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Farm income and production impacts of using GM crop technology 1996–2015

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ABSTRACT. This paper provides an 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 impacts on yields, key variable costs of production, direct farm (gross) income and impacts on the production base of the 4 main crops of soybeans, corn, cotton and canola. The commercialisation of GM crops has occurred at a rapid rate since the mid 1990s, with important changes in both the overall level of adoption and impact occurring in 2015. This annual updated analysis shows that there continues to be very significant net economic benefits at the farm level amounting to $15.4 billion in 2015 and $167.8 billion for the 20 year period 1996–2015 (in nominal terms). These gains have been divided 49% to farmers in developed countries and 51% to farmers in developing countries. About 72% of the gains have derived from yield and production gains with the remaining 28% coming from cost savings. The technology has also made important contributions to increasing global production levels of the 4 main crops, having, for example, added 180 million tonnes and 358 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

INTRODUCTION

2015 represents the twentieth year of widespread cultivation of crops containing genetically modified (GM) traits, with the global planted area of GM-traited crops at about 172 million hectares.

During this 20-year period, there have been many papers assessing the farm level 'economic' and farm income impacts associated with the adoption of this technology. 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 farm level

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'economic' impacts associated with the global adoption of crops containing GM traits. It is also hoped the analysis continues to contribute to greater understanding of the impact of this technology and to facilitate more informed decision-making, especially in countries where crop biotechnology is currently not permitted.

This study updates the findings of earlier analysis into the global impact of GM crops since their commercial introduction in 1996 by integrating data and analysis for 2015. Previous 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), GM Crops 5:1, 65–75 (Brookes and Barfoot, 2014), GM Crops 6: 13–46 (Brookes and Barfoot, 2015) and GM Crops 7:38–77 (Brookes and Barfoot, 2016). 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).

To save readers of this paper the chore of consulting the past papers for details of the methodology and arguments, these are included in full in this updated paper.

The analysis concentrates on gross farm income effects because these are 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 assessment of wider economic impacts would probably merit a separate assessment in its own right.

RESULTS AND DISCUSSION

HT Crops

The main 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 amounts 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 be noted:

- The mix and amounts of herbicides used on GM HT crops and conventional crops are affected by price and availability of herbicides. Herbicides used include both 'older' products that are no longer protected by patents and newer 'patent-protected' chemistry, with availability affected by commercial decisions of suppliers to market or withdraw products from markets and regulation (eg, changes to approval processes). Prices also vary by year and country. For example, in 2008–2009, the average cost associated with the use of GM HT technology globally increased significantly relative to earlier years because of the increase in the global price of glyphosate relative to changes in the price of other herbicides commonly used on conventional crops. This abated in 2010 with a decline in the price of glyphosate back 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 36 weed species that are currently (accessed February 2017) resistant to glyphosate, compared with 159 weed species resistant to ALS herbicides (eg, chlorimuron ethyl commonly used in conventional soybean crops) and 74 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 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 for most users. It should also be noted that many of the herbicides used in conventional production systems had significant resistance issues themselves in the mid 1990s. This was 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 gross 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

TABLE 1. GM HT soybeans: Summary of average gross farm level income impacts 1996–2015 ($/hectare).

Country	Cost of technology	Average gross farm income benefit (after deduction of cost of technology)	Aggregate income benefit (million $)	Type of benefit	References
1st generation GM HT soybeans					
Romania (to 2006 only)	50–60	104	44.6	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 200	17,367.8	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	7–25	32	6,700.7	Cost savings	Parana Department of Agriculture (2004) Galveo (2010, 2012, 2013[16], 2015 and updated to reflect herbicide usage and price changes
US	15–53	32	13,137.5	Cost savings	Marra et al. (2002) Carpenter and Gianessi (2002) Sankala and Blumenthal (2003, 2005) Johnson and Strom (2008) And updated to reflect herbicide price and common product usage
Canada	20–40	21	188.6	Cost savings	George Morris Centre (2004) and updated to reflect herbicide price and common product usage
Paraguay	4–10	16 plus second crop benefits of 272	1,125.5	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	161.4	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	6	22.2	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)

(*Continued on next page*)

TABLE 1. GM HT soybeans: Summary of average gross farm level income impacts 1996–2015 ($/hectare). *(Continued)*

