha; 2005= 2,307 rupees/ha; 2006=2,216 rupees/ha (sources cited in Appendix 2). Crop protection cost savings = insecticide cost savings: 2002=2,032 rupees/ha; 2003=1,767 rupees/ha; 2004,=1,900 rupees/ha; 2005=1,362 rupees/ha; 2006=2,308 rupees/ha (sources cited in Appendix 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. Sources for average yields and prices, USDA FAS & FAOSTAT (n.d.).

**Table A3. Farm-level income impact of using GM HT soybeans in Argentina, 1996-2006.<sup>a</sup>**

Year	Farm-level price of soybeans (\$/ton)	Base yield (tons/ha)	Quality premium on price (reduced level of impurities % on base price)	Cost saving*	Cost savings (net after cost of technology)*	Net increase in farm gross margin income*	Area of GM HT soybeans (million ha)	Increase in farm income at a national level (\$ millions)
1996	208	2.10	+0.5%	26.10	22.49	24.67	0.037	0.9
1997	234	1.72	+0.5%	25.32	21.71	23.72	1.756	42.0
1998	212	2.69	+0.5%	24.71	21.10	23.95	4.800	115.0
1999	167	2.44	+0.5%	24.41	20.80	22.84	6.640	152.0
2000	180	2.34	+0.5%	24.31	20.70	22.81	9.000	205.0
2001	171	2.58	+0.5%	24.31	20.70	22.91	10.925	250.0
2002	154	2.64	+0.5%	29.00	26.00	29.85	12.446	372.0
2003	180	2.80	+0.5%	29.00	27.80	30.27	13.320	400.0
2004	241	2.29	+0.5%	30.00	28.80	31.53	14.058	443.0
2005	243	2.73	+0.5%	30.10	28.85	32.17	15.048	484.0
2006	204	3.50	+0.5%	30.00	27.50	31.06	15.840	492.0

Note. <sup>a</sup>The primary source of information for impact is Qaim and Traxler (2002, 2005). \*\$/ha. Yield impact: neutral plus improvement in quality of crop (less weed impurities) equal to +0.5% to price. Sources for yields and prices: USDA FAS (n.d.). 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. Additional information is available in Appendix 2.

Cost of technology all years to 2002 based on Qaim and Traxler (2002, 2005). 2002-2005 average value applied reduced to reflect large share of total crop planted to farm-saved seed on which no royalty paid. In 2006, seed premium applied based on royalty applied by Monsanto @ \$2 per bag of seed. The net savings to costs, nevertheless, probably understate the total gains in recent years because 66-80% 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).

An additional farm-income benefit that many Argentine soybean growers have derived comes from the additional scope for second cropping of soybeans. This has arisen because of the simplicity, ease, and weed management flexibility provided by the (GM) technology, which has been an important factor facilitating the use of no- and reduced-tillage production systems. In turn, the adoption of low/no-tillage production systems has reduced the time required for harvesting and drilling subsequent crops and, hence, has enabled many Argentine farmers to cultivate two crops (wheat, followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no- or low-tillage methods has increased from 34% in 1996 to 90% by 2005. Also, 20% of the total Argentine soybean crop was second crop in 2006, compared to 8% in 1996. Based on the additional gross margin income derived from second crop soybeans (see below), this has contributed a further boost to national soybean farm income of \$699 million in 2006 and \$3.29 billion cumulatively since 1996.

**Table A4. Farm-level income impact of using GM HT soybeans in Argentina, 1996-2006: Second crop soybeans.<sup>a</sup>**

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	124.00	Negligible
1997	0.65	124.00	24.80
1998	0.80	124.00	43.40
1999	1.40	124.00	117.80
2000	1.60	124.00	142.60
2001	2.40	124.00	272.80
2002	2.70	143.32	372.60
2003	2.80	151.33	416.10
2004	3.00	226.04	678.10
2005	2.30	228.99	526.70
2006	3.20	218.40	698.90

Note. <sup>a</sup>Crop areas and gross margin data based on data supplied by Grupo CEO (no data available before 2000, hence 2001 data applied to earlier years). 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 NT production systems).

## Appendix 2. Key Baseline Assumptions and Sources for Farm-Income Impact Analysis.

Table A5. Yield impact assumptions.

