

# The income and production effects of biotech crops globally 1996–2010

Graham Brookes\* and Peter Barfoot

PG Economics; Dorchester, UK

**Keywords:** yield, cost, income, non-pecuniary benefit, production, biotech crops

A critical feature in evaluating the global value of crop biotechnology in agriculture must include an assessment of its economic impact at the farm level. This paper follows earlier studies which examined economic impacts on yields, key costs of production, direct farm income, indirect (non-pecuniary) farm level income effects and impacts on the production base of the four main crops of soybeans, corn, cotton and canola. The commercialization of biotech crops is continuing to proceed rapidly, with significant changes in the overall level of adoption and impact taking place in 2010. This updated analysis shows that there have been substantial net economic benefits at the farm level amounting to \$14 billion in 2010 and \$78.4 billion for the 15-year period (in nominal terms). The non-pecuniary benefits associated with the use of the technology have also had a positive impact on adoption (in the US accounting for the equivalent of 22% of the total US direct farm income benefit). Biotech crops are, moreover, making important contributions to increasing global production levels of the four main crops. They have, for example, now added 97.5 million tons and 159 million tons respectively, to the global production of soybeans and corn since the introduction of the technology in the mid-1990s.

## Introduction

Integrating the data for 2010 into the context of earlier developments, this study updates the findings of earlier analysis into the global economic impact of genetically modified (GM) crops since their commercial introduction in 1996; earlier analysis by the current authors was published in *AgBioForum* 12:184–208<sup>1</sup> and the *International Journal of Biotechnology* 12:1–49.<sup>2</sup> The methodology and analytical procedures in this present discussion are unchanged to allow a direct comparison of the new with earlier data.<sup>3</sup>

In order to save readers the chore of consulting these earlier papers for details of the methodology and arguments, the journal's editors have agreed that these elements may be included in full in this updated paper.

The analysis concentrates on farm income effects because this is a primary driver of adoption among farmers (both large commercial and small-scale subsistence). It also considers more indirect farm income or non-pecuniary benefits and quantifies the (net) production impact of the technology.

## Methodology

The report is based on extensive analysis of existing farm level impact data for biotech crops. While primary data for impacts of commercial cultivation were not available for every crop, in every year and for each country, a substantial body of representative research and analysis is available and this has been used as the basis for the analysis presented.

As the economic performance and impact of this technology at the farm level varies widely, both between and within regions/countries (as applies to any technology used in agriculture), the measurement of performance and impact is considered on a case by case basis in terms of crop and trait combinations. The analysis presented is based on the average performance and impact recorded in different crops by the studies reviewed; the average performance being the most common way in which the identified literature has reported impact. Where several pieces of relevant research (e.g., on the impact of using a GM trait on the yield of a crop in one country in a particular year) have been identified, the findings used have been largely based on the average of these findings.

This approach may both, overstate or understate, the real impact of GM technology for some trait, crop and country combinations, especially in cases where the technology has provided yield enhancements. However, as impact data for every trait, crop, location and year data are not available, the authors have had to extrapolate available impact data from identified studies to years for which no data are available. Therefore the authors

\*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).

\*Correspondence to: Graham Brookes; Email: graham.brookes@btinternet.com  
Submitted: 03/19/12; Accepted: 03/22/12  
<http://dx.doi.org/10.4161/gmcr.20097>

acknowledge that this represents a weakness of the research. To reduce the possibilities of over/understating impact, 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.<sup>b</sup> 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 as identified by research;

- Uses current farm level crop prices and bases any yield impacts on (adjusted, see below) current average yields. In this way some degree of dynamic has been introduced into the analysis that would, otherwise, be missing if constant prices and average yields identified in year-specific studies had been used;

- Includes some changes and updates to the impact assumptions identified in the literature based on consultation with local sources (analysts, industry representatives) so as to better reflect prevailing/changing conditions (e.g., pest and weed pressure, cost of technology);

- Includes some sensitivity analysis in which the impacts based on average performance are supplemented by a range incorporating “below average” and “above average” performance assumptions (see **Supplemental Materials, Appendix 2** for details);

- Adjusts downwards the average base yield (in cases where GM technology has been identified as having delivered yield improvements) on which the yield enhancement has been applied. In this way, the impact on total production is not overstated.

Detailed examples of how the methodology has been applied to the calculation of the 2010 year results are presented in **Supplemental Materials, Appendix 1. Appendix 2** (also in **Supplemental Materials**) also provides details of the impacts and assumptions applied and their sources.

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

- Impact is quantified at the trait and crop level, including where stacked traits are available to farmers. Where stacked traits have been used, the individual trait components were analyzed separately to ensure estimates of all traits were calculated;

- 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;

- The analysis focuses on changes in farm income in each year arising from impact of GM technology on yields, key costs of production (notably seed cost and crop protection expenditure

but also impact on costs such as fuel and labor<sup>c</sup>), crop quality (e.g., improvements in quality arising from less pest damage or lower levels of weed impurities which result in price premia being obtained from buyers) and the scope for facilitating the planting of a second crop in a season (e.g., second crop soybeans in Argentina following wheat that would, in the absence of the GM herbicide tolerant (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 biotech crop adoption on global crop supply and world prices.

The paper also examines some of the more intangible (more difficult to quantify) economic impacts of GM technology. The literature in this area is much more limited and in terms of aiming to quantify these impacts, largely restricted to the US-specific studies. The findings of this research are summarized<sup>d</sup> and extrapolated to the cumulative biotech crop planted areas in the US over the period 1996–2010.

