GM Crops & Food ›
Biotechnology in Agriculture and the Food Chain
Volume 9, 2018 - Issue 2

Research Paper

Farm income and production impacts of using GM crop technology 1996–2016

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Pages 59-89 | Received 15 Feb 2018, Accepted 05 Apr 2018, Published online: 11 Jun 2018

Cite this article https://doi.org/10.1080/21645698.2018.1464866 Check for updates

ABSTRACT

This paper estimates 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 four 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 2016. This annual updated analysis shows that there continues to be very significant net economic benefits at the farm level amounting to $18.2 billion in 2016 and $186.1 billion for the period 1996–2016 (in nominal terms). These gains have been divided 48% to farmers in developed countries and 52% to farmers in developing countries. About 65% of the gains have derived from yield and production gains with the remaining 35% coming from cost savings. The technology has also made important

example, added 213 million tonnes and 405 million tonnes respectively, to the global production of soybeans and maize since the introduction of the technology in the mid 1990s.

KEYWORDS:

yield cost income production genetically modified crops

INTRODUCTION

2016 represents the twenty first year of widespread cultivation of crops containing genetically modified (GM) traits, with our estimate of the global planted area of GM-traited crops in this year to be about 178 million hectares.

During this 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 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 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 2016. Previous analysis by the current authors has been published in various journals, with the last analysis being Brookes and Barfoot.[1] 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 recognise that an economic assessment could examine a broader range of potential impacts (eg, on labour 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

a Herbicide Tolerant (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 commerical decisions of suppliers to market or withdraw products from markets and regulation (eg, changes to approval processes). Prices also vary by year and country;

- 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)[76]. Worldwide, there are 41 weed species that are currently resistant to glyphosate (accessed February 2018), compared to 160 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, 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 towards 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 minimise and slow down the potential for weeds developing resistance to existing technology solutions.[2] At the macro level, these changes have influenced the mix, total amount, cost and overall control costs associated with growing GM HT crops generally being higher in 2016 than 10–15 years previously, 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). It should also be noted that many of the herbicides used in conventional production systems had significant resistance issues themselves in the mid 1990s and 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 favour 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 summarised in Table 1. The main farm level gain has arisen from a reduction in the cost of production, mainly through lower expenditure on weed control (mostly herbicides). Not surprisingly, where yield gains have occurred from improvements in the level of weed control, the average farm income gain has been higher, in countries such as Romania, Mexico and Bolivia. A second generation of GM HT soybeans became available to commercial soybean growers in the US and Canada in 2009. This technology offered the same tolerance to glyphosate as the first generation (and the same cost saving) but with higher yielding potential. The realisation 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. 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.

TABLE 1. GM HT soybeans: Summary of average gross farm level income impacts 1996–2016 ($/hectare).

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Overall, in 2016, GM HT technology in soybeans (excluding second generation 'Intacta' soybeans: see below) has boosted gross farm incomes by $4.37 billion, and since 1996 has delivered $54.6 billion of extra farm income. Of the total cumulative farm income gains from using GM HT soybeans, $24.6 billion (45%) has been due to yield gains/second crop benefits and the balance, 55%, 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 four years, the technology was used on approximately 49.6 million hectares and contributed an additional $5.2 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).

TABLE 2. GM HT maize: Summary of average gross farm income impacts 1996–2016 ($/hectare).

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In 2016, the total global farm income gain from using this technology was $2.1 billion with the cumulative gain over the period 1996–2016 being $13.1 billion. Within this, $4.5 billion (34%) 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 $130.1 million in

As with other GM HT traits, these farm income gains have mainly arisen from cost savings (71% of the total gains), although there have been some yield gains in Argentina, Brazil, Mexico and Colombia (Table 3).

TABLE 3. GM HT cotton summary of average gross farm income impacts 1996–2016 ($/hectare).

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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 summarised in Table 4. In both cases, the main farm income benefit has derived from yield gains. In 2016, the total global income gain from the adoption of GM HT technology in canola and sugar beet was $559 million and cumulatively since 1996, it was $6.44 billion.