Crop	Country	Yield effect
<b>GM HT soybeans</b>	US	None
	Canada	None
	Argentina	None plus 0.5% price premia for cleaner crops
	Brazil	None plus 0.5% price premia for cleaner crops
	Paraguay	None plus 0.5% price premia for cleaner crops
	Uruguay	None
	Mexico	+9.1%
	South Africa	None
	Romania	+31% & 2% price premia for cleaner crops to 2004 then discontinued
<b>GM HT maize</b>	US	None
	Canada	None
	South Africa	None
	Argentina	+3% in main maize growing belt (80% of crop) +22% in more marginal areas (20% of crop)
	Philippines	+15%
<b>GM HT cotton</b>	US	None
	Australia	None
	South Africa	None
	Argentina	None
	Mexico	+3.6%
<b>GM HT canola</b>	US	All years=+6%
	Canada	All years=+10.7% (but applied to a reduced share of GM HT crop in line with adoption of hybrid varieties—applied to 50% of GM HT area in 2004, 37% in 2005, and 29% in 2006)

Table A5. Yield impact assumptions.

Crop	Country	Yield effect		
<b>GM IR maize</b>	US	All years=+5%		
	Canada	All years=+5%		
	Argentina	All years to 2004=+9% 2005 onwards=+5.5%		
	Philippines	All years=+24.5% plus 10% price premia for better quality		
	Spain	All years to 2004=+6.3% 2005 onwards=+10%		
	South Africa	2000=+11% 2001=+32% 2002=+16% 2004=+5% 2005-2006=+15%		
		Uruguay	2004=+9% 2005 onwards=+5.5%	
		<b>GM IR cotton</b>	US	1996-2002+9% 2003-2004+11% 2005 onwards=+10%
			China	1997-1999=+8% 2000 onwards=+10%
	Australia		None	
Argentina	All years=+30%			
South Africa	All years=+24%			
Mexico	1996=+37% 1997=+3% 1998=+20% 1999=+27% 2000=+17% 2001=+9% 2002=+6.7% 2003=+6.4% 2004=+7.6% 2005-2006=+9.25%			
India	2002=+45% 2003=+63% 2004=+54% 2005=+64% 2006=+50%			
	Brazil	+6.23%		
	<b>GM IR (corn rootworm) maize</b>	US	5%	
Canada		5%		
<b>GM virus-resistant crops</b>	US	<b>Papaya:</b> between +16% and +50% from 1999-2006		
		<b>Squash:</b> +100% on the area planted—assumes virus otherwise destroys crop		

Table A6. Cost of technology assumptions (costs/ha).

Crop	Country	Cost of technology
<b>GM HT soybeans</b>	US	1996-2002=\$14.82
		2003=\$17.30
		2004=\$19.77
		2005 onwards=\$24.71
	Canada	1997-2002=\$32 Canadian
		2003=\$48 Canadian
		2004-2005=\$45 Canadian
		2006=\$41 Canadian
	Argentina	All years to 2001=\$3-\$4
		2002-2005=\$1.20 (reflecting all use of farm saved seed)
		2006=\$2.50 (Monsanto royalty rate)
	Brazil	Same as Argentina to 2002 (illegal plantings)
		2003=\$9.00
		2004=\$15.00
2005=\$16.00		
2006=\$19.80		
Paraguay	Same as Argentina	
Uruguay	Same as Argentina	
Mexico	All years=\$34.50	
South Africa	All years to 2005=170 Rand	
	2006=195 Rand	
Romania	1999-2000=\$160	
	2001=\$148	
	2002=\$135	
	2003-2004=\$130	
	2005=\$121	
	2006=\$100	
		All include 4 liters of herbicide
<b>GM HT maize</b>	US	All years to 2004=\$14.80
		2005 onwards=\$17.30
	Canada	1999-2005=\$27 Canadian
		2006=\$35 Canadian
	South Africa	2003-2005=80 Rand
	2006=120 Rand	
Argentina	All years=\$20	
Philippines	2006=\$24	
<b>GM HT cotton</b>	US	1996-2000=\$12.85
		2001-2003=\$21.32
		2004=\$34.55
		2005 onwards=\$68.22
	Australia	All years=\$50 Australian
	South Africa	2001-2004=133 Rand
		2005=101 Rand
		2006=165 Rand
Argentina	All years=\$30	
Mexico	All years=\$66	
<b>GM IR (corn rootworm) maize</b>	US	2003-2004=\$42
		2005-2006=\$35
	Canada	Same as US

Table A6. Cost of technology assumptions (costs/ha).

