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RESEARCH PAPERS

Global income and production impacts of using GM crop technology 1996–2013

Graham Brookes* and Peter Barfoot

PG Economics Ltd; Dorchester, UK

ABSTRACT. This paper provides an economic assessment of the value of using genetically modified (GM) crop technology in agriculture at the farm level. It follows and updates earlier annual studies which examined economic impacts on yields, key costs of production, direct farm income and effects, and impacts on the production base of the 4 main crops of soybeans, corn, cotton and canola. The commercialisation of GM crops has continued to occur at a rapid rate since the mid 1990s, with important changes in both the overall level of adoption and impact occurring in 2013. This annual updated analysis shows that there continues to be very significant net economic benefits at the farm level amounting to $20.5 billion in 2013 and $133.4 billion for the 18 years period (in nominal terms). These economic gains have been divided roughly 50% each to farmers in developed and developing countries. About 70% of the gains have derived from yield and production gains with the remaining 30% coming from cost savings. The technology have also made important contributions to increasing global production levels of the 4 main crops, having added 138 million tonnes and 273 million tonnes respectively, to the global production of soybeans and maize since the introduction of the technology in the mid 1990s.

KEYWORDS. cost, genetically modified crops, income, production, yield

ABBREVIATIONS. GM, genetic modification; HT, herbicide tolerant; IR, insect resistant; ALS, herbicides that inhibit acetolactate synthese

INTRODUCTION

1996 was the first year in which a significant area of crops containing genetically modified (GM) traits was planted (1.66 million hectares). Since then there has been a significant and steady increase in plantings and by 2013, the global planted area reached over 168 million hectares.

*Correspondence to: Graham Brookes; Email: graham.brookes@btinternet.com
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Since the mid 1990s, there have been many papers assessing the economic impacts associated with the adoption of this technology, at the farm level. The authors of this paper have, since 2005, engaged in an annual exercise to aggregate and update the sum of these various studies, and where possible and appropriate, to supplement this with new analysis. The aim of this has been to provide an up to date and as accurate as possible assessment of some of the key economic impacts associated with the global adoption of GM crops. It is also hoped the analysis contributes to greater understanding of the impact of this technology and facilitates more informed decision-making, especially in countries where crop biotechnology is currently not permitted.

Therefore, integrating the data for 2013 into the context of earlier developments, this study updates the findings of earlier analysis into the global economic impact of GM crops since their commercial introduction in 1996. Earlier analysis by the current authors has been published in various journals, including AgbioForum 12 (Brookes and Barfoot, 2009) (2), 184–208, the International Journal of Biotechnology (Brookes and Barfoot, 2011), vol 12, 1/2, 1–49 and GM Crops 3:4, 265–272 (Brookes and Barfoot, 2012) GM Crops 4:1, 1–10 (Brookes and Barfoot, 2013) and GM Crops 5:1, 65–75 (Brookes and Barfoot, 2014). The methodology and analytical procedures in this present discussion are unchanged to allow a direct comparison of the new with earlier data. Readers should however, note that some data presented in this paper are not directly comparable with data presented in previous analysis because the current paper takes into account the availability of new data and analysis (including revisions to data for earlier years).

In order to save readers the chore of consulting these earlier papers for details of the methodology and arguments, these are included in full in this updated paper.

The analysis concentrates on farm income effects because this is a primary driver of adoption among farmers (both large commercial and small-scale subsistence). It also quantifies the (net) production impact of the technology. The authors recognize that an economic assessment could examine a broader range of potential impacts (eg, on labor usage, households, local communities and economies).

However, these are not included because undertaking such an exercise would add considerably to the length of the paper and an economic assessment of wider economic impacts would probably merit a separate assessment in its own right.

RESULTS AND DISCUSSION

a) HT crops

The primary impact of GM HT (largely tolerant to the broad spectrum herbicide glyphosate) technology has been to provide more cost effective (less expensive) and easier weed control for farmers. Nevertheless, some users of this technology have also derived higher yields from better weed control (relative to weed control obtained from conventional technology). The magnitude of these impacts varies by country and year, and is mainly due to prevailing costs of different herbicides used in GM HT systems versus conventional alternatives, the mix and amount of herbicides applied, the cost farmers pay for accessing the GM HT technology and levels of weed problems. The following important factors affecting the level of cost savings achieved in recent years should, however, be noted:

- In 2008–2009, the average cost associated with the use of GM HT technology globally increased relative to earlier years because of the significant increase in the global price of glyphosate relative to changes in the price of other herbicides commonly used on conventional crops. This has abated since 2009 with a decline in the price of glyphosate to previous historic trend levels;
- The amount farmers pay for use of the technology varies by country. Pricing of technology (all forms of seed and crop protection technology, not just GM technology) varies according to the level of benefit that farmers are likely to derive from it. In addition, it is influenced by intellectual property rights (patent protection, plant

breeders' rights and rules relating to use of farm-saved seed). In countries with weaker intellectual property rights, the cost of the technology tends to be lower than in countries where there are stronger rights. This is examined further in c) below;

- Where GM HT crops (tolerant to glyphosate) have been widely grown, some incidence of weed resistance to glyphosate has occurred and resistance has become a major concern in some regions. This has been attributed to how glyphosate was used; because of its broad-spectrum post-emergence activity, it was often used as the sole method of weed control. This approach to weed control put tremendous selection pressure on weeds and as a result contributed to the evolution of weed populations predominated by resistant individual weeds. It should, however, be noted that there are hundreds of resistant weed species confirmed in the International Survey of Herbicide Resistant Weeds (www.weedscience.com). Worldwide, there are 31 weed species that are currently (accessed January 2015) resistant to glyphosate, compared to 146 weed species resistant to ALS herbicides (eg, chlorimuron ethyl commonly used in conventional soybean crops) and 72 weed species resistant to photosystem II inhibitor herbicides (eg, atriazine commonly used in corn production). In addition, it should be noted that 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. This has also probably contributed to the emergence of weeds resistant to herbicides like glyphosate and to weed shifts toward those weed species that are not well controlled by glyphosate. As a result, 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 change in weed management emphasis also perhaps reflects the broader agenda of developing strategies across all forms of cropping systems to minimise and slow down the potential for weeds developing resistance to existing technology solutions (Norsworthy et al., 2012). At the macro level, these changes have influenced the mix, total amount, cost and overall profile of herbicides applied to GM HT crops. Relative to the conventional alternative, however, the economic impact of the GM HT crop use has continued to offer important advantages. Also, many of the herbicides used in conventional production systems had significant resistance issues themselves in the mid 1990s. This was, for example, one of the reasons why glyphosate tolerant soybeans were rapidly adopted, as glyphosate provided good control of these weeds. If the GM HT technology was no longer delivering net economic benefits, it is likely that farmers around the world would have significantly reduced their adoption of this technology in favor of conventional alternatives. The fact that GM HT global crop adoption levels have not fallen in recent years suggests that farmers must be continuing to derive important economic benefits from using the technology.

These points are further illustrated in the analysis below.

GM HT soybeans. The average impacts on farm level profitability from using this technology are summarised in **Table 1**. The main farm level gain experienced has been a reduction in the cost of production, mainly through reduced expenditure on weed control (herbicides). Not surprisingly, where yield gains have occurred from improvements in the level of weed control, the average farm income gain has tended to be higher, in countries such as Romania, Mexico and Bolivia. A second generation of GM HT soybeans became available to commercial soybean growers in the US and Canada in 2009. This technology offered the same tolerance to glyphosate as the first generation (and the same cost saving) but with higher yielding potential. The realization of this potential is shown in the higher average farm income benefits (**Table 1**).

