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RESEARCH PAPER

Twenty-one years of using insect resistant (GM) maize in Spain and Portugal: farm-level economic and environmental contributions

Graham Brookes

Agricultural Economist at PG Economics Ltd, UK

ABSTRACT. This study assesses the economic and environmental impacts that have arisen from the adoption and use of genetically modified (GM) insect resistant (IR) maize in Spain and Portugal in the 21 years since first planted in Spain in 1998. A total of 1.65 million hectares have been planted to maize containing these traits since 1998, with farmers benefiting from an increase in income of €285.4 million. For every extra €1 spent on this seed relative to conventional seed, farmers have gained an additional €4.95 in extra income. These income gains have mostly arisen from higher yields (+11.5% across the two countries using the technology). The seed technology has reduced insecticide spraying by 678,000 kg of active ingredient (−37%) and, as a result, decreased the environmental impact associated with herbicide and insecticide use on these crops (as measured by the indicator, the Environmental Impact Quotient (EIQ)) by 21%. The technology has also facilitated cuts in fuel use, resulting in a reduction in the release of greenhouse gas emissions from the GM IR maize cropping area and contributed to saving scarce water resources.

KEYWORDS. Spain; Portugal; Insect Resistant maize

Correspondence to: Graham Brookes graham.brookes@btinternet.com
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INTRODUCTION

GM crop technology has been widely used in maize in many parts of the world over the last 21 years and GM IR maize technology was first used in North America (USA and Canada) in 1996. Since then, its use has been extended to 185 million ha (2017) of maize planted in 11 countries outside the EU (USA, Canada, Argentina, Brazil, Colombia, Paraguay, Uruguay, Honduras, South Africa, Philippines and Vietnam). In the European Union (EU), the only GM maize trait authorized for planting has been IR maize (resistant to the Lepidopteran pests *Ostrinia nubilalis* (European corn borer or ECB) and *Sesamia nonagroides* (Mediteranean stem borer or MSB)) which was first authorized for planting in 1998. In 2018, maize using this trait was planted on 121,132 ha, in Spain and Portugal only (Table 1: equal to 0.07% of the total global biotech maize area).

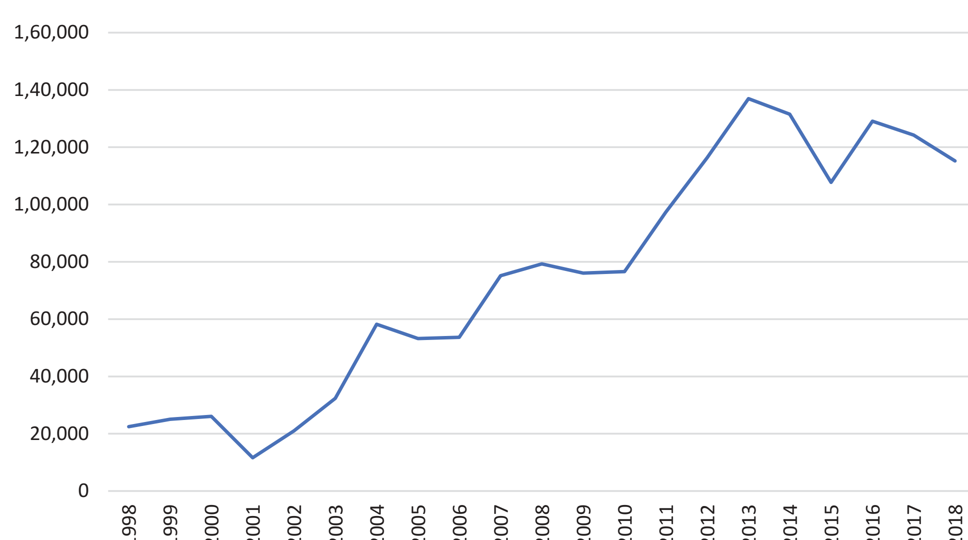
The original IR maize trait approved for planting in the EU was *Bt 176* available in a single variety, *Compa CB*, in Spain in 1998. Subsequently, EU member states introduced a moratorium on the further approval of GM crops which lasted until 2003. During this period, the area planted to IR maize in Spain remained at an average level equal to about 21,500 ha because of a voluntary agreement by Syngenta Seeds to limit seed availability to this level until the EU moratorium on new GMO approvals was formally lifted. After 2003, the trait MON 810 was approved for planting (afterwards Bt 176 was withdrawn from the market) and became available in a number of leading varieties (a total of 90 and 26 varieties respectively in Spain and Portugal (2018)). As a result, the area planted to IR maize in Spain increased (Fig. 1) so that since 2012, approximately 30%–35% of the total maize area in Spain has consistently used this

