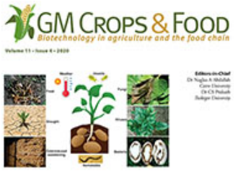

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GM crop technology use 1996-2018: farm income and production impacts

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ABSTRACT

This paper estimates the global value of using genetically modified (GM) crop technology in agriculture at the farm level. It follows and updates earlier studies which examined impacts on yields, key variable costs of production, direct farm (gross) income, and impacts on the production base of the four main crops of soybeans, corn, cotton, and canola. This updated analysis shows that there continues to be very significant net economic benefits at the farm level amounting to $18.9 billion in 2018 and $225.1 billion for the period 1996–2018 (in nominal terms). These gains have been divided 52% to farmers in developing countries and 48% to farmers in developed countries. Seventy-two per cent 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 four main crops, having, for example, added 278 million tonnes and 498 million tonnes, respectively, to the global production of soybeans and maize since the introduction of the technology in the mid-1990 s. In terms of investment, for each extra dollar invested in GM crop seeds (relative to the cost of conventional seed), farmers gained an average US $3.75 in extra income. In developing countries, the average return was $4.41 for each extra dollar invested in GM crop seed and in developed countries the average return was $3.24.

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Yield; cost; income; production; genetically modified crops

Introduction

Crops containing genetically modified (GM) traits have been widely grown for more than twenty years and in 2018, the global area planted to these crops was about 184 million hectares.

Since the mid-1990s, 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 undertaken some of these studies (Brookes)[1] and since 2005, have engaged in a regular (typically annual) exercise to aggregate and update the sum of these various studies, and where possible 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 economic impacts associated with the global adoption of crops containing GM traits. It is also hoped the analysis continues to contribute to understanding 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 2017 and 2018. Previous analysis by the current authors has been published in various journals, with the last analysis being Brookes and Barfoot.[2] 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 of this paper the chore of consulting the past papers for details of the methodology and arguments, these are included in full in this paper.

The analysis concentrates on gross farm income effects because these are a primary driver of adoption amongst 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

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(e.g., on labor usage, household incomes, 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

Herbicide tolerant (HT) crops

GM HT crops were amongst the first to be widely grown, with most largely tolerant to the herbicide active ingredient glyphosate. The main impact of this 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 the variation is due to several factors. These include the prevailing costs of different herbicides used in GM HT systems versus weed control practices in conventional (non-GM crops), which may include different/alternative herbicides to those used with GM HT crops and/or other forms of weed control (e.g., hand or mechanical weeding), the mix and amounts of herbicides applied, the cost farmers pay for accessing the GM HT technology and levels of weed problems faced by farmers. The following important factors affecting the level of cost savings achieved 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 (e.g., changes to approval processes and the imposition of restrictions/bans). Prices also vary by year and country according to factors such as exchange rates, costs of manufacture and distribution;
- The amount farmers pay for use of the technology varies by country and year. 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 below. Also, the HT technology available in 2018 is, in some countries, not the same as the technology available in the early years of adoption. In the first 15–20 years of widespread use of GM HT crop technology, crops tolerant to glyphosate dominated. In 2018, farmers, notably in North America now have the option of using seed tolerant to glyphosate plus other active ingredients like glufosinate, 2,4-D and dicamba. These forms of ‘stacked’ tolerances are typically more expensive than the single herbicide tolerance traits of the early years of use;
- 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 in the early years of adoption of the technology, 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)[3] Worldwide, there are 48 weed species that are currently resistant to glyphosate (accessed February 2020), compared to 165 weed species resistant to ALS herbicides (e.g., chlorimuron ethyl commonly used in conventional soybean crops) and 74 weed species resistant to photosystem II