Country	Cost of technology	Average gross farm income benefit (after deduction of cost of technology)	Aggregate income benefit (million $)	Type of benefit	References
Mexico	20–45	41	6.1	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	722.0	Cost savings plus yield gain of +15%	Fernandez et al. (2009)
2nd generation GM HT soybeans					
US and Canada	50–65	122 (US)	9,996.7 (US)	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
		117 (Can)	567.0 (Can)		
Intacta soybeans					
Brazil	33–56	113	2,264.9	Herbicide cost saving as 1st generation plus insecticide saving $19/ha and yield gain +9% to +10%	Monsanto Brazil pre commercial trials and post marketing farm survey monitoring, MB Agro (2013)
Argentina	33–56	58	80.9	Herbicide cost saving as 1st generation plus insecticide saving $21/ha and yield gain +7% to +9%	Monsanto Argentina pre commercial trials and post market monitoring survey
Paraguay	33–56	102	35.3	Herbicide cost saving as 1st generation plus insecticide saving $33/ha and yield gain +9% to +13%	Monsanto Paraguay pre commercial trials and post market monitoring survey
Uruguay	33–56	48	24.2	Herbicide cost saving as 1st generation plus insecticide saving $19/ha and yield gain +7% to +9%	Monsanto Uruguay pre commercial trials and post market monitoring survey

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

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 gross farm income benefits (Table 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 2015, GM HT technology in soybeans (excluding second generation 'Intacta' soybeans: see below) has boosted gross farm incomes by $3.82 billion, and since 1996 has delivered $50 billion of extra farm income. Of the total cumulative farm income gains from using GM HT soybeans, $23.6 billion (47%) has been due to yield gains/second crop benefits and the balance, 53%, 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 grown commercially in 2013, in South America. In the first 3 years, the technology was used on approximately 22.3 million hectares and contributed an additional $2.4 billion to gross 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 2015, the total global farm income gain from using this technology was $1.8 billion with the cumulative gain over the period 1996–2015 being $11.1 billion. Within this, $3.44 billion (31%) 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 gross farm income gain of about $116.7 million in 2015. In the 1996–2015 period, the total gross farm income benefit was $1.77 billion. As with other GM HT traits, these farm income gains have mainly arisen from cost savings (73% of the total gains), although there have been some yield gains in Argentina, 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 gross 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 2015, the total global income gain from the adoption of GM HT technology in canola and sugar beet was $709 million and cumulatively since 1996, it was $5.89 billion.

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 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

TABLE 2. GM HT maize: Summary of average gross farm income impacts 1996–2015 ($/hectare).

Country	Cost of technology	Average gross farm income benefit (after deduction of cost of technology)	Aggregate income benefit (million $)	Type of benefit	References
US	15–30	27	7,237.9	Cost savings	Carpenter and Gianessi (2002) Sankala and Blumenthal (2003, 2005) Johnson and Strom (2008) Also updated annually to reflect herbicide price and common product usage
Canada	17–35	14	161.6	Cost savings	Monsanto Canada (personal communications) and updated annually since 2008 to reflect changes in herbicide prices and usage
Argentina	16–33	94	1,696.2	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	9–18	5	65.6	Cost savings	Personal communication from Monsanto South Africa and updated since 2008 to reflect changes in herbicide prices and usage
Brazil	10–32	49	1,777.0	Cost savings plus yield gains of +1% to +7%	Galveo (2009, 2010, 2011, 2012, 2013, 2015)
Colombia	14–24	15	4.5	Cost savings	Mendez et al. (2011)
Philippines	24–47	32	156.6	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
Paraguay	13–17	2	2.5	Cost saving	Personal communication from Monsanto Paraguay and AMIS Global – annually updated to reflect changes in herbicide prices and usage
Uruguay	6–17	4	1.87	Cost saving	Personal communication from Monsanto Uruguay and AMIS Global - updated annually 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

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 gross farm income gains from using GM IR maize and cotton in 2015 were $4.46 billion and $3.27 billion respectively. Cumulatively since 1996, the gains have been $46 billion for GM IR maize and $50.3 billion for GM IR cotton.

TABLE 3. GM HT cotton summary of average gross farm income impacts 1996–2015 ($/hectare).