Table 1. GM soybeans: Summary of average farm level economic impacts 1996–2013 ($/hectare)

Country	Cost of technology	Average farm income benefit (after deduction of cost of technology)	Type of benefit	References
1st generation GM HT soybeans				
Romania (to 2006 only)	50–60	104	Small cost savings of about $9/ha, balance due to yield gains of +13% to +31%	Brookes (2005) Monsanto Romania (2007)
Argentina	2–4	22 plus second crop benefits of 237	Cost savings plus second crop gains	Qaim and Traxler (2005) Trigo and CAP (2006) and updated from 2008 to reflect herbicide usage and price changes
Brazil	11–25	34	Cost savings	Parana Department of Agriculture (2004) Galveo (2010, 2012 and 2013) and updated to reflect herbicide usage and price changes
USA	15–53	36	Cost savings	Marra et al. (2002) Carpenter and Gianessi (2002) Sankala and Blumenthal (2003, 2006) Johnson and Strom (2008) And updated to reflect herbicide price and common product usage
Canada	20–40	20	Cost savings	George Morris Centre (2004) and updated to reflect herbicide price and common product usage
Paraguay	4–10	17 plus second crop benefits of 237	Cost savings	Based on Argentina as no country-specific analysis identified. Impacts confirmed by industry sources and herbicide costs and usage updated 2009 onwards from herbicide survey data (AMIS Global)
Uruguay	2–4	18	Cost savings	Based on Argentina as no country-specific analysis identified. Impacts confirmed by industry sources and herbicide costs and usage updated 2009 onwards from herbicide survey data (AMIS Global)
South Africa	2–30	5	Cost savings	As there are no published studies available, based on data from industry sources and herbicide costs and usage updated 2009 onwards from herbicide survey data (AMIS Global)
Mexico	20–41	52	Cost savings plus yield gain in range of +2% to +13%	Monsanto annual monitoring reports submitted to Ministry of Agriculture and personal communications
Bolivia	3–4	90	Cost savings plus yield gain of +15%	Fernandez et al. (2009)

(Continued on next page)

Table 1. GM soybeans: Summary of average farm level economic impacts 1996–2013 ($/hectare) *(Continued)*

Country	Cost of technology	Average farm income benefit (after deduction of cost of technology)	Type of benefit	References
2nd^{t} generation GM HT soybeans				
US and Canada	50–65	141 (US) 141 (Can)	Cost savings as first generation plus yield gains in range of +5% to +11%	As first generation GM HT soybeans plus annual farm level survey data from Monsanto USA
Intacta soybeans				
Brazil	56	135	Herbicide cost saving as 1st generation plus insecticide saving $19/ha and yield gain +10%	Monsanto Brazil pre commercial trials and MB Agro (2013)
Argentina	56	62	Herbicide cost saving as 1st generation plus insecticide saving $21/ha and yield gain +9%	Monsanto Argentina pre commercial trials
Paraguay	56	130	Herbicide cost saving as 1st generation plus insecticide saving $33/ha and yield gain +13%	Monsanto Paraguay pre commercial trials
Uruguay	56	47	Herbicide cost saving as 1st generation plus insecticide saving $19/ha and yield gain +9%	Monsanto Uruguay pre commercial trials

Notes:

1. Romania stopped growing GM HT soybeans in 2007 after joining the European Union, where the trait is not approved for planting
2. The range in values for cost of technology relates to annual changes in the average cost paid by farmers. It varies for reasons such as the price of the technology set by seed companies, exchange rates, average seed rates and values identified in different studies
3. Intacta soybeans (HT and IR) first grown commercially in 2013
4. For additional details of how impacts have been estimated, see examples in **Appendix 1**

GM HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage has enabled 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 considerably to farm incomes and to the volumes of soybean production in countries such as Argentina and Paraguay.

Overall, in 2013, GM HT technology in soybeans (excluding Intacta soybeans: see below) has boosted farm incomes by $5.3 billion, and since 1996 has delivered $41.4 billion of extra farm income. Of the total cumulative farm income gains from using GM HT soybeans, $14.8 billion (36%) has been due to yield gains/second crop benefits and the balance, 64%, has been due to cost savings.

GM HT and IR (Intacta) soybeans. This combination of GM herbicide tolerance (to glyphosate) and insect resistance in soybeans was first commercialised in 2013, in South America. In this first year, the technology was used on approximately 2.5 million hectares and contributed an additional $332 million to farm income of soybean farmers in Argentina, Brazil, Paraguay and Uruguay, through a combination of cost savings (decreased expenditure on herbicides and insecticides) and higher yields (see **Table 1**).

GM HT maize. The adoption of GM HT maize has mainly resulted in lower costs of production, although yield gains from improved weed control have arisen in Argentina, Brazil and the Philippines (**Table 2**).

In 2013, the total global farm income gain from using this technology was $1.76 billion with the cumulative gain over the period 1996–2013 being $7.36 billion. Within this, $2.24 billion (30%) was due to yield gains and the rest derived from lower costs of production.

GM HT cotton. The use of GM HT cotton delivered a net farm income gain of about $121 million in 2013. In the 1996–2013 period, the total farm income benefit was $1.49 billion. As with other GM HT traits, these farm income gains have mainly arisen from cost savings (83% of the total gains), although there have been some yield gains in Brazil, Mexico and Colombia (**Table 3**).

Other HT crops. GM HT canola (tolerant to glyphosate or glufosinate) has been grown in Canada, the US, and more recently Australia, while GM HT sugar beet is grown in the US and Canada. The farm income impacts associated with the adoption of these technologies are summarised in **Table 4**. In both cases, the main farm income benefit has derived from yield gains. In 2013, the total global income gain from the adoption of GM HT technology in canola and sugar beet was $633 million and cumulatively since 1996, it was $4.54 billion.

b) GM IR crops

The main way in which these technologies have impacted on farm incomes has been through lowering the levels of pest damage and hence delivering higher yields (**Table 5**).

The greatest improvement in yields has occurred in developing countries, where conventional methods of pest control have typically been least effective (eg, reasons such as less well developed extension and advisory services, lack of access to finance to fund use of crop protection application equipment and products), with any cost savings associated with reduced insecticide use being mostly found in developed countries. These effects can be seen in the level of farm income gains that have arisen from the adoption of these technologies, as shown in **Table 6**.

At the aggregate level, the global farm income gains from using GM IR maize and cotton in 2013 were $7.67 billion and $4.67 billion respectively. Cumulatively since 1996, the gains have been $37.2 billion for GM IR maize and $40.78 billion for GM IR cotton.

c) Aggregated (global level) impacts

At the global level, GM technology has had a significant positive impact on farm income, with in 2013, the direct global farm income benefit being $20.5 billion. This is equivalent to having added 5.5% to the value of global

Table 2. GM HT maize: summary of average farm level economic impacts 1996–2013 ($/hectare)

Country	Cost of technology	Average farm income benefit (after deduction of cost of technology)	Type of benefit	References
USA	15–30	24	Cost savings	Carpenter and Gianessi (2002) Sankala and Blumenthal (2003, 2006) Johnson and Strom (2008) Also updated annually to reflect herbicide price and common product usage
Canada	17–35	35	Cost savings	Monsanto Canada (personal communications) and updated annually since 2008 to reflect changes in herbicide prices and usage
Argentina	16–33	29	Cost savings plus yield gains over 10% and higher in some regions	Personal communication from Monsanto Argentina, Grupo CEO and updated since 2008 to reflect changes in herbicide prices and usage
South Africa	10–18	3	Cost savings	Personal communication from Monsanto South Africa and updated since 2008 to reflect changes in herbicide prices and usage
Brazil	17–32	64	Cost savings plus yield gains of +1% to +7%	Galveo (2010, 2012, 2013)
Colombia	22–24	17	Cost savings	Mendez et al. (2011)
Philippines	24–47	36	Cost savings plus yield gains of +5% to +15%	Gonsales (2009) Monsanto Philippines (personal communications) Updated since 2010 to reflect changes in herbicide prices and usage

1. The range in values for cost of technology relates to annual changes in the average cost paid by farmers. It varies for reasons such as the price of the technology set by seed companies, exchange rates, average seed rates and values identified in different studies

2. For additional details of how impacts have been estimated, see examples in **Appendix 1**

production of the 4 main crops of soybeans, maize, canola and cotton. Since 1996, farm incomes have increased by $133.4 billion.

