The European Association for Bioindustries

Socio-economic impacts of green biotechnology

1. Status of biotech crops

A. Global Level

1. *Global adoption figures*

A thorough overview of the global status of biotech (or GM) crops is published every year by the International Service for the Acquisition of Agri-biotech Applications (James, 2008).

The most updated information can be found in the executive summary report "Global status of Commercialized Biotech/GM Crops: 2008" (James, 2008). Please find hereby a short summary below. A new ISAAA report is expected in spring 2010.

1996 is generally seen as the starting date for the large-scale commercial application of biotech crops. Since then, the technology has spread rapidly around the world, both in industrialized and developing countries (James, 2008):

- The number of countries electing to grow biotech crops has increased steadily from 6 in 1996, the first year of commercialization, to 18 in 2003 and **25 countries in 2008 on 125 million ha**, comprising 15 developing countries and 10 industrial countries.
- For 2008, the top eight countries growing more than 1 million ha were, in decreasing order of hectarage: USA (62.5 million hectares), Argentina (21.0), Brazil (15.8), India (7.6), Canada (7.6), China (3.8), Paraguay (2.7), and South Africa (1.8 million hectares).
- Global hectarage of biotech crops continued its strong growth in 2008 for the thirteenth consecutive year – a 9.4%, or 10.7 million hectare increase, reaching 125 million hectares.
- The 74-fold hectare increase since 1996 makes biotech crops **the fastest adopted crop technology**.
- In 2008, GM crops were being grown on **9% of the global arable land.**
- In 2008, **13.3 million farmers** cultivated biotech crops in 25 countries. Notably, **90%, or 12.3 million were small and resource-poor farmers** in developing countries. Most were Bt cotton farmers: 7.1 million in China (Bt cotton), 5.0 million in India (Bt cotton), 0.2 million in the Philippines (biotech maize), South Africa

(biotech cotton, maize and soybeans often grown by subsistence women farmers) and the other eight developing countries which grew biotech crops in 2008.

2. Adoption by crop

Biotech soybean is the principal biotech crop, occupying 65.8 million hectares or 53% of global biotech area, followed by biotech maize (37.3 million hectares at 30%), biotech cotton (15.5 million hectares at 12%) and biotech canola (5.9 million hectares at 5% of the global biotech crop area).

Bt cotton with resistance to bollworms and budworms is particularly relevant in developing countries. In 2008, India had the largest Bt cotton area with 7.6 million ha, followed by China with 3.8 million ha. South Africa, Argentina, Mexico, and a few other countries use this technology as well. In the United States, Bt and HT cotton are employed, partly with stacked genes. Until now, HT canola was grown mostly in Canada and the United States. A few other GM crops, including HT alfalfa and sugarbeet as well as virus-resistant papaya and squash, have been approved in individual countries, so far covering only relatively small areas (James, 2008).

3. Adoption by trait

- **In 2008, herbicide tolerance deployed in soybean, maize, canola, cotton and alfalfa occupied 63% or 79 million hectares of the global biotech area of 125 million hectares.** HT soybeans are currently grown mostly in the United States, Argentina, Brazil, and other South American countries. This technology accounts for 70% of worldwide soybean production.
- **Insect resistance (19.1 million ha)** is based on different genes from the soil bacterium *Bacillus thuringiensis* (Bt). These Bt genes control the European corn borer, the corn rootworm, and different stemborers (Romeis et al., 2006). Bt maize is grown mostly in North and South America, but it is also planted to a significant extent in South Africa and the Philippines.
- **Stacked events are a rapidly growing trait group** (26.9 million hectares, or 22% of global biotech crop area in 2008).

B. European Level

For Europe, currently the only commercially cultivated biotech crop is insect-resistant **MON810** maize, approved in 1998. MON810 contains a gene from the bacteria *Bacillus thuringiensis* that combats the corn borer pest which destroys maize crops.

In Europe, insect-resistant biotech maize is grown since 1998. In 2008 **107,719 ha** were dedicated to Bt maize in **7 EU** countries. Spain is the EU country with the largest cultivation area of GM maize (approximately 20% of its total maize area), followed by Czech Republic, Romania, Portugal, Germany, Poland and Slovakia. See Table 1 below.