Crop	Country	Cost of technology	
<b>GM HT canola</b>	US	1999-2001=\$29.50	
		2002-2004=\$33.00	
		2005-2006=\$12.00 <sup>#</sup>	
		All years to 2004=\$17.30 <sup>*</sup>	
		2005 onwards=\$12.00 <sup>*</sup>	
	Canada	All years=\$44.63 Canadian	
<b>GM IR maize</b>	US	1996-1997=\$25	
		1998-1999=\$20	
		2000-2004=\$22	
			2005-2006=\$17
	Canada	Same as US	
	Argentina	Same as US, except 2006=\$20	
	Philippines	All years=1,673 Pesos	
	Spain	1998-1999=30 Euros	
		2000=28 Euros	
		2001-2005=18.5 Euros	
			2006=35 Euros
South Africa	2000-2001=84 Rand		
	2002=90 Rand		
	2004-2005=94 Rand		
	2006=113 Rand		
Uruguay	Same as Argentina		
<b>GM IR cotton</b>	US	1996-2002=\$58.27	
		2003-2004=\$68.32	
		2005-2006=\$49.60	
	China	All years=\$46.30	
	Australia	1996-1997=\$245 Australian	
		1998=\$155 Australian	
		1999=\$138 Australian	
		2000-2001=\$155 Australian	
		2002=\$167 Australian	
		2003=\$190 Australian	
		2004=\$250 Australian	
		2005-2006=\$300 Australian	
Argentina	All years through 2004=\$86		
		2005-2006=\$40	
South Africa	All years to 2005=149 Rand		
		2006=345 Rand	
Mexico	All years to 2005=540 pesos		
		2006=760 Pesos	
India	2002=2,636 Rupees		
	2003=2,512 Rupees		
	2004=2,521 Rupees		
	2005=2,307 Rupees		
	2006=2,211 Rupees		
Brazil	2006=\$40		
<b>GM virus-resistant crops</b>	US	<b>Papaya:</b> 1999-2003=\$0	
		2004=\$42	
		2005-2006=\$148	
		<b>Squash:</b> All years=\$398	

Note. <sup>#</sup> For glyphosate-tolerant. <sup>\*</sup> For (glufosinate-tolerant).

**Table A7. Cost savings (excluding impact of seed premium) assumptions (costs/ha).**

Crop	Country	Cost savings
<b>GM HT soybeans</b>	US	1996-1997=\$25.20
		1998-2002=\$33.90
		2003=\$78.50
		2004=\$60.10
		2005 onward=\$69.40
	Canada	1997-2006=Range of \$66-89 Canadian (converted to \$US at prevailing exchange rate)
	Argentina	\$24-\$30 (varies each year according to exchange rate)
	Brazil	2004=\$88 Applied to all other years at prevailing exchange rate
	Paraguay	Same as Argentina
	Uruguay	Same as Argentina
	Mexico	\$154.50
South Africa	All years=230 Rand (converted to \$US at prevailing exchange rate)	
Romania	1999-2006=\$150-\$192 (depending on Euro to \$ exchange rate)	
<b>GM HT maize</b>	US	All years to 2003=\$39.90
		2004=\$40.55
		2005-2006=\$40.75
	Canada	All years=\$48.75 Canadian
	South Africa	All years=162 Rand
	Argentina	All years=\$20
	Philippines	Not known, so conservative assumption of zero used
<b>GM HT cotton</b>	US	1996-2000=\$34.12
		2001-2003=\$66.59
		2004=\$83.35
		2005-2006=\$71.12
		Australia
	South Africa	All years=160 Rand
Argentina	All years=\$22-\$22	
Mexico	All years=\$105	
<b>GM HT canola</b>	US	1999-2001=\$60.75
		2002-2003=\$67.00
		2004=\$69.00
		2005-2006=\$49.00 <sup>#</sup>
		All years to 2003=\$44.89
		2004=\$44.00
		2005-2006=\$40.00 <sup>*</sup>
		Canada

**Table A7. Cost savings (excluding impact of seed premium) assumptions (costs/ha).**

Crop	Country	Cost savings
<b>GM IR maize</b>	US	All years to 2004=\$15.50
		2005-2006=\$15.90
	Canada	Same as US
	Argentina	All years=\$0
	Philippines	All years=651 Pesos
	Spain	All years=42 Euros
	South Africa	All years=97 Rand
	Uruguay	Same as Argentina
<b>GM IR cotton</b>	US	1996-2002=\$63.26
		2003 onwards=\$74.10
		China
	Australia	1996=\$151 Australian
		1997=\$157 Australian
		1998=\$188 Australian
		1999=\$172 Australian
		2000-2002=\$267 Australian
		2003=\$598 Australian
		2004=\$509 Australian
2005-2006=\$553 Australian		
Argentina	All years=\$17.47	
South Africa	All years=127 Rand	
Mexico	1996=985 pesos	
	1997=\$121	
	1998=\$94 1999 onwards=985 pesos	
India	2002=2,032 Rupees	
	2003=1,767 Rupees	
	2004=1,900 Rupees	
	2005=1,362 Rupees 2006=2,308 Rupees	
Brazil	\$65	
<b>GM IR (corn rootworm) maize</b>	US	2003=\$32.00
		2004 onwards=\$37.00
Canada	Same as US	
<b>GM virus-resistant crops</b>	US	None

Note. <sup>#</sup> For glyphosate-tolerant. <sup>\*</sup> For glufosinate-tolerant.

