# Benefits of Bt maize in Spain (1998-2015). Benefits from an economic, social and environmental viewpoint.

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**Benefits of Bt maize in Spain (1998-2015). Benefits from an economic, social and environmental viewpoint.**

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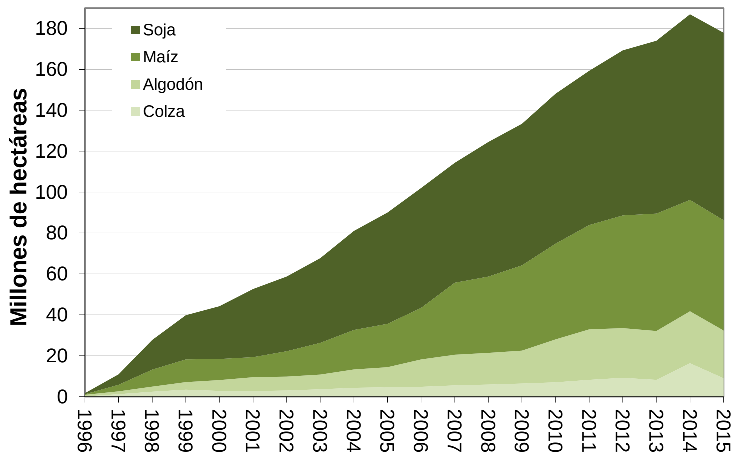
## 1. Introduction

The production of crops with genetically modified organisms (GMOs) has grown fast since their first commercialization of GMOs in 1996, covering a global total area of 179.7 million hectares in 2015 (James, 2016). The distribution of crops by order of importance is as follows: soy (51% of the total cultivated surface of genetically modified crops), corn (30%), cotton (13%) and rapeseed (5%) (Figure 1).

Figure 1. World area cultivated with GM crop varieties (1996-2015)



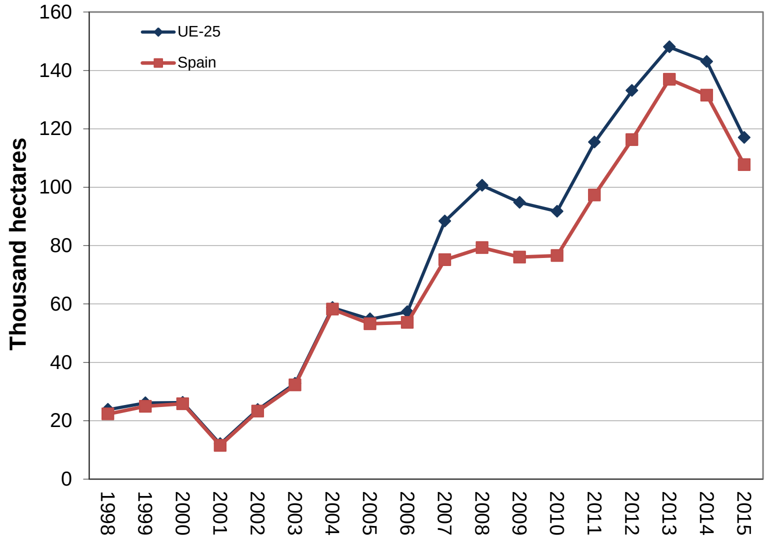

*Fuente*: Compiled from James(1997-2016)

It is worth noting that the small area allocated to genetically modified crops in Europe, 143,016 ha in 2014 and 116,975 ha forecasted for 2015[1] (see Figure 2). Currently, Bt corn is the only GM crop cultivated in the EU with 92% of crop area being located in Spain.

There has been a decrease in the cultivated area of Bt corn in the EU and Spain over the past two years. At the EU level, such a reduction is mainly due to the reduction in the global area cultivated with genetically modified and conventional corn in Spain. It is worth highlighting that the percentage surface cultivated with genetically modified corn is maintained at 30% of the total surface of corn cultivated in Spain since the year 2012.

[1] The acreage figures the EU in 2015 have been calculated from confirmed data for Spain and estimated data for Portugal, Czech Republic, Romania and Slovakia, information published by the respective Ministries of Agriculture (MAGRAMA, 2015; DRAP, 2015; e-AGRI, 2015; Ministerstvo pôdohospodárstva a rozvoja vidieka, 2015, y Ministerul Mediului, Apelor și Pădurilor, 2015).

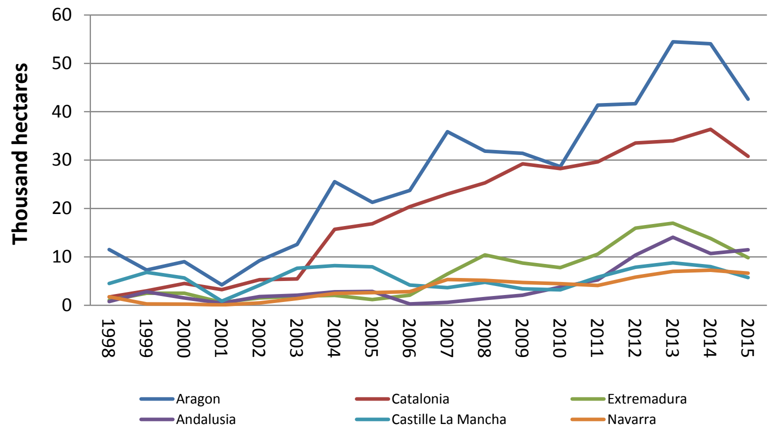
Figure 2. Trends in Bt maize acreage in EU-25 and Spain




Source: Compiled from James (1997-2015), MAGRAMA (2015), DRAP (2015) and eAGRI (2015)

In the particular case of Spain, Bt maize cultivation for the year 2015 is concentrated in Catalonia and Aragon, with 69% of the total EU area, followed by Andalusia (11%), Extremadura (9%), Navarra (6%) and Castilla La Mancha (5%). Acreage in these regions has been increasing since the introduction of Bt corn cultivation, with a marked acceleration in growth since 2010. So, taking into account the final data for 2015 released by the Ministry of Agriculture, Food and Environment (MAGRAMA), during these past 5 years, there has been an increase in the cultivated area of Bt corn in all autonomous communities, with an increase of up to 50% in Aragon and Navarra and even higher growth figures for Castilla la Mancha and Andalusia, with 80% and 204%, respectively.

