

Volume 9, 2018 - Issue 2



Open access

10

Views

CrossRef citations to date

Altmetric

Listen

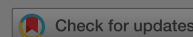
Research Paper

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

Graham Brookes & Peter Barfoot

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>



 [Full Article](#)

 [Figures & data](#)

References

“ Citations

Metrics

© Licensing

 Reprints & Permissions [View PDF](#)

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 the area planted to GM crops increasing from 1.5 million hectares in 1995 to 10.5 million hectares in 2005. The area planted to GM crops in 2005 was 10.5 million hectares, or 10.5% of the total area planted to crops in 2005. The area planted to GM crops in 2005 was 10.5 million hectares, or 10.5% of the total area planted to crops in 2005.

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings



In this article

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

paper are current revision In order of the m

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’ and newer herbicides. The use of older herbicides is often limited by the need to protect the environment and the health of farmers and consumers. The use of newer herbicides is often limited by the need to protect the health of farmers and consumers. The use of older herbicides is often limited by the need to protect the health of farmers and consumers. The use of newer herbicides is often limited by the need to protect the health of farmers and consumers.
- The amount of herbicides used on GM HT crops and conventional crops is affected by the technology used. The use of GM HT technology often results in the use of fewer herbicides than conventional technology. The use of GM HT technology often results in the use of fewer herbicides than conventional technology.

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

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 strategy has the potential to reduce the overall weed control costs by more than 10%.

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click "Settings". For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

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’ systems, has led to the increase in soybean production volumes.

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings



Download

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).

[Download CSV](#) [Display Table](#)

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 was due to yield gains and the balance, \$8.6 billion, was due to cost savings of

GM HT

The use of GM HT technology in 2016. 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 was due to yield gains and the balance, \$8.6 billion, was due to cost savings of \$4.37 billion. 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.

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).



[Download CSV](#)

[Display Table](#)

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).



[Download CSV](#)

[Display Table](#)

b Insect Resistant (GM IR) Crops

The main way in which these technologies have impacted on farm incomes has been through yield gains, which have been substantial in some crops (Table 5).



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

[Accept All](#)

[Essential Only](#)


[Settings](#)

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

[Download CSV](#)

Table 6.

c GM Drought Tolerant Maize



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Settings


value of global production of the four main crops of soybeans, maize, canola and cotton. Since 1996, gross farm incomes have increased by \$186.1 billion.

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



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

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.



[Download CSV](#) [Display Table](#)

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
cost effects
the impact
The
facilitate
has enabled
after a w



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

provide more
moving yields,
the countries.
the
e and how it
mediately
l to

Accept All

Essential Only

Settings



in Argentina and Paraguay between 1996 and 2016 (accounting for 83.4% of the total 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 glyphosate-resistant weeds. This has led to increased use of more potent herbicides, such as dicamba, which has added cost to the GM crop system. In this article

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click "Settings". For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings



relative to the current conventional alternative, the GM HT technology continues to offer important economic benefits in 2016.

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. The impact is also variable across different crops and countries. On a case basis, the impact of GM crops can be significant. For example, the impact of GM crops on the use of insecticides has been significant. The impact of GM crops on the use of herbicides has been significant. The impact of GM crops on the use of pesticides has been significant. The impact of GM crops on the use of fertilisers has been significant. The impact of GM crops on the use of water has been significant. The impact of GM crops on the use of land has been significant. The impact of GM crops on the use of labour has been significant. The impact of GM crops on the use of capital has been significant. The impact of GM crops on the use of technology has been significant. The impact of GM crops on the use of knowledge has been significant. The impact of GM crops on the use of skills has been significant. The impact of GM crops on the use of resources has been significant. The impact of GM crops on the use of time has been significant. The impact of GM crops on the use of energy has been significant. The impact of GM crops on the use of materials has been significant. The impact of GM crops on the use of information has been significant. The impact of GM crops on the use of communication has been significant. The impact of GM crops on the use of transportation has been significant. The impact of GM crops on the use of infrastructure has been significant. The impact of GM crops on the use of services has been significant. The impact of GM crops on the use of products has been significant. The impact of GM crops on the use of processes has been significant. The impact of GM crops on the use of systems has been significant. The impact of GM crops on the use of organisations has been significant. The impact of GM crops on the use of networks has been significant. The impact of GM crops on the use of communities has been significant. The impact of GM crops on the use of societies has been significant. The impact of GM crops on the use of nations has been significant. The impact of GM crops on the use of the world has been significant.

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings



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 IMRB⁵ and IMRB⁶), in Mexico (see Traxler and Godoy-Avila^{7,8} and Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture in Mexico) and in the US (see Sankala & Blumenthal^{7,8} Mullins & Hudson⁹). 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) ... This is not a perfect solution but it is the best available analysis that would ... in years ...
- It is ... in the ... analysts, and some ... varieties

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings



- 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 le... price
premi... nting of a
second... wheat
that w... (anted).
Th... act (impact
on gro... cost of
produc... application
of actu... takes into

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click "Settings". For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

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 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

REFE



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

1. Brook

techn

do

2. Norsw

In this article

Bradley

^

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. Mu...
20...
[Google Scholar](#)

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

0. Brookes G. The farm level impact of using Roundup Ready soybeans in Romania.

Agbioforum. 2005;8(4):235–41. www.agbioforum.org.