Table 1. Biotech crop cultivation figures (ha) in the EU (according to James, 2008)

Country vs. year	**2005**	**2006**	**2007**	**2008**
Spain	53,225	53,667	75,148	79,269
Czech Republic	150	1,290	5,000	8,380
Romania*	110,000 (Soybean)	137,000 (Soybean)	350 (Maize)	7146 (Maize)
Portugal	750	1,250	4,500	4,851
Germany	400	950	2,285	3,173
Poland	-	100	320	3,000
Slovakia	-	30	900	1,900
Total	54,525	62,187	88,903	107,719

*In 2005 and 2006, the EU acceding country Romania was growing biotech herbicide-tolerant soybeans on a large scale. After entering the EU in 2007 this cultivation became officially forbidden as the crop is not yet approved for commercial cultivation in EU.

In 2008, there was an increase in the use of biotech crops for many European countries. Significant increases are evident in the Czech Republic, Romania, Poland and Slovakia. In France, the cultivation of MON810 was stopped in 2008 due to a ban. French farmers had grown GM maize on 21,000 hectares in 2007. Early 2009, also Germany invoked a safeguard clause for MON810 cultivation, bringing the total numbers of Member States with a moratorium to six: Austria, France, Greece, Hungary, Germany and Luxembourg.

No new biotech crop has been approved for cultivation since 1998 in Europe, though several applications have been pending for a long time. For example, the Amflora potato, a high-quality starch potato suitable for the paper industry, is awaiting authorization since 1996. Based on information on EFSA website (www.efsa.europa.eu), currently 18 biotech crops are awaiting cultivation approval in the EU, including maize (14 applications), potato (2), soybean (1) and sugar beet (1).

C. Graphs

- A Global Status Map can be downloaded at Global Status of Commercialized Biotech/GM Crops: 2008 (James, 2008)
- More graphs on the global area of biotech crops (1996-2008) by crop, trait, adoption rate can be downloaded here (James, 2008)
- 13.3 million farmers cultivate GM crops (Marshall, 2009)
- Areaal transgene gewassen wereldwijd 1998 - 2008, LIS Consult, Februari 2009 (de Vriend, 2009)
- Acreage of biotech crops in Europe (2005-2008) (EuropaBio, 2008) http://www.europabio.org/documents/2008%20Cultivation%20chart.pdf

D. GM Crops in the pipeline

D.1. JRC Study – The global pipeline of new GM crops

A comprehensive overview of the GM crops in the pipeline can be found in a database made by the JRC (Stein & Rodriguez-Cerezo, 2009a).

The accompanying JRC report "*The global pipeline of new GM crops: implications of asynchronous approval for international trade*" (Stein & Rodríguez-Cerezo, 2009b) predicts a **significant global increase in the number of individual commercial GM events**. While currently there are around 30 commercial GM events that are cultivated worldwide, the forecast is that by 2015 there will be over 120: for soybeans, currently only 1 GM event is available, but this number is predicted to increase to 17 different events; maize events are expected to increase from 9 to 24, rapeseed events from 4 to 8 and cotton events from 12 to 27. In the case of rice where currently no commercial events are cultivated, the prediction is that by 2015 as many as 15 GM events could be grown; potatoes also are predicted to move from no current cultivation to 8 events, and other, minor crops are predicted to grow from 7 events currently marketed to 23 events by 2015.

D.2. Rapid developments worldwide

China: In a landmark decision in the latter half of November 2009, within the short span of one week, China's Ministry of Agriculture approved biotech Bt rice, (rice is the most important food crop in the world that feeds half of humanity), and biotech phytase maize, (maize is the most important feed crop in the world) (James, 2009).

Brazil: End December 2009, the Brazilian National Technical Commission on Biosafety (CTNBio) approved the use of a new genetically-modified soybean seed developed jointly by the German chemical company BASF and EMBRAPA, the Brazilian Agricultural Research Corporation. The newly approved GM soybean variety is expected to be available to Brazilian farmers from 2011 onwards. Brazil is the world's second-largest soybean producer and the largest exporter. The country produces some 50 million tons of soybean annually, according to Food and Agriculture Organization. http://www.embrapa.br/

Argentina: End December 2009, Argentina effectively ended its 'mirror policy' in the authorization of GM crops by approving a GM maize stack that is yet to be approved in Europe (Reuters). Argentina continues to be the world's second largest biotech crop producer (after the United States) for the 2008/09 planting year, with 16.8 percent of the global area of GM crops located in the country. Almost all soybean area planted in the country is biotech, and 83 percent and 94 percent of corn and cotton areas respectively are also biotech.

