The impact of using GM insect resistant maize in Europe since 1998

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Abstract: Genetically Modified (GM) insect resistant (Bt) maize crops have been grown commercially in the European Union (EU) since 1998, and in 2006, there were plantings in seven EU member states. This paper reviews the specific economic impacts on yield and farm income as well as the environmental impact in respect of insecticide usage (where data exists). The analysis shows that there have been important yield and net economic benefits at the farm level equal to an improvement in profitability of between 12 and 21%. Where farmers have previously used insecticides to control pests, the technology has reduced insecticide spraying and as a result decreased the associated environmental impact. Bt maize has also delivered important improvements in grain quality through significant reductions in the levels of mycotoxins found in the grain.

Keywords: yield; cost; income; Environmental Impact Quotient; EIQ; mycotoxins; GM crops.

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1 Introduction

This paper reviews published and company-produced data on the impacts linked to the use of Genetically Modified (GM) insect resistant (Bt) maize in the European Union (EU) since the trait was first approved for planting in 1998. Its aim is to identify consistencies, differences and trends in the impact of this technology from a number of country-specific pieces of research conducted since 1998, and hence provide a single source of impact analysis for researchers. It presents country-specific analysis followed by a discussion.

Only Bt 176 and MON 810 – resistant to the Lepidopteran pests *Ostrinia nubilalis* European Corn Borer (ECB) and *Sesamia nonagroides* Mediteranean Stem Borer (MSB) have been planted in Europe to date. Currently, only varieties of the event MON 810 are available for cultivation: 41 varieties in Spain, 6 in France, 5 in Germany and 36 have been registered on the EU Common Variety Catalogue (status of December 2006).

Bt maize was planted for the first time in 1998 in Spain and in 2006 the area planted to Bt maize in Spain was about 58,000 ha. Small amounts of Bt maize were also planted in France in 1998, in Portugal in 1999 and in Germany every year since 2000. Renewed activity was seen in 2005 as, France, Portugal and the Czech Republic also reported Bt maize plantings, albeit on limited areas. In total, the area planted to Bt maize in the EU was just below 65,000 ha in 2006, equivalent to approximately 0.6% of total EU 25 maize plantings (including forage maize area). The global GM crop area in 2006 was 102 million ha.

2 Results

These are presented by country below.

2.1 Spain

ECB is the main insect pest that attacks maize crops in Spain, although the MSB is also of economic importance in many areas. The Spanish maize crop may be subject to two generations of ECB (in the North-East, three generations sometimes occur) although the incidence and impact of infestation varies significantly by region and year, influenced by local climatic conditions, use of insecticides and planting times (e.g. early planted crops are usually better able to withstand attacks relative to later plantings). Brookes (2003) classified the maize growing regions of Spain into three regions according to historic annual pest pressure levels (high, medium and low pest pressure regions) and drawing on these classifications, it is evident that the highest concentrations of Bt maize plantings in 2006 were found in regions which have traditionally experienced medium to high pest pressure levels[1] such as Aragon and Catalunya.

Spanish maize farmers have historically either had no active policy/methods for the control of ECB or used insecticides (Brookes, 2003). Insecticide treatments[2] have been used mostly by farmers in high infestation regions (e.g. Huesca) at the rate of one or two insecticide treatments per season. Insecticide use in Spain has, however traditionally been limited because many farmers perceive that insecticides have limited effectiveness: they may control ECB larvae on the surface of maize plants at the time of spraying but are less effective against larvae that have bored into stalks. Also, egg-laying can occur over a three week period and most insecticides are only effective for 7–10 days. Overall, ECB pest pressure varies and hence in some years damage may be limited and some farmers probably do not appreciate the level of damage to yields inflicted by the ECB. Lastly, some Bt maize users indicated that it was only after using Bt maize that they realised fully what adverse impact the ECB caused (Brookes, 2003).

2.1.1 Yield impact of GM insect resistant (Bt) maize seed

As ECB 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. Data obtained in Spain between 1998 and 2005 is summarised in Table 1.

Table 1 Impact of Bt maize on yield in Spain (1998–2005)

Regions	*Base maize yield*	*Yield of Bt compared to conventional maize*		*Comments*	*Reference*
	tonnes/ha	*tonnes/ha*	*%*		
Huesca (Sarinena)	10	+1	+10 (+2– + 20)	High infestation region; insecticides previously used	Brookes (2003)
		+1.5	+15 (+10+40)	No insecticides previously used	Brookes (2003)
Several regions	12.51	0.75	+6	Trial plots across a number of regions in 1997 (insecticides previously used on conventional crops)	Alcalde (1999)
Huesca (Barbastro)	15	+ 0.15	+1	One farmer, low average infestation; no insecticides previously used	Brookes (2003)
15 locations (Catalonia, Aragon and Navarra)	13	+ 1.3	+10	Field trials; conventional crop included treated and not treated (with insecticides) plots	Monsanto Company (2003–2007)
Aragon, Catalunya and Castilla La Mancha	Not cited in original literature		Perceived: +1– +14; Measured average: +5	Survey of 400 farms, incl. 218 Bt maize users; may include some conventional crops treated with insecticides	Gomez-Barbero and Rodriguez-Cerejo (2006a,b)
Range	10–13	0.2–1	1–40	–	–

2.1.2 Farm cost and profit impacts

There have been a number of studies/analyses on the impact of using Bt maize in Spain at the farm or national level. These are summarised below.[3]

2.1.2.1 Brookes (2003) In the Sarinena locality in the Huesca region (locality of high infestation levels): gross margin increases of between +67 and +€330/ha (i.e. +6– +35%), with an average of €147/ha (+13%) were identified. The cost of using the Bt maize (technology fee) was more than recovered via the savings on insecticide costs (where insecticides had previously been used). The main benefit however, came from yield gains, which more than offsets additional cost of the technology (for both farmers who has previously used insecticides and those who had not used insecticides).