Lastly, the paper 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 (where identified), but also from the facilitation of additional cropping within a season (notably in relation to soybeans in South America). Details of how these values were calculated (for 2010) are shown in **Appendix 1 (Supplemental Materials)**.

## Results

GM technology has had a significant positive impact on farm income derived from a combination of enhanced productivity and efficiency gains (**Table 1**). In 2010, the direct global farm income benefit from biotech crops was \$14 billion. This is equivalent to having added 4.3% to the value of global production of the four main crops of soybeans, maize, canola and cotton. Since 1996, farm incomes have increased by \$78.4 billion.

The largest gains in farm income in 2010 have arisen in the cotton sector, largely from yield gains. The \$5 billion additional income generated by GM insect resistant (GM IR) cotton in 2010 has been equivalent to adding 14% to the value of the crop in the biotech growing countries, or adding the equivalent of 11.9% to the \$42 billion value of the global cotton crop in 2010.

Substantial gains have also arisen in the maize sector through a combination of higher yields and lower costs. In 2010, maize farm income levels in the biotech adopting countries increased by almost \$5 billion and since 1996, the sector has benefited from an

<sup>b</sup>Examples where such data are available include the impact of GM insect resistant (IR) cotton: in India [see Bennett R et al. (2004)<sup>3</sup>, IMRB (2006)<sup>4</sup> and IMRB (2007)<sup>5</sup>], in Mexico [see Traxler et al. (2001)<sup>6</sup> and Monsanto Mexico (2005, 2007 and 8)<sup>7</sup>] and in the US [see Sankala and Blumenthal (2003<sup>8</sup> and 2006<sup>9</sup>), Mullins and Hudson (2004)<sup>10</sup>].

<sup>c</sup>Inclusion of impact on these categories of cost are, however, more limited than the impacts on seed and crop protection costs because only a few of the papers reviewed have included consideration of such costs in their analysis. Therefore in most cases the analysis relates to impact of crop protection and seed cost only.

<sup>d</sup>Notably relating to the US—Marra M and Piggott N (2006).<sup>11</sup>

**Table 1.** Global farm income benefits from growing biotech crops 1996–2010: USD million(s)

| Trait                          | Increase in farm income 2010 | Increase in farm income 1996–2010 | Farm income benefit in 2010 as % of total value of production of these crops in biotech adopting countries | Farm income benefit in 2010 as % of total value of global production of crop |
|--------------------------------|------------------------------|-----------------------------------|--|--|
| GM herbicide tolerant soybeans | 3,299.80                     | 28,389.20                         | 3.5  | 3.2  |
| GM herbicide tolerant maize    | 438.5                        | 2,672.80                          | 0.5  | 0.2  |
| GM herbicide tolerant cotton   | 148.3                        | 1,062.40                          | 0.4  | 0.3  |
| GM herbicide tolerant canola   | 472.4                        | 2,657.80                          | 5.7  | 1.4  |
| GM insect resistant maize      | 4,522.30                     | 18,969.30                         | 5.4  | 3.2  |
| GM insect resistant cotton     | 5,030.10                     | 24,371.90                         | 14   | 11.9   |
| Others                         | 90.2                         | 301.5                             | Not applicable   | Not applicable   |
| <b>Totals</b>                  | <b>14,001.60</b>             | <b>78,424.90</b>                  | <b>6.25</b>  | <b>4.3</b>   |

All values are nominal. Others = Virus resistant papaya and squash and herbicide tolerant sugar beet. Totals for the value shares exclude “other crops” (i.e., relate to the 4 main crops of soybeans, maize, canola and cotton). Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality and key variable costs of production (e.g., payment of seed premia, impact on crop protection expenditure).

additional \$21.6 billion. The 2010 income gains are equivalent to adding 6% to the value of the maize crop in these countries, or 3.5% to the \$139 billion value of total global maize production. This is a substantial increase in value added terms for two new maize seed technologies.

Significant increases to farm incomes have also resulted in the soybean and canola sectors. The GM HT technology in soybeans has boosted farm incomes by \$3.3 billion in 2010, and since 1996 has delivered over \$28 billion of extra farm income (the highest cumulative increase in farm income of the biotech traits). In the canola sector (largely North American) an additional \$2.7 billion has been generated (1996–2010).

Table 2 summarizes farm income impacts in key biotech adopting countries. This highlights the important farm income benefit arising from GM HT soybeans in South America (Argentina, Bolivia, Brazil, Paraguay and Uruguay), GM IR cotton in China and India and a range of GM cultivars in the US. It also illustrates the growing level of farm income benefits being obtained in South Africa, the Philippines, Mexico and Colombia.

In terms of the division of the economic benefits obtained by farmers in developing countries relative to farmers in developed countries, Table 3 shows that in 2010, 54.8% of the farm income benefits were earned by developing country farmers. The vast majority of these income gains for developing country farmers have been from GM IR cotton and GM HT soybeans.<sup>c</sup> Over the 15 years, 1996–2010, the cumulative farm income gain derived by developing country farmers was 50% (\$39.24 billion).