TABLE 1. GM insect resistant maize plantings 2013–2017 (ha).

Country	2013	2014	2015	2016	2017	2018
Spain	136,962	131,538	107,749	129,081	124,227	115,246
Portugal	8,202	8,542	8,047	7,057	7,308	5,886
Total	**145,164**	**140,080**	**115,796**	**136,138**	**131,535**	**121,132**

Sources: Ministerio de Agricultural y Pesca Alimentacion, Dados Nacionais Republica Portuguesa, EuropaBio
Note: The GM IR areas in Spain was equivalent to between 28% and 37% of the total maize area (2013–2018). The GM IR areas in Portugal was equivalent to between 5.6% and 7.9% of the total maize area (2013–2018).

FIGURE 1. Area of IR maize in Spain 1998–2018 (hectares).
Source: Ministerio de Agricultura, Pesca y Alimentacion



seed technology. GM IR maize was first planted in Portugal in 1999 on 1,300 ha but was not then planted again until 2005, after the lifting of the moratorium. The area planted followed a similar upward trend to Spain in subsequent years so that from 2011, approximately 7%–9% of the total crop has been planted to seed containing this trait (7,000–9,000 ha).

This paper presents an assessment of some of the key economic and environmental impacts associated with the adoption of IR maize in Spain and Portugal since 1998. The analysis focuses on:

- *Gross farm income effects* on costs of production, yield/production and farm income;
- *Changes in the amount of insecticides applied to the GM crops relative to conventionally grown alternatives and;*
- *The contribution of the technology toward reducing global greenhouse gas (GHG) emissions and water saving.*

METHODOLOGY

The approach used to estimate the impacts of IR maize draws on the farm level and aggregate impacts identified in the global impact studies of Brookes and Barfoot.[1,2] These examined farm level economic impacts on crop yield and production gains and environmental impacts associated with changes in insecticide use and carbon emission savings associated with better pest control with the IR trait in maize. The material presented in this paper combines data presented in these papers for the period 1998–2016 but extends the analysis to include the years 2017 and 2018. The methodology used in the global impact of biotech crops covering the 1998–2016 period has also been applied to the years 2017 and 2018. This analysis is, itself based on a combination of papers, data and analysis of the impact of the technology in Spain and Portugal by other authors plus some 'own analysis'. Additional information about the assumptions can be found in Appendix 1 (together with examples of calculations of impacts for the year 2018). Readers requiring further details relating the methodology should refer to the two references cited above.

THE BASELINE – NATURE OF THE TARGET PEST OF THE TECHNOLOGY AND CONVENTIONAL METHODS OF CONTROL

The primary target of the technology, the ECB is the main insect pest that attacks maize crops in Spain and Portugal, as well as in other EU countries, although the MSB is also of economic importance in many areas. The maize crop may be subject to two generations of ECB (sometimes three generations) although the pest pressure incidence and levels of infestation typically vary by region and year, being influenced by local climatic conditions, the extent to which conventional forms of control (notably the application of insecticides) are used and planting times (early planted crops are usually better able to withstand attacks compared to crops planted later in year).

In Spain, approximately 120,000 ha to 150,000 ha (30%–35% of the total maize crop) regularly experiences ECB/MSB damage (based on a combination of industry estimates and the area traditionally receiving insecticide treatments for corn boring pest control).[3] The regions which have traditionally experienced the highest levels of pest pressure are Aragon and Catalunya.