TABLE 4. Other GM HT crops summary of average gross farm income impacts 1996–2016 ($/hectare).

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b 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).

TABLE 5. Average (%) yield gains GM IR cotton and maize 1996–2016.

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The greatest improvement in yields has occurred in developing countries, where conventional methods of pest control have been least effective (eg, 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. GM IR crops: Average gross farm income benefit 1996–2016 ($/hectare).

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Table 6.

At the aggregate level, the global gross farm income gains from using GM IR maize and cotton in 2016 were $4.81 billion and $3.7 billion respectively. Cumulatively since 1996, the gains have been $50.6 billion for GM IR maize and $54 billion for GM IR cotton.

c GM Drought Tolerant Maize

Drought tolerant maize has been grown in parts of the US since 2014 and in 2016 was planted on 1.34 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[3] Field Trials Network in the Western Great Plains), this suggests that the technology is providing users with a net yield gain of about 2.3% 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 (2014–2016) has been about $15/ha. In 2016, this resulted to an aggregate farm income gain of about $20 million and over the period 2014–2016, a total gain of about $33.3 million.

d Aggregated (Global Level) Impacts

GM crop technology has had a significant positive impact on global gross farm income, which amounted to $18.2 billion in 2016. This is equivalent to having added 5.4% to the value of global production of the four main crops of soybeans, maize, canola and

At the country level, US farmers have been the largest beneficiaries of higher incomes, realising over $80.3 billion in extra income between 1996 and 2016. 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 ($46.4 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 $40.8 billion additional income for cotton farmers in China and India.

In 2016, 55% 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-one years 1996–2016, the cumulative farm income gain derived by developing country farmers was $96 billion, equal to 51.7% of the total farm income during this period.

The cost to farmers for accessing GM technology, across the four main crops, in 2016, 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. 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.

Sixty-five per cent of the total income gain over the 21-year period derives from higher yields and second crop soybean gains with 35% from lower costs (mostly on insecticides and herbicides). In terms of the two main trait types, insect resistance and herbicide tolerance have accounted for 52% and 48% 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

2016 the split of total income gain came 72% from yield/production gains and 28% 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).

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

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The GM IR traits, used in maize and cotton, have accounted for 93.5% 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 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 21 years since 1996 has been +14% 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 166.8 million tonnes to soybean production

GM HT-related additional soybean production). Intacta soybeans added a further 13.46 million tonnes since 2013.

CONCLUDING COMMENTS

In the last 21 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 2016, an average $5 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 2016 levels, without biotech crops, would have required farmers to plant an additional 10.8 million hectares (ha) of soybeans, 8.2 million ha of maize, 2.9 million ha of cotton and 0.5 million ha of canola, an area equivalent to the combined land area of Bangladesh and Sri Lanka.

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 glufosinate and using cultural practices such as mulching). This has added cost to the GM HT production systems compared to about 10–15 years ago, although relative to the current conventional alternative, the GM HT technology continues to

Overall, there continues to be a considerable and growing body of evidence, in peer reviewed literature, and summarised 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. 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 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 labour) 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 (eg, 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 (eg, on the impact of using a GM trait on the yield of a crop in one country in a particular year) has been identified, the findings used in this analysis reflect the authors assessment of which research is most likely to be reasonably representative of impact in the country in that year. For example, there are many papers on the impact of GM insect resistant (IR) cotton in India. Few of these are reasonably representative of cotton growing across the country, with many papers based on small scale, local and unrepresentative samples of cotton farmers. Only the reasonably representative research has been drawn on for use in this paper – readers should consult the references to this paper to identify the sources used.