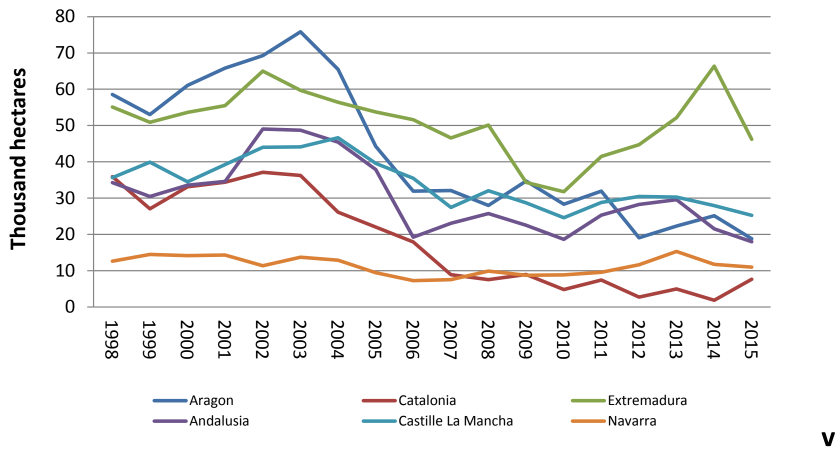
Figure 3. Evolution of Bt corn acreage by autonomous community (AC)




Source: MAGRAMA (1998-2015)

In 2015 the Bt corn cultivated area in Spain has been reduced in almost all analysed areas. However, this is also a common trend  to conventional corn, as mentioned above (see Figure 4).

Figure 4. Evolution of conventional corn acreage by autonomous community (AC)




Source: MAGRAMA (1998-2015)

## 2. Benefits of cultivating Bt corn for agriculture

The growth of the Bt corn cultivated area in Spain since its introduction in 1998 can be explained with different agronomic and economic factors as well as by the way in which farmers handle such crops.

### *2.1. Agronomic reasons*

Several studies have shown that one of the main advantages of Bt maize is its higher yield compared with conventional maize (Carpenter, 2010; Demont and Tollens, 2004; Gianessi et al. 2002; Gomez-Barbero et al. 2008; Riesgo et al, 2012; Areal et al, 2013). This agronomic superiority is due mainly to its pest resistance. Areal et al. (2013) show that at a global level[2] Bt corn has an average yield 0.55 t/ha higher than that of conventional maize. Bt maize is therefore justifiably positioned as the GM crop that shows a higher yield compared to the conventional variety globally.

In the case of Spain, Brookes (2008), Gómez-Barbero et al. (2008) and Hazard et al. (2012) show similar results. Brookes (2008) shows differences ranging between 1.5 and 0.15 t/ha depending on the degree of infestation by the drill in the Aragon area in 2002. The author collected average differences in performance from a later study (2003-2007), amounting to 1.30 t/ha. Gómez -Barbero et al. (2008) analyze differences in yields in three different areas: Albacete, Lleida and Zaragoza, which vary between 1.19 and -0.16 t/ha. Meanwhile Riesgo et al. (2012) show a statistically significant performance difference of 1.34 t/ha in the Ebro Valley in 2009.

[2] Included in this analysis are 33 findings from scientific articles published in international journals, including data from developing and developed countries.

Table 1. Yield differences between Bt and conventional maize

| Study | Zone analyzed | Year | Bt maize yield | Conventional maize yield | Yield differences (t/ha) |
|---|---|---|---|---|---|
| Brookes (2008) | Aragon | 2002 | 11.5 | 10 | 1.5 (n.s.) |
| | Aragon | 2002 | 10.15 | 10 | 0.5 (n.s.) |
| Brookes (2008) | Catalonia, Aragon, Navarre | 2003-2007 | 14.30 | 13.00 | 1.30 (n.s.) |
| Gómez-Barbero et al. (2008) | Albacete | 2002 | 12.36 | 12.14 | 0.22 (n.s.) |
| | | 2003 | 11.85 | 12.01 | -0.16 (n.s.) |
| | | 2004 | 12.59 | 12.53 | 0.06 (n.s.) |
| | Lérida | 2002 | 12.66 | 11.51 | 1.15 (n.s.) |
| | | 2003 | 12.01 | 11.52 | 0.49 (n.s.) |
| | | 2004 | 12.18 | 11.75 | 0.43 (n.s.) |
| | Saragossa | 2002 | 11.06 | 9.87 | 1.19 * |
| | | 2003 | 10.49 | 9.46 | 1.03* |
| | | 2004 | 10.64 | 9.53 | 1.11* |
| Riesgo et al. (2012) | Ebro Valley | 2009 | 11.94 | 10.60 | 1.34* |

(n.s.) shows no statistically significant difference; * shows statistically significant difference at 99%

*Source*: Authors.

It should be noted that in areas where there are no major pest problems, Bt crop performance shows no significant yield differences compared to their corresponding to isogenic varieties.

In addition to the differences in yield performance caused by the corn borer another agronomic reason favouring the adoption of Bt maize for farmers is the reduced incidence of mycotoxins compared to conventional maize (Hammond et al., 2004; Wu, 2006; GENVCE, 2007; Folcher et al., 2010 and López-Querol et al., 2013). Mycotoxins are toxic secondary metabolites produced by fungi that can cause disease and other health problems in animals and humans. The presence of mycotoxins, particularly fumonisins[3], is particularly prevalent in the presence of the hole and in hot, dry climates (FAO, 2003 and GENVCE, 2007). In areas affected by the drill, fumonisins can make it difficult to meet the maximum thresholds of Fusarium toxin content in maize and maize products pursuant to Regulation (EC) 1126/2007 of the European Commission (GENVCE, 2007 and López-Querol et al., 2013). Bt maize, therefore, offers an attractive option to farmers in these areas compared to conventional maize by allowing them to improve the quality in the final product.

[3] Fumonisins are a group of mycotoxins produced mainly by *Fusarium moniliforme*, a mould present worldwide and often found in maize.

### 2.2. Economic reasons

The main economic reasons behind the adoption of Bt maize are associated with a combination of higher crop yields and lower use and costs of pesticides. Thus, resistance to the corn borer incorporated into the crop through genetic modification results in less pesticide use, which means lower pesticide costs than for conventional varieties (Ervin et al., 2010; Qaim, 2009). Globally, Areal et al. (2013) show that Bt corn has higher production costs than conventional maize by nearly 14 euros a year per hectare in 2000. These costs include both the acquisition costs of seed as well as the pesticide cost to combat the corn borer, so that the higher acquisition cost of Bt maize seed compared with the conventional variety exceeds the lower cost obtained from a reduced use of pesticides. Despite the higher acquisition cost of the seed, Areal et al. (2013) show that Bt maize worldwide reaches an average return of €52.81 per hectare per year more than conventional maize in 2000[4]. It is worth noting that this increased profitability of GM crops varies considerably between countries and regions, depending on infestation levels of pests and the cost of acquiring the technology (purchase of seeds).