In one low infestation locality (one farmer in the Barbastro locality of the Huesca region), the net result of using Bt maize has been 'break even' in term of cost and revenue changes (i.e. no net change over four years).[4]

2.1.2.2 Monsanto Company trials, 2003–2005 A summary of the estimated impact on farm margins using trial data from Monsanto Company is shown in Table 2 (the conventional crop was treated with insecticides such as chloropyrifos or pyrethroids). This estimates the average farm income benefit to be +€141/ha, a 12% increase in gross margin profitability compared to growing conventional maize.

Table 2 Impact on gross margin of using Bt maize, based on field trials 2003–2005 (€/ha)

	Conventional maize	*Bt maize*	*Bt versus conventional maize*
Revenue			
Price (€/tonne)	127	127	0
Yield (tonnes/ha)	10.61	11.72	+1.11
Sales revenue	1347	1488	+141
Variable costs			
Seed	166	201	+35
Insecticide	35	0	−35
Total	201	201	0
Gross margin	1146	1287	+141 (+12%)

Note: 1 baseline price, conventional average yield and seed cost is averaged for the three years (Brookes, 2002–2004): European arable crop profit margins, 2–4 editions).

2 insecticide cost and seed premium (€35/ha) – Monsanto Company personal communication.

Source: Monsanto Company trial data (2003–2007).

2.1.2.3 Gomez-Barbero and Rodriguez-Cerezo (2006 a,b) This survey-based analysis covering the 2002–2004 period identified an average gross margin benefit from using Bt maize compared to conventional maize of €85/ha per growing season. The gross margin impacts ranged between +€7/ha in Castilla La Mancha and +€125/ha in Aragon.

2.1.2.4 Brookes and Barfoot (2007) The key farm and national level income impacts, identified between 1998 and 2005 were net annual average saving on cost of production (from lower insecticide use) of 34–€42/ha and a net increase in gross margin of +86 and +€108/ha. At the national level, these yield gains and cost savings have resulted in farm income being boosted, in 2005 by €4.4 million. Cumulatively, since 1998, the increase in farm income (in nominal terms) has been €25.4 million.

2.1.2.5 Demont and Tollens (2003, 2005) This work estimated that for the four year period of 1998–2001 the total benefit distributed between farmers using the technology and the supply chain upstream of farmers (seed supplying sector and technology providers) was €11.2 million. This was split as follows: €8.4 million (75%) to farmers and €2.8 million (25%) to the supply industry. This analysis was updated in 2004 to cover the six year period from 1998 to 2003 and estimated the total welfare gain to have been €15.5 million, of which farmers derived €10.4 million benefit (66% of the total) and the upstream supply industry €5.1 million (33% of the total).

2.1.3 Environmental impact (use of insecticides)

Based on insecticide usage data from 1999 to 2001 (used almost exclusively to control ECB attacks in regions with high infestation levels which used chloropyrifos and pyrethroids), Brookes (2003) estimated that the usage savings would potentially amount to a net reduction in the area sprayed of 59,000–98,000 ha and a reduction in active ingredient usage of 35,000–56,000 kg. Relative to total insecticide usage on maize in Spain (including soil insecticides) this represents a reduction in the total area sprayed of 27–45% and a reduction in active ingredient use of 26–35%.

Further analysis by Brookes and Barfoot (2007) found that the adoption of Bt maize has also resulted in a net decrease in the field Environmental Impact Quotient (EIQ/ha load).[5,6] Since 1998 the cumulative saving (relative to the level of use if the total crop had been non-GM) was 239,000 kg of insecticide ai (a 34% decrease) and the field EIQ/ha load had fallen by 30% since 1999 (−10.4 million units). In 2005, the field EIQ load was about 43% lower than its conventional equivalent.

2.1.4 Mycotoxins

There have been a number of studies examining the presence of fungi that potentially produce mycotoxins, in Bt versus conventional maize in Spain. These include Bakan et al. (2002) who examined *Fusarium* infection levels in Bt versus non-Bt maize trial plots at five locations (three in France and two in Spain). The results indicated that Bt maize had up to 10 times less Fumonisin (FUM) content than the non-Bt maize varieties. In addition, Serra et al. (2006)[7] found that the percentage of maize plants attacked by fungi were significantly lower in Bt maize (1.2%) compared to conventional maize (2.5%). Also FUMs were observed in only 17% of Bt plants compared to 100% of the conventional maize plants analysed.

2.1.5 Intangible impacts

Brookes (2003) identified that the adoption of Bt maize has also delivered non-monetary benefits, including:

- improved production risk management: Bt maize could be seen as an insurance against ECB, taking away the worry of significant ECB damage occurring
- a convenience benefit: farmers devote less time to crop walking and/or applying insecticides
- a small net saving in energy use: mainly from less use of aerial spraying
- reduced exposure to insecticides for farmers and farm workers
- easier harvesting (e.g. fewer problems from fallen crops: ECB damaged crops are easily flattened by late summer winds).

2.2 France

The first commercial plantings of Bt maize were in 1998 (between 1800 and 3000 ha planted), then there were no commercial crops again until 2005. Plantings in 2006 were equivalent to 5200 ha (Association Générale des Producteurs de Maïs (AGPM)/ Arvalis, 2006).