**Table 2.** GM crop farm income benefits 1996–2010 selected countries: USD million(s)

|              | GM HT soybeans | GM HT maize | GM HT cotton | GM HT canola |
|--------------|----------------|-------------|--------------|--------------|
| US           | 12,109.00      | 2,225.00    | 875.4        | 225.5        |
| Argentina    | 11,217.30      | 314.2       | 68.6         | N/a          |
| Brazil       | 3,888.30       | 17.8        | 36.4         | N/a          |
| Paraguay     | 655            | N/a         | N/a          | N/a          |
| Canada       | 163.3          | 57.7        | N/a          | 2,418.90     |
| South Africa | 7.2            | 3.2         | 2.7          | N/a          |
| China        | N/a            | N/a         | N/a          | N/a          |
| India        | N/a            | N/a         | N/a          | N/a          |
| Australia    | N/a            | N/a         | 31.5         | 13.4         |

All values are nominal. Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality and key variable costs of production (e.g., payment of seed premia, impact on crop protection expenditure). N/a = not applicable. US total figure also includes \$296.4 million for other crops/traits (not included in the table). Also not included in the table is \$4.3 million extra farm income from GM HT sugar beet in Canada.

Examining the cost farmers pay for accessing GM technology, Table 4 shows that across the four main biotech crops, the total cost in 2010 was equal to 28% of the total technology gains (inclusive of farm income gains plus cost of the technology payable to the seed supply chain<sup>f</sup>).

<sup>c</sup>The authors acknowledge that the classification of different countries into developing or developed country status affects the distribution of benefits between these two categories of country. The definition used in this paper is consistent with the definition used by James (2009).<sup>12</sup>

<sup>f</sup>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

**Table 3.** GM crop farm income benefits 2010: developing vs. developed countries: USD million(s)

|   | Developed       | Developing      |
|---|-----------------|-----------------|
| GM HT soybeans  | 970.8           | 2,329.00        |
| GM IR maize   | 3,868.60        | 653.7           |
| GM HT maize   | 274.3           | 164.2           |
| GM IR cotton  | 586             | 4,444.10        |
| GM HT cotton  | 65.3            | 83              |
| GM HT canola  | 472.4           | 0               |
| GM virus resistant papaya and squash and GM HT sugar beet | 90.2            | 0               |
| <b>Total</b>  | <b>6,327.60</b> | <b>7,674.00</b> |

Developing countries = all countries in South America, Mexico, Honduras, Burkino Faso, India, China, the Philippines and South Africa.

For farmers in developing countries the total cost was equal to 17% of total technology gains, while for farmers in developed countries the cost was 37% of the total technology gains. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income gains in developing countries relative to the farm income share in 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 on a per hectare basis derived by developing country farmers relative to developed country farmers.

As indicated in the methodology section, the analysis presented above is largely based on estimates of average impact in all years. Recognizing that pest and weed pressure varies by region and year, additional sensitivity analysis was conducted for the crop/trait combinations where yield impacts were identified in the literature. This sensitivity analysis (see **Sup. Material, Appendix 2** for details) was undertaken for two levels of impact assumption; one in which all yield effects in all years were assumed to be “lower than average” (level of impact that largely reflected yield impacts in years of low pest/weed pressure) and one in which all yield effects in all years were assumed to be “higher than average” (level of impact that largely reflected yield impacts in years of high pest/weed pressure). The results of this analysis suggest a range of positive direct farm income gains in 2010 of +\$12 billion to +\$18.5 billion and over the 1996–2010 period, a range of +\$68.5 billion to +\$93.1 billion (Table 5). This range is broadly within 87% to 119% of the main estimates of farm income presented above.

### Indirect (Non-pecuniary) Farm Level Impacts

As well as the tangible and quantifiable impacts on farm profitability presented above, there are other important, more intangible (difficult to quantify) impacts of an economic nature.

Many of the studies<sup>8</sup> on the impact of biotech crops have identified the following reasons as being important influences for adoption of the technology:

#### Herbicide tolerant crops.

- Increased management flexibility and convenience that comes from a combination of the ease of use associated with broad-spectrum, post emergent herbicides like glyphosate and the increased/longer time window for spraying. This not only frees up management time for other farming activities but also allows additional scope for undertaking off-farm, income earning activities;

- In a conventional crop, post-emergent weed control relies on herbicide applications after the weeds and crop are established. As a result, the crop may suffer “knock-back” to its growth from the effects of the herbicide. In the GM HT crop, this problem is avoided because the crop is tolerant to the herbicide;

- Facilitates the adoption of conservation or no tillage systems. This provides for additional cost savings such as reduced labor and fuel costs associated with ploughing, additional moisture retention and reductions in levels of soil erosion;

- Improved weed control has contributed to reduced harvesting costs—cleaner crops have resulted in reduced times for harvesting. It has also improved harvest quality and led to higher levels of quality price bonuses in some regions and years (e.g., HT soybeans and HT canola in the early years of adoption respectively in Romania and Canada);

- Elimination of potential damage caused by soil-incorporated residual herbicides in follow-on crops and less need to apply herbicides in a follow-on crop because of the improved levels of weed control;

- A contribution to the general improvement in human safety (as manifest in greater peace of mind about own and worker safety) from a switch to more environmentally benign products.