Country	Cost of technology	Average gross farm income benefit (after deduction of cost of technology)	Aggregate income benefit (million $)	Type of benefit	References
US	13–82	21	1,098.8	Cost savings	Carpenter and Gianessi (2002) Sankala and Blumenthal (2003, 2005) Johnson and Strom (2008) Also updated to reflect herbicide price and common product usage
South Africa	13–32	34	4.39	Cost savings	Personal communication from Monsanto South Africa and updated since 2008 to reflect changes in herbicide prices and usage
Australia	32–82	28	99.1	Cost savings	Doyle (2003) Monsanto Australia (personal communications) and updated to reflect changes in herbicide usage and prices
Argentina	10–30	40	161.9	Cost savings and yield gain of +9%	Personal communication from Monsanto Argentina, Grupo CEO and updated since 2008 to reflect changes in herbicide prices and usage
Brazil	26–54	67	153.5	Cost savings plus yield gains of +1.6% to +4%	Galveo (2009, 2010, 2011, 2012, 2013, 2015)
Mexico	29–79	248	230.7	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	96	24.3	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

Aggregated (Global Level) Impacts

GM crop technology has had a significant positive impact on global gross farm income, which amounted to $15.4 billion in 2015. This is equivalent to having added 5.2% to the value of global production of the 4 main crops of soybeans, maize, canola and cotton. Since 1996, gross farm incomes have increased by $167.8 billion.

At the country level, US farmers have been the largest beneficiaries of higher incomes, realizing over $72.3 billion in extra income between 1996 and 2015. 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 ($39.1 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 $38.2 billion additional income for cotton farmers in China and India.

TABLE 4. Other GM HT crops summary of average gross farm income impacts 1996–2015 ($/hectare).

Country	Cost of technology	Average farm income benefit (after deduction of cost of technology)	Aggregate income benefit (million $)	Type of benefit	References
GM HT canola					
US	12–33	55	339.6	Mostly yield gains of +1% to +12% (especially Invigor canola)	Sankala and Blumenthal (2003, 2005) Johnson and Strom (2008) And updated to reflect herbicide price and common product usage
Canada	12–32	57	5,066.1	Mostly yield gains of +3% to +12% (especially Invigor canola)	Canola Council (2001) Gusta et al. (2011) and updated to reflect herbicide price changes and seed variety trial data (on yields)
Australia	10–41	48	74.0	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 (2008), Fischer and Tozer (2009) and Hudson (2013)
GM HT sugar beet					
US and Canada	130–151	116	410.6	Mostly yield gains of +3% to +13%	Kniss (2010) Khan (2008) Jon-Joseph and Sprague (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

In 2015, 48.7% 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 20 y 1996–2015, the cumulative farm income gain derived by developing country farmers was $86.1 billion, equal to 51.3% of the total farm income during this period.

The cost to farmers for accessing GM technology, across the 4 main crops, in 2015, was equal to 29% 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 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 20% of total technology gains compared with 36% in developed countries. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income in developing

TABLE 5. Average (%) yield gains GM IR cotton and maize 1996–2015.

	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, 2005) 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	11.2	N/a	24.0	Gouse et al. (2005), Gouse, Piesse, et al. (2006), Gouse, Pray et al. (2006) Van der Weld (2009) Ismael et al. (2002) Kirsten and Gouse (2002) James (2003)
Honduras	23.8	N/a	N/a	Falck Zepeda et al. (2009, 2012)
Mexico	N/a	N/a	11.0	Traxler andGodoy-Avila (2004) Monsanto Mexico annual cotton monitoring reports
Argentina	6.1	N/a	30.0	Trigo (2002) Trigo and CAP (2006) Qaim and De Janvry (2002, 2005) Elena (2006)
Philippines	18.0	N/a	N/a	Gonsales (2005) Gonsales (2009) Yorobe (2004) Ramon (2005)
Spain	11.1	N/a	N/a	Brookes (2003, 2008) Gomez-Barbero et al. (2008) Riesgo et al. (2012)
Uruguay	5.6	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	31.0	Bennett et al. (2004) IMRB (2006, 2007) Herring and Rao (2012)
Colombia	21.7	N/a	18.0	Mendez et al. (2011) Zambrano (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	11.9	N/a	0.8	Galveo (2009, 2010, 2012, 2013[70], 2015) Monsanto Brazil (2007)
Pakistan	N/a	N/a	21.0	Nazli et al. (2010), Kouser and Qaim (2013, 2014)
Myanmar	N/a	N/a	30.9	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)

Notes: N/a = not applicable

TABLE 6. GM IR crops: Average gross farm income benefit 1996–2015 ($/hectare).