Annually, between 1 and 2 million ha of maize are affected by ECB and MSB in France, of which approximately 0.3–0.75 million ha experience economic levels of losses from these pests. These areas tend to be concentrated in the South-West, including areas within the principal maize growing regions of Midi Pyrénées, Aquitaine and Poitou-Charentes where 1–2 generations of ECB, and 2–3 generations of MSB occur. ECB (one generation) also causes problems for maize growers further north, including the other primary maize growing region of Alsace. As in all regions with ECB/MCB problems, the impact varies by location, year, climatic factors, time of planting and use of insecticides, according to the level of infestation.

Where they decide to treat against ECB and/or MCB, French farmers use insecticides or biological control methods, consisting of the release of the parasitic wasp *Trichogramma*. From 2003 to 2005, the area treated with insecticides or *Trichogramma* was between 0.2 and 0.7 million ha (*source*: unpublished Kleffmann market research data). This is equivalent to between 6 and 23% of the total French maize crop (inclusive of fodder maize plantings).

2.2.1 Yield impact of Bt maize seed

Data obtained in France on the yield impact of using Bt maize is summarised below. The efficacy against ECB of this technology is reported to range between 95 and 99%[8] (Grenouillet, 2006; Labatte et al., 1996).

- Poeydemenge (2006a,b) identified an average yield improvement in 2005 of 0.7 tonnes/ha on a base yield of 10 tonnes/ha (+7%) relative to crops treated with insecticides.
- AGPM/Arvalis trials identified a yield gain of 0.55 tonnes/ha (+6%) in 2006 where there had been low levels of pest infestation and 1.15 tonnes/ha (+13%) where medium to high levels of pest infestation had occurred. The average yield gain was 0.92 tonnes/ha (+11%).
- Grenouillet (2006) cites average yield gains within a range of +5–+17%. In high infestation regions, the gains were in a range of +5–+25% in six of the seven years analysed.
- The Monsanto Company field trials in 2006 found an average 12% increase in yield (on a base conventional maize yield of 11.13 tonnes/ha). When analysed according to pest pressure, the yield benefits of using Bt maize seed was +2, +10 and +15%, respectively for low, medium and high infestation zones.

2.2.2 Farm cost and profit impacts

Analysis based on AGPM/Arvalis (2006) found that the technology delivered an increase in average gross margin profitability of +€98/ha (+18%) in 2005 and +€120/ha (+35%) in 2006 (Table 3).[9]

A similar level of positive farm income impact has been identified based on findings from commercial farms growing Bt maize (*Source:* Monsanto, 2003–2007). The technology delivered an increase in average gross margin profitability of +€114/ha (+16%) compared to a conventional crop not previously treated with insecticide.

2.2.3 Environmental impact (use of insecticides)

Drawing on unpublished Kleffmann market research data of the French maize crop that was treated with insecticides targeted at ECB and *Sesamia* in 2006, if this area adopted Bt maize and was no longer sprayed, the savings in the insecticide spray area would be 251,000 ha.

Table 3 Impact of using Bt maize on farm profitability in France relative to a conventional crop treated with insecticides, 2005–2006 (€/ha)

	2005			*2006*		
	Conventional maize	*Bt maize*	*Bt versus Conventional maize*	*Conventional maize*	*Bt maize*	*Bt versus conventional maize*
Revenue						
Price (€/tonne)	120	120	0	120	120	0
Yield (tonnes/ha)	10	11	+1	9	10	+1
Sales revenue	1248	1336	+88	1032	1142	+110
Variable costs						
Seed	150	190	+40	150	190	+40
Fertiliser	139	139	0	139	139	0
Crop protection	100	50	−50	100	50	−50
Irrigation	300	300	0	300	300	0
Total	689	679	−10	689	679	−10
Gross margin	559	657	+98 (+18%)	343	463	+120 (+35%)

Note: Analysis based on Poeydemenge (2006a,b) and AGPM/Arvalis (2006) applied to average variable costs for maize in Brookes (2007a) European arable crop profit margins 2006–2007 and average harvest prices at the farm level for the average of 2004–2006; Conv: conventional. Crop protection = expenditure on insecticides or biological control for insect control and herbicides for weed control.

2.2.4 Mycotoxins

Poeydemenge (2006a,b) reports findings from the 2005 trials comparing FUM levels in maize from conventional and Bt maize. For both FUM types B1 and B2, there was a reduction of 90% or more in the levels in Bt crops relative to the conventional alternative (baseline levels in the conventional crops were about 3900 parts per billion (ppb) for FUM B1 and about 1200 ppb for FUM B2. The AGPM/Arvalis (2006) reports similar findings from 2006 trials. For both FUM types B1 and B2, there was a 33% reduction in the levels in Bt maize relative to the conventional alternative where low levels of pest infestation were experienced (baseline conventional levels for these FUMs were 1000 ppb) and for maize in locations with medium to high levels of pest infestation, the reduction in FUM B1 and B2 levels was 58% (baseline levels in the conventional crops were 3100 ppb). Lastly, Grenouillet (2006) found significant reductions in the levels of FUM B1, Deoxynivalenol (DON) and Zearalenone in Bt Yieldgard maize compared to conventional maize in Monsanto Company trials conducted between 1998 and 2003. When compared to the recently introduced EU maximum limits for FUM B1 in human foods of 2 ppm (Regulation (EC) No. 856/2005), 17 of the conventional samples from the trials would have failed this threshold and in 15 of these cases the Yieldgard equivalent would have been below (i.e. passed) the threshold.

2.2.5 Intangible impacts

The intangible benefits observed in France are potentially the same as have occurred in other adopting countries like Spain, including greater management flexibility and improved production risk management.