inhibitor herbicides (e.g., a triazine commonly used in maize production). In addition, 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 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 minimize and slow the potential for weeds developing resistance to existing technology solutions (Norsworthy et al.[4]). In addition, in the last 2–3 years, the increasing array of new GM HT technology referred to above has entered the market offering farmers (notably in the US in 2018) crops that are tolerant to other herbicide active ingredients typically in combination with tolerance to glyphosate (and sometimes offering tolerance to three active ingredients). At the macro level, these changes have influenced the mix, total amount, cost, and overall profile of herbicides applied to GM HT crops. It has also resulted in the weed control costs associated with growing GM HT crops generally being higher in 2018 than in the early 2000s. However, relative to the conventional alternative, GM HT crops have continued to offer important economic advantages for most users, either in the form of lower costs of production or higher yields (arising from better weed control). An important contributory factor to this (maintenance of cost saving advantage of GM HT systems versus conventional alternatives) is that many of the herbicides used in conventional production systems also face significant weed 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). It is also important to note that if 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 impact of this technology on gross farm income is summarized in Table 1. The farm-level gain has arisen from a reduction in the cost of production, mainly through lower expenditure on weed control (typically herbicides). Where yield gains have occurred (from improvements in weed control), the average farm income gain has been higher, for example 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 gross farm income benefits (see 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. The second crop, additional to traditional 'one crop' soybean production, has added considerably to farm incomes and to the volumes of soybean production in countries such as Argentina and Paraguay.

Overall, in 2018, GM HT technology in soybeans (excluding second generation 'Intacta' soybeans: see below) has boosted gross farm incomes by 4.78 USD billion, and since 1996 has delivered

Table 1. GM HT soybeans: summary of average gross farm level income impacts 1996–2018 ($/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[1] Monsanto Romania[5]
Argentina	2–4	22.4 plus second crop benefits of 216	21,137.2	Cost savings plus second crop gains	Qaim and Traxler[6] Trigo and CAP[7] and updated from 2008 to reflect herbicide usage and price changes
Brazil	7–25	32.5	8,267.9	Cost savings	Parana Department of Agriculture[8] Galveo[9-12] and updated to reflect herbicide usage and price changes
US	15–57	35.4	13,773.6	Cost savings	Marra et al[13] Carpenter and Gianessi[14] Sankala and Blumenthal[15,16] Johnson and Strom[17] And updated to reflect herbicide price and common product usage
Canada	20–40	20.3	223.5	Cost savings	George Morris Center[18] and updated to reflect herbicide price and common product usage
Paraguay	4–10	16.7 plus second crop benefits of 245	1,384.2	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/Kleffman)
Uruguay	2–4	20.9	227.6	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/Kleffman)
South Africa	2–30	8.1	46.8	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/Kleffman)
Mexico	20–47	40	6.1	Cost savings plus yield impacts in range of −2% to +13%	Monsanto annual monitoring reports submitted to Ministry of Agriculture and personal communications
Bolivia	3–4	109	874.0	Cost savings plus yield gain of +15%	Fernandez W et al[19]
2nd[t] generation GM HT soybeans					
US and Canada	46–67	115.6 (US) 97.5 (Can)	17,379 (US) 904.7 (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	33–56	110.9	8,486.6	Herbicide cost saving as 1st generation plus insecticide saving $19/ha and yield gain +9% to +10%	Monsanto Brazil pre commercial trials and post market (farm survey) monitoring, MB Agro[20]
Argentina	19–56	64.5	840.2	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 surveys

(*Continued*)

Table 1. (Continued).

Country	Cost of technology	Average gross farm income benefit (after deduction of cost of technology)	Aggregate income benefit (million $)	Type of benefit	References
Paraguay	19–56	130.9	880.8	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 surveys
Uruguay	19–56	66	118.2	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 surveys

1. Romania stopped growing GM HT soybeans in 2007 after joining the European Union, where the trait is not approved for planting. Mexico did not plant any GM HT soybeans in 2017 or 2018
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
5. AMIS Global/Kleffmann are subscription-based data sources (derived from farmer surveys) on pesticide use
6. References to Monsanto Argentina, Brazil, Paraguay and Uruguay as sources of data from pre-commericalisation trials and post market monitoring – this is unpublished data provided to the authors by these companies on a yearly basis covering seed premium, yield comparisons and cost of insecticide/number of insecticide treatment comparisons for Intacta crops versus conventional and GM HT (only) crops. The data derives from survey-based monitoring of sites growing each crop

64.3 USD billion of extra farm income. Of the total cumulative farm income gains from using GM HT soybeans, 34.5 USD billion (54%) has been due to yield gains/second crop benefits and the balance, 45%, 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 six years, the technology was used on approximately 98.1 million hectares and contributed an additional 10.3 USD 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, the Philippines, and Vietnam (Table 2).