This approach may still both, overstate, or understate, the impact of GM technology for some trait, crop and country combinations, especially in cases where the technology has provided yield enhancements. However, as impact data for every trait, crop, location and year data is not available, the authors have had to extrapolate available impact data from identified studies to years for which no data are available. In addition, if the only studies available took place several years ago, there is a risk that basing current assessments on 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,[4] IMRB[5] and IMRB[6]), in Mexico (see Traxler and Godoy-Avila[75] and Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture in Mexico) and in the US (see Sankala & Blumenthal[7,8] Mullins & Hudson[9]). 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 2016 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 analysed 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 labour. 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 calculateed (for 2016) are shown in Appendix 1.

ACKNOWLEDGEMENTS

The authors acknowledge that funding towards the researching of this paper was provided by Monsanto. The material presented in this paper is, however, the independent views of the authors – it is a standard condition for all work undertaken by PG Economics that all reports are independently and objectively compiled without influence from funding sponsors.

Additional information

Funding

Monsanto Company

REFERENCES

1. Brookes G, Barfoot P. Farm income and production impacts of using GM crop technology 1996–2016. GM Crops. 2017;8(3):156–93. doi:10.1080/21645698.2017.1317919.

   Google Scholar

2. Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, et al. Reducing the risk of herbicide resistance: best management practices and recommendations. Weed Sci. 2012, Herbicide Resistant Weeds Special Issue, 60:31–62. doi:10.1614/WS-D-11-00155.1.

Web of Science ® | Google Scholar

3. Monsanto US. Field trials network in the Western Great Plains. https://monsanto.com/products/learning-centers/gothenburg-learning-center/.

Google Scholar

4. Bennett R, Ismael Y, Kambhampati U, Morse S. Economic impacts of GM cotton in India. AgBioforum. 2004;7(3):96–100.

Google Scholar

5. IMRB. Socio-economic benefits of Bollgard and product satisfaction (in India). Mumbai, India: IMRB International; 2006.

Google Scholar

6. IMRB. Socio-economic benefits of Bollgard and product satisfaction (in India). Mumbai, India: IMRB International; 2007.

Google Scholar

7. Sankala S, Blumenthal E. Impacts on US agriculture of biotechnology-derived crops planted in 2003- an update of eleven case studies. NCFAP, Washington. 2003. www.ncfap.org.

Google Scholar

8. Sankala S, Blumenthal E. Impacts on US agriculture of biotechnology-derived crops planted in 2005- an update of eleven case studies. 2005. NCFAP, Washington. www.ncfap.org.

Google Scholar

9. Mullins W, Hudson J. Bollgard II versus Bollgard sister line economic comparisons. 2004 Beltwide cotton conferences, San Antonio, USA; Jan 2004.

Google Scholar

10. Brookes G. The farm level impact of using Roundup Ready soybeans in Romania. Agbioforum. 2005;8(4):235–41. www.agbioforum.org.

Google Scholar

11. Monsanto Romania. Unpublished results of farmer survey amongst soybean growers in 2006 – published in 2007.

Google Scholar

12. Qaim M, Traxler G. Roundup Ready soybeans in Argentina: farm level & aggregate welfare effects. Agric Econ. 2005;32(1):73–86. doi:10.1111/j.0169-5150.2005.00006.x.

Web of Science ® | Google Scholar

13. Trigo E, Cap E. Ten years of GM crops in Argentine Agriculture, ArgenBio. 2006. http://argenbio.org/biblioteca/Ten_Years_of_GM_Crops_in_Argentine_Agriculture_02_01_07.pdf

.

Google Scholar

14. Parana Department of Agriculture. Cost of production comparison: biotech and conventional soybeans, in USDA GAIN report, 2004. BR4629 of 11 November 2004. www.fas.usad.gov/gainfiles/200411/146118108.pdf.

Google Scholar

15. Galveo A. Farm survey findings of impact of insect resistant corn and herbicide tolerant soybeans in Brazil, 2010, Celeres, Brazil. www.celeres.co.br.

Google Scholar

16. Galveo A. Farm survey findings of impact of GM crops in Brazil, 2012, Celeres, Brazil. www.celeres.co.br.

Google Scholar

17. Galveo A. Farm survey findings of impact of GM crops in Brazil, 2015, Celeres, Brazil. www.celeres.co.br.

Google Scholar

18. Marra M, Pardey P, Alston J. The pay-offs of agricultural biotechnology: an assessment of the evidence, 2002, International Food Policy Research Institute, Washington, USA.