In Portugal, a smaller area is estimated to regularly suffer pest damage from the ECB/MSB pest (up to 15,000 ha: Source),[4] equal to about 14%–15% of the grain maize area). The main regions that experience the highest levels of ECB/MSB pest pressure are Alentejo, Coastal Centro and Lisboa e Vale do Tejo.

Traditionally, conventional maize growers in these two countries have taken two alternative approaches toward the control of these pests. Firstly, there is the "no active policy of treatment," which is a fairly common approach, both in the EU and worldwide, with the second main approach being based on the use of insecticides. The no active policy of treatment reflects the variability in the levels of pest pressure by year and the limited efficacy of insecticide-based control. Insecticides have limited effectiveness because they may control pest larvae on the surface of maize plants at the time of spraying but are less effective against larvae that have bored into stalks, egg-laying can occur over a three-week period and most insecticides are only effective for 7–10 days. Also, as most pest damage takes place inside stalks rather than being readily visible on the plant surface, some farmers may not be fully aware of the level of damage to yields caused by the ECB and MCB. This was highlighted in surveys of farmers using GM IR maize technology.[3]

The use of insecticides for the control of the ECB/MSB pests in conventional maize was concentrated in the regions of highest infestation (e.g., Huesca). In Spain, the maize area typically treated with insecticides for control of these pests was between 60,000 ha and 100,000 ha per year, with the number of treatments being one or two per season. This compares with the area regularly experiencing significant levels of pest damage of between 120,000 ha and 150,000 ha (30%–35% of the total crop).

In Portugal, prior to the availability of GM IR maize technology, very little insecticide use is reported to be have been used for control of these pests.

When GM IR maize technology became available to farmers, the highest concentrations of early (GM IR) maize plantings were found in regions which have traditionally experienced the highest pest pressure levels such as Aragon and Catalunya in Spain and the Alentejo and Coastal Centro regions of Portugal. In subsequent years, as adoption levels increased, farmers in all regions where these pests have traditionally had a negative impact on crop yields adopted the technology (Table 2).

TABLE 2. GM IR maize area by region Spain and Portugal 2018.

Spain	Area (ha)	Portugal	Area (ha)
Region		***Region***	
Aragon	44,932	Norte	61
Catalonia	38,752	Coastal Centro	1,312
Extremadura	14,138	Lisboa e Vale do Tejo	1,175
Navarra	8,101	Alentejo	3,338
Castilla-la Mancha	3,805		
Andalusia	4,972		
Others	546		
Total	**115,246**		**5,886**

Sources: Ministerio de Agricultura, Pesca y Alimentacion, Dados Nacionais Republica Portuguesa

RESULTS

Impacts on Farm Income and Crop Production

At the farm level, GM IR maize has provided Spanish and Portuguese farmers with higher yields from better pest control (relative to pest control obtained from conventional insecticide technology). 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 varies. Table 3 summarizes the findings of analysis on the impact of GM IR maize on yields in the two countries. Additional information is provided in Appendix 1. For the purposes of this analysis,

TABLE 3. Yield impacts from using GM IR maize in Spain and Portugal.

Country	Average yield of GM IR maize relative to conventional % difference	Range of yield impacts (where identified)	Comments
Spain	+6.3% 1998–2003 +10% to +13% 2004 onwards	+1% to +30%	Bottom of range is low infestation locality in a year of low pest pressure and top of range is high infestation locality in year of high pest pressure
Portugal	+12.5% to +13.5%	+8% to +17%	Range of impacts recorded in different regions with differing levels of pest pressure; low end of range = low pest pressure, high end of range = high pest pressure

Sources: Various – see appendix 1

all of these empirical findings are utilized, which in terms of average yield gains over the respective periods of adoption were +11.5% in Spain and +12.5% in Portugal.