2.3 Germany

Between 1998 and 2004, there were only limited precommercial plantings (up to 5 tonnes of seed per variety) as no appropriate Bt maize varieties were listed on the German variety catalogue. In 2005, one variety was approved in Germany and plantings increased to 250 ha, then reached 950 ha in 2006, as five varieties were approved.

Estimates of the area of the German maize crop annually affected by ECB fall between 0.3 and 0.5 million ha (Deutscher Bundestag, 2006; Degenhardt et al., 2003). The largest ECB problems are found in Bavaria and Baden-Wurtenberg.

2.3.1 Conventional treatment

German maize farmers have historically had either no active policy for ECB control, used insecticides or worked with biological control methods (*Trichogramma).* Unpublished Kleffmann farmer survey data identified that nearly two-thirds of farmers with ECB infestation did nothing to control the problem in 2006. Less than 20% of farmers used either insecticides or *Trichogramma*, the rest indicated they used crop rotation or ploughing as the main control method.

2.3.2 Yield impact of Bt maize seed

Findings from Degenhardt et al. (2003) shows that yield increases for Bt maize crops relative to untreated maize were of 14 and 15% in the Rhine Valley and the Oderbruch region, respectively. The yield increase compared to insecticide-treated plots and *Trichogramma* were in the range of +3–+4% and 8–11%, respectively for both these regions.

2.3.3 Farm cost and profit impacts

The impact on costs of production and profitability of Bt maize versus conventional maize are summarised in Table 4. In terms of the average gross margin for conventional maize in 2006/2007, the gains from using Bt maize (relative to an untreated crop) are equal to +12–+14%.[10]

2.3.4 Mycotoxins

Magg et al. (2003) examined Moniliformin (MON) concentrations in early maturing Bt maize hybrids, their isogenic counterparts, commercial cultivars and experimental hybrids and any correlation between resistance to the ECB and MON concentrations. This research was conducted at five locations in Germany. It is found that MON concentrations were significantly lower (and grain yields higher) in Bt maize hybrids relative to their isogenic counterparts, commercial cultivars and experimental hybrids. Correlations between concentrations of MON and other *Fusarium* mycotoxins were however, not significant. The work concluded that the use of Bt maize hybrids reduces the contamination of maize grains with MON in Central Europe.

Table 4 Average impact of using Bt maize on farm profitability in 2006–2007 in Germany (€/ha)

Origin/basis	*Bt versus untreated conventional maize*	*Bt versus conventional maize treated with insecticides*	*Bt versus conventional maize treated with Trichogramma*
Degenhardt et al. (2003)[a]	+83–+93	+38–+66	+136–+150
Gianessi et al. (2004)	–	+61	+154

[a]Values for the Rhine Valley and the Oderbruch region.

Note: Conv: Conventional.

Papst et al. (2005) investigated the association between concentrations of mycotoxins and ECB resistance. The study made comparisons between early maturing Bt hybrids, their isogenic counterparts and commercial hybrids. The field experiments were conducted at three locations in the main maize growing regions of Germany (See low in the east and Freising and Heilbron in the south). It is found that the Bt maize hybrids (protected against ECB attack) had significantly lower levels of DON and FUM concentrations than their isogenic counterparts and commercial hybrids. The study concluded that the use of Bt maize cultivars may represent a short-term solution to minimising toxin levels in maize kernels.

2.3.5 Intangible impacts

As in other countries, potentially the same impacts of greater management flexibility and improved production risk management.

2.4 Czech Republic

The first commercial plantings were in 2005 and the Bt maize area planted in 2006 was 1290 ha. ECB is the main pest of maize in the Czech Republic and the highest infestation regions can be found in the southern part of the country, although medium levels of infestation occur in parts of the North and the Centre. One, sometimes two generations of ECB are common. The State Phytosanitary Service (SRS), Prague (2006) estimates high infestations of ECB in an area of about 80,000–90,000 ha, particularly in Moravia although the area subject to levels of damage that are economically significant and which have been subject to regular conventional insecticide treatments or treated with trichogramma is about 40,000 ha (Daems et al., 2006; Monsanto Company estimates (2003–2007)).

2.4.1 Yield impact of using Bt maize seed

Monsanto Company trials undertaken in 2005 showed a +9–+10% yield increase across 11 trials undertaken in Bohemia/Moravia. The base yield was 11.64 tonnes/ha. Daems et al. (2006), in reviewing the impact of ECB on yield put the range of positive yield impact between +5 and +20% and Abel (2006) cited a yield benefit of +10% for the one Bt maize grower in Brno.

2.4.2 Farm cost and profit impact

Abel (2006) cites an increase in gross margin profitability of 10% (+€44/ha) based on insecticide costs of 18 to €36/ha, spray application costs of 8.4–€16.8/ha and a seed premium for Bt maize seed of €35/ha. Table 5 applies this impact analysis to an adjusted average maize gross margin for the country. This suggests that Bt maize would deliver, to an average maize grower with ECB infestation problems, additional gross margin income of €65.4/ha (+15%).

Table 5 Estimated impact of using Bt maize in the Czech Republic (€/ha)

	Conventional maize	*Bt maize*	*Bt versus conventional maize*
Revenue			
Price (€/tonne)	103	103	0
Yield (tonnes/ha)	7.2	7.92	+10%
Sales revenue	742	816	+74
Variable costs			
Seed	52	87	+35
Fertiliser	59	59	0
Crop protection[a]	55	37	−18
Other variable costs	132	124	−8
Total	298	307	+9
Gross margin	444	509	+65 (+15%)

[a]One spray at €18/ha for insect pest control ECB, with the balance of crop protection expenditure being on herbicides for weed control.