Google Scholar

19. Carpenter J, Gianessi L. Agricultural Biotechnology: updated benefit estimates. Washington, USA: National Centre for Food and Agricultural Policy (NCFAP); 2002.

Google Scholar

20. Johnson S, Strom S. Quantification of the impacts on US agriculture of biotechnology-derived crops planted in 2006, 2008. NCFAP, Washington. www.ncfap.org.

Google Scholar

21. George Morris Centre. Economic & environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario. 2004, unpublished report for Monsanto Canada.

Google Scholar

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

Google Scholar

23. Fernandez W, Paz R, Zambrano P, Zepeda JF. GM soybeans in Bolivia. 2009, paper presented to the 13th ICABR conference, Ravello, Italy, June 2009.

Google Scholar

24. MB Agro. Intacta soybeans: An economic view of the benefits of adopting the new technology. 2014 report commissioned by Monsanto Brazil.

Google Scholar

25. Mendez K, Chaparro Giraldo A, Reyes Moreno G, Silva Castro C. Production cost analysis and use of pesticides in the transgenic and conventional crop in the valley of San Juan (Colombia). GM Crops. 2011;2(3):June-Dec 2011:163–8. doi:10.4161/gmcr.2.3.17591. PMID:22008311.

PubMed | Google Scholar

26. Gonsales L. Modern Biotechnology and Agriculture: a history of the commercialisation of biotechnology maize in the Philippines. Los Banos, Philippines: Strive Foundation; 2009. ISBN:978-971-91904-8-6.

Google Scholar

27. Brookes G. The potential socio-economic and environmental impacts from adoption of corn hybrids with biotech trait/technologies in Vietnam. 2017. PG Economics, UK. www.pgeconomics.co.uk.

Google Scholar

28. Doyle B. The Performance of Roundup Ready cotton 2001–2002 in the Australian cotton sector. Armidale, Australia: University of New England; 2003.

Google Scholar

29. Canola Council of Canada. An agronomic & economic assessment of transgenic canola. 2001, Canola Council, Canada. www.canola-council.org.

Google Scholar

30. Gusta M, Smyth S, Belcher K, Phillips P, Castle D. Economic benefits of GM HT canola for producers. AgBioForum. 2011;14(1):1–12.

31. Monsanto Australia. Survey of herbicide tolerant canola licence holders 2008.

Google Scholar

32. Fischer J, Tozer P. Evaluation of the environmental and economic impact of Roundup Ready canola in the Western Australian crop production system, 2009. Curtin University of Technology Technical Report 11/2009.

Google Scholar

33. Hudson D, Richards R. Evaluation of agronomic, environmental, economic and co-existence impacts following the introduction of GM canola in Australia 2010–2012. Agbioforum. 2014;17(1):1–12.

Google Scholar

34. Kniss A. Comparison of conventional and glyphosate resistant sugarbeet the year of commercial introduction in Wyoming. J Sugar Beet Res. 2010;47:127–34. doi:10.5274/jsbr.47.3.127.

Google Scholar

35. Khan M. Roundup Ready sugar beet in America. Br Sugar Beet Rev Winter. 2008;76(4):16–9.

Google Scholar

36. Jon-Joseph AQ, Sprague CL. Weed management in wide-and narrow-row glyphosate resistant sugar beet. Weed Technol. 2010;24:523–8. doi:10.1614/WT-D-10-00033.1.

Web of Science ® | Google Scholar

37. Hutchison W, Burkness EC, Mitchel PD, Moon RD, Leslie TW, Fleicher SJ, Abrahamson M, Hamilton KL, Steffey KL, Gray ME, et al. Area-wide suppression of European Corn Borer with Bt maize reaps savings to non-bt maize growers. Science. 2010;330:222–5. www.sciencemag.org. doi:10.1126/science.1190242. PMID:20929774.