#### Insect resistant crops.

- Production risk management/insurance purposes—the technology takes away much of the worry of significant pest damage occurring and is, therefore, highly valued. Piloted in 2008 and more widely operational from 2009, US farmers using stacked corn traits (containing insect resistant and herbicide tolerant traits together) are being offered discounts on crop insurance premiums (for crop losses) equal to \$12.97/ha in 2010. Over the three years, this has applied to 12.7 million ha, resulting in insurance premia savings of \$137.8 million;

- A “convenience” benefit derived from having to devote less time to crop walking and/or applying insecticides;

- Savings in energy use—mainly associated with less use of aerial spraying;

- Savings in machinery use (for spraying and possibly reduced harvesting times);

- Higher quality of crop. There is a growing body of research evidence relating to the superior quality of GM IR corn relative to conventional and organic corn from the perspective of

<sup>8</sup>For example, relating to HT soybeans; USDA (1999),<sup>13</sup> Gianessi and Carpenter (2000),<sup>14</sup> Qaim and Traxler (2002),<sup>15</sup> Brookes (2008),<sup>16</sup> relating to insect resistant maize, Rice (2004),<sup>17</sup> relating to insect resistant cotton Ismael et al. (2002),<sup>18</sup> Pray et al. (2002).<sup>19</sup>

**Table 4.** Cost of accessing GM technology [USD million(s)] relative to the total farm income benefits 2010

|                | Cost of technology: all farmers | Farm income gain: all farmers | Total benefit of technology to farmers and seed supply chain | Cost of technology: developing countries | Farm income gain: developing countries | Total benefit of technology to farmers and seed supply chain: developing countries |
|----------------|---------------------------------|-------------------------------|--|--|--|--|
| GM HT soybeans | 1,605.10                        | 3,299.80                      | 4,904.90   | 564.4                                    | 2,329.00                               | 2,893.40   |
| GM IR maize    | 1,767.50                        | 4,522.30                      | 6,289.80   | 515.2                                    | 653.7                                  | 1,168.90   |
| GM HT maize    | 789.6                           | 438.5                         | 1,228.10   | 94.6                                     | 164.2                                  | 258.8  |
| GM IR cotton   | 610.3                           | 5,030.10                      | 5,640.40   | 400.8                                    | 4,444.10                               | 4,844.90   |
| GM HT cotton   | 348                             | 148.3                         | 496.3  | 32.8                                     | 83                                     | 115.8  |
| GM HT canola   | 122.8                           | 472.4                         | 595.2  | N/A                                      | N/A                                    | N/A  |
| Others         | 72                              | 90.2                          | 162.2  | N/A                                      | N/A                                    | N/A  |
| <b>Total</b>   | <b>5,315.30</b>                 | <b>14,001.60</b>              | <b>19,316.90</b>   | <b>1,607.80</b>                          | <b>7,674.00</b>                        | <b>9,281.80</b>  |

N/A = not applicable. Cost of accessing technology based on the seed premia paid by farmers for using GM technology relative to its conventional equivalents.

having lower levels of mycotoxins. Evidence from Europe [as summarized in Brookes (2008)]<sup>16</sup> has shown a consistent pattern in which GM IR corn exhibits significantly reduced levels of mycotoxins compared with conventional and organic alternatives. In terms of revenue from sales of corn, however, no premia for delivering product with lower levels of mycotoxins have, to date, been reported although where the adoption of the technology has resulted in reduced frequency of crops failing to meet maximum permissible fumonisin levels in grain maize (e.g., in Spain), this delivers an important economic gain to farmers selling their grain to the food using sector. GM IR corn farmers in the Philippines have also obtained price premia of 10% [Yorobe J (2004)]<sup>20</sup> relative to conventional corn because of better quality, less damage to cobs and lower levels of impurities;

- Improved health and safety for farmers and farm workers (from reduced handling and use of pesticides, especially in developing countries where many apply pesticides with little or no use of protective clothing and equipment);

- Shorter growing season (e.g., for some cotton growers in India) which allows some farmers to plant a second crop in the same season.<sup>h</sup> Also some Indian cotton growers have reported knock on benefits for bee keepers as fewer bees are now lost to insecticide spraying.

Some of the economic impact studies have attempted to quantify some of these benefits (e.g., Yorobe J: see above).<sup>20</sup> Where identified, these cost savings have been included in the analysis presented above. Nevertheless, it is important to recognize that these largely intangible benefits are considered by many farmers as a primary reason for adoption of GM technology, and in some cases farmers have been willing to adopt for these reasons alone, even when the measurable impacts on yield and direct costs of production suggest marginal or no direct economic gain.

Since the early 2000s, a number of farmer-survey based studies in the US have also attempted to better quantify these non-pecuniary benefits. These studies have usually employed contingent

**Table 5.** Direct farm income benefits 1996–2010 under different impact assumptions [USD million(s)]

| Crop         | Consistent below average pest/weed pressure | Average pest/weed pressure (main study analysis) | Consistent above average pest/weed pressure |
|--------------|---|--|---|
| Soybeans     | 28,220                                      | 28,389.20  | 28,558                                      |
| Corn         | 15,772                                      | 21,642.10  | 27,618                                      |
| Cotton       | 22,065                                      | 25,434.30  | 33,520                                      |
| Canola       | 2,281                                       | 2,657.80   | 2,793                                       |
| Others       | 159   | 301.5  | 631   |
| <b>Total</b> | <b>68,497</b>                               | <b>78,424.90</b>                                 | <b>93,120</b>                               |

No significant change to soybean production under all three scenarios as almost all gains due to cost savings and second crop facilitation.