[Google Scholar](#)

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

[Google Scholar](#)

2. 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](#)

3. 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](#)

4. 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](#)

5. 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](#)

6. 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](#)

7. 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](#)

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

 Accept All

Essential Only

Settings



8. 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](#)
9. Carpenter J, Gianessi L. Agricultural Biotechnology: updated benefit estimates. Washington, USA: National Centre for Food and Agricultural Policy (NCFAP); 2002.
[Google Scholar](#)
10. 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](#)
11. George Morris Centre. Economic & environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario. 2004, unpublished report for Monsanto Canada.
[Google Scholar](#)
12. AMIS Global/Kleffmann. Subscription-based data sources (derived from farmer surveys) on pesticide use. Kleffmann Gmbh, Ludinghausen, Germany.
www.kleffmann.com.
[Google Scholar](#)
13. 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](#)
14. MB Agro. Intacta soybeans: An economic view of the benefits of adopting the new technology.
[Google Scholar](#)
15. Meade N, et al. The economic impact of GM crops in the valley of the Amazon. [doi:10.1017/S0022278X00000000](#)

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click "Settings". For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings



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.

[Google Scholar](#)

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

Univer

Goog

33. Hu... and co-
ex... 10–2012.

Agbio

Goog

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

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](#)

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

 Accept All

Essential Only

Settings

40. Gousev A. The impact of Bt cotton on the cotton bollworm in Africa: the case of Burkina Faso. Entomol exp appl. 2010;[158](#):1–10. doi:10.1016/j.entexpappl.2010.07.010. PMID:20734701.

41. Gousev A. The impact of Bt cotton on the cotton bollworm in Africa: the case of Burkina Faso. Entomol exp appl. 2010;[158](#):1–10. doi:10.1016/j.entexpappl.2010.07.010. PMID:20734701.

[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, Italy, 2002.

[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-Huacón 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.

[Goog](#)

48. Falck Zepeda J, Sanders A, Trabanino R, Medina O, Batallas-Huacón 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.

[Goog](#)



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click "Settings". For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

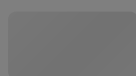
9. Trigo E. Genetically Modified Crops in Argentina agriculture: an opened story. Buenos Aires, Argentina: Libros del Zorzal; 2002.

[Google Scholar](#)

10. 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](#)

11. 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](#)

12. Elena M. Economic advantages of transgenic cotton in Argentina, INTA. 2006, cited in Trigo and CAP 2006.

[Google Scholar](#)

13. 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](#)

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

[Google Scholar](#)

15. Ramon G. Acceptability survey on the 80–20 bag in a bag insect resistance management system (BCP); 2005.

[Google Scholar](#)



16. Br... 2003, [Google Scholar](#)

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

[Accept All](#)

[Essential Only](#)

[Settings](#)

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. doi:10.5424/sjar/2012104-448-11.

 | [Web of Science ®](#) | [Google Scholar](#)

60. 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](#)

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

[Google Scholar](#)

62. 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.

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

 [Accept All](#)

[Essential Only](#)

[Settings](#)

63. 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.

64. 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](#)

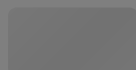
65. Monsanto Brazil. Farm survey of conventional and Bt cotton growers in Brazil 2007. unpublished.

[Google Scholar](#)

66. 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.

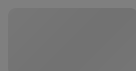
[Google Scholar](#)

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.

[Goog](#)

71. Jan... Bt cotton.



[Goog](#)

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

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

[Google Scholar](#)

3. 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](#)

4. Monsanto Comercial Mexico. Official reports to Mexican Ministry of Agriculture of the (year) cotton crop, unpublished papers for 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016.

[Google Scholar](#)

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

[Google Scholar](#)

6. Weedsience.org. Website of International Survey of Herbicide Resistant Weeds. www.weedsience.org.

[Google Scholar](#)

[Download PDF](#)

Related



About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings

In this article



Information for

- Authors
- R&D professionals
- Editors
- Librarians
- Societies

Opportunities

- Reprints and e-prints
- Advertising solutions
- Accelerated publication
- Corporate access solutions

Open access


- Overview
- Open journals
- Open Select
- Dove Medical Press
- F1000Research

Help and information

- Help and contact
- Newsroom
- All journals
- Books

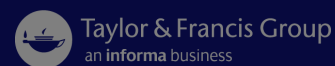
Keep up to date

Register to receive personalised research and resources by email

 Sign me up



Copyright © 2024 Informa UK Limited Privacy policy Cookies Terms & conditions



Accessibility

Registered in England & Wales No. 3099067
5 Howick Place | London | SW1P 1WG

About Cookies On This Site

We and our partners use cookies to enhance your website experience, learn how our site is used, offer personalised features, measure the effectiveness of our services, and tailor content and ads to your interests while you navigate on the web or interact with us across devices. You can choose to accept all of these cookies or only essential cookies. To learn more or manage your preferences, click “Settings”. For further information about the data we collect from you, please see our [Privacy Policy](#).

Accept All

Essential Only

Settings