In the case of Spain, Brookes (2008) shows an average return of 147 €/ha more for Bt maize in 2002 compared to conventional maize in the Aragon area. This figure remained more or less constant in a subsequent study by the same author (Brookes, 2008), which establishes a higher average return of 141 €/ha for areas of Aragon, Catalonia and Navarre. Gómez-Barbero et al. (2008) show differences in profitability of around 3.17 €/ha in the Lleida area, 9.49 €/ha in the Albacete area and around 120 €/ha in the Zaragoza area between 2002-2004. In a more recent study, Riesgo et al. (2012) show an outperformance of 53.51 euros/ha a year 2010 for the area of the Ebro valley. In all case studies, the performance differences are explained by the increased agronomic performance of Bt maize. Thus, even though production costs are higher[5] for Bt and there no differences in the prices received by farmers as between the two varieties of maize grain[6], there is a greater economic return with Bt maize than for the conventional variety. These returns have prompted the adoption of Bt in these areas in recent years, thus experiencing a significant increase in its surface as shown in Figure 3.

### 2.3. Reasons related to ease of cultivation

Besides the agronomic and economic reasons for explaining the increase in adoption of Bt corn, there are a series of reasons that have boosted Bt corn adoption and which are associated with the advantages perceived by farmers in relation to how crops are handled and cultivated. One of the characteristics that farmers view as most positive when choosing genetically modified crops is their ease of use (Areal et al., 2011). Specifically, farmers who choose Bt technologies claim that one of its main advantages is its effectiveness in the fight against the corn borer, not only allowing a reduction in the time taken to inspect the farm or collecting the maize cobs but also in the reduction of the number of insecticide treatments

[4] Included in this analysis are 16 findings from scientific articles published in international journals, including data from developing and developed countries.

[5] Differential production costs for Bt corn ({(Bt seed acquisition cost – conventional seed acquisition cost) + (Bt pesticide cost - cost conventional pesticides)} are higher, on average, than for the conventional variety. Thus Gómez-Barbero et al. (2008) obtained differential costs 25.62 euros / ha in the area of Lleida and 22.78 euros / ha in the region of Aragon for the years 2002-2004. For the Ebro area, Riesgo et al (2012) estimated production cost differentials of Bt are 8.48 euros / ha greater than conventional maize. In this latter study, the differential costs are due to the difference in acquisition costs of the seed (about 14.89 euros / ha higher) and the difference in costs of pesticide use (6.41 euros / ha lower) in Bt maize compared to conventional maize.

[6] Riesgo et al. (2012) show that there are no significant differences between the prices received by farmers for Bt maize grain Bt and conventional maize grain in the Ebro valley.

necessary (Antama Foundation, 2012). The corn borer is very difficult to control in conventional crops as insecticide use is effective only if used within a very specific period of time from the onset of the problem (Agustí et al., 2005; Brookes, 2008; Farinós et al. 2004).

Another advantage of Bt maize is related to the harvest. In the absence of insect-damaged maize, farmers can harvest quicker and collect more straw per hectare for fodder (Antama Foundation, 2012).

Farmers mention that these advantages not only affect the use of these crops but also their costs of production. Fewer treatments and faster harvesting[7] can cut diesel costs and other energy costs associated with this type of farming. For its part, the generation of a larger amount of straw for fodder allows farmers to reduce their costs through consumption on site or by sale to third parties in case it is not needed.

## 3. Benefits of cultivating Bt corn for the environment

The adoption of Bt corn by some Spanish farmers has led to a series of environmental benefits, such as the reduction in the use of insecticides, lower use of water for irrigation per ton of corn produced, smaller water footprint, less land required for the production of corn and higher fixation of carbon.

### *3.1. Pesticide Use*

As many authors have shown, Bt crops need fewer insecticide treatments against the Lepidoptera insect pests (Barwale et al., 2004, Bennett et al., 2004, Carpenter, 2010; Gandhi et al., 2006, Qaim et al., 2006, Wang et al., 2008, Riesgo and Areal, 2013). At an aggregated level, Brookes and Barfoot (2012) estimate that the use of Bt corn has led to a 37.7% reduction in the use of insecticides against the corn borer from 1996 to 2010. For Spain, Gomez-Barbero et al. (2008) estimated an average use of 0.86 annual pesticide treatments with conventional maize in the period 2002-2004 while this figure reduces to 0.32 in the case of Bt maize. Brookes (2008) estimates that the reduction in insecticide use derived from Bt maize cultivation in Spain was between 27% and 45% in the treated area, and from 26% to 35% in the use of insecticides between 1999 and 2001, this would be equivalent to a reduction of 35,000 to 56,000 kg of active ingredients.

Such reductions in the use of insecticides translate into the application of less phytosanitary products, which has a lower impact on the environment and decreases the risks to which non-target organisms are exposed (Wesseler et al., 2011).

The lower environmental impact of genetically modified crops on plentiful non-target organisms and the use of insecticides also appears in the report of Areal and Riesgo (2015), at both the individual level and when the aggregate environmental impact was taken into account (use of insecticides and plentiful non-target organisms), observing that genetically modified crops perform environmentally better than conventional crops, with a probability ranging from 70 to 78%.

[7] Harvesting is slower when dealing with corn borer-damaged maize, so Bt maize cultivation encourages faster harvesting.

*3.2. Use of irrigation water*

Given the better agronomic performance of Bt maize, it is possible to estimate the volume of water use that has been averted by using this type of maize compared to conventional maize. Thus, taking into account the average use of irrigation water to produce corn in the analysed regions (see Table 2), we can calculate the amount of water needed to replace lost production that would have occurred if Bt maize had not been available to farmers.

Table 2. Consumption of the estimated irrigation water for maize by AC.

| **Autonomous Community** | **Use of irrigation water ($m^3$/ha)** | **Reference** |
|---|---|---|
| Aragon | 5,372 | Sánchez-Chóliz y Sarasa (2013) |
| Catalonia | 6,613 | Rufat-Lamarca et al. (2006) |
| Navarre | 6,500 | Diario de Navarra (2012) |
| Castille- La Mancha | 5,507 | MAGRAMA (2013b) |
| Andalusia | 5,100 | MAGRAMA (2013c) |
| Estremadura | 5,507 | MAGRAMA (2013d) |

*Source*: Own analysis

Considering the average use of water for irrigation and conventional maize yield in each of the study areas[8] for each year of the analysis (1998-2013), we can obtain a figure for the cubic meters of water needed to produce each ton of conventional maize in these areas. Then, taking into account the annual losses that would have occurred in each of the analysed ACs if the maize had not been available (see Figure 9b), we can estimate the total amount in cubic meters of irrigation water savings in these areas, as shown in Table 3. Adding all these quantities together it can be concluded that the additional production provided by Bt maize in the areas analyzed would not only have meant an increase in the area of conventional maize cultivation, but an additional aggregate water demand of 615,778 thousand $m^3$ , or about of 34,210 thousand $m^3$ per year in the period 1998-2015. These irrigation water requirements saved thanks to Bt maize are particularly important in some of the areas analyzed, with periodic problems of water supply for agriculture.