**Table 6.** Values of non-pecuniary benefits associated with biotech crops in the US

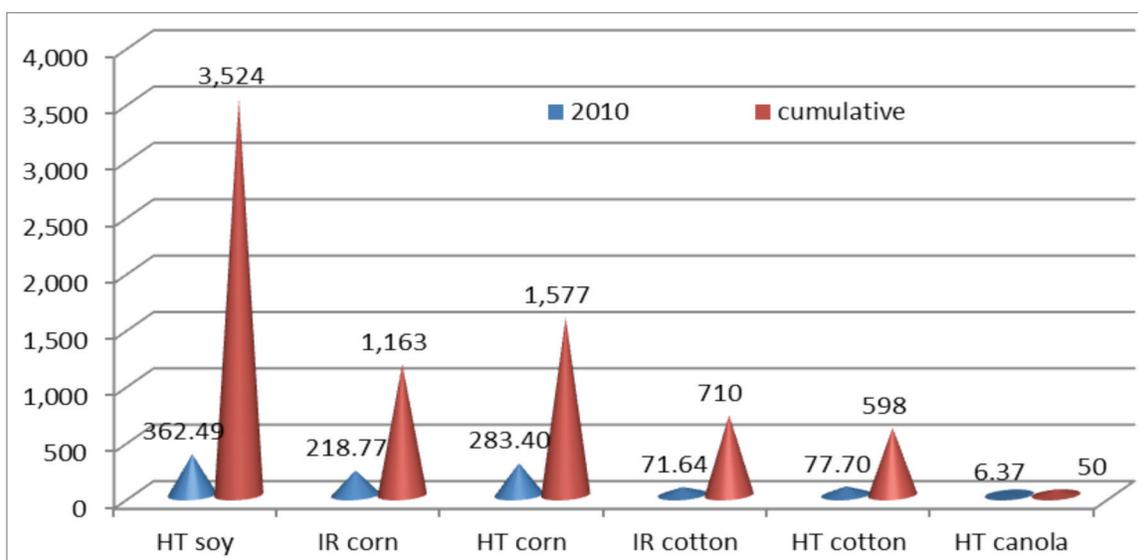
| Survey  | Median value (\$/hectare)                      |
|---|--|
| 2002 IR (to rootworm) corn growers survey                           | 7.41   |
| 2002 soybean (HT) farmers survey                                    | 12.35  |
| 2003 HT cropping survey (corn, cotton and soybeans), North Carolina | 24.71  |
| 2006 HT (flex) cotton survey*                                       | 12.35 (relative to first generation HT cotton) |

Source: Marra and Piggott (2006)<sup>11</sup> and (2007).<sup>21</sup> \*Additionally cited by Marra and Piggott (2007) in "The net gains to cotton farmers of a natural refuge plan for Bollgard II cotton" in *Agbioforum*.<sup>21</sup>

valuation techniques<sup>i</sup> to obtain farmers valuations of non-pecuniary benefits. A summary of these findings is shown in (Table 6).

<sup>i</sup>Survey based method of obtaining valuations of non-market goods that aim to identify willingness to pay for specific goods (e.g., environmental goods, peace of mind, etc.) or willingness to pay to avoid something being lost.

<sup>h</sup>Notably maize in India.



**Figure 1.** Non-pecuniary benefits derived by US farmers 1996–2010 by trait (USD million).

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

|          | 1996–2010 additional production<br>(million tons) | 2010 additional production<br>(million tons) |
|----------|---|--|
| Soybeans | 97.5  | 13.07  |
| Corn     | 159.4   | 28.29  |
| Cotton   | 12.5  | 2.06   |
| Canola   | 6.1   | 0.65   |

**Aggregating the impact to US crops 1996–2010.** The approach used to estimate the non-pecuniary benefits derived by US farmers from biotech crops over the period 1996–2010 has been to draw on the values identified by Marra and Piggot (2006 and 2007: Table 6) and to apply these to the biotech crop planted areas during this 15 year period. Figure 1 summarizes the values for non-pecuniary benefits derived from biotech crops in the US (1996–2010) and shows an estimated (nominal value) benefit of \$1,020 million in 2010 and a cumulative total benefit (1996–2010) of \$7.62 billion. Relative to the value of direct farm income benefits presented above, the non-pecuniary benefits were equal to 18.5% of the total direct income benefits in 2010 and 21.6% of the total cumulative (1996–2010) direct farm income. This highlights the important contribution this category of benefit has had on biotech trait adoption levels in the US, especially where the direct farm income benefits have been identified to be relatively small (e.g., HT cotton).

**Estimating the impact in other countries.** It is evident from the literature review that GM technology-using farmers in other countries also value the technology for a variety of non-pecuniary/intangible reasons. The most appropriate methodology for identifying these non-pecuniary benefit valuations in other countries would be to repeat the type of US

farmer-surveys in other countries. Unfortunately, the authors are not aware of any such studies having been undertaken to date.