Country	GM IR maize: cost of technology	GM IR maize (income benefit after deduction of cost of technology)	Aggregate income benefit GM IR maize (million $)	GM IR cotton: cost of technology	GM IR cotton (income benefit after deduction of cost of technology)	Aggregate income benefit GM IR cotton (million $)
US	17–32 IRCB, 22–42 IR CRW	82 IRCB, 79 IR CRW	35,423.5	26–58	104	5,022.0
Canada	17–26 IRCB, 22–42 IR CRW	76 IRCB 90 IR CRW	1,334.9	N/a	N/a	N/a
Argentina	10–33	26	946.7	21–86	240	868.8
Philippines	30–47	115	485.1	N/a	N/a	N/a
South Africa	9–17	102	1,925.5	14–50	154	32.1
Spain	17–51	209	251.3	N/a	N/a	N/a
Uruguay	11–33	30	28.1	N/a	N/a	N/a
Honduras	100	53	10.2	N/a	N/a	N/a
Colombia	30–49	263	103.4	50–175	69	20.8
Brazil	44–69	78	5,392.9	26–52	36	100.6
China	N/a	N/a	N/a	38–60	348	18,654.5
Australia	N/a	N/a	N/a	85–299	202	849.9
Mexico	N/a	N/a	N/a	48–75	2015	252.3
India	N/a	N/a	N/a	12–54	214	19,598.7
Burkina Faso	N/a	N/a	N/a	51–54	97	204.6
Myanmar	N/a	N/a	N/a	17–20	152	307.9
Pakistan	N/a	N/a	N/a	4–15	239	4,311.6
Paraguay	16–20	17	22.9	N/a	N/a	N/a
Average across all user countries		**78**			**223**	

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

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 with those in developed countries.

Seventy-two per cent of the total income gain over the 20-year period derives from higher yields and second crop soybean gains with 28% from lower costs (mostly on insecticides and herbicides). In terms of the 2 main trait types, insect resistance and herbicide tolerance have accounted for 58% and 42% 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 2015 the split of total income gain came 84% from yield/production gains and 16% 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).

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

	1996–2015 additional production (million tonnes)	2015 additional production (million tonnes)
Soybeans	180.3	21.9
Corn	357.7	40.30
Cotton	25.2	2.19
Canola	10.6	1.44
Sugar beet	1.1	0.15

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

The GM IR traits, used in maize and cotton, have accounted for 94.7% of the additional maize production and 98.9% 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 with average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). The average yield impact across the total area planted to these traits over the 20 y since 1996 has been +13.1% for maize and +15% 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 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 148 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2015 (accounting for 84.9% of the total GM HT-related additional soybean production). Intacta soybeans added a further 5.84 million tonnes since 2013.

CONCLUDING COMMENTS

The use of crop biotechnology, by 18 million farmers in 2015, has delivered important farm income benefits over the 20-year period to 2015. 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 GM HT technology-driven farm income gains have mostly arisen from reduced costs of production, notably on weed control. In South America, the technology has also facilitated the move away from conventional to low/no-tillage production systems and, by effectively shortening the production cycle for soybeans, enabled many farmers to plant a second crop of soybeans after wheat in the same season. In addition, second generation GM HT soybeans, now widely used in North America, are delivering higher yields, as are the new ‘stacked’ traited HT and IR soybeans being used in South America since 2013.

In relation to HT crops, over reliance on the use of glyphosate and the lack of crop and herbicide rotation by farmers, in some regions, has contributed to the development of weed resistance. To address this problem and maintain good levels of weed control, farmers have increasingly adopted more integrated weed management strategies incorporating a mix of herbicides, other HT crops and cultural weed control measures (in other words using other herbicides with glyphosate rather than solely relying on glyphosate, using HT crops which are tolerant to other herbicides, such as glufosinate and using cultural practices such as mulching). This has added cost to the GM HT production systems compared with about 10 y ago, although relative to the current conventional alternative, the GM HT technology continues to offer important economic benefits in 2015.