[8] The figure for the use of irrigation water as $m^3$ / ton was obtained by using the following equation: (use of water ($m^3$ / ha / (conventional maize yield ton / ha). This was how water needs in $m^3$/ha for each year of analysis were estimated. These needs were multiplied by the annual yield losses that would have happened if Bt maize had not been available in the autonomous regions analyzed, thus obtaining the additional water needs in each of these areas.

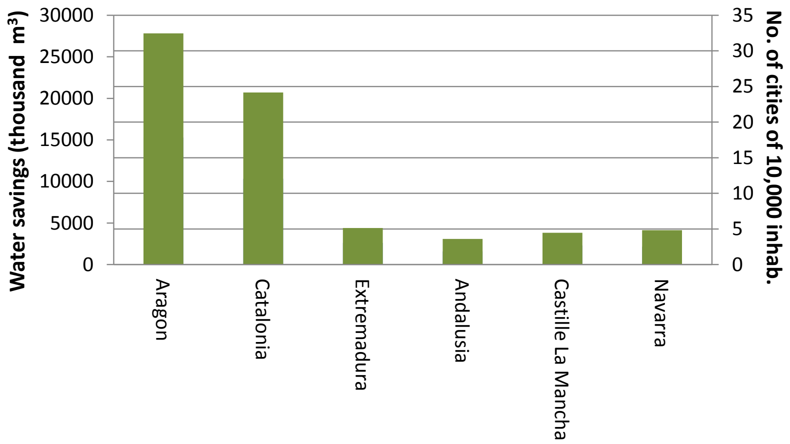
Table 3. Amount of water needed to replace the loss of production by AC

| Autonomous Community | Requirements autonomous irrigation water added (thousands of $m^3$) | Annual water requirements for irrigation (thousands of $m^3$) |
|---|---|---|
| Aragon | 275,152 | 15,286 |
| Catalonia | 185,649 | 10,314 |
| Navarre | 38,548 | 2,142 |
| Castille- La Mancha | 41,123 | 2,285 |
| Andalusia | 28,239 | 1,569 |
| Estremadura | 47,068 | 2,615 |
| *TOTAL* | *615,778* | *34,210* |

*Source*: Own analysis

Taking into account the annual average water savings associated with Bt corn production, and considering the average water consumption per person and day in each of the analysed AC[9] we find that these savings could be used to supply water to a population of 746,000 inhabitants during a period of one year. Likewise, this water could be used to cover the supply for at least half of the inhabitants of Zaragoza and the inhabitants of Lérida, Tarragona and Badajoz (INE, 2015a). Specifically, the largest water savings would be generated in Aragon and Catalonia, equivalent to an annual urban supply for almost 566,164 people (see Figure 4).

Figure 4. Irrigation water saved per year and the number of cities that could be supplied




*Source*: Own analysis

[9] Household water consumption (in litres/habitant/day) is 129 in Aragon, 117 in Catalonia, 140 in Estremadura, 120 in Andalusia, 140 in Castille- La Mancha and 112 in Navarra (INE, 2015b).

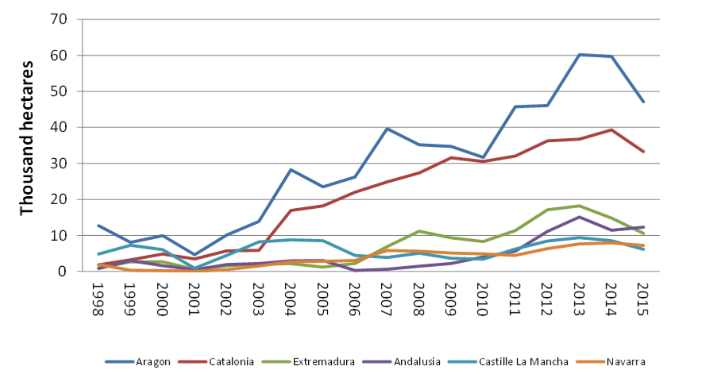
*3.3. Water Footprint*

The concept of water footprint details the relationship between human consumption and freshwater use (Hoekstra , 2003; Hoekstra and Chapagain, 2008), being an indicator of the direct and indirect use of water resources. Hence water footprint considering all uses of water (consumption uses are divided into the blue water footprint, which refers to fresh surface and ground water, and the green water footprint, which refers to water that comes from rainfall) and the water resources to assimilate the pollution associated with well water (the grey water footprint) . To calculate the water footprint one should add together the water footprints of all processes from the point of collection or storage to the final consumption by the consumer, and this is expressed in the volume of water per unit of product. In the case of maize grain, the average global water footprint is estimated at 1,222 $m^3$/ton, of which 947 corresponds to the green water footprint, 81 to the blue water footprint, and 194 to the grey water footprint (Mekonnen and Hoekstra , 2011). Given this amount and the production losses averted by the adoption of Bt maize in Spain (1,093,868 tonnes), it can be estimated globally that a water footprint of 1,335 million $m^3$ has been averted during the 18 years of Bt maize cultivation.

*3.4. Use of land*

The cultivation of Bt corn has not only decreased the pressure on the water resources per ton produced, but also the pressure on the water currently used for irrigation. Maintaining the same total corn production figures in areas affected by the European corn borer plague would have greatly increased the current surface area destined to conventional maize[10] (see Figure 5 and Table A2.1 in Annex 2).

Figure 5. Surface of conventional corn to compensate the increase in the yield of Bt corn




*Source: Own analysis*

[10] To calculate the annual surface of conventional corn required to compensate the production of Bt corn in the areas analysed, the Bt corn production registered and the conventional corn yield of each Autonomous Community have been taken into account.