Philippines: Golden Rice may be approved in the Philippines and Bangladesh as early as 2012, and introduced to the public in those countries soon after. Other countries developing Golden Rice in local varieties are India, Indonesia, and Vietnam (IRRI , Fighting Vitamin A deficiency) Golden Rice will be made available to people with vitamin A deficiency in different ways depending on community needs and preferences. The technology behind Golden Rice has been donated by its inventors. Different governments and private charities are supporting the development and testing costs.

India: Mid October 2009, regulators in India declared Bt brinjal (eggplant) safe for environmental release and recommended commercial approval to the Ministry of Environment and Forest. Bt brinjal would be the first biotech vegetable crop which is grown by 1.4 million small and marginal farmers on 550,000 hectare in India. Many transgenic crops are currently being developed and tested at various public and private institutions in the country. Such efforts include among others, development of insect resistant rice at Calcutta University, late blight resistant potato at Central Potato Research Institute, pro-Vitamin A enriched rice at IARI, DRR and TNAU, Bt brinjal and Bt cotton at Mahyco, Jalna (ISAAA).

D.3. Different Generations of GM crops in the pipeline (Qaim, 2009)

- **First-generation** GM crops: different Bt vegetables—including eggplant, cauliflower, and cabbage—are likely to be commercialized soon in India and other countries in Asia and Africa (Krishna & Qaim, 2007; Shelton et al., 2008). HT rice is also in a relatively advanced phase within the research and development (R&D) pipeline (Hareau et al., 2006). Other first-generation GM technologies that are being developed include fungal, bacterial, and virus resistance in major cereal as well as root and tuber crops (Halford, 2006). Their market introduction can be expected in the short to medium run. Plant tolerance to abiotic stress—such as drought, heat, and salt—is also being worked on intensively. Yet, because the underlying genetic mechanisms are complex, the work is at a more basic level, so significant commercial releases can be expected only in the medium run (Herdt, 2006; Ramasamy et al., 2007).
- **Second-generation** GM technologies in the pipeline include product quality improvements for nutrition and industrial purposes. Examples are oilseeds with improved fatty acid profiles; high-amylose maize; staple foods with enhanced contents of essential amino acids, minerals, and vitamins; and GM functional foods with diverse health benefits (Jefferson-Moore & Traxler, 2005). Enhancing food crops with higher nutrient contents through conventional or GM breeding is also called biofortification. A well-known example of a GM biofortified crop is Golden Rice, which contains significant amounts of provitamin A. Golden Rice could become commercially available in some Asian countries by 2012 (Stein et al., 2006; Potrykus, 2008). Other biofortification projects include the development of GM sorghum, cassava, banana, and rice enhanced with multiple nutrients (Qaim et al., 2007). Such crops may become commercially available over the next 5–10 years.
- **Third-generation** GM crops involve molecular farming where the crop is used to produce either pharmaceuticals such as monoclonal antibodies and vaccines or industrial products such as enzymes and biodegradable plastics (Moschini, 2006; Halford, 2006). Although concepts have been proven for a number of these technologies, product development and regulatory aspects are even more complex than they are for first- and second- generation crops. Substances produced in the plants must be guaranteed not to enter the regular food chain with a zero-tolerance threshold. Therefore, plants that are not used for food and feed purposes will likely be chosen for product development, or approvals for third-generation GM crops will be given for use under contained conditions only.

2. Socio-economic impacts at the global level

A vast amount of scientific publications have measured the economic impacts of biotech crops during the first decade of its commercialization. A thorough overview was recently published by IFPRI (Smale et al., 2009).

The following recent articles give a comprehensive overview:

Brookes and Barfoot (2009b) made an assessment of the impact of commercialized agricultural biotechnology on global agriculture from an economic perspective. It examines specific global economic impacts on farm income, indirect (non-pecuniary) farm- level income effects and impacts on the production base of the four main crops—soybeans, corn, cotton, and canola. The analysis shows that there have been **substantial net economic benefits at the farm level, amounting to $10.1 billion in 2007 and $44.1 billion for the 12-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 25% of the total direct farm income benefit). Biotech crops have also made important contributions to increasing global production levels of the four main crops—adding, for example, **68 million ton and 62 million ton** respectively to global production of soybeans and corn.