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. Most of this literature broadly refers to itself as 'economic impact' literature and applies farm accounting or partial budget approaches to assess the impact of GM crop technology on revenue, key costs of production (notably cost of seed, weed control, pest control and use of labor) and gross farm income. 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 are 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 such comparisons 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. 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 are 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 andGodoy-Avila (2004) and Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture in Mexico) and in the US (see Sankala and Blumenthal (2003, 2005), Mullins and 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. This introduces a degree of dynamic analysis that would, otherwise, be missing if constant prices and average yields identified in year-specific studies had been used;
- 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 2015 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. 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 2015) 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 2015 farm income calculations

GM IR corn (targeting corn boring pests) 2015

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	26,470	+7	10.0	144	−28.0	−26.04	+74.86	+2,170,816	+19,848
Canada	999	+7	9.82	141	−26.0	−23.3	+73.4	+73,337	+687
Argentina	2,595	+5.5	7.98	173	−10.2	−10.2	+65.8	+170,740	+1,139
Philippines	646	+18	2.8	326	−44.0	−30.0	+103.4	+66,791	+326
South Africa	2,388	+10.6	4.2	204	−8.9	−1.25	+89.5	+213,594	+1,063
Spain	107	+12.6	9.83	196	−38.8	−31.7	+182	+19,613	+133
Uruguay	71	+5.5	5.60	180	−10.2	−10.2	+45.2	+3,232	+22
Honduras	27	+24	3.51	138	−100.0	−100.0	+16.2	+438	+23
Portugal	8	+12.5	8.26	191	−38.8	−38.8	+158.8	+1,273	+8
Czech Republic	1	+10	5.92	154	−38.8	−18.8	+72.2	+72	+1
Brazil	12,383	+11.1	4.04	183	−43.6	−32.8	+48.9	+605,784	+5,544
Colombia	69	+22	5.33	257	−29.3	+3.6	+305.0	+20,931	+80
Paraguay	297	+5.5	5.10	173	−15.6	−15.6	+32.9	+9,771	+83

Notes:

1. 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 = $1.96/ha. After deduction of the cost of technology which is shown as a negative 'in farm income terms' (−$28/ha) is deducted to leave a net impact on costs of −$26.04 (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)
2. 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 are available)

GM IR maize (targeting maize rootworm) 2015

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	15,816	+5	10.0	144	−28	−5.4	+66.67	+1054,439	+7,911
Canada	695	+5	9.82	141	−26	+7.3	+76.35	+53,115	+341

Notes:

1. 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 are available)

GM IR cotton 2015

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	2,693	+10	0.792	1,497	−49.92	−17.61	+100.9	+271,849	+213
China	2,796	+10	1.442	2,146	−58.4	+28.30	+337.7	+1,005,036	+429
South Africa	9	+24	.368	1,725	−23.88	−15.09	+137.3	+1,257	+1
Australia	253	Zero	1.91	1,773	−225.4	+190.3	+190.3	+48,196	Zero
Mexico	118	+15.3	1.33	1,546	−59.21	−49.33	+266.9	+31,518	+24
Argentina	377	+30	0.38	1,251	−21.25	−32.36	+174.6	+65,858	+43
India	11,305	+24	0.4	1,057	−12.5	+16.47	+117.67	+1,330,303	+1,083
Colombia	15	+10	0.954	1,737	−103.8	−51.0	+114.7	+1,724	+1
Brazil	477	+2.3	1.47	1,467	−26.0	+8.7	+58.6	+27,962	+16
Burkina Faso	330	+18.15	0.347	1,315	−53.48	−0.9	+81.9	+27,027	+21
Pakistan	2,716	+22	0.452	1,414	−3.94	+6.0	+146.56	+397,399	+270
Myanmar	223	+30	0.52	1,414	−20	−10.1	+210.5	+46,978	+35