*Conventional corn surface required = production of Bt corn / conventional corn yield*

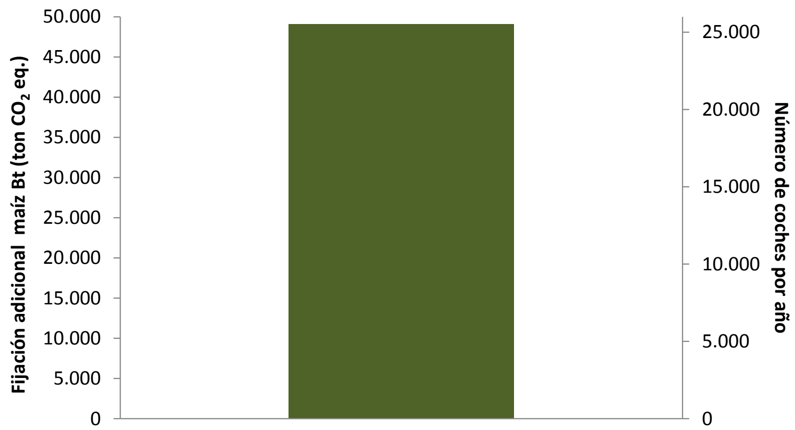
For example, a total of 116,663 hectares would have been required to compensate the reduction in the use of Bt corn and maintain the corn production levels in the areas affected by the European corn borer only during the year 2015. This would have increased the cultivated corn surface by 9,608 hectares, as compared to the total corn surface registered in the areas analysed and as required to maintain the same production figures in Spain during 2015 (see Annex 2 for a detailed analysis of the total surface of conventional corn required to maintain the annual production levels (Table A2.1) and the additional surface of corn that would have been required when compared to that registered (Table A2.2)).

In cumulative terms for the whole time period, the total surface of conventional corn in Spain could have increased by 1,293,733 hectares to compensate the additional production volumes generated by the cultivation of Bt corn. This would have led to a net increase of 106,775 hectares to grow corn in relation to the total surface used to grow corn during the 1998-2015 period, thus maintaining the production levels registered.

### *3.5. Carbon fixation*

Due to the photosynthetic activity of plants, carbon fixation in cereal grains is much higher than the emissions associated with agricultural production. In this way, grain acreage can be considered as natural storage for $CO_2$. In the case of irrigated corn the net fixation of carbon is estimated at 777 kg $CO_2$ equivalents / ton of corn produced (Altuna et al., 2012). With the net $CO_2$ fixation and the additional productivity of Bt maize compared to conventional (1,093,868 tonnes) , Bt maize cultivation in Spain during the period 1998-2015 can be estimated to have added benefitted carbon fixation by the equivalent of 849,935 ton $CO_2$, which represents an annual average of 47,219 ton $CO_2$ for the period of study. Such aggregated net carbon fixation means that the use of Bt corn has contributed to compensate the emissions of over 5,735 million km travelled by vehicles for the period during which it has been cultivated, i.e., the past 18 years, or in annual terms, Bt corn has contributed to compensate the emissions produced by 25,004 vehicles[11] (ver Figura 6).

Figure 6. Additional $CO_2$ fixation of Bt maize and annual equivalent number of cars




*Source*: Own analysis

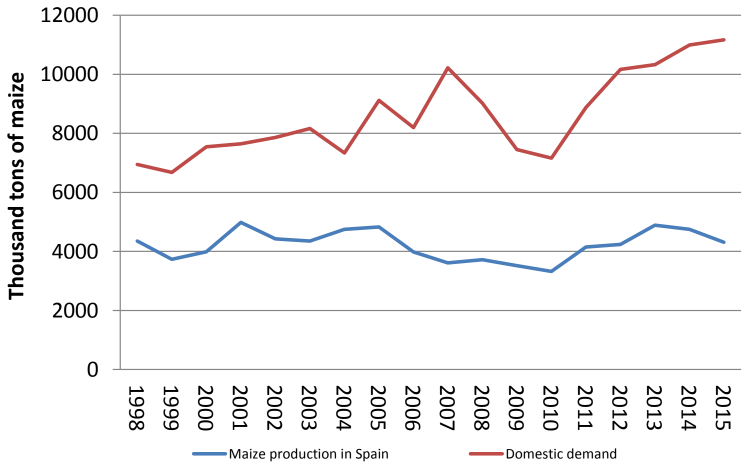
[11] To calculate the number of the average $CO_2$ emissions of a car in Spain have taken the data published by the Institute for Diversification and Saving of Energy (IDEA, 2015) compared to equivalent $CO_2$ emissions in diesel cars and gasoline per kilometer, figures from the Directorate General of Traffic (DGT, 2015) to calculate the proportion of diesel and gasoline vehicles circulating in Spain and INE (2010) for the average number of kilometers traveled each vehicle type. It has been assumed that the average gas consumption of a car is 6 liters per 100 kilometers.

Agriculture is the sector with the highest land occupation levels, with the use and exploitation of land resulting in the emission of greenhouse gases, approximately 5,000 million equivalent annual tons of $CO_2$ during the 2001-2010 period (Tubiello *et al.*, 2014). However, it has a noteworthy capacity to reduce the effects that are contributing to climatic change, such as through carbon fixation. This is precisely one of the tasks in which the cultivation of Bt corn can have the most positive effect, not only increasing the $CO_2$ fixation rates but also reducing the use of fossil fuels and associated emissions by means of reducing the volume of field operations, such as the phytosanitary treatments required in areas affected by the European corn borer.

#### 4. Benefits of cultivating Bt corn for foreign trade

Domestic demand[12] for maize grain has been growing since 2010, showing a progressively bigger margin of increase compared with maize grain production (see Figure 7).

Figure 7. Domestic demand and production of maize in Spain




*Source*: Compiled from MINECO (1998-2015)

Given the inability of domestic production to meet demand, the Spanish economy needs to import maize. From 2006, imports have exceeded domestic production including maize production (see Figure 8a). Among the leading suppliers of maize to Spain in 2015 are, in order of magnitude, the Ukraine (36%), France (30%), Brazil (8%) and Romania (6%), (MINECO, 2015).

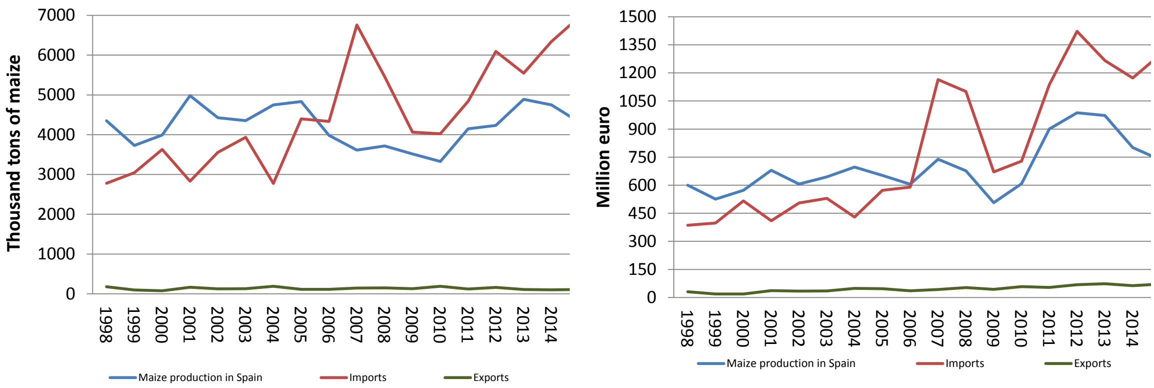
Due to the large increase in grain prices over recent years[13], this increase in maize imports has produced a notable increase in the value of the imports (see Figure 8b). Since 2010, therefore, the volume of imports increased by 56 % while their value increased by 93%.