In 2018, the total global farm income gain from using this technology was 1.66 USD billion with the cumulative gain over the period 1996–2018 being 17 USD billion. Within this, 6.1 USD billion (36%) 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 188.3 USD million in 2018. In the 1996–2018 period, the total gross farm income benefit was 2.25 USD billion. As with other GM HT traits, these farm income gains have mainly arisen from cost savings (63% 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, whilst GM HT sugar beet is grown in the US and Canada. The gross farm income impacts associated with the adoption of these technologies are summarized in Table 4. In both cases, the main farm income benefit has derived from yield gains. In 2018, the total global income gain from the adoption of GM HT technology in canola and sugar beet was 670 USD million and cumulatively since 1996, it was 7.78 USD billion.

Insect resistant (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 (e.g., reasons such as poorly 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 gross farm income gains from using GM IR maize and cotton in 2018 were 4.53 USD billion and 4.38 USD billion, respectively. Cumulatively since 1996, the gains have been 59.6 USD billion for GM IR maize and 63.6 USD billion for GM IR cotton.

GM drought tolerant maize

Drought tolerant maize has been grown in parts of the US since 2014 and in 2018 was planted on 1.41 million hectares. Drawing on yield comparison data with other drought tolerant maize (varieties conveying drought tolerance that is not derived from GM technology) from field trials (source: Monsanto US Field Trials Network in the Western Great Plains[21]) this suggests that the technology is providing users with a net yield gain of about 2.6% and a small cost saving in irrigation costs. After taking into consideration, the additional cost of the seed compared to non-GM drought tolerant maize), the average gross farm income gain (2014–2018) has been about 21

Table 2. GM HT maize: summary of average gross farm income impacts 1996–2018 ($/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	30.1	10,798.1	Cost savings	Carpenter and Gianessi[14] Sankala and Blumenthal[15,16] Johnson and Strom[17] Also updated annually to reflect herbicide price and common product usage
Canada	17–35	13.7	210.2	Cost savings	Monsanto Canada (personal communications) and updated annually since 2008 to reflect changes in herbicide prices and usage
Argentina	13–33	106.1	3,437.8	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	7	90.3	Cost savings	Personal communication from Monsanto South Africa and updated since 2008 to reflect changes in herbicide prices and usage
Brazil	10–32	29	2,238.5	Cost savings plus yield gains of +1% to +7%	Galveo[9-12]
Colombia	14–24	15.7	9.5	Cost savings	Mendez et al[22]
Philippines	24–47	29.7	198.4	Cost savings plus yield gains of +5% to +15%	Gonsales[23] Monsanto Philippines (personal communications) Updated since 2010 to reflect changes in herbicide prices and usage
Paraguay	13–17	2.9	6.3	Cost saving	Personal communication from Monsanto Paraguay and AMIS Global/Kleffman – annually updated to reflect changes in herbicide prices and usage
Uruguay	6–17	2.8	1.81	Cost saving	Personal communication from Monsanto Uruguay and AMIS Global/Kleffman – updated annually to reflect changes in herbicide prices and usage
Vietnam	25–28	38.2	5.1		Brookes[24]

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
3. AMIS Global/Kleffmann are subscription-based data sources (derived from farmer surveys) on pesticide use
4. References to Monsanto Argentina, Canada, South Africa, Philippines, Paraguay, and Uruguay as sources of data – this is unpublished data provided to the authors by these companies on a yearly basis covering seed premium and typical herbicide treatments used on GM HT and conventional crops
5. Reference to changes in herbicide prices and usage – author estimates drawing on AMIS Global/Kleffmann data and other similar database sources e.g., Kynetec (for the US) and extension services (e.g., Ontario Ministry of Agriculture in Canada)

USD/ha. In 2018, this resulted to an aggregate farm income gain of about 33.1 USD million and over the period 2014–2018, a total gain of 106.2 USD million.

Aggregated (global level) impacts

GM crop technology has had a significant positive impact on global gross farm income, which amounted to 18.9 USD billion in 2018. This is equivalent to having added 5.8% to the value of global production of the four main crops of soybeans, maize, canola, and cotton. Since 1996, gross farm incomes have increased by 225.1 USD billion.