Note: Myanmar price based on Pakistan

GM HT soybeans 2015 (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	10,500	Nil	3.23	305	−48.97	+19.29	+19.29	+202,553	Nil
US 2nd generation	20,636	+8.9	3.23	305	−57.17	+11.09	+94.42	+1,948,406	+5,638
Canada 1st generation	567	Nil	2.85	328	−35.18	+39.66	+39.66	+22,473	Nil
Canada 2nd generation	1,295	+8.9	2.85	328	−55.45	+19.4	+98.60	+127,688	+312
Argentina	18,603	Nil	2.91	267	−2.5	+24.10	+24.10	+448,345	Nil
Brazil	19,501	Nil	2.88	358	−7.12	+19.67	+19.67	+383,524	Nil
Paraguay	2,851	Nil	2.59	255	−4.4	+17.08	+17.08	+48,709	Nil
South Africa	478	Nil	1.56	371	−1.18	+8.72	+8.72	+4,169	Nil
Uruguay	800	Nil	2.0	260	−2.5	+22.84	+22.84	+18,275	Nil
Mexico	18	−0.75	1.33	358	−38.5	+0.56	−3.0	−54	−0.2
Bolivia	1,204	+15	2.16	296	−3.32	+5.96	+84.08	+86,095	+332

Notes:

1. Price discount for GM soybeans relative to non GM soybeans in Bolivia of 2.7% - price for non GM soybeans was $399/tonne - price shown above is discounted

GM IR/HT (Intacta) soybeans 2015

Country	Area of trait (000' ha)	Yield assumption % change	Base yield sucrose (tonnes/ ha)	Farm level price: $/tonne)	Cost of tech ($/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)
Brazil	11,800	+9.4	2.78	358	−32.88	+4.87	+98.64	+1,163,985	+3,087
Argentina	700	+7.1	2.90	267	−30	+7.65	+62.53	+43,770	+144
Paraguay	98	+9.1	2.58	255	−30	+31.48	+91.59	+8,976	+23
Uruguay	200	+7	1.97	260	−30	+14.34	+50.38	+10,075	+28

GM HT corn 2015

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	29,084	Nil	8.20	144	−28.85	+38.91	+38.91	+1,131,801	Nil
Canada	1,273	Nil	9.36	141	−27.05	+19.09	+19.09	+24,297	Nil
Argentina: as single trait	238	+3% con belt, +22% marginal areas	6.04 corn belt, 3.73 marginal areas	173	−5.8	+9.78	+31.37 corn belt, +142.06 marginal areas	+25,599	+134
Argentina: as stacked trait	2,000	+10.25	7.98	173	−12.4	+3.2	+144.80	+289,591	+1,636
South Africa	1,647	Nil	4.60	204	−9.04	+10.51	+10.51	+17,316	Nil
Philippines	702	+5	2.81	264	−43.96	−15.57	+21.46	+15,063	+98
Colombia	73	Zero	4.57	257	−14.28	+10.12	+10.12	+739	Nil
Brazil	9,941	+3	4.04	183	−10.11	+6.12	+28.29	+281,232	+1,206
Uruguay	73	Nil	5.87	180	−5.85	+9.78	+9.78	+714	Nil
Paraguay	252	Nil	5.21	173	−13.34	+6.21	+6.21	+1,565	Nil

Notes:

1. 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)

2. 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 2015

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	2,853	Nil	0.859	1,497	−74.13	+8.65	+8.65	+24,683	Nil
S Africa	9	Nil	0.46	1,725	−12.6	+25.73	+25.73	+235	Nil
Australia	270	Nil	1.91	1,773	−56.26	+28.08	+28.08	+7,584	Nil
Argentina	410	Farm saved seed area nil Certified seed area +9.3%	0.943	1,251	− 7.76 certified seed, − 10 farm saved seed	+9.84 certified seed, + 7.6 farm saved seed	+ 119.55 certified seed, +7.6 farm saved seed	+16,887	+6
Mexico	123	+19.6	1.33	1,547	−52	−31.84	+372.09	+45,767	+32
Colombia	16	+4.0	0.954	1,737	−110.8	+17.40	+83.63	+1,339	+1
Brazil	540	+1.6	1.43	1,467	−25.98	+3.87	+37.74	+20,218	+9

Notes:

1. 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)