At the country level, US farmers have been the largest beneficiaries of higher incomes, realizing over $58.4 billion in extra income between 1996 and 2013. This is not surprising given that US farmers were first to make widespread use of GM crop technology and for several years the GM adoption levels in all 4 US crops have been in excess of 80%. Important farm income benefits ($31.1 billion) have occurred in South America (Argentina, Bolivia, Brazil, Colombia, Paraguay and Uruguay), mostly from GM technology in soybeans and maize. GM IR cotton has also been responsible for an additional $32.9 billion additional income for cotton farmers in China and India.

In 2013, 49.8% of the farm income benefits were earned by farmers in developing countries. The vast majority of these gains have been from GM IR cotton and GM HT soybeans. Over the 18 years, 1996–2013, the cumulative farm income gain derived by developing country farmers was $68.3 billion, equal to 51.2% of the total farm income during this period.

The cost to farmers for accessing GM technology, across the 4 main crops, in 2013, was equal to 25% of the total value of technology gains. This is defined as the farm income gains referred to above plus the cost of the technology payable to the seed supply chain. Readers

Table 3. GM HT cotton summary of average farm level economic impacts 1996–2013 ($/hectare)

Country	Cost of technology	Average farm income benefit (after deduction of cost of technology)	Type of benefit	References
USA	13–82	22	Cost savings	Carpenter and Gianessi (2002) Sankala and Blumenthal (2003, 2006) Johnson and Strom (2008) Also updated to reflect herbicide price and common product usage
South Africa	15–32	35	Cost savings	Personal communication from Monsanto South Africa and updated since 2008 to reflect changes in herbicide prices and usage
Australia	32–82	29	Cost savings	Doyle (2003) Monsanto Australia (personal communications) and updated to reflect changes in herbicide usage and prices
Argentina	14–30	40	Cost savings	Personal communication from Monsanto Argentina, Grupo CEO and updated since 2008 to reflect changes in herbicide prices and usage
Uruguay	13	2	Cost savings	Personal communications from Monsanto Uruguay
Paraguay	17	1	Cost savings	Personal communications Monsanto Paraguay
Brazil	33–52	69	Cost savings plus yield gains of +2% to +4% (-2% 2013)	Galveo (2010, 2012, 2013)
Mexico	29–79	202	Cost savings plus yield gains of +3% to +18%	Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture and personal communications
Colombia	96–187	99	Cost savings plus yield gains of +4%	Monsanto Colombia annual personal communications

1. The range in values for cost of technology relates to annual changes in the average cost paid by farmers. It varies for reasons such as the price of the technology set by seed companies, exchange rates, average seed rates, the nature and effectiveness of the technology (eg, second generation 'Flex' cotton offered more flexible and cost effective weed control than the earlier first generation of HT technology) and values identified in different studies

2. For additional details of how impacts have been estimated, see examples in **Appendix 1**

should note that 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.

In developing countries, the total cost was equal to 24% of total technology gains compared with 26% in developed countries. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income in developing countries relative to 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 per hectare derived by farmers in developing countries compared to those in developed countries.

Seventy percent of the total income gain over the 18 years period derives from higher yields and second crop soybean gains with 30% from lower costs (mostly on insecticides and herbicides). In terms of the 2 main trait types, insect resistance and herbicide tolerance have accounted

Table 4. Other GM HT crops summary of average farm level economic impacts 1996–2013 ($/hectare)

Country	Cost of technology	Average farm income benefit (after deduction of cost of technology)	Type of benefit	References
GM HT canola				
US	12–33	52	Mostly yield gains of +1% to +12% (especially Invigor canola)	Sankala and Blumenthal (2003, 2006) Johnson and Strom (2008) And updated to reflect herbicide price and common product usage
Canada	18–32	53	Mostly yield gains of +3% to +12% (especially Invigor canola)	Canola Council (2001) Gusta (2009) and updated to reflect herbicide price changes and seed variety trial data (on yields)
Australia	13–41	56	Mostly yield gains of +12% to +22% (where replacing triazine tolerant canola) but no yield gain relative to other non GM (herbicide tolerant canola)	Monsanto Australia (2009), Fischer and Tozer (2009) and Hudson (2013)
GM HT sugar beet				
US and Canada	130–151	115	Mostly yield gains of +3% to +13%	Kniss (2008) Khan (2008) Jon-Joseph et al. (2010) Annual updates of herbicide price and usage data

Notes:

1. In Australia, one of the most popular type of production has been canola tolerant to the triazine group of herbicides (tolerance derived from non GM techniques). It is relative to this form of canola that the main farm income benefits of GM HT (to glyphosate) canola has occurred
2. InVigor' hybrid vigour canola (tolerant to the herbicide glufosinate) is higher yielding than conventional or other GM HT canola and derives this additional vigour from GM techniques
3. The range in values for cost of technology relates to annual changes in the average cost paid by farmers. It varies for reasons such as the price of the technology set by seed companies, exchange rates, average seed rates and values identified in different studies
4. For additional details of how impacts have been estimated, see examples in **Appendix 1**

for 74% and 26% respectively of the total income gain. The balance of the income gain arising from yield/production gains relative to cost savings is changing as second generation GM crops are increasingly adopted. Thus in 2013 the split of total income gain came 87% from yield/production gains and 13% from cost savings.

Crop production effects

Based on the yield impacts used in the direct farm income benefit calculations above and taking account of the second soybean crop facilitation in South America, GM crops have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (**Table 7**).

The GM IR traits, used in maize and cotton, have accounted for 95.3% of the additional maize production and 99.3% of the additional cotton production. Positive yield impacts from the use of this technology have occurred in all user countries, except for GM IR cotton in Australia where the levels of *Heliothis sp* (boll and bud worm pests) pest control previously obtained with intensive insecticide use were very good. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings and the associated environmental gains from reduced insecticide use, when compared to average

Table 5. Average (%) yield gains GM IR cotton and maize 1996–2013

	Maize insect resistance to corn boring pests	Maize insect resistance to rootworm pests	Cotton insect resistance	References
US	7.0	5.0	9.9	Carpenter and Gianessi (2002) Marra et al. (2002) Sankala and Blumenthal (2003, 2006) Hutchison et al. (2010) Rice (2004) Mullins and Hudson (2004)
China	N/a	N/a	10.0	Pray et al. (2002) Monsanto China (personal communications)
South Africa	11.4	N/a	24.0	Gouse et al. (2005), Gouse, Piesse, et al. (2006), Gouse, Pray, et al. (2006) Van der Weld (2010) Ismael et al. (2002) Kirsten et al. (2002) James (2003)
Honduras	23.7	N/a	N/a	Falck Zepeda et al. (2009, 2012)
Mexico	N/a	N/a	10.0	Traxler et al. (2001) Monsanto Mexico annual cotton monitoring reports
Argentina	6.2	N/a	30.0	Trigo (2002) Trigo and Cap (2006) Qaim and De Janvry (2002, 2005) Elena (2001)
Philippines	18.3	N/a	N/a	Gonsales (2005) Gonsales (2008) Yorobe (2004) Ramon (2005)
Spain	10.7	N/a	N/a	Brookes (2003 and 2008) Gomez-Barbero and Rodriguez-Corejo (2006) Riesgo et al. (2012)
Uruguay	5.5	N/a	N/a	As Argentina (no country-specific studies available and industry sources estimate similar impacts as in Argentina)
India	N/a	N/a	33.0	Bennett et al. (2004) IMRB (2006, 2007) Herring and Rao (2012)
Colombia	21.5	N/a	20.0	Mendez et al. (2011) Zambrano et al. (2009)
Canada	7.0	5.0	N/a	As US (no country-specific studies available and industry sources estimate similar impacts as in the US)
Burkina Faso	N/a	N/a	18.0	Vitale et al. (2008), Vitale (2010)
Brazil	13.4	N/a	-1	Galveo (2009, 2010, 2012, 2013) Monsanto Brazil (2008)
Pakistan	N/a	N/a	20.0	Nazli et al. (2010), Kouser and Qaim (2013; 2014)
Burma	N/a	N/a	31.0	USDA (2011)
Australia	N/a	N/a	Nil	Doyle (2005) James (2002) CSIRO (2005) Fitt (2001)
Paraguay	5.5	N/a	Not available	As Argentina (no country-specific studies available and industry sources estimate similar impacts as in Argentina)