Qaim (2009) made an in-depth analysis of available impact studies of insect-resistant and herbicide-tolerant crops. His conclusions state that these technologies are beneficial to farmers and consumers, producing **large aggregate welfare gains as well as positive effects for the environment and human health**. The advantages of future applications could even be much bigger. Given a conducive institutional framework, GM crops can contribute significantly to global food security and poverty reduction. Nonetheless, widespread public reservations have led to a complex system of regulations. Overregulation has become a real threat for the further development and use of GM crops. The c**osts in terms of foregone benefits may be large,** especially for developing countries. Economics research has an important role to play in designing efficient regulatory mechanisms and agricultural innovation systems.

A large amount of scientific, peer-reviewed literature on socio-economic impacts of biotech crops, among others with specific case-studies in India, China, Argentina, Australia, Africa, etc. can also be found in the CropLife database on: http://croplife.intraspin.com/BioTech/search2.asp?keyword=&button=Search

3. Socio-economic impacts at the European level

A. *Ex post* analysis versus *ex ante* studies

Only insect-resistant maizes Bt176 (no longer cultivated today) and MON810 have been planted commercially in the EU to date.

Romania, before its accession to the EU in 2007, also has ample experience with the cultivation of HT GM soybean.

Given the lack of *ex post* data on other GM traits and crops in Europe, an overview is presented of *ex ante* analyses estimating the socio-economic impact of biotech crops in the EU.

B. Insect-resistant (IR) maize in Europe

GM maize MON810 is the only GMO cultivated today in the EU on approximately 100.000 ha. It was planted for the first time in 1998 in Spain. In June 2009, 124 different varieties derived from MON810 were authorised for cultivation in Spain (Esteban, 2009).

Several applications for the authorisation of cultivation of other GM IR maize varieties have been pending for a long time in the EU. The main purpose of cultivating MON810 is to increase yields by reduced infestation with the Lepidopteran pests *Ostrinia nubilalis* (European corn borer or ECB) and *Sesamia nonagroides* (Mediteranean stem borer or MSB). The ECB is the main insect pest that attacks maize crops, although the MSB is also of economic importance in many areas (Brookes, 2009c)

ECB causes severe physical damage to the plant by penetrating the stalk and excavating large tunnels that result in important yield losses. ECB larvae are difficult to control with insecticides because they are vulnerable to sprays or residues only for a short time before they bore into and are protected by the cob, sheath-collar or stalk (Velasco et al., 1999). Therefore, proper timing is crucial for success and often, repeated applications are necessary (Demont et al., 2007).

B.1. Areas suffering damage from corn boring pests in Europe

The European Corn Borer is found throughout the whole of Europe, with the exception of Scandinavia and the British Isles and is most harmful in Southern and South-East Europe (Szoke et al., 2002). However, recent climate changes indicate that its importance might increase in Central Europe (Trnka et al., 2007).

According to industry figures, across the EU 27, the estimated area that annually suffers from economic levels of damage from corn boring pests is **within a range of about 2.25 million hectares and 4 million hectares**, with the lower end of the range probably representative of the area experiencing economic losses in a year of below average (low) pest problems and the higher end of the range representative of the area suffering economic losses in years of above average (high) infestation levels. The impact varies by location, year, climatic factors, time of planting and use of insecticides, according to the level of infestation.

A detailed overview of damage levels per country can be found in Brookes (2009c). The existing and potential impact of using GM insect resistant (GM IR) maize in the European Union.

B.2. Economic impacts of Bt maize: Focus on Spain

A thorough, large-scale impact analysis of the performance of Bt maize in Spain was carried out by the JRC (Gómez-Barbero et al., 2007, 2008a, 2008b).

The main conclusions were:

- Spanish farmers adopting Bt maize experienced **higher average yields** than conventional maize growers. Average **yield benefits** have often been **+10%** and sometimes higher, although impacts vary by region and year according to pest pressure. Significant yield gains have been reported for example in the province of Zaragoza, with a **yield increase of 1.11 kg/ha or 11.8%** (Gómez-Barbero et al., 2008a, 2008b).