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

GM HT canola 2015

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	316	+4.3	1.76	348	−17.3	−2.06	+28.38	+8,973	+26
US glufosinate tolerant	329	+11.6	1.76	348	−17.3	+14.26	+56.74	+18,672	+54
Canada glyphosate tolerant	3,071	+4.3	2.1	395	−28.93	−32.94	+39.59	+121,673	+277
Canada glufosinate tolerant	4,462	+11.6	2.1	395	Nil	+13.59	+109.59	+488,971	+1,084
Australia glyphosate tolerant	444	+11	1.17	377	−9.77	−0.98	+37.73	+16,738	+57

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

GM virus resistant crops 2015

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	455	+17	22.86	924	−494	−494	+3,096	+1,410	+1.8
US squash	1,000	+100	19.46	571	−736	−736	+10,373	+10,373	+19

GM herbicide tolerant sugar beet 2015

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	454	+3.55	9.04	327.01	−148	+9.69	+114.67	+52,091	+159
Canada	15	+3.55	10.22	327.01	−148	+9.69	+128.37	+1,926	+5

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 1996–2015 (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
2014	4.0	195.91	783.6
2015	3.76	128.51	483.9

Source and notes:

1. 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

2. The second cropping benefits are based on the gross margin derived from second crop soybeans multiplied by the total area of second crop soybeans (less an assumed area of second crop soybeans that equals the second crop area in 1996 – this was discontinued from 2004 because of the importance farmers attach to the GM HT system in facilitating them remaining in no tillage production systems)

Base yields used where GM technology delivers a positive yield gain

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 (2015)

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	0.859	3,206	2,754	2,693	513	+10%	0.792	2,346	406
China	1.58	3,100	4,898	2,976	124	+10%	1.442	4,721	179

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 and 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 and Blumenthal (2003, 2005) 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 and CAP (2006) +10%, 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 and 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 onward +18%	Average of 3 studies used all years to 2006. Thereafter based on Gonsales (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)

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 Weld (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 Weld (2009)	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 and Rodriguez-Corejo (2008) 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 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 onward	Impacts based on average of available impact data in each country	Based on Brookes (2008) which drew on several 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 +26%; Romania based on reported impact by industry sources	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
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, +11.1% 2013–2015	Farmer surveys	Galveo (2009, 2010, 2012, 2013, 2014)	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 onward	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, 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 and Blumenthal (2003, 2005) 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 and 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 and Blumenthal (2005) and Johnson and 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

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 and Blumenthal (2003, 2005) 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 and Blumenthal (2005) and Johnson and Strom (2008) that take into account the increasing use of Bollgard II technology, and draws on work by Mullins and 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 and De Janvry (2002, 2005) analysis based on farm level analysis in 1999/00 and 2000/01 +35% yield gain, Trigo and CAP (2006) used an average gain of +30% based on work by Elena (2006)	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. (2002) identified yield gain of +24% for the years 1998/99 and 1999/2000. Kirsten and Gouse (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, +15.8% 2014, 15.% 2015	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 and Godoy-Avila (2004). For all other years the data are 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% 2012–15	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, 2007). 2007 impact data based on lower end of range of impacts identified in previous 3 y (2007 being a 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 and Qaim (2012)	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 pesticide usage data (2011)
Brazil	+6.23% 2006\ −3.6% 2007 −2.7% 2008, −3.8% 2009, 2010 nil 2011 +3.04%, 2012 −1.8%, 2013 +2.4%, 2014–2015 +2.38%	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, 2015)	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 onward +10%	Farm survey 2007 comparing performance of GM IR vs. conventional growers. 2009 onwards based on trade estimates	Based on Zambrano (2009) and trade estimates (2009, 2011, 2013)	Assumed as Mexico – no breakdown of seed premium provided in Zambrano (2009). From 2008 based on weighted cost of seed sold as single and stacked traits	Data derived from Zambrano (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), Vitale (2010)	Based on Vitale et al. (2008), 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
Myanmar	+30%	Extension service estimates	USDA (2011)	No data available so based on India and Pakistan	No data available so based on Pakistan