PubMed | Web of Science ® | Google Scholar

38. Rice M. Transgenic rootworm corn: assessing potential agronomic, economic and environmental benefits. Plant Health Prog. 2004;10:423–430.

Google Scholar

39. Pray C, Hunag J, Hu R, Roselle S. Five years of Bt cotton in China – the benefits continue. Plant J. 2002;31(4):423–30. doi:10.1046/j.1365-313X.2002.01401.x. PMID:12182701.

PubMed | Web of Science ® | Google Scholar

40. Gouse M, Pray C, Kirsten J, Schimmelpfennig D. A GM subsistence crop in Africa: the case of Bt white maize in S Africa. Int J Biotechnol. 2005;7(1/2/3):84–94. doi:10.1504/IJBT.2005.006447.

Google Scholar

41. Gouse M, Piesse J, Thirtle C. Output & labour effect of GM maize and minimum tillage in a communal area of Kwazulu-Natal. J Dev Perspect. 2006;2(2):192–207.

Google Scholar

42. Gouse M, Pray C, Kirsten J, Schimmelpfennig D. Three seasons of insect resistant maize in South Africa: have small farmers benefited. AgBioforum. 2006;9(1):15–22.

Google Scholar

43. Van der Weld W. Final report on the adoption of GM maize in South Africa for the 2008/09 season, South African Maize Trust, 2009.

Google Scholar

44. Ismael Y, Bennet R, Morse S. Benefits of bt cotton use by smallholder farmers in South Africa. Agbioforum. 2002;5(1):1–5.

Google Scholar

45. Kirsten J, Gouse M. Bt cotton in South Africa: adoption and the impact on farm incomes amongst small-scale and large-scale farmers. ICABR conference, Ravello,

Google Scholar

46. James C. Global review of commercialized transgenic crops 2002: feature Bt maize. ISAAA No 29, 2003.

Google Scholar

47. Falck Zepeda J, Sanders A, Trabanino R, Medina O, Batallas-Huacon R. Small ‘resource poor’ countries taking advantage of the new bio-economy and innovation: the case of insect protected and herbicide tolerant corn in Honduras, 2009. paper presented to the 13th ICABR conference, Ravello, Italy, June 2009.

Google Scholar

48. Falck Zepeda J, Sanders A, Trabanino R, Medina O, Batallas-Huacon R. Caught between Scylla and Charybdis: impact estimation issues from the early adoption of GM maize in Honduras. Agbioforum. 2012;15(2):138–51.

Google Scholar

49. Trigo E. Genetically Modified Crops in Argentina agriculture: an opened story. Buenos Aires, Argentina: Libros del Zorzal; 2002.

Google Scholar

50. Qaim M, De Janvry A. Bt cotton in Argentina: analysing adoption and farmers’ willingness to pay. 2002, American Agricultural Economics Association Annual Meeting, California.

Google Scholar

51. Qaim M, De Janvry A. Bt cotton and pesticide use in Argentina: economic and environmental effects. Environ Dev Econ. 2005;10:179–200. doi:10.1017/S1355770X04001883.

Web of Science ® | Google Scholar

52. Elena M. Economic advantages of transgenic cotton in Argentina, INTA. 2006, cited in

Google Scholar

53. Gonsales L. Harnessing the benefits of biotechnology: the case of Bt corn in the Philippines. ISBN 971-91904-6-9. Laguna, Philippines: Strive Foundation; 2005.

Google Scholar

54. Yorobe J. Economics impact of Bt corn in the Philippines. 2004, Paper presented to the 45th PAEDA Convention, Querzon City.

Google Scholar

55. Ramon G. Acceptability survey on the 80–20 bag in a bag insect resistance management strategy for Bt corn. Biotechnology Coalition of the Philippines (BCP); 2005.

Google Scholar

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

Google Scholar

57. Brookes G. The benefits of adopting GM insect resistant (Bt) maize in the EU: first results from 1998–2006. Int J Biotechnol. 2008;10(2/3):148–66. doi:10.1504/IJBT.2008.018351.