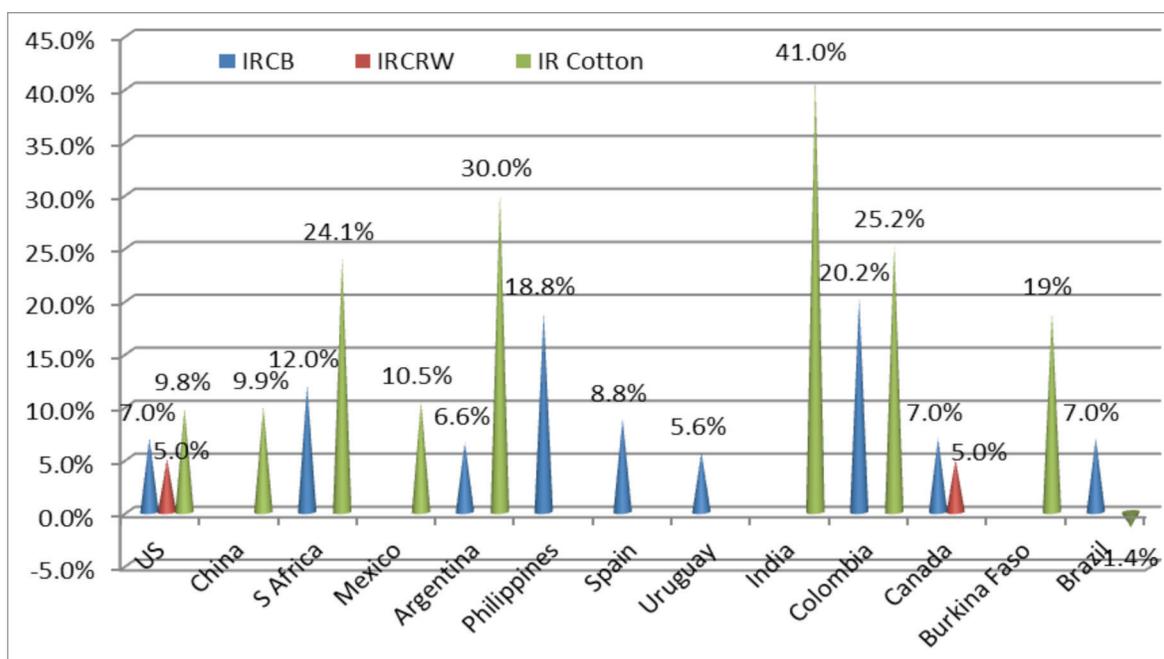
### Production Effects of the Technology

Based on the yield assumptions used in the direct farm income benefit calculations presented above (see Supplemental Material, Appendix 1) and taking account of the second soybean crop facilitation in South America, biotech crops have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (Table 7).

The biotech IR traits, used in the corn and cotton sectors, have accounted for 98% of the additional corn production and 99.4% of the additional cotton production. Positive yield impacts from the use of this technology have occurred in all user countries (except GM IR cotton in Australia<sup>7</sup>) when compared with average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). The average yield impact across the total area planted to these traits over the 15 y period since 1996 has been +9.6% for corn traits and +14.4% for cotton traits (Fig. 2).

Although the primary impact of biotech HT technology has been to provide more cost effective (less expensive) and easier weed control vs. improving yields from better weed control (relative to weed control obtained from conventional technology), improved weed control has, nevertheless, occurred delivering higher yields in some countries (e.g., HT soybeans in Romania, Bolivia and Mexico, HT corn in Argentina and the Philippines: see Supplemental Material, Appendix 2).

<sup>7</sup>This reflects the levels of *Heliothis* pest control previously obtained with intensive insecticide use. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings (on insecticides) and the associated environmental gains from reduced insecticide use.



**Figure 2.** Average yield impact of biotech IR traits 1996–2010 by country and trait. IRCB = resistant to corn boring pests, IRCRW = resistant to corn rootworm.

Biotech HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage enables 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 96.1 million tons to soybean production in Argentina and Paraguay between 1996 and 2010 (accounting for 98.5% of the total biotech-related additional soybean production).

Using the same sensitivity analysis as applied to the farm income estimates presented above to the production impacts (one scenario of consistent lower than average pest/weed pressure and one of consistent higher than average pest/weed pressure), **Table 8** shows the range of production impacts.

### Concluding Comments

This study quantified the cumulative global impact of GM technology between 1996 and 2010, on farm income and on production. It shows that there have been substantial direct economic benefits at the farm level, amounting to a cumulative total of \$78.4 billion. Half of this has been derived by farmers in developing countries. Important non-pecuniary benefits have also been derived by many farmers, which in the case of US farmers added a further \$7.6 billion to the farm income benefits derived from the technology. GM technology has also resulted in additional production of important crops, equal to an extra 97.5 million tons of soybeans and 159.4 million tons of corn (1996–2010).

The authors undertook this (updated) analysis to provide interested readers with on-going and current assessments of some

**Table 8.** Additional crop production arising from positive yield effects of biotech crops 1996–2010 under different pest/weed pressure assumptions and impacts of the technology (million tons)

| Crop     | Consistent below average pest/weed pressure | Average pest/weed pressure (main study analysis) | Consistent above average pest/weed pressure |
|----------|---|--|---|
| Soybeans | 97  | 97.5   | 98  |
| Corn     | 137.2                                       | 159.4  | 197.7                                       |
| Cotton   | 8.8   | 12.5   | 18.2  |
| Canola   | 4.6   | 6.1  | 6.5   |

No significant change to soybean production under all three scenarios as 99% of production gain due to second cropping facilitation of the technology.

of the key economic impacts associated with the global adoption of biotech crops. By doing so, it is hoped that the data and analysis presented will contribute to wider and greater understanding of the impact of this technology adoption in agriculture and facilitate more informed decision making relating to the use of the technology, especially in countries where crop biotechnology is currently not permitted.

#### Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

#### Supplemental Materials

Supplemental materials may be found here: [www.landesbioscience.com/journals/gmcrops/article/20097/](http://www.landesbioscience.com/journals/gmcrops/article/20097/)

## References

- Brookes G, Barfoot P. The income and production effects of biotech crops globally 1996–2009. *Int J Biotechnol* 2011; 12:1-49; <http://dx.doi.org/10.1504/IJBT.2011.042680>.
- Brookes G, Barfoot P. Global impact of biotech crops: socio-economic effects 1996–2007. *Journal of Agrobiotechnology Management and Economics*. *Agbioforum* 2009; 12:184-208.
- Bennett R, et al. Economic impacts of GM cotton in India. *AgBioforum* 2004; 7:3.
- IMRB. Socio-economic benefits of Bollgard and product satisfaction (in India), IMRB International, Mumbai, India 2006.
- IMRB. Socio-economic benefits of Bollgard and product satisfaction (in India), IMRB International, Mumbai, India 2007.
- Traxler G, et al. Transgenic cotton in Mexico: economic and environmental impacts. ICABR conference, Ravello, Italy 2001.
- Monsanto Commercial Mexico. (2005–2009) Official reports to Mexican Ministry of Agriculture of each year's cotton crop, unpublished.
- 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](http://www.ncfap.org).
- Sankala S, Blumenthal E. Impacts on US agriculture of biotechnology-derived crops planted in 2005—an update of eleven case studies, NCFAP, Washington 2006. [www.ncfap.org](http://www.ncfap.org).
- Mullins W, Hudson J. Bollgard II versus Bollgard sister line economic comparisons, 2004 Beltwide cotton conferences, San Antonio USA 2004.
- Marra M, Piggott N. The value of non-pecuniary characteristics of crop biotechnologies: a new look at the evidence, North Carolina State University 2006.
- James C. (2011) Global status of commercialised biotech/GM crops: 2010 ISAAA Brief No. 42.
- USDA. Farm level effects of adopting genetically engineered crops, preliminary evidence from the US experience, *Economic Issues in Agricultural Biotechnology* 1999.
- Gianessi L, Carpenter J. Agricultural biotechnology insect control benefits, NCFAP, Washington USA 1999.
- Qaim M, Traxler G. Roundup Ready soybeans in Argentina: farm level, environmental and welfare effects, 6<sup>th</sup> ICABR conference, Ravello, Italy 2002.
- Brookes G. The impact of using GM insect resistant maize in Europe since 1998. *Int J Biotechnol* 2008; 10:148-66.
- Rice M. Transgenic rootworm corn: assessing potential agronomic, economic and environmental benefits, *Plant Health Progress* 2004; 10,094/php-2001-0301-01-RV.
- Ismael Y, et al. A case study of smallholder farmers in the Mahathini flats, South Africa, ICABR conference, Ravello Italy 2002.
- Pray CE, Huang J, Hu R, Rozelle S. Five years of Bt cotton in China—the benefits continue. *Plant J* 2002; 31:423-30; PMID:12182701; <http://dx.doi.org/10.1046/j.1365-3113X.2002.01401.x>.
- Yorobe J. Economics impact of Bt corn in the Philippines. Paper presented to the 45<sup>th</sup> PAEDA Convention, Querson City 2004.
- Marra M, Piggott N. The net gains to cotton farmers of a national refuge plan for Bollgard II cotton, *Agbioforum* 2007; 10:1-10; [www.agbioforum.org](http://www.agbioforum.org).
- Carpenter J, Gianessi L. Agricultural Biotechnology: updated benefit estimates, National Centre for Food and Agricultural Policy (NCFAP), Washington USA 2002.
- Marra M, Pardey P, Alston J. The pay-offs of agricultural biotechnology: an assessment of the evidence, International Food Policy Research Institute, Washington USA 2002.
- James C. (2003) Global review of commercialized transgenic crops 2002: feature Bt maize, ISAAA No. 29.
- Hutchison WD, Burkness EC, Mitchell PD, Moon RD, Leslie TW, Fleischer SJ, 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](http://www.sciencemag.org); PMID:20929774; <http://dx.doi.org/10.1126/science.1190242>.
- Trigo E, et al. Genetically Modified Crops in Argentina agriculture: an opened story. *Libros del Zorzal*, Buenos Aires, Argentina 2002.
- Trigo E, Cap E. Ten years of GM crops in Argentine Agriculture, *ArgenBio* 2006.
- Gonsales L. Harnessing the benefits of biotechnology: the case of Bt corn in the Philippines. ISBN 971-91904-6-9. Strive Foundation, Laguna, Philippines 2005.
- Ramon G. Acceptability survey on the 80-20 bag, insect resistance management strategy for Bt corn, Biotechnology Coalition of the Philippines (BCP) 2005.
- Gonsales L, et al. Modern Biotechnology and Agriculture: a history of the commercialisation of biotechnology maize in the Philippines. Strive Foundation, Los Banos, Philippines 2009; ISBN 978-971-91904-8-6.
- Gouse M, et al. A GM subsistence crop in Africa: the case of Bt white maize in S Africa, *Int Journal Biotechnology* 2005; 7.
- Gouse M, et al. Output & labour effect of GM maize and minimum tillage in a communal area of Kwazulu-Natal. *Journal of Development Perspectives* 2006; 2:2.
- Gouse M, et al. Three seasons of insect resistant maize in South Africa: have small farmers benefited. *AgBioforum* 2006; 9:15-22.