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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
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 and Blumenthal (2003, 2005) Johnson and Strom (2008) and updated post 2008 from industry estimates of seed premia	Marra et al. (2002) Carpenter and Gianessi (2002) Sankala and Blumenthal (2000, 2006) Johnson and Strom (2008) and updated post 2008 to reflect herbicide price and common product usage
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), Ontario Ministry of Agriculture 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, +9% 2014, 8.9% 2015	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 and CAP (2006) and 2006 onwards (Monsanto royalty rate)	Qaim and Traxler (2005), Trigo and 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, 2013, 2015)	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, 2015
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, 2015
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, 2015
Mexico	+9.1% 2004 and2005 +3.64% 2006 +3.2% 2007 +2.4% 2008 +13% 2009, +4% 2010–2–12, +9.9% 2013, −2.1% 2014, −0.75% 2015	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)

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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
GM HT & IR soybeans					
Brazil	+9.6% 2013, +9.1% 2014, 9.4% 2015	Farm trials and post market monitoring survey	Monsanto farm trials and commercial crop monitoring (survey)	As yield source	As yield source
Argentina	+9.1% 2013, +7.8% 2014, 7.1% 2015	As Brazil	Monsanto farm trials and commercial crop monitoring (survey)	As yield source	As yield source
Paraguay	+12.8% 2013, +11.9% 2014, 9.1% 2015	As Brazil	Monsanto farm trials and commercial crop monitoring (survey)	As yield source	As yield source
Uruguay	+8.8% 2013, +7.8% 2014, 7% 2015	As Brazil	Monsanto farm trials and 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 and Gianessi (2002) Sankala and Blumenthal (2003, 2005) Johnson and Strom (2008). 2008 and 2009 onwards based on weighted seed sales (sold as single and stacked traits)	Carpenter and Gianessi (2002) Sankala and Blumenthal (2003, 2005) Johnson and Strom (2008). 2009 onwards updated to reflect changes in common herbicide treatments and prices
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 onwards	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
Brazil	+2.5% 2010 +3.6% 2011. +6.84% 2012 and 2013, +3% 2014–2015	Farm survey	Galveo (2010, 2012, 2013, 2015)	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

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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
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 and Blumenthal (2003, 2005) Johnson and Strom (2008) and updated from 2008 based on weighted seed sales (by single and stacked traited seed)	Carpenter & Gianessi) Sankala and Blumenthal (2003, 2005) Johnson and Strom (2008) and updated from 2008 to reflect changes in weed control practices and prices of herbicides
Australia	Nil	Not relevant	Not relevant	Doyle (2003) Monsanto Australia (personal communications 2005, 2007, 2009, 2010 and 2012)	Doyle (2003) Monsanto Australia (personal communications 2005, 2007, 2009, 2010, 2012), 2016
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, 2012, 2016)
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, 2012)	No published studies identified – based on personal communications with Grupo CEO and Monsanto Argentina (2007, 2008, 2010, 2012, 2013, 2016)
Mexico	+3.6% all years to 2007 0% 2008, +5.11% 2009, +18.1% 2010, +5.1% 2011, +13.1% 2012, +14.2% 2013, +13.3% 2014, +19.6% 2015	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, +1.6% 2013, +1.6% 2014–15	Farm survey	Galveo (2010, 2012, 2013, 2015)	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 and Blumenthal (2003, 2005)) Johnson and Strom (2008). These are the only studies identified that examine GM HT canola in the US. Updated based on industry and extension service estimates	Sankala and Blumenthal (2003, 2005)) Johnson and Strom (2008). These are the only studies identified that examine 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, +3.4% 2014, +4.3% 2015 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, +11% 2014, +11.6% 2015	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 (personal communication, 2008) plus Gusta et al. (2011)	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. (2011) 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)

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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	+21.08% 2008, +20.9% 2009, +15.8% 2010, +7.6% 2011 and 2012, +11% 2013–2015	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
GM HT sugar beet					
US & Canada	+12.58% 2007 +2.8% 2008 +3.3% 2009–2012, +3.1% 2013, +3.2% 2014, +3.55% 2015	Farm survey and extension service analysis	Kniss (2010) Khan (2008)	Kniss (2010) Khan (2008),	Kniss (2010) Khan (2008), Jon-Joseph and Sprague (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 and Blumenthal (2003, 2005), Johnson and 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 and Blumenthal (2003, 2005), Johnson and Strom (2008)	Sankala and Blumenthal (2003, 2005), Johnson and 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 several 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.