[12] Domestic demand for maize is defined as: maize production in Spain plus Imports less Exports.
[13] In the case of corn, the average price of imports has grown over 34% since 1998, the year in which Bt corn started to be cultivated in Spain (MINECO, 1998-2015).

Figure 8. Changes in production, imports and exports of maize

8a. Quantity (thousands of tons)

8b. Value (€ millions)




*Source*: Own compilation from MINECO(1998-2015), Taric maize classification (1005)

As mentioned in the previous section, one of the main advantages of Bt maize is its higher yield in relation to conventional maize in areas affected by the scourge of the corn borer. So taking into account the growing areas of this GM variety in Spain, it is possible to estimate the additional maize requirements that would have been needed if the Bt variety of maize had not been available to farmers. Due to the lack of data on the extent of corn borer damage in Spain, it is assumed that this disease had a significant presence in those regions in which Bt maize acreage was greater than or equal to 5% of the total maize acreage over the past 18 years. These autonomous communities (ACs) are Aragon, Catalonia, Navarra, Castilla La Mancha , Andalusia and Extremadura .

Given the lack of official data on the difference in yield between Bt and conventional maize, a review of published data on the Spanish case has been conducted in authoritative peer-reviewed scientific journals. Table 4 gathers together these yield differences between distinct types of maize.

Table 4. Yield differences between Bt and conventional maize in Spain

| **Analyzed area** | **Increase of Bt maize yield compared to conventional (%)** | **Reference** |
|---|---|---|
| Aragon | 10.00 (year 1999-2001) | Brookes (2008) |
| Aragon, Catalonia and Navarre | 10.46 (average for the years 2004-2007) | Brookes (2008) |
| Aragon | 12.00 (average for 2004-2006) | Gómez-Barbero et al. (2008)* |
| Catalonia | 5.97 (average for 2004-2006) | Gómez-Barbero et al. (2008)* |
| Castilla La Mancha | 7.40 (average for 2004-2006) | Gómez-Barbero et al. (2008)* |
| Ebro Valley | 12.64 (year 2009) | Riesgo et al. (2012)* |

* Data taken from studies published in authoritative scientific journals

*Source*: Own analysis

In this paper we present the results obtained assuming average yields obtained from the studies listed in Table 4, and consider the differences in yield by area[14] between the two maize varieties.

Table 5. Assumed yield differences between Bt and conventional maize (%)[15]

| Autonomous Community | Yield increase of Bt maize compared to conventional maize |
|---|---|
| Aragon | 10.53 |
| Catalonia | 8.11 |
| Navarre | 9.48 |
| Castilla- La Mancha | 7.38 |
| Andalusia | 7.38 |
| Extremadura | 7.38 |

*Source*: Own analysis

With reference to the differences in yields listed in Table 5 and taking into account the areas planted with Bt and conventional maize, it is possible to estimate the performance of both maize varieties by AC in the period 2008-2015[16]

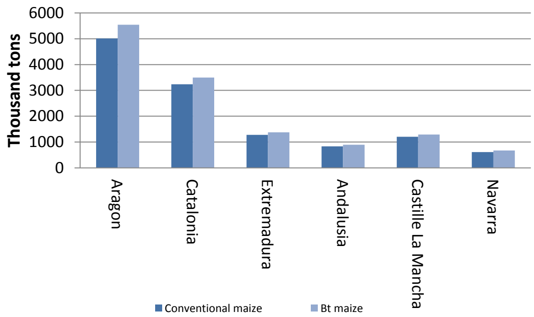
[14] The studies published on the Spanish case represent a conservative analysis of the calculations. As seen from Annex 1, the results obtained from authoritative research data do not take into account the studies conducted by the biotech industry, which publish higher values of the averted imports.

[15] In the case of Aragon the arithmetic mean of the differences in yields was calculated and published by Brookes (2008), Gómez-Barbero et al. (2008) for Aragon and Riesgo et al. (2012) for the Ebro Valley. For Catalonia the arithmetic mean of the differences in yields was calculated and published by Brookes (2008), Gómez-Barbero et al. (2008) for Catalonia and Riesgo et al. (2012) for the Ebro Valley. For Navarre, the average of the yield gap was taken as the reference for the arithmetic mean as published by Brookes (2008) For Catalonia, Aragon and Navarra, Gómez-Barbero et al. (2008) for Aragon and Catalonia, and Riesgo et al. (2012) for the Ebro Valley. Finally, in the case of Castilla La Mancha, Andalusia and Extremadura taken as reference the arithmetic average of the yield gap as published by Gómez-Barbero et al. (2008) for Castilla La Mancha.

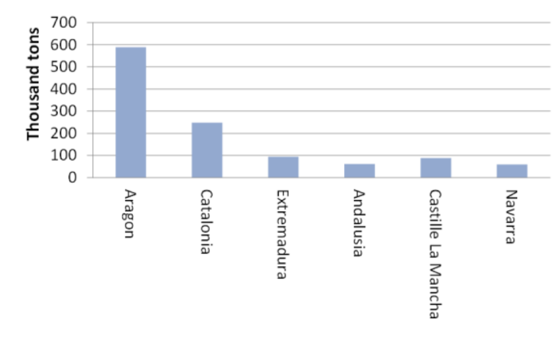
[16] Maize Yield Performance by AC = Bt · ((Bt maize area) / (Total area maize)) + Yield conventional maize · ((conventional maize area) / (Total area maize)). Performance data of maize by AC, Bt maize acreage and total maize area is taken from data collected from MAGRAMA (1999-2012). Given the assumed differences in yields listed in Table 3 yields of Bt maize and conventional maize have been estimated.