  According to recent figures of the Spanish Ministry of Environment (Esteban, 2009):
  - When the level of infestation is high, the increase of yield ranges from 10 to 20%
  - When level of infestation is low, the increase of yield ranges from 0 to 1%
  - As an average, **the increase of yield is 6.3% (ranging from 2.9 to 12.9%)**

- **Decreased use of insecticides**: Conventional corn farmers in Spain applied 0.86 treatments/year compared with 0.32 treatments/year for Bt maize farmers. The percentage of farmers applying no insecticides was 70% for Bt maize growers and 42% for conventional growers.
- A **price premium** of Bt maize seeds relative to conventional seeds was observed, but it was significant only in Zaragoza, the province showing the highest yield increase for Bt maize. This suggests that seed distributors may adjust the price premium of GM seed reflecting the performance of the technology in a particular region.
- Yield gains for Spanish farmers adopting Bt maize translated directly into revenues increase, as no differences were found in the crop price paid to Bt or conventional maize farmers. The yield advantage of Bt maize, together with reduced pesticide costs, increased **farmer income by up to 120€ per ha**, compensating for the significant price premium of Bt maize seeds.
- In Spain, the average size of farmer adopting GM IR maize was 50 ha and many were much smaller than this. Therefore size can not be considered to be an important factor affecting adoption, with many small farmers using the technology. Furthermore, no statistical differences were found in age, education or experience of the maize growers.
- IR crops produce a **higher quality** of crop. In long-term field experiments with MON810 maize by the European project ECOGEN, the GM maize was found to produce a **higher grain size** or allowed a **significant reduction in pesticide use** (Andersen et al., 2007).
- 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 having **lower levels of mycotoxins**. Evidence from the Spanish Ministry of Environment

(Esteban, 2009) has shown a consistent pattern in which GM IR corn exhibits significantly reduced levels of mycotoxins compared to conventional and organic alternatives. In terms of revenue from sales of corn, however, no premia for delivering product with lower levels of mycotoxins have been reported to date; however, 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.

B.3. Other economic impacts of Bt maize

Spain is the only EU member state where GM IR maize adoption levels are currently delivering farm income and environmental gains at or near full potential levels.

A thorough overview of the realised and foregone benefits of GM IR maize adoption in the EU is presented by Brookes (2007, 2009c):

- **Higher yields**: As ECB and MCB damage varies by location, year, climatic factors, timing of planting, whether insecticides are used or not and the timing of application, the positive impact on yields of planting Bt maize also varies. Yield impacts have been observed between neutral and +30% in different EU countries.
- **Insecticide reductions**: Where maize growers have traditionally used insecticides to control corn boring pests, the switch to using GM IR technology has resulted in important reductions in insecticide use and its associated environmental impact.
  For France, it was estimated that the 22,000 ha of Bt maize cultivated in 2007 allowed for saving up to 8 800 liters of insecticide sprays (Orama, 2007).
  Brookes (2009a) estimated that for the EU-27 annual savings of between 0.41 million kg and 0.7 million kg of insecticide active ingredient could be realised if GM IR maize technology was used on its full potential.
- **Higher farm income**: The annual direct farm income benefit potential of Bt maize in the EU ranges between €160 million and €247 million. Across the EU only between 8% and 12% of this total potential benefit is being realised;
  In 2007, users of GM IR maize earned average, additional income levels of +€186/ha, within a range of +€25/ha (Romania) and €201/ha in Spain. Across all users of the technology, the total increase in farm income directly attributable to the technology in 2007 was +€20.6 million, and cumulatively, the increase in farm income (in nominal terms) has been €55.7 million. The largest share of these farm income gains have, not surprisingly, gone to Spanish farmers who have been using GM IR technology since 1998 compared to the more recent use in other countries. Across all years of adoption, the average farm income benefit has been €131/ha.

B.4. Social impacts of Bt maize in Spain

The JRC listed the following social impacts of Bt maize cultivation in Spain (Gómez-Barbero & Rodríguez-Cerezo, 2007):

- Adoption of Bt maize has no impact on the amount of farm labour employed.
- Adoption of Bt maize in Spain is not statistically related to farm size.
- The prices received by farmers in Spain for Bt or conventional maize are the same.
  (all Bt maize grain produced is sold entirely for animal feed production).
- The economic welfare resulting from adoption of Bt maize in Spain is basically

shared between farmers and seed companies, including the seed developer, seed producers and seed distributors. The largest share of welfare (74.4% on average) went to Bt maize farmers and the rest to the seed companies (25.6% on average).