Note: N/a = not applicable

Table 6. GM IR crops: average farm income benefit 1996–2013 ($/hectare)

Country	GM IR maize: cost of technology	GM IR maize (average farm income benefit (after deduction of cost of technology)	GM IR cotton: cost of technology	GM IR cotton (average farm income benefit (after deduction of cost of technology)
US	17–32 IRCB, 22–42 IR CRW	83 IRCB, 80 IR CRW	26–58	109
Canada	17–25 IRCB, 22–42 IR CRW	76 IRCB 98 IR CRW	N/a	N/a
Argentina	20–33	20	26–86	239
Philippines	30–47	96	N/a	N/a
South Africa	8–17	93	14–50	160
Spain	17–51	214	N/a	N/a
Uruguay	20–33	28	N/a	N/a
Honduras	100	65	N/a	N/a
Colombia	43–49	253	50–175	67
Brazil	47–69	102	31–52	-4
China	N/a	N/a	38–60	349
Australia	N/a	N/a	85–299	215
Mexico	N/a	N/a	48–75	184
India	N/a	N/a	14–54	242
Burkina Faso	N/a	N/a	51–54	104
Burma	N/a	N/a	17–20	94
Pakistan	N/a	N/a	4–15	127
Paraguay	20	15	N/a	N/a
Average across all user countries		81		226

Notes:

1. GM IR maize all are IRCB unless stated (IRCB = insect resistance to corn boring pests), IRCRW = insect resistance to corn rootworm
2. The range in values for cost of technology relates to annual changes in the average cost paid by farmers. It varies for reasons such as the price of the technology set by seed companies, the nature and effectiveness of the technology (eg, second generation 'Bollgard' cotton offered protection against a wider range of pests than the earlier first generation of 'Bollgard' technology), exchange rates, average seed rates and values identified in different studies.
3. Average across all countries is a weighted average based on areas planted in each user country
4. n/a = not applicable

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 18 y since 1996 has been +11.7% for maize and +17% for cotton.

As indicated earlier, the primary impact of GM HT technology has been to provide more cost effective (less expensive) and easier weed control, as opposed to improving yields, the improved weed control has, nevertheless, delivered higher yields in some countries. The main source of additional production from this technology has been via the facilitation of no tillage production systems, shortening the production cycle and how it has enabled many farmers in

Table 7. Additional crop production arising from positive yield effects of GM crops

	1996–2013 additional production (million tonnes)	2013 additional production (million tonnes)
Soybeans	138.20	15.91
Corn	273.48	44.21
Cotton	21.70	2.78
Canola	8.00	1.07
Sugar beet	0.76	0.15

Note: Sugar beet, US and Canada only (from 2008)

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 123.6 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2013 (accounting for 89.9% of the total GM HT-related additional soybean production). Intacta soybeans added a further 0.7 million tonnes in 2013.

CONCLUDING COMMENTS

During the last 18 years, the adoption of crop biotechnology (by 18 million farmers in 2013) has delivered important economic benefits. The GM IR traits have mostly delivered higher incomes through improved yields in all countries. Many farmers, especially in developed countries, have also benefited from lower costs of production (less expenditure on insecticides). The gains from GM HT traits have come from a combination of effects. The GM HT technology-driven farm income gains have mostly arisen from reduced costs of production, though in South America, it facilitated the move away from conventional to low/no-tillage production systems and enabled many farmers to plant a second crop of soybeans after wheat in the same season. More recently, second generation GM HT soybeans used in North America is offering higher yields, as the new 'stacked' traited HT and IR soybeans being used in South America.

In relation to HT crops, over reliance on the use of glyphosate and the lack of crop and herbicide rotation by some farmers, in some regions, has contributed to the development of weed resistance. In order to address this problem and maintain good levels of weed control, farmers have increasingly adopted a mix of reactive and proactive weed management strategies incorporating a mix of herbicides and other HT crops (in other words using other herbicides with glyphosate rather than solely relying on glyphosate or using HT crops which are tolerant to other herbicides, such as glufosinate). This has added cost to the GM HT production systems compared to several years ago, although relative to the conventional alternative, the GM HT technology continues to offer important economic benefits in 2013.

Overall, there is a considerable body of evidence, in peer reviewed literature, and summarised in this paper, that quantifies the positive economic impacts of crop biotechnology. The analysis in this paper therefore provides insights into the reasons why so many farmers around the world have adopted and continue to use the technology. Readers are encouraged to read the peer reviewed papers cited, and the many others who have published on this subject (and listed in the references below) and to draw their own conclusions.

METHODOLOGY

The report is based on extensive analysis of existing farm level impact data for GM crops, much of which can be found in peer reviewed literature. While 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. In addition, the authors have undertaken their own analysis of the impact of some trait-crop combinations in some countries (notably GM herbicide tolerant (HT) traits in North and South America) based on herbicide usage and cost data.

As indicated in earlier papers, the economic impact of this technology at the farm level varies widely, both between and within regions/countries. Therefore the measurement of impact is considered on a case by case basis in terms of crop and trait combinations and is based on the average performance and impact recorded in different crops by the studies reviewed. Where more than one piece 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) has been identified, the findings used in this analysis reflect the authors assessment of which research is most likely to be reasonably representative of impact in the country in that year. For example, there are many papers on the impact of GM insect resistant (IR) cotton in India. Few of these are reasonably representative of cotton growing across the country, with many papers based on small scale, local and unrepresentative samples of cotton farmers. Only the reasonably representative research has been drawn on for use in this paper – readers should consult the references to this paper to identify the sources used.

This approach may still both, overstate, or understate, the 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 data is not available, the authors have had to extrapolate available impact data from identified studies to years for which no data are available. In addition, if the only studies available took place several years ago, there is a risk that basing current assessments on comparisons from several years ago may not adequately reflect the nature of currently available alternative (non GM seed or crop protection) technology. The authors acknowledge that these factors represent potential methodological weaknesses. Therefore to reduce the possibilities of over/understating impact due to these factors, 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. 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 monitoring reports submitted to the Ministry of Agriculture in Mexico) and in the US (see Sankala & Blumenthal (2003 and 2006), Mullins & Hudson (2004)). 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;
- Uses current farm level crop prices and bases any yield impacts on (adjusted – see below) current average yields. In this way a degree of dynamic has been introduced into the analysis that would, otherwise, be missing if constant prices and average yields identified in year-specific studies had been used;
- As indicated above, it includes some changes and updates to the impact assumptions identified in the literature based on new papers, annual consultation with local sources (analysts, industry representatives, databases of crop protection usage and prices) and some 'own analysis' of changes in crop protection usage and prices;
- 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.

Detailed examples of how the methodology has been applied to the calculation of the 2013 y results are presented in **Appendix 1**. **Appendix 2** also provides details of the impacts and assumptions applied and their sources.

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

- Where stacked traits have been used, the individual trait components were analyzed separately to ensure estimates of all traits were calculated. This is possible because the non stacked seed has been (and in many cases continues to be) available and used by farmers and there are studies that have assessed trait-specific impacts;
- 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 (source: United States Department of Agriculture Economics Research Service);

- 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 labor. Inclusion of these costs is, 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, 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 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 GM crop adoption on global crop supply and world prices.

The paper also 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 and the facilitation of additional cropping within a season (notably in relation to soybeans in South America). Details of how these values were calculated (for 2013) are shown in **Appendix 1**.

DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST

No potential conflicts of interest were disclosed.

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APPENDIX 1: DETAILS OF METHODOLOGY AS APPLIED TO 2013 FARM INCOME CALCULATIONS

GM IR corn (targeting corn boring pests) 2013

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	26,964	+7	9.46	185	-29.1	-27.0	+95.2	+3,585,912	+19,120
Canada	1,243	+7	9.06	165	-20.4	-18.01	+86.61	+107,739	+788
Argentina	3,432	+5.5	6.36	145	-23.0	-23.0	+27.8	+95,269	+1,200
Philippines	715	+18	2.74	274	-47.1	-31.8	+103.2	+73,814	+353
South Africa	2,360	+10.6	4.87	252	-11.7	-1.66	+128.30	+304,741	+1,218
Spain	137	+12.6	10.4	219	-46.0	-38.0	+214.5	+29,382	+179
Uruguay	106.8	+5.5	5.39	217	-23.0	-23.0	+41.3	+4,412	+32
Honduras	20	+24	3.45	224	-100	-100.0	+185.4	+1,709	+16.6
Portugal	8.2	+12.5	7.43	224	-46	-46	+161.7	+1,321	+8
Czech Republic	2.6	+10	6.82	259	-46	-23.9	+153.9	+314	+2
Brazil	11,880	+14.6	4.61	283	-47.31	-35.3	+155.7	+1,849,477	+8,012
Colombia	65.9	+22	3.55	340	-47.5	+5.8	+271.1	+17,867	+51.4
Paraguay	550	+5.5	4.38	145	-19.92	-19.92	+15.01	+8,254	+132

Notes:

One. Impact on costs net of cost of technology = cost savings from reductions in pesticide costs, labor use, fuel use etc from which the additional cost (premium) of the technology has been deducted. For example (above) US cost savings from reduced expenditure on insecticides = +$15.88/ha, limited to an area equivalent to 10% of the total crop area (the area historically treated with insecticides for corn boring pests). This converted to an average insecticide cost saving equivalent per hectare of GM IR crop of =$2.09/ha. After deduction of the cost of technology which is shown as a negative 'in farm income terms' (-$29.1/ha) is deducted to leave a net impact on costs of -$27.04 (ie, a negative sign for impact on costs = an incease in costs so that the cost of the trait is greater than the savings on insecticide expenditure)

Two. There are no Canadian-specific studies available, hence application of US study findings to the Canadian context (US being the nearest country for which relevant data is available)

GM IR corn (targeting corn rootworm) 2013

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	18,942	+5	9.46	185	-29.13	-6.69	+80.60	+1,527,575	+8,960
Canada	885	+5	9.06	165	-29	+0.35	+75.12	+66,485	+401

Notes:

One. There are no Canadian-specific studies available, hence application of US study findings to the Canadian context (US being the nearest country for which relevant data is available)

GM IR cotton 2013

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	2,296	+10	0.86	1,728	-49.92	-17.61	+131.02	+300,814	+197
China	4,200	+10	1.31	2,657	-59.19	+27.96	+376.03	+1,579,316	+550
South Africa	8	+24	0.31	1,285	-35.75	-22.58	+73.02	+555	+1
Australia	399	Zero	2.05	2,239	-290	+244.3	+244.3	+97,425	Zero
Mexico	100	+8.95	1.57	1,831	-74.58	-57.75	+199.52	+19,926	+14
Argentina	484	+30	0.38	2,443	-21.25	-32.36	+310.81	+150,431	+55
India	11,000	+24	0.46	1,572	-13.66	+18.03	+191.57	+2,107,291	+1,214
Colombia	25	+10	0.72	2,087	-168.43	-82.83	+67.47	+1,695	+2
Brazil	440	-1.84	1.52	1,995	-30.89	-6.63	-49.15	-21,669	-12
Burkina Faso	386	+18.15	0.42	1,285	-53.48	-0.9	+97.06	+37,502	+29
Pakistan	2,800	+22	1.06	537	-3.99	+6.03	+131.33	+367,718	+653
Burma	255	+30	0.74	537	-20	-9.98	+109.30	+27,871	+57

Note price is for lint, except in Burma and Pakistan which is for seed

GM HT soybeans 2013 (excluding second crop soybeans – see separate table)

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US 1st generation	11,153	Nil	2.96	473	-49.42	+12.55	+12,55	+139,965	Nil
US 2nd generation	17,402	+11	2.78	473	-62.05	-0.08	+144.53	+2,515,107	+5,321
Canada 1st generation	378	Nil	2.86	534	-25.55	+19.50	+19.50	+7,372	Nil
Canada 2nd generation	1,044	+11	2.69	534	-43.54	+1.51	+159.51	+166,533	+309
Argentina	19,589	Nil	2.54	306	-2.5	+24.27	+24.27	+475,333	Nil
Brazil	23,441	Nil	2.84	462	-12.06	+30.14	+30.14	+766,146	Nil
Paraguay	2,898	Nil	2.61	408	-4.4	+11.23	+11.23	+32,554	Nil
South Africa	463	Nil	1.88	345	-1.55	+8.77	+8.77	+4,027	Nil
Uruguay	1,393	Nil	2.41	302	-2.5	+16.83	+16.83	+23,104	Nil
Mexico	12	+9.87	1.59	467	-40.91	-14.33	+87.84	+1,504	+1.9
Bolivia	1,001	+15	1.67	487	-3.32	+5.96	+102.75	+102,852	+251

Notes:

One. Price discount for GM soybeans relative to non GM soybeans in Bolivia of 2.7% - price for non GM soybeans was $474/tonne - price shown above is discounted

GM HT corn 2013

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	30,157	Nil	9.97	185	-30.02	+33.12	+33.12	+998,909	Nil
Canada	1,428	Nil	9.59	165	-35.59	+20.03	+20.03	+28,600	Nil
Argentina: as single trait	312	+3% con belt, +22% marginal areas	7.15 corn belt, 4.36 marginal areas	145	-13.2	+1.26	+31.1 corn belt, +139.08 marginal areas	+30,311	+206
Argentina: as stacked trait	2,457	+10.25	6.36	145	-28	-13.58	+80.95	+198,890	+1,602
South Africa	1,690	Nil	5.32	252	-12.43	+11.57	+11.57	+19,555	Nil
Philippines	794	+5	2.74	274	-47.12	-14.44	+23.07	+18,321	+109
Colombia	7	Zero	3.66	340	-23.19	+16.43	+16.43	+181	Nil
Brazil	6.291	+6.84	4.61	283	-28.88	-15.57	+73.77	+464,093	+1,985
Uruguay	97	Nil	5.63	217	-13.19	+1.3	+1.3	+122	Nil
Paraguay	550	Nil	4.5	145	-17.08	+0.8	+0.8	+438	Nil

Notes:

One. Where no positive yield effect due to this technology is applied, the base yields shown are the indicative average yields for the crops and differ (are higher) than those used for the GM IR base yield analysis, which have been adjusted downwards to reflect the impact of the yield enhancing technology (see below)

Two. Argentina: single trait. In the Corn Belt it is assumed that 70% of trait plantings occur in this region and marginal regions account for the balance. In relation to stacked traits, the yield impact (+10.25%) is in addition to the yield 5.5% impact presented for the GM IR trait (above). In other words the total estimated yield impact of stacked traits is +15.75%. The cost of the technology also relates specifically to the HT part of the technology (sold within the stack)