At the country level, US farmers have been the largest beneficiaries of higher incomes, realizing 96 USD billion in extra income between 1996 and 2018. This is not surprising given that US farmers were first to make widespread use of GM crop technology and for many years the GM adoption levels in all four US crops have been in excess of 80%. Important farm income benefits ($58.7 billion) have occurred in South America (Argentina, Bolivia, Brazil, Colombia, Paraguay, and Uruguay), mostly from GM technology in soybeans and maize. GM IR

Table 3. GM HT cotton summary of average gross farm income impacts 1996–2018 ($/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	17.9	1,161.9	Cost savings	Carpenter and Gianessi[14] Sankala and Blumenthal[15,16] Johnson and Strom[17] Also updated to reflect herbicide price and common product usage
South Africa	13–32	32.6	7.2	Cost savings	Personal communication from Monsanto South Africa and updated since 2008 to reflect changes in herbicide prices and usage
Australia	32–82	27.9	134.0	Cost savings	Doyle et al[25] Monsanto Australia (personal communications) and updated to reflect changes in herbicide usage and prices
Argentina	10–30	42	210.3	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	58.4	286.5	Cost savings plus yield gains of +1.6% to +4%	Galveo[9-12])
Mexico	29–79	294	431.7	Cost savings plus yield gains of +3% to +20%	Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture and personal communications
Colombia	34–96	62.8	17.5	Cost savings plus yield gains of +4% (note −5% in first year of adoption – 2008/09)	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 (e.g., 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
3. Note negative yield impact of yield in first year of adoption mainly due to technology not being available in leading and locally adapted varieties
4. References to Monsanto Argentina, Australia, South Africa, and Colombia as sources of data – this is unpublished data provided to the authors by these companies on a yearly basis covering seed premium and typical herbicide treatments used on GM HT and conventional crops
5. Reference to Monsanto Mexico annual monitoring reports. These are unpublished, annual monitoring of crop reports that the company is required to submit to the Mexican Ministry of Agriculture, as part of post-market monitoring requirements. This provides data on seed premia, cost of weed control and production and yields for GM HT cotton versus conventional to a regional level
6. Reference to changes in herbicide prices and usage – author estimates drawing on AMIS Global/Kleffmann data and other similar database sources e.g., Kynetec (for the US) and extension services (e.g., New South Wales Department of Agriculture in Australia)

cotton has also been responsible for an additional 47.5 USD billion additional income for cotton farmers in China and India.

In 2018, 53.7% 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 twenty-three years 1996–2018, the cumulative farm income gain derived by developing country farmers was 117.1 USD billion, equal to 52% of the total farm income during this period.

The cost to farmers for accessing GM technology, across the four main crops, in 2018, was equal to 27% 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 23% of total technology gains compared with 31% in developed countries. Whilst 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.

Table 4. Other GM HT crops summary of average gross farm income impacts 1996–2018 ($/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	46	408.9	Mostly yield gains of +1% to +12% (especially Invigor canola)	Sankala and Blumenthal[15,16] Johnson and Strom[17] And updated to reflect herbicide price and common product usage
Canada	11–32	58	6,608.3	Mostly yield gains of +3% to +12% (especially Invigor canola)	Canola Council[26] Gusta et al[27] and updated to reflect herbicide price changes and seed variety trial data (on yields)
Australia	10–41	39	117.4	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[28], Fischer and Tozer[29] and Hudson and Richards[30]
GM HT sugar beet					
US and Canada	130–151	131	645.2	Mostly yield gains of +3% to +13%	Kniss[31] Khan[32] Armstrong et al[33] Annual updates of herbicide price and usage data

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 vigor canola (tolerant to the herbicide glufosinate) is higher yielding than conventional or other GM HT canola and derives this additional vigor 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
5. References to Monsanto Australia as a source of data – this is unpublished data provided to the authors by this company on a yearly basis covering seed premium and typical herbicide treatments used on GM HT and conventional crops
6. Reference to changes in herbicide prices and usage – author estimates drawing on AMIS Global/Kleffmann data and other similar database sources e.g., Kynetec (for the US)

In terms of investment, this means that for each extra dollar invested in GM crop seeds (relative to the cost of conventional seed), farmers gained an average 3 USD.75 in extra income. In developing countries, the average return was 4.41 USD for each extra dollar invested in GM crop seed and in developed countries the average return was 3.24. USD

Seventy-two percent of the total income gain over the 23-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 two main trait types, insect resistance and herbicide tolerance have accounted for 56.9% and 42.9% respectively of the total income gain (other traits of drought resistant maize and virus resistant papaya and squash accounted for the 0.2% balance). 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 2018, the split of total income gain came 88% from yield/production gains and 12% 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 maize, cotton, canola, and soybeans since 1996 (Table 7).