Demont et al. (2007) concluded in the study “GM crops in Europe: How much value and for whom” that:

- In Europe, as in the rest of the world - **2/3 of the benefits of growing GM are shared among European farmers and consumers**, while 1/3 goes to the gene developers and seed suppliers.
- The European farmers gain substantially from GM technologies. Growing GM crops gives European farmers access to potentially cost-reducing technologies in an increasingly competitive environment.

C. Herbicide tolerant (HT) soybeans: a Romanian story

- Herbicide tolerant soybeans were grown commercially in Romania from 1999-2006 and accounted for 68% (or in absolute figures 137,000 ha) of all soybeans planted in 2006. Farmers who used HT GM soybeans indicated that this crop was the most profitable arable crop grown in Romania, with gains derived from higher yields and improved quality of seed coupled with lower costs of production. Other advantages: increased convenience and management flexibility; small saving on harvest cost; significant benefits in the crop rotation pattern. In a representative sample of commercial farms, the profit margin per hectare ranked between EUR 100 and 187, corresponding to a production range varying from 3 to 3.5 tonnes/ha, while, in the same market year (2006), conventional soybean growers were running losses. The increase in income was the result of herbicide cost reduction (on average, 1.9 treatments applied to HT soybeans and, respectively, 4.3 treatments to the conventional one) as well as the higher yields (3-3.5t/ha for HT versus 2 t/ha for the conventional product) (Otiman et al., 2008).
- **Yield gains** of an average of 31% have been recorded for GM HT soybeans in Romania (Brookes, 2009a).
- Improved weed control arising from the adoption of GM HT crops has also **reduced harvesting costs** for many farmers in Romania. 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. Examples of countries where this has arisen include Romania (GM HT soybeans: Brookes, 2005), Canada (GM HT canola: Canola Council, 2001) and Argentina (GM HT soybeans: Qaim & Traxler, 2005).
- The **cost of the technology** to farmers in Romania tended to be higher than other countries, with seed being sold in conjunction with the herbicide. For example, in the 2002-2006 period, the average cost of seed and herbicide per hectare was $120/ha to $130/ha. This relatively high cost however, did not deter adoption of the technology because of the major yield gains, improvements in the quality of soybeans produced (less weed material in the beans sold to crushers which resulted in price premia being obtained) and cost savings derived (Brookes, 2009a).
- The average net increase in gross margin in 2006 was $220/ha (an average of $175/ha over the eight years of commercial use) (Brookes, 2009a).
- At the national level, the increase in farm income amounted to $28.6 million in 2006.
- Cumulatively in the period 1999-2006 the increase in farm income was **$92.7 million** (in nominal terms) (Brookes, 2009a).

- In added value terms, the combined effect of higher yields, improved quality of beans and reduced cost of production on farm income in 2006 was equivalent to an annual increase in production of 33% (124,000 tonnes) (Brookes, 2009b).
- **Also small scale farmers can benefit from GM crops**: in Romania, the average size of farmer adopting GM HT soybeans was 30-40 ha. Size can not be therefore considered to be an important factor affecting adoption, with many small farmers using the technology (Brookes, 2005).

D. *Ex ante* study: Herbicide tolerant (HT) sugar beet

- **HT sugar beet** has a high potential for European farmers, as the conventional crop **has high weed controls costs** and secondly, sugar beet is **grown in all the EU** countries. If HT sugar beet were to be adopted on a global scale, EU farmers would substantially gain from the technology (€194 million) (Demont et.al., 2007).
- In another ex ante analysis, Dillen et al. (2009) estimated the **global value of HT sugar beet** for society in the period 1996-2014 at **€15.4 billion of which 29% would be captured by EU-27 farmers**.

