# Genetically Engineered Crops: Environmental Impacts 1996-2009

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## Introduction

Although the first commercial genetically engineered (GE) crops were planted in 1994 (tomatoes), 1996 was the first year in which a significant area of crops containing GE traits were planted (1.66 million hectares). Since then there has been a dramatic increase in plantings, and by 2010/11 the global planted area reached over 139 million hectares. This rapid rate of adoption of GE crop technology is probably without precedent in terms of speed of adoption for a new technology. It largely reflects the significant benefits that farmers using the technology have derived[1] . A considerable body of literature exists that consistently reports the economic benefits derived from use of GE technology and the reasons why farmers have adopted the technology. However, the literature examining impacts of GE technology adoption in agriculture on the environment is less prolific.

This article summarizes the findings of research into the global environmental impact of biotech crops since their commercial introduction in 1996. It is largely drawn from analysis by Brookes and Barfoot that annually assesses the global economic and environmental impact of GE crops, the latest of which can be found in the peer reviewed journal *GM Crops* 2:1, 1-16, January–March 2011.

The environmental impact analysis focuses on the impacts associated with changes in the amount of insecticides and herbicides applied to the GE crops relative to conventionally grown alternatives. The analysis also examines the contribution of GE crops towards reducing global greenhouse gas (GHG) emissions.

## Environmental impacts of insecticide and herbicide use changes

GE traits have contributed to a significant reduction in the environmental impact associated with insecticide and herbicide use in areas devoted to GE crops (**Table 1**). Since 1996, the use of pesticides on GE crops has decreased by 393 million kg of active ingredient (8.7% reduction), and the environmental impact associated with herbicide and insecticide use on these crops, as measured by the EIQ indicator[2], fell by 17.1%.

In absolute terms, the largest environmental gain has been associated with the adoption of GE insect resistant (IR) cotton and reflects the significant reduction in insecticide use that the technology has allowed, in what has traditionally been an intensive user of insecticides.

The volume of herbicides used in GE soybean crops also decreased by 41 million kg (1996–2009), a 2.2% reduction, whilst the overall environmental impact associated with herbicide use on these crops decreased by a significantly larger 16%. These data rflect the switch in herbicides used with most GE herbicide tolerant (HT) crops to active ingredients with a more environmentally benign profile than the ones generally used on conventional crops.

Important environmental gains have also been made in the maize and canola sectors. In the maize sector, herbicide and insecticide use decreased by 176.7 million kg, and the associated environmental impact of pesticide use on this crop area decreased due to a combination of reduced insecticide use (34.8%) and a switch to more environmentally benign herbicides (10.5%). In the canola sector, farmers reduced herbicide use by 14 million kg (a 16.2% reduction) and the associated environmental impact of herbicide use on this crop area fell by 23.2% (due to a switch to more environmentally benign herbicides).

In terms of the division of the environmental benefits associated with less insecticide and herbicide use for farmers in developing countries relative to farmers in developed countries, **Table 2** shows a 54%**:**46% split of the environmental benefits (1996–2009), respectively, in developed (54%) and developing countries (46%). Over three-quarters of the environmental gains in developing countries have resulted from the use of GE IR cotton.

1 The cumulative global farm income benefit derived by farmers from using GE traits between 1996 and 2009 was $64.7 billion (source: Brookes G and Barfoot P (2011)).

2 The environmental impact quotient (EIQ), developed by Kovach et al., effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare'. The EIQ value is multiplied by the amount of pesticide active ingredient (ai) used per hectare to produce a field EIQ value. For example, the EIQ rating for glyphosate is 15.33. By using this rating multiplied by the amount of glyphosate used per hectare (e.g., a hypothetical example of 1.1 kg applied per ha), the field EIQ value for glyphosate would be equivalent to 16.86/ha. The EIQ indicator provides an improved assessment of the impact of GE crops on the environment when compared to only examining changes in volume of active ingredient applied, because it draws on some of the key toxicity and environmental exposure data related to individual products, as applicable to impacts on farm workers, consumers and ecology.