Figure 9. Estimated corn production

9a. Estimated production of Bt maize and conventional maize



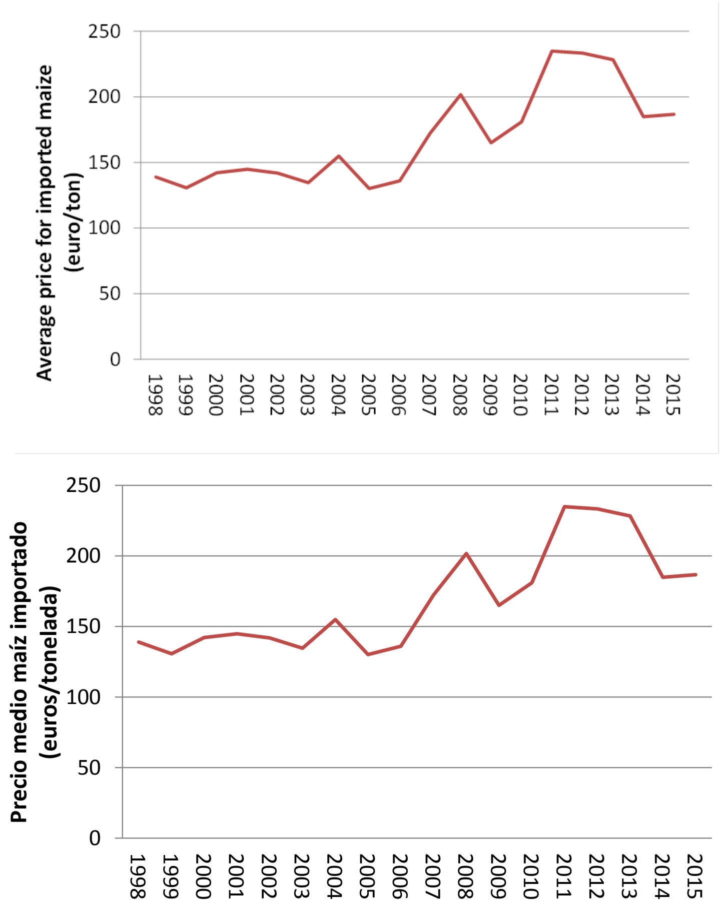

9b. Maize production losses




*Source*: Own analysis

On the basis of these estimates, we can calculate the total production of maize if conventional maize had been planted on the same acres in each region since 1998-2015 ('planned production') instead of Bt maize. Figure 8a shows the total production of Bt maize and 'planned production' conventional corn for each region for the years covered in the analysis. The difference between Bt maize production and 'planned production' conventional maize by region and year, allows us to ascertain the production losses that would have occurred if Bt maize had not been available to farmers (see Figure 9b). Such aggregate losses amounted to 1,093,868 tonnes for the period analyzed.

Figure 10. Changes in the average price of imported maize in Spain




*Source*: Own analysis of date from MINECO (1998-2015)

These production losses would had led to an increase in maize imports to meet Spanish domestic demand during the period analyzed (imports that would had occurred had Bt maize not been grown). Considering the average price of maize imported by Spain during the period 1998 to 2015[17] (Figure 10) it is possible to calculate the value of the imports that would otherwise had been necessary.

[17] The average price of maize imports has been calculated as follows: Average price = (Value of maize imports) / (Quantity imported maize), using the values given for the years 1998-2013 MINECO.

Table 6. Actual value of averted imports, by ACs

| Autonomous Community | Value of averted imports (euros in 2016) |
|---|---|
| Aragon | 93,036,915 |
| Catalonia | 46,409,743 |
| Navarre | 10,447,266 |
| Castille- La Mancha | 13,770,789 |
| Andalusia | 11,373,874 |
| Estremadura | 17,793,580 |
| *TOTAL* | *192,832,167* |

*Source*: Own analysis

The actual value[18] of maize imports during the years 1998 and 2015 averted through the adoption of Bt maize in Spain amounts to nearly 193 million euros in 2016 (see Table 6).

**5. Conclusions**

The Bt maize area in Spain has increased since its introduction in 1998. This increase in the Bt maize area has accentuated since 2010. The adoption of Bt maize during the 18 year period has brought a number of advantages in agronomic, economic and term, as well as for the International trade and the environment.

From an *agronomic* point of view, Bt maize resistance to the corn borer leads to higher yields than the conventional maize. According to some studies, the average yield differences vary between 7.38% and 10.53% depending on the geographical area analysed as well as the pest incidence. The adoption of this crop provides benefits associated with the quality of the crop as a consequence of its relatively low content in fumonisins (mycotoxins).

The high yields of Bt maize lead to higher *economic benefits* for the farmer, due to a higher gross margin compared to the conventional maize. This difference in gross margins varies between 3.17 and 147 euros/ha depending on the geographical area and the year in which the study was conducted. Apart from the economic benefits, farmers also consider other reasons to adopt Bt maize such as its *greater* flexibility and simplicity in crop management. Amongst these reasons farmers highlight the reduction in time spent in scouting and spraying fields to address weed problems.

Apart from the direct economic benefits for the farmer, Bt maize has also yield benefits for the Spanish international trade. Thus, Bt maize has allowed Spain to fulfil its internal demand for maize with domestic production, making it less dependent to additional maize imports. More specifically, the value of the avoided maize imports as a consequence of Bt maize adoption in Spain during the 18 years is almost 193 million euros.

It is worth noting that besides the benefits for farmers and the trade balance associated with Bt maize adoption, there have been other non-monetary benefits related with the environmental function of agriculture.

Thus, there are benefits associated with a lower use of insecticides, a lower use of irrigation water per tonne of maize produced, and a higher carbon fixation. Thus, biodiversity benefits

[18] The value of averted imports in each year has been updated for 2013. To do this we used the coefficients provided by the INE (based on 2011 figures), and we have taken the rate of inflation for 2013 until the October 2013.

are obtained by optimising the use of insecticides. As pointed out above, Bt maize produces higher yields than conventional maize, which leads to a lower irrigation water consumption per tonne of maize produced.  Such irrigation water savings has been estimated to be 615,778,000 $m^3$ for the 18 year period of Bt maize cultivation in Spain, which is equivalent to the provision of water for 746,000 people per year (equivalent to the Spanish cities of Lérida, Tarragona and Badajoz all together). Taking into account the whole production process of grain maize and its impact on hydrological resources at a global level, the adoption of Bt maize in Spain has avoided a hydrological footprint of almost 1,335 million $m^3$. Bt maize in Spain has also contributed to lower pressure on land use, since by keeping the same level of maize production would have meant an increase of 106,775 ha of maize. Finally, considering maize capability as a natural drain for $CO_2$, Bt maize cultivation in Spain has yield a net fixation of additional carbon of 849,935 t $CO_2$ eq., which makes up for the emissions associated with 25,004 cars in Spain for a year.