The technology has also provided savings in expenditure on insecticides for many farmers. In Spain, the farm level studies identified average reductions in annual expenditure of between €6/ha and €50/ha (annual average of about €19/ha: see appendix 1: sources Brookes,[3] Gomez-Barbero and Rodriguez-Cerezo[5] and Riesgo et al.[6]) For Portugal, where insecticide use on conventional maize has traditionally been more limited, we have assumed that no insecticide cost savings have arisen with use of GM IR maize.

The combination of these impacts has increased the incomes of farmers using the technology by €285.4 million over the 21-year period of 1998–2018. This is the equivalent of an average farm income gain of €173/ha per year. In 2018, the income gain was €22.2 million (Table 4).

The largest share of the farm income benefits has been in Spain – 96% of total, where 95% of total plantings of IR maize have been.

Examining the cost farmers pay for accessing the IR seed technology, the average additional cost of seed (seed premium) relative to conventional maize seed, over the period 1998–2018 was €36/ha equal to 17% of the total (gross) technology gains (before deduction of the additional cost of the technology payable to the seed supply chain – the cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers). In terms of investment, over the 21 years of adoption, this means that for each extra euro invested in IR maize crop seeds in Spain and Portugal, farmers gained an average €4.95.

TABLE 4. Farm income gains derived from GM IR maize (‘000€).

Country	2018	Cumulative 1998–2018	Cumulative area planted to IR maize ('000 ha)
Spain	21,401	274,676	1,569
Portugal	774	10,698	83
Total	**22,175**	**285,374**	**1,652**

Sources: Brookes and Barfoot[2] updated.

Based on the yield gains referred to in Table 3, the GM IR technology has added 1.89 million tonnes of maize to production since 1998 (Table 5). This extra production contributes to reducing pressure on farmers to use additional land for crop production. To illustrate, if IR maize technology had not been available to farmers in 2018, maintaining production levels for this year using conventional technology would have required the planting of an additional 15,240 ha of agricultural land to maize in the two countries. This equates to about 3.5% of the total area planted to maize in these two countries in 2018. Over the 21-year period, the land-saving equivalent derived from the extra production of GM IR maize has been 188,890 ha.

Impacts on the Environment Associated with Insecticide Use and Greenhouse Gas Emissions

GM IR maize traits have contributed to a reduction in the environmental impact associated with insecticide use on a significant proportion of the areas devoted to these crops. Since 1998, the use of insecticides on the Spanish GM IR crop area was reduced by 678,000 kg of active ingredient (−37% reduction), and the environmental impact associated with insecticide use on these crops, as measured by the EIQ indicator-[7], fell by 21% (Table 6).

The scope for impacts on greenhouse gas emissions associated with GM IR maize use comes from one principal source; fuel savings associated with less frequent insecticide applications. As indicated in the baseline, the maize area regularly treated with insecticides for the control of the ECB and MSB pests before the availability of

TABLE 5. Additional maize production from positive yield effects of IR maize (‘000 tonnes).

Country	2018	Cumulative 1998–2018
Spain	156.2	1,815.6
Portugal	5.8	72.0
Total	**162.0**	**1,887.6**

Sources: Brookes and Barfoot[1] updated

TABLE 6. Impact of using GM IR maize in Spain and Portugal: changes in insecticide use and associated environmental impact (as measured by EIQ indicator) 1998–2018.

Trait	Change in volume of active ingredient used ('000 kg)	Change in field EIQ impact (in terms of million field EIQ/ha units)	Percent change in active ingredient use on GM crops	Percent change in environmental impact associated with insecticide use on GM crops	Cumulative IR maize area 1998–2018 ('000 ha)
Total	– 678	– 18.2	– 37	– 21	1,652

Source: Derived from Brookes and Barfoot[2]

GM IR seed technology was limited to about 10% of the total crop in Spain and few farms in Portugal. As a result, the potential maximum savings in fuel use arising from fewer insecticide treatments is limited. Thus, over the 21-year period, 1998–2018 of GM IR use in Spain, the total savings have been equal to 1.58 million kg of carbon dioxide not released into the atmosphere, arising from less fuel use of 593,000 liters. This is equivalent to taking 980 cars off the road for a year. To provide context, this represents a very small, positive contribution to greenhouse gas reduction when compared to the 23.5 million cars registered in Spain (2017: source Eurostat).