**Table 1: Impact of changes in the use of herbicides and insecticides from growing GE crops globally 1996-2009**

| Trait | Change in volume of active ingredient used (million kg) | Change in field EIQ impact (in terms of million field EIQ/ha units) | % change in ai use on GE crops | % change in environmental impact associated with herbicide & insecticide use on GE crops | Area GE traits 2009 (million ha) |
|---|---|---|---|---|---|
| GE herbicide tolerant soybeans | -40.85 | -5,632.0 | -2.2 | -16.0 | 67.9 |
| GE herbicide tolerant maize | -140.26 | -3,435.4 | - 9.22 | -10.49 | 25.2 |
| GE herbicide tolerant canola | -13.98 | -455.8 | -16.2 | -23.2 | 6.03 |
| GE herbicide tolerant cotton | -8.87 | -281.5 | -4.0 | -6.9 | 3.0 |
| GE insect resistant maize | -36.46 | -1,292.3 | -40.6 | -34.8 | 29.6 |
| GE insect resistant cotton | -152.66 | -7,088.0 | -21.8 | -24.7 | 13.4 |
| GE herbicide tolerant sugar beet | +0.35 | -1.0 | +18.0 | -2.0 | 0.45 |
| **Totals** | **-392.73** | **-18,186.0** | **-8.7** | **-17.1** | **145.58** |

**Table 2: GE crop environmental benefits from lower insecticide and herbicide use 1996-2009: developing versus developed countries**

| | Change in field EIQ impact (in terms of million field EIQ/ha units): developed countries | Change in field EIQ impact (in terms of million field EIQ/ha units): developing countries |
|---|---|---|
| GE HT soybeans | 4,053.9 | 1,578.1 |
| GE HT maize | 3,354.3 | 81.1 |
| GE HT cotton | 236.7 | 44.8 |
| GE HT canola | 455.8 | 0 |
| GE IR corn | 1,124.7 | 167.7 |
| GE IR cotton | 515.6 | 6,572.4 |
| GE HT sugar beet | 1.0 | 0 |
| **Total** | **9,742.0** | **8,444.1** |

It should be noted, however, that in some regions where GE HT crops have been widely grown, some farmers have relied too much on the use of single herbicides like glyphosate to manage weeds in GE HT crops, which has contributed to the development of weed resistance. Worldwide, there were 21 weed species that were resistant to glyphosate in 2010[1] compared to, for example, 68 weed species resistant to triazine herbicides such as atrazine, and several of the confirmed glyphosate resistant weed species have been found in areas where GE HT crops have been grown (e.g., marestail (Conyza Canadensis) and palmer pigweed (Amaranthus Palmeri) are reasonably widespread in the US). Where this has occurred, farmers have had to adopt reactive weed management strategies incorporating the use of a mix of herbicides.

3 www.weedscience.org

4 No-till farming means that the ground is not plowed at all, while reduced tillage means that the ground is disturbed less than it would be with traditional tillage systems. For example, under a no-till farming system, soybean seeds are planted through the organic material that is left over from a previous crop such as maize, cotton or wheat

In recent years, there has also been a growing consensus among weed scientists of a need for changes in the weed management programs in GE HT crops because of the evolution of these weed populations that are resistant to glyphosate. While the overall level of weed resistance in areas planted to GE HT crops is still low, growers of GE HT crops are increasingly being advised to be more proactive and include other herbicides in combination with glyphosate in their weed management systems, even where instances of weed resistance to glyphosate have not been found. This is because proactive weed management programs generally require less herbicide and are more economical than reactive weed management programs. At the macro level, the adoption of both reactive and proactive weed management programs in GE HT crops has already begun to influence the mix, total amount, and overall environmental profile of herbicides applied to GE HT soybeans, cotton, maize, and canola and, where relevant, this is reflected in the data presented in this paper for the most recent years.

### Impact on greenhouse gas (GHG) emissions

GE crops are contributing to lower levels of GHG emissions by two principle means:

- Reduced fuel use from less frequent herbicide or insecticide applications and a reduction in the energy used for soil cultivation. The fuel savings associated with making fewer spray runs (relative to conventional crops) and the switch to conservation, reduced, and no-till farming systems have resulted in permanent savings in carbon dioxide emissions. In 2009 this amounted to about 1,409 million kg (arising from reduced fuel use of 512 million litres). Over the period from 1996 to 2009, the cumulative permanent reduction in fuel use is estimated at 9,947 million kg of carbon dioxide (arising from reduced fuel use of 3,616 million litres);
- The use of 'no-till' and 'reduced-till'[4] farming systems. These production systems have increased significantly with the adoption of GE HT crops because the GE HT technology has improved growers' ability to control competing weeds, reducing the need to rely on soil cultivation and seed-bed preparation as a means to getting good weed control. As a result, tractor fuel use for tillage is reduced, soil quality is enhanced, and levels of soil erosion are reduced. In turn, more carbon remains in the soil, which leads to lower GHG emissions. Based on savings from the rapid adoption of no till/reduced tillage farming systems in North and South America, an extra 4,430 million kg of soil carbon is estimated to have been sequestered in 2009 (equivalent to 16,261 million tons of carbon dioxide that has not been released into the global atmosphere). Cumulatively, the amount of carbon sequestered may be higher due to year-on-year benefits to soil quality. However, with only an estimated 15%–25% of the crop area in continuous no-till systems, it is currently not possible to confidently estimate cumulative soil sequestration gains.