The GM IR traits, used in maize and cotton, have accounted for 92.2% of the additional maize production and 98.5% 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

Table 5. Average (%) yield gains GM IR cotton and maize 1996–2018.

	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[14] Marra et al[13] Sankala and Blumentha[15,16] Hutchison et al[34] Rice[35] Mullins and Hudson[36]
China	N/a	N/a	10.0	Pray et al[37]
South Africa	11.1	N/a	24.0	Gouse et al[38-40] Van der Wald[41] Ismael et al[42]Kirsten and Gouse[43] James[44]
Honduras	23.9	N/a	N/a	Falk Zepeda et al[45,46]
Mexico	N/a	N/a	11.0	Traxler and Godoy-Avila S[47] Monsanto Mexico annual cotton monitoring reports[48]
Argentina	5.9	N/a	30.0	Trigo[49] Trigo and Cap[7] Qaim and De Janvry[50,51] Elena[52]
Philippines	18.2	N/a	N/a	Gonsales[23,53] Yorobe[54] Ramon[55]
Spain	11.5	N/a	N/a	Brookes[56,57] Gomez-Barbero et al[58] Riesgo et al[59]
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	29.0	Bennett et al[60] IMRB[61,62]) Herring and Rao[63]
Colombia	17.4	N/a	26.0	Mendez et al[22] Zambrano[64]
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 J et al[65], Vitale J[66]
Brazil	11.6	N/a	1.6	Galveo[9-12,67]) Monsanto Brazil[68]
Pakistan	N/a	N/a	21.0	Nazli et al,[69] Kouser and Qaim[70,71]
Myanmar	N/a	N/a	30.6	USDA[72]
Australia	N/a	N/a	Nil	Doyle[73] James[74] CSIRO[75] Fitt[76]
Paraguay	5.5	N/a	Not available	As Argentina (no country-specific studies available and industry sources estimate similar impacts as in Argentina)
Vietnam	7.2	N/a	N/a	Brookes[24]

1. N/a = not applicable
2. Not included in table – also IR brinjal grown in Bangladesh an average yield gain 2013/14 to 2018/19 of +17.3%
3. Reference to Monsanto Mexico annual monitoring reports. These are unpublished, annual monitoring of crop reports that the company is required to submit to the Mexican Ministry of Agriculture, as part of post-market monitoring requirements. This provides data on seed premia, cost of pest control and production and yields for GM IR cotton versus conventional to a regional level
4. GM IR maize performance in Uruguay and Paraguay. Industry sources consulted for using Argentina impact data as a suitable proxy for impact in these countries include Monsanto Argentina, Uruguay and Paraguay, Argenbio (Argentine Biotechnology Association) and Trigo E (Grupo CEO)

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 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 23 years since 1996 has been +16.5% for maize and +13.7% for cotton.

Table 6. GM IR crops: average gross farm income benefit 1996–2018 ($/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	81 IRCB, 78 IR CRW	45,590.0	26–58	113	6,390.5
Canada	17–26 IRCB, 22–42 IR CRW	75 IRCB 85 IR CRW	1,754.6	N/a	N/a	N/a
Argentina	10–33	30	1,486.2	21–86	238	1,081.3
Philippines	30–47	101	674.2	N/a	N/a	N/a
South Africa	9–17	94	2,197.6	14–50	210	62.2
Spain	17–51	207	324.3	N/a	N/a	N/a
Uruguay	11–33	34	38.5	N/a	N/a	N/a
Honduras	100	68	20.9	N/a	N/a	N/a
Colombia	30–49	278	178.6	50–175	295	96.0
Brazil	44–69	63	7,091.9	26–52	55	276.0
China	N/a	N/a	N/a	38–60	366	22,221.0
Australia	N/a	N/a	N/a	85–299	207	1,081.7
Mexico	N/a	N/a	N/a	48–75	213	360.8
India	N/a	N/a	N/a	12–54	194	24,314.2
Burkina Faso	N/a	N/a	N/a	51–54	97	204.6
Myanmar	N/a	N/a	N/a	17–20	173	461.8
Pakistan	N/a	N/a	N/a	4–15	230	5,835.0
Paraguay	16–20	21	47.0	N/a	N/a	N/a
Vietnam	38–42	106	14.0		N/a	
Average across all user countries		**82**			**217**	

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 (e.g., 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
5. Sources – as Table 5

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

	1996–2018 additional production (million tonnes)	2018 additional production (million tonnes)
Soybeans	277.63	35.30
Maize	497.74	47.87
Cotton	32.60	2.43
Canola	14.07	1.32
Sugar beet	1.59	0.13

Sugar beet, US and Canada only (from 2008)

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 202.3 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2018 (accounting for 81% of the total GM HT-related additional soybean production). Intacta soybeans added a further 27.3 million tonnes since 2013.