The adoption of GM IR maize has also provided other environmental benefits. The reduced spraying of insecticides has also resulted in water usage savings. Over the 21 years, 1998–2018, the area no longer sprayed with insecticides for the control of ECB and MSB in Spain has been about 705,000 ha, which has resulted in water usage savings of between 141,000 and 705,000 m^3 of water (see appendix 1 for assumptions). On an annual basis (average over the last five years), there is a reduced spray area of about 36,260 ha, resulting in an insecticide application water saving of between 7,250 and 36,260 m^3.

Indirectly, the GM IR technology has also contributed to water savings through the higher yields/additional production of maize. If this extra production had otherwise been derived from conventional (non-GM) technology, an additional area equal to nearly 189,000 ha in Spain and Portugal would have needed to have been planted to conventional maize in the 1998–2018 period. Based on estimated usage of irrigation water in maize production in Spain (source: Ariel and Riesgo[8]: see appendix 1) this suggests that the additional irrigation water required to produce conventional maize on this area is equal to about 1,042 million m^3 of water. On an annual basis (average over the last five years), the additional area of conventional maize that would be required to be planted to produce the equivalent of the extra production derived from the GM IR technology is about 16,780 ha and this would have used an additional 94.7 million m^3 of water (89.4 million m^3 in Spain and 5.3 million m^3 in Portugal). Within each country, these volumes of water saved by the use of GM IR technology are respectively equal to about 0.5% and 0.2% of total annual water used for irrigation in agriculture (source derived from and based on Eurostat, 2010).

Other Impacts

The ECB and MCB pests damage maize crops making them susceptible to fungal damage and the development/build up of fumonisins (a group of cancer-causing mycotoxins produced by a number of fusarium mold species) in the grain. This increases the possibility of grain failing to meet the maximum permitted thresholds for the presence of these toxins, as laid down in Regulation (EC) 1126/2007. A number of studies have identified that the use of GM IR maize has, through a significant reduction in pest damage and the levels of fumonisins found in grains, led to an improvement in grain quality.[9,10] This then is likely to result in less maize being rejected by users in both the food and feed using sectors (the author is not aware of any publicly available data that has examined this issue).

The adoption of GM IR maize has also provided a number of other benefits, identified in analysis such as Brookes.[4] These include improved production risk management, with the seed technology being seen by many farmers as a form of insurance against ECB/MCB damage. Farmers have also been able to reduce the amount of time spent crop walking to monitor levels of pest pressure and the technology has made harvesting easier because of fewer problems of fallen crops (ECB/MCB damaged crops are easily flattened by late summer winds).[3] Whilst, there is no data available on the time saving derived from these changes, the gains are likely to be limited (e.g., savings associated with reduced insecticide application, where applicable have been typically only one treatment) but valued by farmers because it has freed up more time for other on-farm or off-farm activities.

It is noteworthy that the evidence presented above in this paper has identified largely positive impacts associated with the use of GM IR technology in the maize crops of Spain and Portugal. Examining whether any negative economic or environmental impacts have occurred, there is a lack of evidence of negative impacts in the peer reviewed literature relating to the adoption of this maize-seed technology in Spain or Portugal (or worldwide). The use, implementation and reasonable adherence to refuge and coexistence requirements by farmers of GM IR maize crops in Spain and Portugal has probably contributed to this.

Concluding Comments

GM IR maize technology has now been used by many farmers in Spain and Portugal for 21 years and, in 2018, about 121,000 ha were planted to seeds containing this technology (equal to 35% and 6% respectively of the total maize area in Spain and Portugal). This proportion of the total maize crop using GM IR technology broadly equates to the area in each country that regularly suffers significant levels of yield loss from the ECB and MSB pests, if left uncontrolled. The seed technology has helped farmers grow more food and feed (1.89 million tonnes of additional maize 1998–2018), using fewer resources and therefore contributed to reducing the pressure on scarce resources such as water. The extra production and reduced cost of insecticides have provided farmers with higher incomes equal to an average of €173/ha and an average return on investment equal to +€4.95 for each extra €1 spent on GM IR maize seed relative to conventional seed. The additional farm income from growing GM IR maize has boosted farm household incomes and so provided an economic boost to the rural and national economies of the two countries.