E. Other *ex ante* studies on GM crops in the EU

- **Benefit sharing of GM crops in the EU** (Demont et al., 2007)
  The potential annual value of GM technologies for European agriculture ranges from **€0.1 million to €42 million for single Member States and to €668 million for the EU-25.** Per-hectare values of GM technologies for maize and oilseed rape range from €30 to €78/ha and are very much in line with global observations. After a decade of commercialisation of first-generation GM crops, the global benefits of these technologies are established. A review of the benefit-sharing literature reveals a general rule of thumb: **two thirds of the benefits flow downstream, while upstream input suppliers capture one third**. This rule of thumb applies in developing countries as well as in industrial countries, including Europe. Our analyses suggest that, in spite of the quasi-monopolistic upstream sector (gene developers and seed companies), European farmers would substantially gain from GM technologies. This is at odds with the popular view of the opponents of agricultural biotechnology.
- **Willingness of EU farmers to adopt GM crops** (Rodriguez-Cerezo, 2009)
  Based on field surveys in 2007 (over 1200 farms) the JRC carried out an e*x ante* analysis of adoption and effects of HT maize and HT oilseed rape in Europe. The preliminary conclusions suggest a high potential adoption (41.5%) by farmers of HT oilseed rape, HT maize and stacked HT/Bt maize.
- Overview of ex ante studies by Gómez-Barbero & Rodríguez-Cerezo (2007):
    - If 75% of French farmers were to grow HT oilseed rape they would save €24 million in weed control costs with a **total economic benefit of 38** million euros.
    - If UK growers adopted HT sugar beet their weed control savings would be 217 euros per ha and total benefits would be **€33.5 million**.
    - If Andalusian cotton farmers in Spain were to use Bt insect resistant cotton their insect control costs would be reduced by **€148 per ha**.

4. Ecological impacts of biotech crops

Plant biotechnology is safely delivering large environmental benefits around the world. By helping to increase crop yields per hectare, while at the same time increasing efficiency of inputs (such as water and fertiliser) and helping to protect biodiversity, biotechnology is a key tool for sustainable agriculture by minimising the environmental footprint of modern agricultural practices.

Biotech crops are **stringently tested and regulated** for environmental safety. Plant biotechnology is a key technology for a sustainable agriculture, because it:

- Increases yield and has the potential to improve the quality of food, feed and renewable resources
- Enables the efficient use of limited resources such as land and water
- Allows efficient cropping practices that reduce the use of energy, fertiliser (on a per product basis)
- Helps to sustain biodiversity
- Is crucial in mitigation and adaptation of climate change and reduce the use of CO_2

A. The optimized production of food, feed and renewable resources

Over the past years, rapidly rising food prices have highlighted a crisis in the sustainability of global food supplies. In addition to posing near-term threats to human welfare – driving the global total of hungry people close to one billion – the crisis poses a major challenge of ensuring adequate, sustainable food production systems for the world's growing population.

Food value chains are complex, involving multiple stakeholders and industries. In poor regions, the potential for increasing food production and local incomes is constrained by numerous challenges.

The challenge of providing enough – and the right type of food, feed and fuel in a sustainable way is of major importance for the EU countries. The objective of EU is thus to strengthen and intensify the research effort within sustainable food, feed and bioenergy production.

The use of GMO crops (James, 2008):

- Increases productivity. This is particulary important in regions of the world which suffer from difficult climatic conditions. GMOs can therefore play an important role in mitigating the effects of the food crisis.
- Produce better, safer and healthier food and feedstuff, including crops with an altered oil content and composition.
- Produce food and feed containing fewer cancer causing natural toxins such as mycotoxins.
- Mitigate the impact of climate change by enabling farmers to grow more food, more reliably, in harsher climatic conditions.

B. Improved land and water use

Biotech crops assist in bringing higher yields per hectare, making farming more efficient and productive on limited land area. Since habitat destruction is the biggest single threat to biodiversity, higher yields mean farmers can produce increasing amounts of food without increasing the use of arable land, and this has a major impact on protecting wildlife habitats.

Biotech crops are a land-saving technology, capable of higher productivity on the current 1.5 billion hectares of arable land, and thereby can help preclude deforestation and protect biodiversity in forests and in other in situ biodiversity sanctuaries. Approximately 13 million hectares of biodiversity-rich forests are lost in developing countries annually. During the period 1996 to 2007 biotech crops have already precluded the need for an additional area of 43 million hectares of crop land, and the potential for the future is enormous (James, 2008).

If biotech traits had not been available to the 12 million farmers using biotech crops in 2007, maintaining global production levels at the 2007 levels would have required additional plantings of 5.89 million ha of soybeans, 3 million ha of corn, 2.54 million ha of cotton and 0.32 million ha of canola (Brookes & Barfoot, 2009a).