Concluding comments

In the last 23 years, crop biotechnology has helped farmers grow more food using fewer resources by reducing the damage caused by pests and better controlling weeds. The highest yield increases have occurred in developing countries and this has contributed to a more reliable and secure food supply base in these countries. In South America, HT technology has helped farmers reduce tillage, shortening the time between planting and harvesting, allowing them the opportunity to grow an additional soybean crop after wheat in the same growing season.

With higher yields and less time and money spent managing pests and weeds, farmers have earned higher incomes. This has proved to be especially valuable for farmers in developing countries where, in 2018, an average 4.41 USD was received for each extra dollar invested in biotech crop seeds.

The widespread use of GM crop technology is also changing agriculture's land footprint by allowing farmers to grow more without needing to use additional land. To maintain global production levels at 2018 levels, without biotech crops, would have required farmers to plant an additional 12.3 million hectares (ha) of soybeans, 8.1 million ha of maize, 3.1 million ha of cotton and 0.7 million ha of canola, an area equivalent to the combined agricultural area of Philippines and Vietnam.

Nevertheless, in relation to the use of 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. In order 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 dicamba, 2,4-D and glufosinate and using cultural practices such as mulching). This has added cost to the GM HT production systems compared to about 15 years ago, although relative to the current conventional alternative, the GM HT technology continues to offer important economic benefits in 2018.

Overall, there continues to be a considerable and growing body of evidence, in peer reviewed literature, and summarized in this paper, that quantifies the positive economic impacts of crop biotechnology. The analysis provides insights into the reasons why so many farmers around the world have adopted and continue to use the technology.

Methodology

The report is based on detailed 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. Whilst primary data for impacts of commercial cultivation were not available for every crop, in every year and for each country, a substantial body of representative research and analysis is available and this has been used as the basis for the analysis presented. The authors have also 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 key input (e.g., herbicide and insecticide usage) and cost data.

The farm level economic impact of the technology varies widely, both between and within regions/countries. Therefore, the analysis is considered on a case by case basis, using average performance and impact recorded in different crop and trait combinations by the studies reviewed. Where more than one piece of relevant research (e.g., 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 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 is available include the impact of GM insect resistant (IR) cotton: in India (see Bennett R et al.,[60]) IMRB[61,62]) in Mexico (see Traxler and Godoy-Avila[47]) and Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture in Mexico[48]) and in the US (see Sankala & Blumenthal,[15,16]) Mullins & Hudson.[36] 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 and of seed varieties planted;
- 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 calculate the 2018 impacts are presented in Appendix 1.

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 (e.g., improvements in quality arising from less pest damage or lower

levels of weed impurities which result in price premia being obtained from buyers) and the scope for facilitating the planting of a second crop in a season (e.g., second crop soybeans in Argentina following wheat that 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 (gross revenue minus 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 2018) are shown in Appendix 1.

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Statistical sources

AMIS Global/Kleffmann. Subscription-based data sources (derived from farmer surveys) on pesticide use. Kleffmann Gmbh, Ludinghausen, Germany. www.kleffmann.com

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Appendix 1: Details of Methodology as Applied to 2018 Farm Income Calculations