Note: Based on data from Abel (2006), Monsanto Company 2005 trial data, adjusted variable costs for 2006–2007 (Brookes, 2007a) and prices are average for the years 2004–2006.

2.4.3 Environmental impact (use of insecticides)

Where Bt maize technology is replacing the use of insecticides, this is clearly reducing the level of insecticide use and its associated impact on the environment. Given that about 33,000 ha of maize in the Czech Republic used insecticides targeted at the ECB in 2006 (and assuming that the area planted to Bt maize replaced previously sprayed crops), then the potential for reducing the spray area annually with insecticides is 34,000 ha.

2.4.4 Mycotoxins

Findings from the Monsanto Company trials of 2005 showed significant reductions in the levels of mycotoxins (DON, FUM) in the kernels of a Bt maize variety relative to its conventional equivalent. Parts per million levels for FUM fell from about 600 ppb to about 50 ppb and DON levels fell from about 100 ppb to about 10 ppb.

2.5 Portugal

Around 1300 ha of Bt maize were planted in 1999, then no further commercial crops were grown until 2005. The areas of Bt maize planted in 2005 and 2006 were 500 and 1240 ha, respectively.

The potential market for Bt maize in Portugal (targeted at the ECB, where there are relatively high levels of annual infestation) is 15,000 ha, equal to about 10% of the grain maize area, or 6% of the total maize (including forage maize) in Portugal (*source*: Monsanto Company, 2003–2007). The main high infestation regions are Alentejo and Ribatejo, with some presence also in Porto.

2.5.1 Yield impact of using Bt maize seed

Monsanto Company trials conducted in 2005 identified an average yield improvement of 1.19 tonnes/ha (+12%) relative to untreated crops. Provisional results from the 2006 trials (for five fields) identified a range of positive yield impact of +8–+17%.

2.5.2 Farm cost and profit impact

Data from the Monsanto Company 2005 field trials, assuming no insecticide costs and a seed premium of €35/ha, indicates an increase in average gross margin profitability of +€112/ha (+22%) for Bt maize users compared to untreated conventional maize (Table 6).

Table 6 Impact of using Bt maize on farm profitability in Portugal, 2006 (€/ha)

	Conventional maize	*Bt maize*	*Bt versus conventional maize*
Revenue			
Price (€/tonne)	133	133	0
Yield (tonnes/ha)	8.8	9.9	+1.1
Sales revenue	1170	1317	+147
Variable costs			
Seed	164	199	+35
Fertiliser	211	211	0
Crop protection	71	71	0
Irrigation	209	209	0
Total	655	690	+35
Gross margin	515	627	+112 (+22%)

Note: The average yield used for the gross margin analysis is the country average for irrigated crops – this is lower than the average conventional crop yield in the trials undertaken by Monsanto Company. Variable costs are for 2006–2007.

Source: Brookes (2007a) and prices are the average for 2004–2006. Crop protection costs are all for herbicides with farmers not using any insecticides for control of ECB/MCB.

2.5.3 Environmental impact (use of insecticides)

This is likely to be small if only limited amounts of insecticide are currently being used.

2.6 Poland

No commercial crops of Bt maize have been planted to date; very small 'precommercial test' plantings took place in 2006 (30 ha). A few years ago, ECB presence in Poland was largely limited to some regions in the South and South-East of the country. However, its prevalence has increased and almost all regions of Poland are reported to currently experience some level of infestation. Whilst levels of infestation vary by year and region, the Plant Protection Institute (Beres, 2007) estimates that annually since 2003, between 93 and 98% of maize crops in South-East Poland experience problems with ECB attacks. The use of insecticides or trichogramma for ECB control has been negligible mainly because ECB pest pressure varies and hence in some years damage may be limited, some farmers probably do not appreciate the level of damage to yields inflicted by the ECB, the cost of treatments is perceived to be high (64–€77/ha *Trichogramma*, €26/ha insecticides (Monsanto Company, 2003–2007) and there is a perception of limited effectiveness (insecticides 62–89% efficacy, *Trichogramma* 57–59% efficacy (Berés and Lisowicz, 2005).

2.6.1 Yield impact of using Bt maize

Preliminary official variety registration trials conducted in 2005 and comparing three Bt maize varieties from different companies against their conventional equivalents identified a positive yield impact of Bt maize in the range of +2– +23% (+0.2– +2.7 tonnes/ha). Specific trials conducted by Monsanto Company in 2006 comparing two Bt maize varieties with their conventional equivalent varieties found a positive yield gain of 25–26% (+2.15– +2.19 tonnes/ha).

2.6.2 Farm cost and profit impact

Applying the yield impacts from the 2005 and 2006 trials (see above) to current gross margins, Table 7 highlights the range of potential impact (that is dependent largely upon the level of ECB infestation). In regions of low ECB infestation (or years of lower than average infestation), the yield gains are small and may result in a net reduction in gross margin profitability. However, in high infestation regions/years, significant yield and income gains are likely to occur.

Table 7 Impact of using Bt maize on average Polish maize gross margins, 2006 (€/ha)

	Conventional maize	*Bt maize*	*Bt versus conventional maize*
Revenue			
Price (€/tonne)	128	128	0
Yield (tonnes/ha)	5.75	5.84–7.19	0.09–1.44
Sales revenue	736	748–920	+12–+184

Table 7 Impact of using Bt maize on average Polish maize gross margins, 2006 (€/ha) (continued)

	Conventional maize	*Bt maize*	*Bt versus conventional maize*
Variable costs			
Seed	95	140	+45
Fertiliser	166	166	0
Crop protection	62	62	0
Other variable costs	235	235	0
Total	558	603	+45
Gross margin	178	145–317	−33–+139 (−18–+78%)

Note: Price of grain maize based on average for 2004–2006, Yield: range of impact based on +1.6–+25%, seed premium based on +€45/ha, crop protection assumed to be unaltered (i.e. no treatments for corn borer were being used on the conventional crop) with all costs for herbicides.