The technology has also contributed to reducing the environmental impact associated with insecticide use and lowered fossil fuel use for crop spraying.

Overall, the impact evidence from the 21 years of adoption of GM IR maize points to a positive contribution toward addressing the crop production and environmental challenges facing agriculture in both countries. These findings are also consistent with analysis by other authors.[11,12]

It is, however, noteworthy that whilst this maize-seed technology has been approved for planting for many years throughout the EU, many other EU member states have chosen to utilize the provisions of EU Directive 2015/412 that allows member states to restrict or ban the cultivation of EU-approved GM crops in their territories for nonscientific reasons. Eighteen-member states, and four regions, in two countries (Wallonia in Belgium, Northern Ireland, Scotland and Wales in the United Kingdom) have used this opt out to ban the cultivation of GM IR maize and therefore have foregone the economic and environmental benefits identified in the peer review literature. For example, in France, where annually between 0.3 million ha and 0.75 million ha of maize regularly suffers yield losses from the pests that GM IR maize controls, farmers are foregoing income gains of about €200/ha and wider French society is foregoing the environmental gains associated with reduced insecticide use on much of this area.[4]

DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST

No potential conflicts of interest were disclosed.

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STATISTICAL SOURCES

Kleffmann is a subscription-based data source (derived from farmer surveys) on pesticide use International Service for the Acquisition of Agri-biotech Applications (ISAAA)

APPENDIX 1: DETAILS OF APPLICATION OF DATA AND METHODOLOGY TO CALCULATING 2018 FARM INCOME GAIN AND INSECTICIDE USE CHANGES FOR GM IR MAIZE AND KEY ASSUMPTIONS

Farm income gains

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price: €/tonne)	Cost of tech (€/ha)	Impact on costs, net of cost of tech (€/ha)	Change in farm income (€/ha)	Change in farm income at national level ('000 €)	Production impact ('000 tonnes)
Spain	115.2	+ 12.6	10.76	181	+ 36.5	+30.09	+ 185.70	+ 21,401	+156.2
Portugal	5.9	+ 12.5	7.85	180.5	+ 37.5	+ 37.5	+ 131.54	+774	+ 5.8

Sources:
Areas planted: Ministry of Agriculture, Food and Environment (MAGRAMA), Spain, Ministry of Agriculture, Forestry and Rural Development (MAFDR), Portugal
Cost of technology: Brookes and Barfoot.[1] and Bayer Spain (personal communication) 2018
Insecticide use changes based on Brookes.[4] and saving equal to €6.41/ha, Riesgo et al,[6] Kleffmann insecticide use data.

3. Notes:

(1) Insecticide cost changes: Spain based on findings from Brookes.[4] and Ariel and Riesgo,[8] equals an average of €19/ha. For Portugal, where insecticide use has traditionally been more limited, it is assumed that the average Bt grower had not previously used insecticides for ECB/MCB control and therefore the assumed insecticide savings from using GM IR maize are zero.
(2) The cost of the technology represents the value paid by farmers to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers. It does not represent the value accruing to the technology providers but to the whole seed supply chain. The range in values across countries for cost of technology reflects reasons such as the price charged by different stages in the supply chain, exchange rates and average seed rates.
(3) Yield gains derive from a reduction of pest damage (IR trait).