- 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.
- Brookes G. The farm level impact of using Bt maize in Spain, ICABR conference paper 2003, Ravello, Italy. Also on [www.pgeconomics.co.uk](http://www.pgeconomics.co.uk).
- Gomez-Barbero, Rodriguez-Cerezo. The adoption of GM insect-resistant Bt maize in Spain: an empirical approach, 10<sup>th</sup> ICABR conference on agricultural biotechnology, Ravello, Italy, July 2006.
- Galveo A. Unpublished (in January 2010) data on first survey findings of impact of insect resistant corn (first crop) in Brazil, Celeres, Brazil 2009. [www.celeres.co.br](http://www.celeres.co.br).
- Galveo A. Farm survey findings of impact of insect resistant corn and herbicide tolerant soybeans in Brazil, Celeres, Brazil 2010. [www.celeres.co.br](http://www.celeres.co.br).
- Zepeda JF, et al. Small 'resource poor' countries taking advantage of the new bio-economy and innovation: the case of insect protected and herbicide tolerant corn in Honduras, paper presented to the 13<sup>th</sup> ICABR conference, Ravello, Italy, June 2009.
- Mendez K, et al. Production cost analysis and use of pesticides in the transgenic and conventional crop in the valley of San Juan (Colombia). *GM Crops* 2011; 2:163-8; PMID:22008311; <http://dx.doi.org/10.4161/gmcr.2.3.17591>.
- Johnson S, Strom S. Quantification of the impacts on US agriculture of biotechnology-derived crops planted in 2006, NCFAP, Washington 2008. [www.ncfap.org](http://www.ncfap.org).
- 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.
- Doyle B. The Performance of Ingard and Bollgard II Cotton in Australia during the 2002/2003 and 2003/2004 seasons, University of New England, Armidale, Australia 2005.
- James C. Global review of commercialized transgenic crops 2001: feature Bt cotton 2002, ISAAA No. 26.
- CSIRO. The cotton consultants Australia 2005 Bollgard II comparison report, CSIRO, Australia 2005.
- Qaim M, De Janvry A. Bt cotton in Argentina: analysing adoption and farmers willingness to pay, American Agricultural Economics Association Annual Meeting, California 2002.
- Qaim M, De Janvry A. Bt cotton and pesticide use in Argentina: economic and environmental effects. *Environ Dev Econ* 2005; 10:179-200; <http://dx.doi.org/10.1017/S1355770X04001883>.
- Elena M. (2001) Economic advantages of transgenic cotton in Argentina, INTA, cited in Trigo & Cap 2006.
- Kirsten J, et al. Bt cotton in South Africa: adoption and the impact on farm incomes amongst small-scale and large-scale farmers, ICABR conference, Ravello, Italy 2002.
- Monsanto Brazil. (2008) Farm survey of conventional and Bt cotton growers in Brazil 2007, unpublished.
- Galveo A. (2009 & 2010) Farm survey findings of impact of insect resistant cotton in Brazil, Celeres, Brazil. [www.celeres.co.br](http://www.celeres.co.br).
- Zambrano P, et al. Insect resistant cotton in Columbia: impact on farmers, paper presented to the 13<sup>th</sup> ICABR conference, Ravello, Italy, June 2009.
- Vitale J, et al. The economic impact of 2<sup>nd</sup> generation Bt cotton in West Africa: empirical evidence from Burkina Faso, *International Journal of Biotechnology* 2008; 10:167-83.
- 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 Survey 14<sup>th</sup> ICABR conference, Ravello, Italy, June 2010.
- George Morris Centre. Economic & environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario, unpublished report for Monsanto Canada.
- Qaim M, Traxler G. Roundup Ready soybeans in Argentina: farm level & aggregate welfare effects. *Agric Econ* 2005; 32:73-86; <http://dx.doi.org/10.1111/j.0169-5150.2005.00006.x>.
- Parana; Department of Agriculture. Cost of production comparison: biotech and conventional soybeans, in USDA GAIN report BR4629 of 11 November 2004. [www.fas.usad.gov/gainfiles/200411/146118108.pdf](http://www.fas.usad.gov/gainfiles/200411/146118108.pdf).
- Brookes G. The farm level impact of using Roundup Ready soybeans in Romania. *Agbioforum* 2005; 8:4; [www.agbioforum.org](http://www.agbioforum.org).
- Fernandez W, et al. GM soybeans in Bolivia, paper presented to the 13<sup>th</sup> ICABR conference, Ravello, Italy, June 2009.
- Doyle B, et al. The Performance of Roundup Ready cotton 2001–2002 in the Australian cotton sector, University of New England, Armidale, Australia 2003.
- Canola Council of Canada. An agronomic & economic assessment of transgenic canola, Canola Council, Canada 2001. [www.canola-council.org](http://www.canola-council.org).
- Gusta M, et al. Economic benefits of GMHT canola for producers, University of Saskatchewan, College of Biotechnology Working Paper 2009.
- Monsanto Australia. (2009) Survey of herbicide tolerant canola licence holders 2008.
- Kniss A. Farm scale analysis of glyphosate resistant sugar beet in the year of commercial introduction in Wyoming, University of Wyoming 2009.
- Khan M. Roundup Ready sugar beet in America. *British Sugar Beet Review* 2008; 76:16-9.