GM HT cotton 2013

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	2,510	Nil	0.921	1,728	-74.13	+20.60	+20.60	+51,708	Nil
S Africa	8	Nil	0.38	1,285	-18.9	+37.5	+37.5	+285	Nil
Australia	417	Nil	2.05	2,239	-72.39	+20.84	+20.84	+20,870	Nil
Argentina	550	Farm saved seed area nil Certified seed area +9.3%	0.474	2,443	- 13.82 certified seed,- 10 farm saved seed	+3.84 certified seed, + 7.66 farm saved seed	+ 111.51 certified seed, +7.66 farm saved seed	+21,349	+7
Mexico	102	+14.2	1.57	1,831	-79.2	+74.88	+333.43	+34,010	+23
Colombia	27	+4.0	0.72	2,087	-179.9	-28.25	+88.37	+2,378	+1
Brazil	361	-1.84	1.52	1,995	-20.11	+62.76	+6.98	+2,519	-10

Notes:

One. Where no positive yield effect due to this technology is applied, the base yields shown are the indicative average yields for the crops and differ (are higher) than those used for the GM IR base yield analysis, which have been adjusted downwards to reflect the impact of the yield enhancing technology (see below)

Two. Argentina: 30% of area assumed to use certified seed with 70% farm saved seed

GM HT canola 2013

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US glyphosate tolerant	213	+3.1	1.85	481	-17.3	+2.2	+29.8	+6,343	+13
US glufosinate tolerant	194	+10.15	1.85	481	-17.3	+15.3	+75.05	+14,560	+30
Canada glyphosate tolerant	3,891	+3.1	2.11	495	-35.92	-2.95	+29.63	+115,294	+254
Canada glufosinate tolerant	3,555	+10.2	2.11	495	Nil	+15.13	+121.17	+430,715	+762
Australia glyphosate tolerant	222	+11	1.56	440	-12.55	-0.85	+60.66	+13,489	+38

Note: Baseline (conventional) comparison in Canada with herbicide tolerant (non GM) 'Clearfield' varieties

GM virus resistant crops 2013

Country	Area of trait (ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US Papaya	395	+17	22.86	749.7	-494	-494	+2,420	+955	+1.5
US squash	2,000	+100	19.21	746	-736	-736	+13,595	+27,191	+38

GM herbicide tolerant sugar beet 2013

Country	Area of trait (000' ha)	Yield assumption % change	Base yield sucrose (tonnes/ha)	Farm level price equivalent (sucrose: $/ tonne)	Cost of tech ($/ha)	Impact on costs, net of cost of tech ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	458	+3.12	10.29	345.42	-148	+1.81	+112.63	+51,548	+149
Canada	15	+3.12	7.78	545.42	-148	+1.81	+85.60	+1,284	+4

Second soybean crop benefits: Argentina

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 2 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 and has remained at over 90% since then.

Farm level income impact of using GM HT soybeans in Argentina 1996–2013 (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	207.24	736.0
2010	4.40	257.70	1,133.8
2011	4.60	257.40	1,184.0
2012	2.90	291.00	844.6
2013	3.46	289.80	1,001.6

Source and notes:

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

Two. 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)

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 (2013)

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	0.921	3,061	2,819	765	873	+10%	0.86	2,172	889
China	1.422	4,900	6,968	4,200	987	+10%	1.31	6,052	916

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	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
GM IR corn: resistant to corn boring pests					
US & Canada	+7% all years	Broad average of impact identified from several studies/papers and latest review/analysis covering 1996–2010 period	Carpenter & Gianessi (2002) found yield impacts of +9.4% 1997, +3% 1998, +2.5% 1999 Marra et al. (2002) average impact of +5.04% 1997–2000 based a review of 5 studies, James (2003) average impact of +5.2% 1996–2002, Sankala & Blumenthal (2003 and 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 (annual personal communications)	As identified in studies to 2008 and onwards based on weighted seed premia according to sale of seed sold as single and stacked traited seed	As identified in studies to 2005 and in subsequent year adjusted to reflect broad cost of 'foregone' insecticide use
Argentina	+9% all years to 2004, +5.5% 2005 onwards	Average of reported impacts in first 7 years, later revised downwards for more recent years to reflect professional opinion	James (2003) cites 2 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 and 2008) personal communication estimates average yield impact since 2005 to be lower at between +5% and +6%	Cost of technology drawn from Trigo (2002) and Trigo & Cap (2006), ie, costed/ priced at same level as US From 2007 based on Trigo and industry personal communications	None as maize crops not traditionally treated with insecticides for corn boring pest damage
Philippines	+24.6% to 2006, 2007–11 +18%	Average of 3 studies used all years to 2006. Thereafter based on Gonzales et al. (2009)	Gonsales (2005) found average yield impact of +23% dry season crops and +20% wet season crops; Yorobe (2004) +38% dry season crops and +35% wet season crops; Ramon (2005) found +15.3% dry season crops and +13.3% wet season crops. Gonsales (2009) +18%	Based on Gonsales (2005) & Gonsales (2009) – the only sources to break down these costs. Seed premia from 2012 based on based on weighted cost of seed sold as single and stacked traits	Based on Gonsales (2005) & Gonsales (2009)

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
South Africa	+11% 2000 and 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, Piesse et al. (2006), Gouse, Pray et al. (2006) reported yield impacts as shown (range of +11% to +32%), Van der Wald (2010)	Based on the same papers as used for yield, plus confirmation in 2006–2011 that these are representative values from industry sources	Sources as for cost of technology
Spain	+6.3% 1998–2004 +10% 2005–2008. 2009 onwards +12.6%	Impact based on authors own detailed, representative analysis for period 1998–2002 then updated to reflect improved technology based on industry analysis. From 2009 based on Riesgo et al. (2012)	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-Cereozo (2006) reported an average impact of +5% for Bt 176 used in 2002–2004. Riesgo et al. (2012) +12.6% identified as average yield gain	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 representative. From 2009, based on Riesgo et al. (2012)	Sources as for cost of technology
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 and +4.8% 2009 and 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 2 y period, for Czech Republic 3 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	Data derived from the same source(s) referred to for yield	Data derived from the same source(s) referred to for yield

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
			+26%; Romania based on reported impact by industry sources		
Uruguay	As Argentina	As Argentina	No country-specific studies identified, so impact analysis from nearest country of relevance (Argentina) applied	As Argentina	As Argentina
Paraguay	As Argentina	As Argentina	No country-specific studies identified, so impact analysis from nearest country of relevance (Argentina) applied	As Argentina	As Argentina
Brazil	+4.66% 2008, +7.3% 2009 and 2010, +20.1% 2011, +14.6% 2012	Farmer surveys	Galveo (2009, 2010, 2012, 2013)	Data derived from the same references as cited for yield impacts. Seed premium based on weighted average of seed sales	Data derived from the same references as cited for yield impacts
Honduras	+13% 2003–2006 +24% 2007-2011	Trials results 2002 and farmer survey findings in 2007–2008	James (2003) cited trials results for 2002 with a 13% yield increase Falck Zepeda et al. (2009 and 2012) +24%	A proxy seed premium of $30/ha used during trials (to 2005) based on seed premia in S Africa and the Philippines. From 2006 when commercialised based on industry sources	Nil – no insecticide assumed to be used on conventional crops
Colombia	+22%	Mendez et al. (2011)	Mendez et al. (2011) farm survey from 2009	Mendez et al. (2011)	Mendez et al. (2011)
GM IR corn (resistant to corn rootworm)	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
US & Canada	+5% all years	Based on the impact used by the references cited	Sankala & Blumenthal (2003 and 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 & Strom (2008) used the same basis as Sankala & 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 and 2010)	Data derived from Sankala & Blumenthal (2006) and Johnson & Strom (2008). Seed costs 2008 onwards based on weighted seed sales of single and stacked traits Canada - no studies identified – as US - impacts qualitatively confirmed by industry sources	As identified in studies to 2005 and in subsequent year adjusted to reflect broad cost of 'foregone' insecticide use

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
IR cotton	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
US	+9% 1996–2002 +11% 2003 and 2004 +10% 2005 onwards	Based on the (conservative) impact used by the references cited	Sankala & Blumenthal (2003 and (2006) 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 2 values was used for the period to 2002. The higher values applied from 2003 reflect values used by Sankala & Blumenthal (2006) 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	Data derived from the same sources referred to for yield and updated from 2008 based on industry sources (for the estimated share of the insect resistance trait in the total seed premia for stacked traited seed	As identified in yield study references and in subsequent years adjusted to reflect broad cost of 'foregone' insecticide use
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 (2007–2014)	Data derived from the same sources referred to for yield	Data derived from the same sources referred to for yield