Source: Conventional cost data derived from the Polish Farm Advisory Service (WODR) and presented in Brookes (2007a), European arable crop profit margins, 2006–2007.

2.6.3 Environmental impact (use of insecticides)

This is likely to be limited because negligible amounts of insecticide are currently being used on maize in Poland. The increasing incidence of ECB in Polish maize crops does, however suggest that insecticide use specifically targeted at the ECB may develop in the next few years and hence this (possible future use of insecticides) could be displaced by Bt maize technology.

2.6.4 Mycotoxins

Tekiela and Gabarkiewicz (2007) studied and compared *Fusarium* occurrence and mycotoxin content in Bt versus conventional maize in 2005. The comparisons were made between four Bt and equivalent conventional maize varieties, at two locations in South-East Poland. In all cases, the levels of mycotoxins (FUMs B1, B2 and B3 and Deoxynivalenone) and were significantly lower in the Bt maize relative to the conventional maize (Table 8).

Table 8 Mycotoxin levels in Bt versus conventional maize (trial results) Poland, 2005

Parts per million	*Bt maize*	*Conventional maize*
Deoxynivalenol (DON)	Less than 50–155	148–1141
Fumonisin (FUM) B1	0–25	121–409
Fumonisin (FUM) B2	0–8	44–103
Fumonisin (FUM) B3	0	6.7–13

Source: Tekiela and Gabarkiewicz (2007).

2.7 Slovakia

Commercial plantings of Bt maize first occurred in 2006 (30 ha). ECB is estimated to cause economic levels of damage to about one-third of the country's maize crop, for example, 50,000 ha (Brookes, 2007b). Very little insecticide use is reported to be used for ECB control in Slovakia. This reflects the same reasons outlined above for other countries (e.g. ECB pest pressure varies, perception of limited effectiveness of insecticides).

2.7.1 Yield impact of using Bt maize seed

Findings from the 2006 commercial plantings identified a positive yield impact within a range of +10–+14.7% (Monsanto Company, 2003–2007).

2.7.2 Farm cost and profit impact

Analysis presented in Brookes (2007b) which assumed no insecticide costs identified an increase in average gross margin profitability in the range of +32–+€63/ha (+8.9–+17.5%, Table 9).

Table 9 Impact of using Bt maize on farm profitability in Slovakia, 2006 (€/ha)

	Conventional maize	*Bt maize*	*Difference*
Revenue			
Price (€/tonne)	96	96	0
Yield (tonnes/ha)	6.97	7.67–7.99	+0.7–1.02
Sales revenue	669	736–767	+67–98
Variable costs			
Seed	90	125	+35
Fertiliser	79	79	0
Crop protection	60	60	0
Other variable costs	79	79	0
Total	308	343	+35
Gross margin	361	393–424	+€32–+€63 (+8.9–+17.5%)

Source: Yield impact of +10–+14.7% used by Brookes (2007a) based on findings of trials and commercial experience in the Czech Republic and commercial plantings in Slovakia. Variable costs for 2006–2007 (Brookes 2007a) and prices are the average for 2004–2006. Crop protection costs are for herbicides with no insecticides used.

At the national level the annual positive impact on farm income is likely to be between +1.5 and +3 million euros (based on one-third of the total maize adopting the technology.

2.7.3 Environmental impact

The positive environmental impact of Bt maize is likely to be limited because negligible amounts of insecticide are currently used on maize in Slovakia. The increasing incidence of ECB, however suggest that insecticide use specifically targeted at this pest may develop in the next few years and hence this (possible future use of insecticides) could be displaced by Bt maize technology.

3 Discussion

This paper has reviewed data on the impacts linked to the use of GM insect resistant (Bt) maize in a number of EU member states since 1998. A summary of the key findings is presented in Table 10 this shows a number of consistencies relating to the impact of the technology together with some differences. These are summarised and discussed further below:

- In all of the EU maize growing regions affected by ECB and MSB, where Bt maize has been adopted, the evidence of the various studies reviewed shows consistently that the primary impact of the adoption of Bt maize has been higher yields compared to conventional non-GM maize. Average yield benefits have often been +10% and sometimes higher.

- It is, however important to recognise that variations in the impact of the technology have occurred between years and across member states (and between localities within regions and member states). This largely reflects variability in the incidence of ECB and MCB attacks on maize crops. If crops suffer little or no pest attack then yield losses tend to be small and hence the positive yield impact of using Bt maize has also been limited (e.g. as low as +1%). In contrast, in years and regions where ECB and Sesamia damage has been significant (i.e. caused significant yield losses; often as high as −10–−20%), the positive yield impact of using Bt maize has been much higher (e.g. as high as +24%). This pattern of (variable) yield impact of the Bt technology is no different to the impact of any other technology used to control pests in maize (e.g. use of insecticides or biological controls) except that the efficacy levels for Bt maize (in controlling ECB and MCB) have been significantly higher than the conventional alternatives.

- In 2006, users of Bt maize have, on average, earned additional income levels of between €65 and €141/ha. This is equal to an improvement in profitability of +12–+21%. The evidence of impact on income levels for other years (where data is available) also shows a consistent positive impact of the technology, although as indicated above for impact on yield, this has varied according to the level and extent of pest damage by year and region.