Placing these carbon sequestration benefits within the context of the carbon emissions from cars, **Table 3**, shows that:

- In 2009, the permanent carbon dioxide savings from reduced fuel use were the equivalent of removing 0.626 million cars from the road;
- The additional probable soil carbon sequestration gains in 2009 were equivalent to removing 7.227 million cars;
- In total, in 2009 the combined GE crop-related carbon dioxide emission savings from reduced fuel use and additional soil carbon sequestration were equal to the removal from the roads of 7.853 million cars, equivalent to about 27.6% of all registered cars in the UK;
- It is not possible to confidently estimate the probable soil carbon sequestration gains since 1996 (see above). If the entire GE crop using reduced or no tillage agriculture during the last 15 years had remained in permanent reduced/no tillage, then this would have resulted in a carbon dioxide saving of 115,178 million kg, equivalent to taking 51.19 million cars off the road. This is, however, a maximum possibility and the actual levels of carbon dioxide reduction are likely to be lower.

**Table 3: Context of carbon sequestration impact 2009: car equivalents**

| Crop/trait/country | Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide) | Permanent fuel savings: as average family car equivalents removed from the road for a year | Potential additional soil carbon sequestration savings (million kg of carbon dioxide) | Potential soil carbon sequestration savings: as average family car equivalents removed from the road for a year |
|---|---|---|---|---|
| US: GE HT soybeans | 291 | 130 | 4,711 | 2,094 |
| Argentina: GE HT soybeans | 695 | 309 | 7,018 | 3,119 |
| Other countries: GE HT soybeans | 102 | 45 | 1,507 | 670 |
| Canada: GE HT canola | 244 | 108 | 3,025 | 1,344 |
| Global: GE IR cotton | 33 | 15 | 0 | 0 |
| Brazil: GE IR corn | 43 | 19 | 0 | 0 |
| **Total** | **1,408** | **626** | **16,261** | **7,227** |

Notes: Assumption: an average family car produces 150 grams of carbon dioxide per km. A car does an average of 15,000 km/year and therefore produces 2,250 kg of carbon dioxide/year

## Concluding comments

GE crop technology has, to date, delivered several specific agronomic traits that have overcome a number of production constraints for many farmers. This has resulted in improved productivity and profitability for the 15.4 million adopting farmers who have applied the technology in 2010. During the last 15 years, this technology has delivered important positive environmental contributions through a combination of inherent technical advances and the role of the technology in the facilitation and evolution of environmentally friendly farming practices. More specifically:

- The environmental gains from the GE IR traits have mostly been delivered directly from the technology in the form of decreased use of insecticides;
- The gains from GE HT traits have come from a combination of effects. In terms of the environmental impact associated with herbicide use, important changes have occurred in the profile of herbicides used (in favor of more environmentally benign products). Secondly, GE HT technology has facilitated changes in farming systems. Thus, GE HT technology (especially in soybeans) has allowed farmers to capitalize on the availability of a low cost, broad-spectrum herbicide (glyphosate), and in turn, facilitated the move away from conventional to low/no-tillage production systems in both North and South America. This change in production system has delivered important environmental benefits, notably reduced levels of GHG emissions (from reduced tractor fuel use and additional soil carbon sequestration).

Use of GE HT crops, however, has led to an overreliance on glyphosate by some farmers in some regions, which has contributed to the development of weed resistance. As a result, farmers are increasingly adopting a mix of reactive and proactive weed management strategies incorporating a mix of herbicides. Despite this, the overall environmental gains arising from the use of GE crops have been, and continue to be, substantial.

**References**

1. Brookes G and Barfoot P. Global impact of biotech crops: environmental effects 1996-2009. *GM Crops* 2:1, 1-16, January-March 2011 (2011)
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