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
Australia	None	Studies have usually identified no significant average yield gain	Fitt (2001) Doyle (2005) James (2002) CSIRO (2005)	Data derived from the same sources referred to for yield covering earlier years of adoption, then CSIRO for later years. For 2006–2009 cost of technology values confirmed by personal communication from Monsanto Australia	Data derived from the same sources referred to for yield covering earlier years of adoption, then CSIRO for later years
Argentina	+30% all years	More conservative of the 2 pieces of research used	Qaim & De Janvry (2002 and 2005) analysis based on farm level analysis in 1999/00 and 2000/01 +35% yield gain, Trigo & Cap (2006) used an average gain of +30% based on work by Elena (2001)	Data derived from the same sources referred to for yield. Cost of technology all years based on industry sources	Data derived from the same sources referred to for yield and cost of technology.
South Africa	+24% all years	Lower end of estimates applied	Ismael et al. (2001) identified yield gain of +24% for the years 1998/99 and 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	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	Data derived from the same sources referred to for yield.
Mexico	+37% 1996 +3% 1997 +20% 1998 +27% 1999 +17% 2000 +9% 2001 +6.7% 2002 +6.4% 2003 +7.6% 2004 +9.25% 2005 +9% 2006 +9.28 2007 and 2008, +14.2% 2009, +10.34% 2010 and 2011, +7.2% 2012, +8.95% 2013	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 annual crop monitoring reports submitted to the Mexican Ministry of Agriculture by Monsanto Mexico	Data derived from the same sources referred to for yield. 2009 onwards seed cost based on weighted average of single and stacked traited seed sales	Data derived from the same sources referred to for yield.
India	+45% 2002 +63% 2003 +54% 2004 +64% 2005 +50% 2006 and 2007 +40% 2008, +35% 2009 and 2010, +30% 2011, +24% 2012	Recorded yield impact used for years where available	Yield impact data 2002 and 2003 is drawn from Bennett et al. (2004), for 2004 the average of 2002 and 2003 was used. 2005 and 2006 are derived from IMRB (2006 and 2007). 2007 impact databased on lower end of range of impacts identified in previous 3 y (2007 being a	Data derived from the same sources referred to for yield. 2007 onwards cost of technology based on industry sources	Data derived from the same sources referred to for yield. 2007 onwards cost savings based on industry estimates and AMIS Global

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
			year of similar pest pressure to 2006). 2008 onwards based on assessments of general levels of pest pressure Industry sources), Herring and Rao (2012) and Kathage, Jonas and Qaim (2012)		pesticide usage data (2011)
Brazil	+6.23% 2006 -3.6% 2007 -2.7% 2008, -3.8% 2009, 2010 nil 2011 +3.04%, 2012 and 2013 -1.8%	Recorded yield impacts for each year – 2013 not available so 2012 value assumed	2006 unpublished farm survey data – source: Monsanto (2008) 2007- 2010 farm survey data from Galveo (2009, 2010, 2012, 2013))	Data derived from the same sources referred to for yield	Data derived from the same sources referred to for yield
Colombia	+30% all years except 2009 +15%, 2010 +10%	Farm survey 2007 comparing performance of GM IR vs. conventional growers. 2009 onwards based on trade estimates	Based on Zambrano P et al. (2009) and trade estimates (2009 , 2011, 2013)	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	Data derived from Zambrano et al. (2009). Cost savings excluding seed premium derived from Zambrano as total cost savings less assumed seed premium. 2010 onwards seed premium and cost savings from industry sources
Burkina Faso	+20 2008, +18.9% 2009 onwards	Trials 2008, farm survey 2009	Vitale et al. (2008) & Vitale (2010)	Based on Vitale et al. (2008) and Vitale (2010)	Based on Vitale et al. (2008) and Vitale (2010)
Pakistan	+12.6% 2009, 2010 onwards +22%	Farm surveys	Nazli et al. (2010), Kouser and Qaim (2013)	Based on data from same sources as yield impacts	Based on data from same sources as yield impacts
Burma	+30%	Extension service estimates	USDA (2011)	No data available so based on India and Pakistan	No data available so based on Pakistan
GM HT soybeans	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
US: 1st generation	Nil	Not relevant	Not relevant	Marra et al. (2002) Carpenter & Gianessi (2002) Sankala & Blumenthal (2000 and 2006) Johnson & Strom (2008) and updated post 2008 from industry estimates of seed premia	Marra et al. (2002) Carpenter & Gianessi (2002) Sankala & Blumenthal (2000 and 2006) Johnson & Strom (2008) and updated post 2008 to reflect herbicide price and common product usage

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
Canada: 1st generation	Nil	Not relevant	Not relevant	George Morris Centre (2004) and updated from 2008 based on industry estimates of seed premia	George Morris Centre (2004) and updated for 2008 to reflect herbicide price changes
US & Canada: 2nd generation	+5% 2009 and 2010, +10.4% 2011, +11.2% 2012, +11% 2013	Farm level monitoring and farmer feedback	Monsanto farmer surveys (annual)	Industry estimates of seed premia relative to 1st generation GM HT seed	as 1st generation
Argentina	Nil but second crop benefits	Not relevant except 2nd crop – see separate table	Not relevant	Qaim & Traxler (2005), Trigo & CAP (2006) and 2006 onwards (Monsanto royalty rate)	Qaim & Traxler (2005), Trigo & CAP (2006) and updated from 2008 to reflect herbicide price changes
Brazil	Nil	Not relevant	Not relevant	As Argentina to 2002 (illegal plantings). Then based on Parana Department of Agriculture (2004). Also agreed royalty rates from 2004 applied to all years to 2006. 2007 onwards based on Galveo (2009, 2010, 2012 and 2013)	Sources as in cost of technology
Paraguay	Nil but second crop benefits	Not relevant except 2nd crop	Not relevant	As Argentina: no country-specific analysis identified. Impacts confirmed from industry sources (annual personal communications 2006–2012). Seed cost based on royalty rate since 2007	As Argentina – herbicide cost differences adjusted post 2008 based on industry sources and AMIS Global herbicide usage data 2011, 2013
South Africa	Nil	Not relevant	Not relevant	No studies identified. Seed premia based on industry sources (annually updated)	No studies identified. Based on industry estimates (annually updated) and AMIS Global herbicide usage data 2011, 2013

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
Uruguay	Nil	Not relevant	Not relevant	As Argentina: no country-specific analysis identified. Seed premia based on industry sources	As Argentina: no country-specific analysis identified. Impacts based on industry sources and AMIS Global herbicide usage data 2011, 2013
Mexico	+9.1% 2004 and2005 +3.64% 2006 +3.2% 2007 +2.4% 2008 +13% 2009, +4% 2010–2–12, +9.9% 2013	Recorded yield impact from studies	From Monsanto annual monitoring reports submitted to Ministry of Agriculture	No published studies identified based on Monsanto annual monitoring reports	No published studies identified based on Monsanto annual monitoring reports
Romania	+31% , 15% 2006	Based on only available study covering 1999–2003 (note not grown in 2007) plus 2006 farm survey	For previous year – based on Brookes (2005) – the only published source identified. Also, Monsanto Romania (2007)	Brookes (2005) Monsanto Romania (2007)	Brookes (2005) Monsanto Romania (2007)
Bolivia	+15%	Based on survey in 2007–08	Fernandez et al. (2009) farm survey	Fernandez et al. (2009)	Fernandez et al. (2009)
GM HT & IR soybeans					
Brazil	+10%	Farm trials	Monsanto farm trials on commercial crop monitoring (survey)	As yield source	As yield source
Argentina	+9.1%	Farm trials	Monsanto farm trials on commercial crop monitoring (survey)	As yield source	As yield source
Paraguay	+12.8%	Farm trials	Monsanto farm trials on commercial crop monitoring (survey)	As yield source	As yield source
Uruguay	+8.8%	Farm trials	Monsanto farm trials on commercial crop monitoring (survey)	As yield source	As yield source
GM HT corn	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
US	Nil	Not relevant	Not relevant	Carpenter & Gianessi (2002) Sankala & Blumenthal (2003 and 2006) Johnson & Strom (2008). 2008 and 2009 onwards based on weighted seed sales (sold as single and stacked traits)	Carpenter & Gianessi (2002) Sankala & Blumenthal (2003 and 2006) Johnson & Strom (2008). 2009 onwards updated to reflect changes in common herbicide treatments and prices