- In certain regions where studies have been conducted, Bt maize has delivered important and consistent improvements in grain quality through significant reductions in the levels of mycotoxins found in the grain. This is not surprising given that the ECB and MCB pests damage maize crops making them susceptible to fungal damage and the development/build up of mycotoxins in the grain. As with the impact of the technology on yield and income, the positive impact on grain quality has varied by region and year according to the level of pest attack and extent to which this has caused fungal damage and mycotoxin development in crops.

Table 10 Agronomic and economic benefits of adopting Bt maize resistant to ECB in the EU (1998–2006)

	Spain	*France*	*Germany*	*Czech Republic*	*Portugal*	*Poland*	*Slovakia*
Bt maize area (2006, ha)	53,667	5200	950	1290	1240	30	30
Area of high ECB infestation (ha)	80,000	300,000 – 750,000	300,000– 500,000	31,000 37,000	15,000	Not available	50,000
Average yield of Bt versus conventional Maize (%)[a]	+1– +15	+5– +24	+14– +15	+9– +10	+12%	Average not available	Average not available
Average Bt maize seed premium (2006, €/ha)[a]	35	40–45	39–42	31–38	35	45	35
Average conventional maize gross margin (2006–2007, €/ha)[b]	1146	559	683	444	515	178	361
Average impact on profitability (€/ha)	+141 (+12%) in high infestation regions	+98– +120 (+16– +21%)	+83– +93 (+12%– +14%)	+65 (+15%)	+112 (+22%)	Average not available	Average not available
Impact on grain quality (reduction in mycotoxin levels)	Significant reduction	Significant reduction	Significant reduction	Significant reductic	No studies	Significant reduction	No studies

[a]Average across various regions, infestation levels and studies.

[b]Variable costs largely from Brookes (2007a) European Arable Crop Profit Margins 2006–2007, 5th edition, prices based on averages for the years 2004–2006.

Note: Conv: Conventional.

The findings presented in this review are also consistent with analysis of the impact of Bt maize technology in other countries outside the EU (e.g. North and South America, South Africa and the Philippines). In all countries where the technology has been adopted farmers have seen consistent increases in both yields and income levels, with annual and regional variations in impact reflecting the variable incidence of pest attacks and damage.[11]

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References

Abel, C. (2006) 'Czech in time for GM crops', *Farmers Weekly*, Vol. 145, No. 18, pp.36–38.

AGPM/Arvalis (2006) Programme PACB 2006-Annexe 1: Mais OGM en plein champ: des résultats probants.

Bakan, B., Melcion, D., Richard-Molard, D. and Canagnier, B. (2002) 'Fungal growth and fusarium mycotoxin content in isogenic traditional maize and GM maize grown in France and Sapin', *Journal of Agriculture and Food Chemistry*, Vol. 50, pp.728–731.

Beres, P. (2007) 'Effects of chemical control of the European corn borer *(Ostrinia nubilalis* Hbn), In South-Eastern Poland in 2003–2005', *Journal of Plant Protection Research*, (submitted for publication in 2006).

Berés, P. and Lisowicz, F. (2005) 'Effectiveness of *Thrichoramma* spp. in maize protection against European corn borer (*Ostrinia nubilalis* Hbn.) in ecological farms', *Progress in Plant Protection/Postepy W Ochronie Roslin*, Vol. 45, pp.47–51.

Brookes, G. (2002–2004) *European Arable Crop profit Margins*, 2nd to 4th editions, Gloucester, UK: GBC Ltd.

Brookes, G. (2003) 'The farm level impact of using Bt maize in Spain', *7th ICABR Conference on Public Goods and Public Policy for Agricultural Biotechnology*, Ravello, Italy. Available at: http://www.pgeconomics.co.uk. Accessed on January 2007.

Brookes, G. (2007a) *European Arable Crop Profit Margins*, 5th edition, Gloucester, UK: GBC Ltd.

Brookes, G (2007b) 'The potential role of GM cost reducing technology in helping the Slovak arable cropping sector remain competitive', *PG Economics*, Dorchester, UK, Available at: http://www.pgeconomics.co.uk. Accessed on January 2007.

Brookes, G. and Aniol, A. (2005) 'The possible impact of using GM agronomic traits in Polish arable crops', *9th ICABR Conference on Public Goods and Public Policy for Agricultural Biotechnology*, Ravello, Italy, Available at: http://www.pgeconomics.co.uk. Accessed on January 2007.

Brookes, G. and Barfoot, P. (2005) 'GM crops: the global economic and environmental impact: the first nine years 1996–2004', *AgBioforum*, Vol. 8, Nos. 2/3, pp.187–196. Available at: http://www.agbioforum.org. Accessed on January 2007.

Brookes, G. and Barfoot, P. (2007) 'GM crops: the first ten years– global socio-economic and environmental impacts', *AgbioForum*, Vol. 9, No. 3, pp.1–13.

Daems, W., Demont, M., Muska, F., Sonkups, J. and Tollens, E. (2006) 'Potential impact of biotechnology in Eastern Europe: transgenic maize, sugar beet and oilseed rape in the Czech Republic', *10th ICABR Conference on Agricultural Biotechnology*, Ravello, Italy.

Degenhardt, H., Horstmann, F. and Mulleder, N. (2003) 'Bt maize in Germany: experience with cultivation from 1998 to 2002', *Mais*, Vol. 2.

Demont, M. and Tollens, E. (2003) 'Impact of biotechnology in Europe: the first four years of Bt maize adoption in Spain', *EUWAB-project*, Department of Agricultural and Environmental Economics, K U Leuven, Belgium, Available at: http://www.agr.kuleuven.ac.be/aee/clo/wp/demont2003h.pdf. Accessed on January 2007.