Google Scholar

58. Gomez-Barbero M, Barbel J, Rodriguez-Cerezo E. Adoption and performance of the first GM crop in EU agriculture: Bt maize in Spain. 2008. JRC, EU Commission. Eur 22778. http://www.jrc.ec.europa.eu.

Google Scholar

59. Riesgo L, Areal F, Rodriguez-Cerezo E. How can specific market demand for non-GM maize affect the profitability of Bt and conventional maize? A case study for the middle Ebro Valley, Spain. Spanish J Agric Res. 2012;10(4):867–76.

Web of Science ® | Google Scholar

50. Herring R, Rao C. On the ‘failure of Bt cotton’: analysing a decade of experience. Econ Polit Wkly. 2012;47(18):5/5/2012.

Google Scholar

51. Zambrano P. Insect resistant cotton in Colombia: impact on farmers. paper presented to the 13th ICABR conference, 2009, Ravello, Italy.

Google Scholar

52. Vitale J, Glick H, Greenplate J, Traore O. The economic impact of 2nd generation Bt cotton in West Africa: empirical evidence from Burkina Faso. Int J Biotechnol. 2008;10(2/3):167–83. doi:10.1504/IJBT.2008.018352.

Google Scholar

53. Vitale J. Impact of Bollgard II on the Socio Economic and Health Welfare of Smallholder Cotton Farmers in Burkina Faso. Results of the 2009 Field Survey14th ICABR conference, Ravello, Italy, June 2010.

Google Scholar

54. Galveo A. Unpublished data on first survey findings of impact of insect resistant corn (first crop) in Brazil, 2009, Celeres, Brazil. www.celeres.co.br.

Google Scholar

55. Monsanto Brazil. Farm survey of conventional and Bt cotton growers in Brazil 2007. unpublished.

Google Scholar

56. Nazli H, Sarker R, Meilke K, Orden D. Economic performance of Bt cotton varieties in Pakistan. Conference paper at the Agricultural and Applied Economics Association 2010 AAEA, CAES and WACA Joint Annual Meeting, Denver, USA.

Google Scholar

67. Kouser S, Qaim M. Valuing financial, health and environmental benefits of Bt cotton in Pakistan. Agric Econ. 2013;44:323–35. doi:10.1111/agec.12014.

Web of Science ® | Google Scholar

68. Kouser S, Qaim M. Bt cotton, damage control and optimal levels of pesticide use in Pakistan. Environ Dev Econ. 2014;19(06):704–23. doi:10.1017/S1355770X1300051X.

Web of Science ® | Google Scholar

69. USDA. New technologies aiding Burmese cotton farmers. GAIN report BM 0025 of 14th January 2011.

Google Scholar

70. Doyle B. The Performance of Ingard and Bollgard II Cotton in Australia during the 2002/2003 and 2003/2004 seasons. Armidale, Australia: University of New England; 2005.

Google Scholar

71. James C. Global review of commercialized transgenic crops 2001: feature Bt cotton. ISAAA No 26, 2002.

Google Scholar

72. CSIRO. The cotton consultants Australia 2005 Bollgard II comparison report, CSIRO, Australia.

Google Scholar

73. Fitt G. Deployment and impact of transgenic Bt cotton in Australia, reported in James C (2001), Global review of commercialised transgenic crops: 2001 feature: Bt cotton, ISAAA.

Google Scholar

74. Monsanto Comercial Mexico. Official reports to Mexican Ministry of Agriculture of the (year) cotton crop, unpublished papers for 2008, 2009, 2010, 2011, 2012, 2013

Google Scholar

75. Traxler G, Godoy-Avila S. Transgenic cotton in Mexico. Agbioforum. 2004;7(1&2):57–62.

Google Scholar

76. Weedscience.org. Website of International Survey of Herbicide Resistant Weeds. www.weedscience.org.

Google Scholar