Table A8. Data sources.

Crop	Country	Sources of data for assumptions
<b>GM HT soybeans</b>	US	Carpenter and Gianessi (2001) Gianessi and Carpenter (1999) Marra et al. (2002) Sankula (2006) Sankula and Blumenthal (2004)
	Argentina	Qaim and Traxler (2002, 2005)
	Brazil	Parana Department of Agriculture (2004)
	Paraguay & Uruguay	Same as Argentina, no country-specific analysis identified
	Canada	George Morris Centre (2004)
	South Africa	No studies identified, based on Monsanto South Africa (personal communication, 2005, 2007)
	Mexico	No studies identified, based on Monsanto Comercial Mexico (2007)
	Romania	Brookes (2005)
	<b>GM HT maize</b>	US
Canada		No studies identified, based on industry sources and Monsanto Canada (personal communication)
South Africa		No studies identified, based on Monsanto South Africa (personal communication, 2005, 2007)
Argentina		No studies identified, based on Monsanto Argentina and Grupo CEO (personal communication, 2007)
Philippines		No studies identified, based on Monsanto Philippines (personal communication, 2007)
<b>GM HT cotton</b>	US	Carpenter and Gianessi (2001) Sankula (2006) Sankula and Blumenthal (2004)
	Australia	Doyle et al. (2003) Monsanto Australia (personal communication, 2005, 2007)
	South Africa	No studies identified, based on Monsanto South Africa (personal communication, 2005, 2007)
	Argentina	No studies identified, based on Grupo CEO and Monsanto Argentina (personal communication, 2007)
	Mexico	No studies identified, based on Monsanto Comercial Mexico (personal communication, 2007)
<b>GM HT canola</b>	US	Sankula (2006) Sankula and Blumenthal (2004)
	Canada	Canola Council of Canada (2001) Farmer groups (personal communication, 2007)

Table A8. Data sources.

Crop	Country	Sources of data for assumptions	
<b>GM IR maize</b>	US	Carpenter and Gianessi (2001) Gianessi and Carpenter (1999) Marra et al. (2002) Sankula (2006) Sankula and Blumenthal (2004)	
	Canada	No studies identified, same as US Impacts qualitatively confirmed by industry sources (personal communication, 2005, 2007)	
	Argentina	James (2003) Trigo (personal communication, 2007) Trigo et al. (2002)	
	Philippines	Gonzales (2005) Ramon (2005) Yorobe (2004)	
	Spain	Brookes (2003, 2008)	
	South Africa	Gouse, Piesse, and Thirtle (2006) Gouse, Pray, Kirsten, and Schimmelpfennig (2005) Gouse, Pray, Schimmelpfennig, and Kirsten (2006)	
	Uruguay	No studies identified, same as Argentina	
	<b>GM IR cotton</b>	US	Marra et al. (2002) Mullins and Hudson (2004) Sankula (2006) Sankula and Blumenthal (2004)
		China	Monsanto China (personal communication, 2007) Pray, Huang, Hu, and Rozelle (2002)
		Australia	Commonwealth Scientific & Industrial Research Organisation (2005) Doyle (2005) Fitt (as cited in James, 2002) James (2002)
Argentina		Qaim and De Janvry (2002, 2005)	
South Africa		Ismael, Bennett, Morse, and Buthelezi (2002) James (2002) Kirsten, Gouse, and Jenkins (2002) Morse, Bennett, and Ismael (2004)	
Mexico		Monsanto Comercial Mexico (2004, 2005, 2007) Traxler et al. (2001)	
India		APCoAB (2006) Bennett et al. (2004) IMRB International (2007)	
Brazil		Monsanto Brazil (2008)	
<b>Others</b>		US & Canada	<b>GM IR corn rootworm maize:</b> Sankula (2006); Sankula and Blumenthal (2004); Rice (2004)
		US	<b>GM virus-resistant papaya &amp; squash:</b> Sankula (2006) Sankula and Blumenthal (2004)

Readers should note that the assumptions are drawn from the references listed below. In some cases (trait/crop/country combinations), the authors have not been able to identify specific studies. Where this has occurred, data has been sought from farm advisers and seed-supplying companies in each country. This has been particularly of relevance for some of the HT traits more recently adopted in several developing countries. Accordingly, the authors are grateful to industry sources that have provided information on impact, notably on

cost of the technology and impact on costs of crop protection. While 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.