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## ANNEX 1

Considering only the data published in authoritative scientific journals (Gómez -Barbero et al., 2008, Riesgo et al., 2012), the average yield differences between Bt and conventional maize were as shown in the following table:

Table A1-1. Assumed yield differences between Bt and conventional maize[19]

| Autonomous Community | Increased Bt maize yield compared to conventional (%) |
|---|---|
| Aragon | 11.81 |
| Catalonia | 7.64 |
| Navarre | 9.72 |
| Castilla- La Mancha | 7.38 |
| Andalusia | 7.38 |
| Estremadura | 7.38 |

Source: Various[20]

Based on the yield gap shown by the data, we estimate the 'planned production' of maize if Bt maize acres had been planted with conventional corn in each region from 1998 to 2015. The difference between Bt maize production and 'planned production ' conventional corn, by region and year, allows us to estimate that production losses would have amounted to 1,140,976 tonnes.

Considering the average import price of maize by Spain during the years 1998 and 2015 (Figure 8) it is possible therefore to calculate the value of imports avoided.

Table A1-2.Actual value of imports averted by the ACs.

| Autonomous Community | Value of imports averted (euros in 2011) |
|---|---|
| Aragon | 103,587,605 |
| Catalonia | 43,855,499 |
| Navarre | 10,706,181 |
| Castille- La Mancha | 13,770,789 |
| Andalusia | 11,373,874 |
| Estremadura | 17,793,580 |
| *TOTAL* | *201,087,528* |

*Source*: Own analysis

[19] In the case of Aragon the arithmetic mean of the differences in yields was calculated and published by Gómez-Barbero et al. (2008) for Aragon and Riesgo et al. (2012) for the Ebro Valley. For Catalonia the arithmetic mean of the differences in yields was calculated and published by Gómez-Barbero et al. (2008) for Catalonia and Riesgo et al. (2012) for the total of the Ebro Valley. To the case of Navarre, the average of the yield gap published by Gómez-Barbero et al. (2008) was taken as reference for Aragon and Catalonia, and Riesgo et al. (2012) for the Ebro Valley. Finally, in the case of Castilla La Mancha, Andalusia and Extremadura the average of the yield gap published by Gómez-Barbero et al. (2008) for Castilla La Mancha has been taken as reference.

The present value of corn imports averted through the cultivation of Bt maize in Spain during the years 1998 to 2015 amount to over 201 million euros. This figure is higher than that contained in the present study (192,832,167 euros of 2016), which shows the restrained approach followed by the authors in estimating the averted value of maize imports.

## ANNEX 2

Table A2.1 shows the annual surface of conventional corn that would have been required to compensate the annual production of Bt corn in Spain. In cumulative terms for the 1998 to 2015 period, not cultivating Bt corn would have required a surface of 1,293,733 hectares of conventional corn to maintain the national corn production levels.

Tabla A2.1. Annual evolution of the conventional corn surface required to compensate the production of Bt corn in Spain

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aragón** | 12,711 | 8,069 | 9,948 | 4,670 | 10,169 | 13,918 | 28,238 | 23,498 | 26,230 | 39,637 | 35,213 | 34,704 | 31,670 | 45,726 | 46,059 | 60,187 | 59,733 | 47,100 |
| **Cataluña** | 1,838 | 3,243 | 4,865 | 3,514 | 5,730 | 5,870 | 16,972 | 18,195 | 22,016 | 24,879 | 27,349 | 31,588 | 30,550 | 32,035 | 36,250 | 36,753 | 39,331 | 33,287 |
| **Extremadura** | 1,074 | 2,685 | 2,685 | 644 | 1,611 | 2,039 | 2,176 | 1,257 | 2,224 | 6,937 | 11,185 | 9,375 | 8,343 | 11,347 | 17,129 | 18,232 | 14,835 | 10,553 |
| **Andalucía** | 838 | 3,007 | 1,611 | 483 | 1,933 | 2,220 | 2,974 | 3,087 | 320 | 636 | 1,473 | 2,238 | 4,052 | 5,631 | 11,127 | 15,118 | 11,481 | 12,317 |
| **Castilla La Mancha** | 4,832 | 7,302 | 6,067 | 934 | 4,456 | 8,249 | 8,802 | 8,544 | 4,484 | 3,929 | 5,089 | 3,669 | 3,423 | 6,246 | 8,465 | 9,413 | 8,562 | 6,157 |
| **Navarra** | 1,927 | 328 | 241 | 88 | 547 | 1,518 | 2,678 | 2,851 | 3,088 | 5,832 | 5,638 | 5,136 | 4,901 | 4,484 | 6,351 | 7,678 | 7,953 | 7,248 |
| ***Total*** | *23,220* | *24,634* | *25,416* | *10,333* | *24,446* | *33,815* | *61,840* | *57,433* | *58,363* | *81,850* | *85,947* | *86,710* | *82,939* | *105,468* | *125,380* | *147,381* | *141,895* | *116,663* |

The said surface of conventional corn would have led to a net increase in the total surface of corn in the areas analysed, as shown in Table A2.2.

Tabla A2.2. Annual evolution of the additional conventional corn surface required to compensate the production of Bt corn in Spain

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aragón** | 1,211 | 769 | 948 | 445 | 969 | 1,326 | 2,691 | 2,239 | 2,500 | 3,777 | 3,356 | 3,307 | 3,018 | 4,357 | 4,389 | 5,736 | 5,692 | 4,488 |
| **Cataluña** | 138 | 243 | 365 | 264 | 430 | 440 | 1,273 | 1,365 | 1,651 | 1,866 | 2,051 | 2,369 | 2,291 | 2,403 | 2,719 | 2,757 | 2,950 | 2,497 |
| **Extremadura** | 74 | 185 | 185 | 44 | 111 | 140 | 150 | 86 | 153 | 477 | 769 | 644 | 574 | 780 | 1,178 | 1,253 | 1,020 | 725 |
| **Andalucía** | 58 | 207 | 111 | 33 | 133 | 153 | 204 | 212 | 22 | 44 | 101 | 154 | 279 | 387 | 765 | 1,039 | 789 | 847 |
| **Castilla La Mancha** | 332 | 502 | 417 | 64 | 306 | 567 | 605 | 587 | 308 | 270 | 350 | 252 | 235 | 429 | 582 | 647 | 589 | 423 |
| **Navarra** | 167 | 28 | 21 | 8 | 47 | 131 | 232 | 247 | 267 | 505 | 488 | 445 | 424 | 388 | 550 | 665 | 689 | 628 |
| ***Total*** | *1,980* | *1,934* | *2,046* | *858* | *1,996* | *2,758* | *5,155* | *4,737* | *4,902* | *6,939* | *7,115* | *7,172* | *6,821* | *8,745* | *10,183* | *12,097* | *11,729* | *9,608* |

In net terms, not cultivating Bt corn would have resulted in a net increase of 106,775 the cultivated corn surface in Spain between 1998 and 2015.