GM IR corn (targeting corn boring pests) 2018

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	27,125	+7	10.47	137	+23.52	+21.58	+78.54	+2,363,238	+21,586
Canada	1,232	+7	9.16	150	+26.0	+23.54	+72.94	+89,897	+790
Argentina	5,114	+5.5	7.95	151	+19.9	+19.9	+46.27	+236,667	+2,237
Philippines	593	+18	3.0	266	+38.0	+25.62	+119.0	+70,849	+324
South Africa	1,528	+10.6	4.48	174	+11.33	0.00	+82.43	+125,963	+725
Spain	115	+12.6	10.76	214	+43.09	+35.53	+219.24	+25,267	+156
Uruguay	107	+5.5	7.24	226	+19.86	+19.86	+70.26	+7,067	+40
Honduras	32	+24	3.38	310	+100.0	+100.0	+151.46	+14,851	+26
Portugal	6	+12.5	7.85	203	+44.27	+44.27	+155.30	+914	+6
Brazil	13,949	+11.1	5.03	128	+57.18	+42.10	+29.67	+413,878	+7,792
Colombia	70	+16	5.20	244	+47.60	+5.80	+196.67	+13,835	+58
Paraguay	322	+5.5	5.46	151	+16.79	+16.79	+28.61	+9,226	+97
Vietnam	49	+7.2	4.65	235	+37.94	+27.29	+105.81	+5,185	+16

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 -$1.94/ha. After deduction of the cost of technology (+$23.52/ha) is deducted to leave a net impact on costs of +$21.58
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 is available)

GM IR corn (targeting corn rootworm) 2018

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	13,457	+5	10.47	137	+24.23	+8.20	+79.72	+1,072,803	+7,045
Canada	740	+5	9.16	150	+26.0	+8.12	+77.03	+56,990	+338

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 2018

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	3,622	+10	0.892	1,614	+48.26	+16.47	+127.58	+462,130	+323
China	3,182	+10	1.576	2,811	+55.41	−26.19	+469.26	+1,493,408	+502
South Africa	42	+24	0.907	1,918	+26.06	−16.46	+400.95	+16.732	+9
Australia	278	Zero	1.74	2,160	+231.69	−181.79	+181.79	+50,609	Zero
Mexico	230	+10.3	1.41	1,670	+57.75	−40.60	+200.70	+46,241	+33
Argentina	391	+30	0.50	1,325	+21.25	−32.36	+231.98	+90,610	+58
India	11,637	+24	0.373	1,279	+11.74	+15.41	+129.95	+1,512,267	+1,041
Colombia	12	+20.7	0.82	1,730	+73.10	+13.17	+279.94	+3,317	+2
Brazil	1,015	+2.4	1.72	1,821	+25.96	−8.68	+83.07	+84,280	+41
Pakistan	2,328	+22	0.575	1,702	+4.06	−5.98	+221.26	+515,101	+294
Myanmar	214	+30	0.50	1,702	+20	+9.96	+245.82	+52,508	+32

Myanmar price based on Pakistan.

GM HT soybeans 2018 (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	9,799	Nil	3.47	351	+30.93	−24.42	+24.42	+239,281	Nil
US 2nd generation	23,719	+8.9	3.47	351	+45.67	−9.68	+107.67	+2,553,900	+6,913
Canada 1st generation	543	Nil	2.86	313	+34.72	−22.0	−22.00	+11,960	Nil
Canada 2nd generation	1,565	+8.9	2.86	313	+54.72	−2.0	+77.56	+121,353	+337
Argentina	14,840	Nil	3.14	216	+2.5	−21.49	+21.49	+318,958	Nil
Brazil	13,357	Nil	3.23	306	+8.76	−33.28	+33.28	+444,474	Nil
Paraguay	1,620	Nil	2.73	300	+4.4	−17.89	+17.89	+28,991	Nil
South Africa	694	Nil	1.75	385	+1.13	−11.73	+11.73	+8,143	Nil
Uruguay	664	Nil	2.0	354	+2.5	−31.73	+31.73	+21,068	Nil
Bolivia	1,274	+15	1.7	144	+3.32	−5.96	+35.14	+44,763	+325

Price discount for GM soybeans relative to non-GM soybeans in Bolivia of 2.7% – price for non-GM soybeans was $148/tonne – price shown above is discounted.

GM trait not available in leading varieties in Mexico.

GM IR/HT (Intacta) soybeans 2018

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	21,299	+9.4	3.06	306	+32.84	−19.84	+107.87	+2,297,557	+6,126
Argentina	2,625	+7.1	3.10	216	+19.30	−19.30	+66.96	+175,759	+578
Paraguay	1,614	+11.5	2.58	300	+19.30	−43.48	+132.76	+214,250	+480
Uruguay	285	+7	2.89	354	+19.30	−29.27	+110.47	+28,591	+57