Demont, M. and Tollens, E. (2005) 'Potential impact of biotechnology in Eastern Europe: transgenic maize, sugar beet and oilseed rape in Hungary', Katholieke Universiteit Leuven. Available at: http://www.agr.kuleuven.ac.be/aee/clo/ep/demont2005a.pdf. Accessed on January 2007.

Deutscher Bundestag (2006) *Drucksache*, 16/3059.

Gianessi, L., Sankala, S. and Reigner, N. (2004) 'Potential impact for improving pest management in European agriculture: maize case study', Available at: http://www.ncfap.org. Accessed on January 2007.

Gomez-Barbero, M. and Rodriguez-Cerezo (2006a) 'The adoption of GM insect-resistant Bt maize in Spain and its economic consequences for farmers: an empirical approach', *Paper Presented to the 10th International Conference on Agricultural Biotechnology: Facts, Analysis and Policies*, Ravello Italy.

Gomez-Barbero, M. and Rodriguez-Cerezo (2006b) 'Economic impact of dominant GM crops worldwide (2006b) Eur 22547', Joint Research Council, http://ftp.jrc.es/eur22547en.pdf.

Grenouillet, C. (2006) 'Intérêt du maïs Bt Yieldgard pour limiter le risque de développement de fusarioses des épis et la présence de mycotoxines dans les grains', *AFPP 8th Conférence sur les maladies des plantes*, Tours, France, 5–6 December 2006.

Kovach, J., Petzoldt, C., Degni, J. and Tette, J. (1992) 'A method to measure the environmental impact of pesticides', *New York's Food and Life Sciences Bulletin*, NYS Agricultural Experiment State Cornell University, Geneva, NY, Vol. 139, p.8 annually updated.

Labatte, J., et al. (1996) 'Field evaluation of and modelling the impact of three control methods on the larval dynamics of Ostrinia nubilalis', *Journal of Economic Entomology*, Vol. 89, pp.852–862.

Magg, T., Bohn, M., Klein, D., Merditaj, V. and Melchinger, A. (2003) 'Concentration of moniliformin produced by Fusarium species in grains of transgenic Bt maize hybrids compared to their isogenic counterparts and commercial varieties under European corn borer pressure', *Plant Breeding*, Vol. 122, pp.322–327.

Monsanto Company (2003–2007) *Trial results From Several Years in Spain, Portugal, France, Czech Republic, Poland and Slovakia*.

Papst, C., Utz, H., Melchinger, A., Eder, J., Magg, T., Klein, D. and Bohn, M. (2005) 'Mycotoxins produced by Fusarium spp. In isogenic Bt vs. non-Bt maize hybrids under European corn borer pressure', *American Journal of Agronomy*, Vol. 97, pp.219–224.

Poeydemenge, C. (2006a) 'Les bénéfices du maïs Bt observés en France', *Presentation to the SEPROMA General Assembly*, 21 September 2006.

Poeydemenge, C. (2006b) 'Bt maize benefits observed in France, *Presentation to 10th ICABR Conference on Agricultural Biotechnology*, Ravello, Italy, July 2006.

Serra, J., Lopez, A. and Salva, J. (2006) 'Varietats de blat de moro geneticamente modificades (GM) amb resistencia al barrinadors', *Productivitat I alters parameters agronomiques*, Dossier Tecnic del DARP, Generalitat de Catalunya, Vol. 10, pp.13–18.

Tekiela, A. and Gabarkiewicz, R. (2007) 'Fusarium spp. occurrence and mycotoxin content in grain of GM corn varieties', *Institute of Plant Protection*, Rzeszow, and Monsanto Poland, Warsaw.

Notes

[1]Readers should note that this classification is a simplification of experience as areas of relatively low pest pressure and experience can be found within regions of traditionally high pest pressure and vice versa.

[2]Mostly of chloropyrifos and pyrethroids.

[3]The reader should note that the cost and profit impacts are closely linked to infestation levels and their associated impact on yield. Also, in 2006, the seed premium for the MON 810 maize was reported to be about €35/ha (Monsanto Company, 2003–2007). The seed premium for using the Bt 176 trait, now no longer available, was reported back in 2002 to be between 18 and €30/ha (Brookes, 2003).

[4]This farmer indicated that year one was one of average ECB attack and the impact of Bt maize use was positive, year two was one of low infestation and hence the impact of Bt maize use was negative, year three was one of high ECB attack and the impact of Bt maize use was positive and year four was one of no ECB attack for which Bt maize impact was negative.

[5]This universal indicator, developed by Kovach et al. (1992) and updated annually, effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare'. This provides a more balanced assessment of the impact of GM crops on the environment as it draws on all of the key toxicity and environmental exposure data related to individual products, as applicable to impacts on farm workers, consumers and ecology, and provides a consistent and comprehensive measure of environmental impact.

[6]The average volume of insecticide ai used is 0.96 kg/ha and the average field EIQ is 42/ha.

[7]Based on research conducted at two sites; one in Girona (coastal area) and one in Lleida over the two years 2004 and 2005.

[8]Efficacy against the target pests – in terms of % mortality.

[9]The cost of the technology is €40–€45/ha (AGPM/Arvalis, 2006; Monsanto Company, 2003–2007; Poeydemenge, 2006a,b).

[10]The seed premium payable by farmers in 2006 was €23/unit of seed, equivalent to between 39 and €42/ha, depending on seed planting density.

[11]Seed planting density varies across countries and therefore may contribute to differences in the Bt seed premium cited for each country.

[12]See for example Brookes and Barfoot (2007) for a review of global impacts.