C. Reduced use of energy and fertilisers

Biotech crops have helped reduce the use of pesticides for several economically important crops, contributing to reductions in fuel, water and packaging that are eliminated from the manufacturing, distribution and application processes. Also for the nitrogen use efficient crops in the pipeline, there is a strong potential to further improve the environmental footprint of agriculture by reducing the energy use. Biotech crops can directly contribute to the reduction of energy consumption on farms by decreasing the amount of tractor fuel used for seedbed preparation, spraying and fertiliser applications. Conservation tillage and no-till approaches can reduce tractor fuel consumption by 40-70% respectively, leading to reductions in CO2 emissions of 40.43 to 89.44 kg/ha respectively (Barfoot & Brookes, 2009b). Through a reduction in the dependency on crop protection products and fertilisers, biotech crops offer additional opportunities to increase global food security while further reducing the environmental footprint of agriculture.

Biotech crops have helped reduce the use of pesticides for several economically important crops, contributing to reductions in fuel, water and packaging that are eliminated from the manufacturing, distribution and application processes.

Insect resistant crops offer an alternative to chemical inputs on some crops and have allowed development of more targeted, flexible, effective and sustainable integrated pest management programmes.

Since their commercial introduction in 1996, the usage of biotech crops have reduced pesticide spraying by 359 million kg of active ingredients (-9% in pesticide applications) and as a result decreased the environmental impact associated with herbicide and insecticide use on the area planted to biotech crops by 17.2% (Brookes & Barfoot, 2009a).

Also fertiliser use can contribute to water pollution. Since nitrogen (N) is the most essential nutrient for plants and a major limiting factor in plant productivity, doubling agricultural food production worldwide over the past four decades is associated with a 20-fold increase in N fertilizer use.

Moreover, the majority of grain crops are inefficient users of nitrogen—barely more than half of the nitrogen applied to grain fields is utilized for plant growth. As a result, the remainder may run off into area waterways or volatize as nitrous oxide, a potent greenhouse gas.

The availability of biotech crops with improved nitrogen-use efficiency can significantly reduce the amount of nitrogen farmers apply to fields, which can increase on-farm productivity and profitability while decreasing the potential environmental impacts from nitrogen fertilizer use. Reduced use of nitrogen fertilizer will also reduce the carbon footprint and increase the net energy of biofuels based on grain crops (Shrawat & Good, 2008).

D. Protection of biodiversity

Apart from the benefits of saving land and avoiding habitat destruction by bringing higher yields per hectare, biotech crops can also directly contribute to more biodiversity. Herbicide tolerant crops allow the farmer to control the weeds much later. Leaving the weeds in the field for a longer period provides food for insects (and, in turn, birds) before the weeds are sprayed, and later leaves behind a mulch of dead weeds which is also a good habitat for insects. After harvest in the autumn, new winter crops can be planted directly, with no need to disturb the soil structure by ploughing. This no-till system also maintains greater soil biodiversity and reduces fuel use. The broad-spectrum herbicides used affect only green plants and are safe for people and wildlife.

Another example is insect resistant biotech maize, which is grown commercially on more than 100,000 ha in several European countries. These insect-resistant crops are more specific in their pest control activity and numerous studies have demonstrated that they have no adverse effects on non-target insects (Marvier et al., 2007; Romeis et al., 2006).

A number of trials with glyphosate-resistant fodder beets showed a lower herbicide use and thereby a lower negative impact on the environment than with conventional beets and traditional use of herbicide. The trials also showed that for most weeds satisfactory weed control was achieved by postponing the praying, which can benefit cultivation and can improve the biodiversity in the field. The yield of the GM beets was on a level with conventional beet varieties (Danish Ministry of Food, Agriculture and Fisheries, 2009).

E. Mitigation of climate change and reducing greenhouse gases

Biotech crops are already contributing to reducing CO2 emissions by precluding the need for ploughing a significant portion of cropped land, conserving soil and particularly moisture, reducing pesticide spraying as well as sequestering CO2.

Biotech crops can contribute to a reduction of greenhouse gases and help mitigate climate change in two principal ways:

1) Permanent savings in carbon dioxide emissions through reduced use of fossil-based fuels, associated with fewer insecticide and herbicide sprays; in 2007, this was an estimated saving of 1.1 billion kg of carbon dioxide (CO2), equivalent to reducing the number of cars on the roads by 0.5 million.

2) Additional savings from conservation tillage for biotech crops, led to an additional soil carbon sequestration equivalent in 2007 to 13.1 billion kg of CO2, or removing 5.8 million cars off the road.

Thus in 2007, the combined permanent and additional savings through sequestration was equivalent to a saving of 14.2 billion kg of CO2 or removing 6.3 million cars from the road (Brookes & Barfoot, 2009a).

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