GM HT corn 2018

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	29,772	Nil	11.07	137	+24.23	−32.11	+32.11	+955,993	Nil
Canada	1,402	Nil	9.71	150	+26.69	−8.89	+8.89	+12,469	Nil
Argentina: as single trait	200	+3% con belt, +22% marginal areas	9.06 corn belt, 5.48 marginal areas	151	+6.64	−2.54	+41.10 corn belt, +182.3 marginal areas	+25,676	+166
Argentina: as stacked trait	5,065	+10.25	7.95	151	+19.90	−10.68	+112.57	+570,281	+4,130
South Africa	1,781	Nil	4.79	174	+12.08	−0.84	+0.84	+1,490	Nil
Philippines	630	+5	3.02	266	+37.98	+13.14	+26.78	+16,868	+95
Colombia	76	Zero	5.47	244	+23.16	−9.82	+9.82	+746	Nil
Brazil	14,740	+3	5.04	128	+28.16	+14.12	+2.54	+77	+2,231
Uruguay	107	Nil	7.61	226	+6.64	−2.54	+2.54	+272	Nil
Paraguay	380	Nil	5.59	151	+12.82	+3.23	+3.23	+1,227	Nil
Vietnam	49	+5	4.65	234	+25.29	+15.99	+38.50	+4,429	+11

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). 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)

M HT cotton 2018

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	3,878	Nil	0.968	1,615	+72.42	−5.53	+5.53	+21,450	Nil
S Africa	44	Nil	1.13	1,918	+13.8	−32.71	+32.71	+1,437	Nil
Australia	290	Nil	1.74	2,160	−59.79	−27.51	+27.51	+7,977	Nil
Argentina	391	Farm saved seed area nil Certified seed area +9.3%	0.642	1,325	+11.76 certified seed, nil farm saved seed	−5.84 certified seed, −17.6 farm saved seed	+ 84.98 certified seed, +17.6 farm saved seed	+14,771	+7
Mexico	235	+16	1.41	1,670	+42.9	−25.86	+449.11	+82,111	+53
Colombia	12	+4.0	0.82	1,730	+34.2	−29.73	+86.49	+1,047	+0.4
Brazil	1,104	+1.6	1.72	1,821	+25.96	−3.86	+53.96	+59,550	+30

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

GM HT canola 2018

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	397	+4.28	1.98	348	+17.3	−7.78	+37.29	+14,810	+42
US glufosinate tolerant	381	+5.9	1.98	348	+17.3	+12.88	+27.81	+10,611	+30
Canada glyphosate tolerant	3,511	+4.28	2.09	383	+28.55	−3.06	+28.82	+101,208	+213
Canada glufosinate tolerant	5,262	+5.9	2.09	383	Nil	−13.47	+89.62	+471,581	+1,045
Australia glyphosate tolerant	499	+8	1.14	407	+9.72	+0.98	+27.14	+13,538	+45

Baseline (conventional) comparison in Canada with herbicide tolerant (non-GM) 'Clearfield' varieties.

GM virus resistant crops 2018

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	249	+17	11.50	1,610	+494	+494	+2,653	+661	+0.5
US squash	1,000	+100	20.72	524	+736	+736	+10,111	+10,111	+21

GM herbicide tolerant sugar beet 2018

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	443	+3.25	8.82	319	+148	−2.39	+130.35	+57,783	+127
Canada	7	+3.25	9.37	319	+148	−2.39	+136.04	+1,003	+2

GM drought tolerant maize 2018

Country	Area of trait (000′ ha)	Yield assumption % change	Base yield (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)
US	1,412	+2.57	10.47	137	+13.41	+13.34	+23.42	+33,082	+242

GM IR brinjal 2018

Country	Area of trait (ha)	Yield assumption % change	Base yield (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)
Bangladesh	2,975	+19.6	9.91	1,975	Nil	−86.21	+704.02	+2,094	+6

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 two crops (wheat followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no or low tillage methods has increased from 34% in 1996 to 90% by 2005 and has remained at over 90% since then.

Farm level income impact of using GM HT soybeans in Argentina 2018 (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 $)
2018	6.0	154.19	932.9

Source & notes: Crop area and gross margin data based on data supplied by Grupo CEO and the Argentine Ministry of Agriculture. The second cropping benefits are based on the gross margin derived from second crop soybeans multiplied by the total area of second crop soybeans.

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 (2018)

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	0.968	4,262	4,125	3,622	639	+10%	0.892	3,554	570
China	1.726	3,350	5,782	3,182	167	+10%	1.576	5,517	264

Figures subject to rounding.