Summary of yield impact assumptions and sources

	Base maize yield	Yield of Bt compared to conventional maize			
Country/regions	Tonnes/ha	Tonnes/ha	%	Comments	Reference
Spain					
Huesca (Sarinena)	10	+ 1	+10 (+2 to + 20)	High infestation region; insecticides previously used	Brookes[3]
		+2	+15 (+10 to +40)	No insecticides previously used	Brookes[3]
Several regions	-	-	+6	Trial plots across a number of regions in 1997	Alcalde[13]
Huesca (Barbastro)	-	+ 0.2	+1	One farmer, low average infestation; no insecticides previously used	Brookes[3]
15 locations (Catalonia, Aragon and Navarra)	13	+ 1	+10	Field trials; conventional crop included treated and not treated (with insecticides) plots	Monsanto Company, 2003 – 2005
Aragon, Catalunya and Castilla La Mancha	-		Perceived: +1 to +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[5]
Aragon and Catalunya	11.94	+1.34	+12.6	Survey of 85 farms: two-thirds Bt maize users, one third conventional	Riesgo et al.[6]
Spain range	**10–13**	**0.2–1.34**	**1–40**	-	-
Portugal					
	9.92	+1.19	+8 to +17. Average +12	Field trials in Alentejo and Ribatejo	Monsanto Company (2005)
			+2.8 to +25. Average +13.5	Odemira (Alentejo) region	Skevos, Fevereiro and Wesseler[14]
	9.92	**1.19**	**2.8 to 25**		

Insecticide use change (2018)

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
Spain	115.2	0.36	1.32	0.9	26.9	31.4	0.85

Sources: Insecticide use changes based on Brookes,[4] Kleffmann pesticide usage data (1999–2003) and personal communications with industry staff about more recent/current insecticides that are/would need to be used to control these pests, if GM IR maize technology was not used

Note:

(1) The area on which insecticide use changes are calculated in Spain is constrained to the lower of the area planted to GM IR maize or the historic, maximum area traditional treated with insecticides for control of the pests that GM IR maize provides control. This is a maximum area treated of 10% of the total crop.
(2) The insecticide savings relate only to savings associated with treatments that targeted the pests that the GM IR technology controls and do not relate to total insecticide use. This is deliberate because total insecticide use includes use of insecticides applied for control of pests that the GM IR maize technology does not target. Use of insecticides for this purpose will vary on a yearly basis according to pest pressures. The baseline assumptions for what insecticides are used for control of pests now controlled by GM IR maize technology, their typical usage levels and frequency of application are based on Kleffmann data from the immediate years before Intacta was commercially available and field-based experience of industry in-country staff.

Reduction in fuel and water use from less frequent insecticide applications

For insecticide applications, the quantity of energy required to apply the insecticide is based on use of a 50-foot boom sprayer which consumes approximately 0.84 liters/ha.[15] In terms of carbon emissions, each liter of tractor diesel consumed contributes an estimated 2.67 kg of carbon dioxide into the atmosphere (so 1 less application reduces carbon dioxide emissions by 2.24 kg/ha).

In relation to water usage for spraying, based on manufacturer (label) recommendations for use of chlorpyrifos, the application of one hectare of this insecticide is likely to use between 200 and 1,000 liters of water (1 m^3 of water = 1,000 liters).

Water use savings attributed to GM IR maize via extra yield that otherwise would have been required to be used if lower yielding, conventional seed technology was used based on Areal and Riesgo.[8] This is a weighted average (weighted by area planted to GM IR maize in each region) of 5,839 m^3 of irrigation water per hectare of maize.

Base yields used where GM technology delivers a positive yield gain

In order to avoid overstating the positive yield effect of GM technology (where studies have identified such an impact) when applied at a national level, average (national level) yields used have been adjusted downwards (see example below). Production levels based on these adjusted levels were then cross checked with total production values based on reported average yields across the total crop.

Example: GM IR maize Spain (2018).

Average yield all crop (t/ha)	Total maize area ('000 ha)	Total production ('000 tonnes)	GM IR area ('000 ha)	Conventional area ('000 ha)	Assumed yield effect of GM IR technology	Adjusted base yield for conventional maize (t/ha)	GM IR production ('000 tonnes)	Conventional production ('000 tonnes)
11.24	327	3,675	115.2	211.8	+12.6%	10.76	1,396	2,279

Note: Figures subject to rounding