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
Canada	Nil	Not relevant	Not relevant	No studies identified – based on annual personal communications with industry sources	No studies identified – based on industry and extension service estimates of herbicide regimes and updated since 2008 on the basis of changes in herbicide price changes
Argentina: sold as single trait	+3% corn belt +22% marginal areas	Based on only available analysis - Corn Belt = 70% of plantings, marginal areas 30% - industry analysis (note no significant plantings until 2006)	No studies identified – based on personal communications with industry sources in 2007 and 2008 Monsanto Argentina & Grupo CEO (personal communications 2007, 2008 and 2011)	Industry estimates of seed premia and weighted by seed sales according to whether containing single or stacked traits	No studies identified - based on Monsanto Argentina & Grupo CEO (personal communications 2007 and 2008). 2008 and 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	As single trait	As single trait
South Africa	Nil	Not relevant	Not relevant	Industry sources – annual checked	No studies identified - based on Monsanto S Africa (personal communications 2005, 2007 and 2008). 2008 onwards updated to reflect herbicide price changes
Philippines	+15% 2006 and 2007, +5% 2008 and 2009	Farm survey	Based on unpublished industry analysis for 2006 and 2007, thereafter Gonsales (2009)	Monsanto Philippines (personal communications 2007 and 2008). Gonsales (2009). 2010 updated to reflect changes in seed costs	Monsanto Philippines (personal communications 2007 and 2008). Gonsales (2009). 2010 onwards updated annually to reflect changes in herbicide costs

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
Brazil	+2.5% 2010 +3.6% 2011. +6.84% 2012 and 2013	Farm survey	Galveo (2010, 2012 and 2013). No data yet available for 2013 so 2012 impacts assumed	Data derived from the same sources referred to for yield	Data derived from the same sources referred to for yield plus AMIS Global herbicide use data
Colombia	Zero	Mendez et al. (2011)	Mendez et al. (2011) farm survey from 2009	Mendez et al. (2011)	Mendez et al. (2011)
Uruguay	Zero	Not relevant	Not relevant	No studies available – based on Argentina	No studies available – based on Argentina plus annual AMIS Global herbicide use data
Paraguay	Zero	Not relevant	Not relevant	No studies available – based on Argentina	No studies available – based on Argentina plus annual AMIS Global herbicide use data
GM HT Cotton	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
US	Nil	Not relevant	Not relevant	Carpenter & Gianessi) Sankala & Blumenthal (2003 and 2006) Johnson & Strom (2008) and updated from 2008 based on weighted seed sales (by single and stacked traited seed)	Carpenter & Gianessi) Sankala & Blumenthal (2003 and 2006) Johnson S & Strom S (2008) and updated from 2008 to reflect changes in weed control practices and prices of herbicides
Australia	Nil	Not relevant	Not relevant	Doyle et al. (2003) Monsanto Australia (personal communications 2005, 2007, 2009, 2010 and 2012)	Doyle et al. (2003) Monsanto Australia (personal communications 2005, 2007, 2009, 2010 and 2012)

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
South Africa	Nil	Not relevant	Not relevant	No studies identified - based on Monsanto S Africa (personal communications 2005, 2007, 2008, 2010 and 2012)	No studies identified - based on Monsanto S Africa (personal communications 2005, 2007, 2008, 2010 and 2012)
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, 2012)	No published studies identified – based on personal communications with Grupo CEO and Monsanto Argentina (2007, 2008 and 2010 and 2012)	No published studies identified – based on personal communications with Grupo CEO and Monsanto Argentina (2007, 2008 and 2010, 2012, 2013)
Mexico	+3.6% all years to 2007 0% 2008, +5.11% 2009, +18.1% 2010, +5.1% 2011, +13.1% 2012, +14.2% 2013	Based on annual monitoring reports to Ministry of Agriculture by Monsanto Mexico	Same as source for cost data	No published studies identified - based on personal communications with Monsanto Mexico and their annual reporting	No published studies identified - based on annual personal communications with Monsanto Mexico and their annual reporting
Colombia	+4%	Based on only available data – company monitoring of commercial plots	As cost data	No published studies identified – based on personal communications with Monsanto Colombia (2010, 2012, 2013)	No published studies identified – based on personal communications with Monsanto Colombia (2010, 2012, 2013)
Brazil	+2.35% 2010 +3.1% 2011, -1.8% 2012 and 2013	Farm survey	Galveo (2010, 2012 and 2013). No data yet available so 2012 yield impact assumed for 2013	Data derived from the same sources referred to for yield	Data derived from the same sources referred to for yield
GM HT canola	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
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	Sankala & Blumenthal (2003 and 2006)) Johnson & Strom (2008). These are the only studies identified that examine GM HT canola in the US. Updated	Sankala & Blumenthal (2003 and 2006)) Johnson & Strom (2008). These are the only studies identified that examine

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
				based on industry and extension service estimates	GM HT canola in the US. Updated since 2008 based on changes in herbicide prices
Canada	+10.7% all years to 2004. Post 2004; for GM glyphosate tolerant varieties no yield difference 2004, 2005, 2008, 2010 +4% 2006 and 2007, +1.67% 2009, +1.6% 2011, +1.5% 2012, +3.1% 2013. For GM glufosinate tolerant varieties: +12% 2004, +19% 2005, +10% 2006 and 2007 +12% 2008 +11.8% 2009, +10.9% 2010, +4.6% 2011, +4.8% 2012, +10.1% 2013	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	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 et al. (2009)	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 et al. (2009) which includes spillover benefits of $ Can13.49 to follow on crops – applied from 2006. Also adjusted annually to reflect changes in typical herbicides used on different crops (GM HT, conventional, clearfields)
Australia	+21.08% 2008, +20.9% 2009, +15.8% 2010, +7.6% 2011 and 2012	Survey based with average yield gain based on weighting yield gains for different types of seed by seed sales or number of farmers using different seed types	Based on survey of license holders by Monsanto Australia, Fischer and Tozer (2009) and Hudson (2013)	Sources as for yield changes	Sources as for yield changes

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Country	Yield impact assumption used	Rationale	Yield references	Cost of technology data/ assumptions	Cost savings (excluding impact of seed premium) assumptions
US & Canada	+12.58% 2007 +2.8% 2008 +3.3% 2009 onwards	Farm survey and extension service analysis	Kniss (2008) Khan (2008)	Kniss (2008) Khan (2008),	Kniss (2008) Khan (2008), Jon-Joseph et al. (2010) and updated annually to reflect changes in herbicide usage and prices
GM VR crops US					
Papaya	between +15% and +77% 1999–2012 – relative to base yield of 22.86 t/ha	Based on average yield in 3 y before first use	Draws on only published source disaggregating to this aspect of impact	Sankala & Blumenthal (2003 and 2006), Johnson & Strom (2008)	Nil – no effective conventional method of protection
Squash	+100% on area planted	assumes virus otherwise destroys crop on planted area	Draws on only published source disaggregating to this aspect of impact	Sankala & Blumenthal (2003 and 2006), Johnson & Strom (2008)	Sankala & Blumenthal (2003 and 2006), Johnson & Strom (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). 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.