Bt corn in Spain—the performance of the EU's first GM crop

To the editor:

Your March issue[1] indicates that last year 114 million hectares of farmland across the world were planted with genetically modified (GM) crops. And yet in Europe, the cultivation of these crops remains both limited and controversial. Indeed, scientific and policy debates in the European Union (EU) have rarely focused on the agronomic aspects of GM crops and economic impacts for EU farmers. Currently, the only GM crop authorized for commercial cultivation in the EU is a GM corn resistant to corn borer by virtue of the transgenic expression of a gene encoding *Bacillus thuringiensis* (*Bt*) toxin. Spain now has over nine years of experience in commercial cultivation of this type of GM corn (and is the European member state with the highest adoption rate for this GM variety). It is thus an opportune time to analyze *ex post* the agronomic and economic performance of *Bt* corn in Spain. We present the results of this analysis below—the first for a GM crop cultivated in the EU.

In 1998, the first planting of *Bt* corn (transgenic event Bt-176 by Syngenta, Basel) in Spain reached 20,000 hectares (http://www.mapya.es). The cultivated area remained fairly stable up to 2003, when the EU approved another *Bt* corn (transgenic event MON-810 by Monsanto, St. Louis). By 2006, over 53,000 hectares of *Bt* corn were grown in Spain—15% of the country's total corn hectarage. In regions where there is a high incidence of corn borer infestation, however, the adoption rate can reach as high as 60% of total corn area. Details on the regional changes in *Bt* corn adoption in Spain are provided in **Supplementary Table 1** online.

Ex post economic analysis of GM crop impacts are usually based on surveys of farmers cultivating GM crops under commercial conditions[2–5]. We conducted a face-to-face survey among Spanish commercial corn farmers with the aim both of obtaining data on the agronomic and economic performance of *Bt* corn during three growing seasons (2002–2004) and of comparing the socioeconomic profile of farmers who adopted *Bt* corn versus those who did not. The survey was conducted in the three leading *Bt* corn-growing regions (Aragon, Catalonia and Castilla-La Mancha), which accounted for ~90% of the *Bt* corn–growing area in Spain in 2006. A province was selected within each region based on the importance of corn cultivation and the presence of farmers growing *Bt* corn (the provinces of Zaragoza in Aragon, Albacete in Castilla-La Mancha and Lleida in Catalonia). Details on the survey and selection of farmers can be found in **Supplementary Table 2** online.

Survey results (**Table 1**) show that farmers adopting *Bt* corn experienced higher average yields than conventional corn growers for the three growing seasons studied (2002–2004). These higher yields were, however, statistically significant ($P < 0.001$) only for the province of Zaragoza (a yield increase of 1,110 kg/hectare or 11.8%). *Bt* crops, like other pest-control technologies, produce variable yield gains, depending mainly on local pest pressure and damage[6]. There are no published records of corn borer populations or damage in the three provinces studied during 2002–2004, although Zaragoza seems to have been particularly affected (P. Castañera, personal communication).

The possibility that variability in yield gains is related to the development of resistance to the *Bt* toxin in corn borer populations is not supported by monitoring studies performed in Spain[7]. Regional variation in yield gains could also result from the slow process of introducing *Bt* genes technology in corn hybrids suitable for all regions. Although hundreds of conventional corn hybrids are marketed in the EU every year, by 2003 there were only two commercial hybrids of *Bt* corn marketed in Spain. By 2006, this number had risen to just over 40. Yield gains of *Bt* corn farmers showed limited variations between years (**Table 1**), except for favorable yields of *Bt* corn grown in Lleida in 2002. These variations are likely to be attributable to season-to season variations in pest pressure.

Yield gains for *Bt* corn adopters translated directly into increased revenues (**Table 1**), as no differences were found in the crop price paid to *Bt* or conventional corn farmers (€0.13 per kilogram). This suggests that non-GM corn for feed manufacturing (the sector using the vast majority of corn produced in Spain) has not commanded any price premium in the years studied. Pesticide and seed costs are the only two variables that showed differences between farmers who did or did not grow *Bt* corn.

Insecticide-based control of corn borers in conventional corn is difficult because treatment is effective only in the narrow time span from when eggs hatch to when larvae begin boring into stems; thus some farmers apply chemical treatments against corn borers even when these treatments are ineffective[6]. **Tables 2** and **3** show insecticide use for corn borer control on surveyed farms. On average, conventional corn farmers applied 0.86 treatments/year (2002–2004 period) compared with 0.32 treatments/year for *Bt* corn farmers. The percentages of farmers applying no insecticides were 70% for *Bt* corn growers and 42% for conventional corn growers (**Table 3**). Estimates of the average cost of an insecticide application, deduced from the survey, are provided in **Table 1**, along with subsequent savings on pest control costs for *Bt* corn growers. A significant ($P < 0.001$) price premium of *Bt* corn seeds relative to conventional seeds (**Table 1**) was observed in Zaragoza, the province showing the highest yield increase for *Bt* corn. This suggests that seed distributors may adjust the price of GM seeds to reflect the performance of the technology in a particular region.

The on-farm economic balance for *Bt* corn (**Table 1**) was expressed as a difference in gross margin (total revenues minus variable costs) obtained by *Bt* corn farmers, compared with conventional corn farmers for 2002–2004. Gross margin differences mirrored the variability in agronomic yield increase described above, which seems to be a key factor defining the economic balance. Gross margin increase was as high as €122/hectare per year in Zaragoza, possibly becoming the main driver behind adoption of *Bt* corn in this province and compensating for the significant price

premium of *Bt* corn seeds. In Albacete, where technology is neutral regarding yield effects and gross margin increases are small, the absence of a significant price penalty for *Bt* corn should provide an incentive for adopting *Bt* corn.

The survey also included direct questions to farmers on reasons for adopting or not *Bt* corn. The most quoted reason for adopting *Bt* corn was "lowering the risk of corn borer damage" (**Supplementary Table 3** online). For GM insect-resistant crops, lowering the uncertainty from variable seasonal levels of pest infestations[8] has been suggested as the primary incentive for adoption elsewhere. After "risk lowering," other reasons declared by Spanish farmers for adoption were "obtaining higher yields" and, perhaps surprisingly, "better quality of the harvest." Accordingly, reductions in ear damage, susceptibility to post-harvest fungal infection and contamination by mycotoxins have been associated with adoption of *Bt* corn varieties[9]. Reticence to change was the most common reason provided for not adopting *Bt* corn.

It is unlikely that the yield and economic effects reported by *Bt* corn adopters in Spain result from differences in the competence of the two groups of farmers surveyed. We compared the socioeconomic profiles of farmers who adopted *Bt* corn with those who did not. We found (**Supplementary Table 4** online) no statistical differences between the two groups for such variables as land ownership, farm size, main crop cultivated, age, education, agricultural training or years of experience as a corn grower. Although other

Table 1 Economic benefits of adopting conventional or *Bt* corn in three Spanish provinces over three growing seasons

	2002			2003			2004		
	Conventional corn	*Bt* corn	Difference	Conventional corn	*Bt* corn	Difference	Conventional corn	*Bt* corn	Difference
Albacete									
Yield (tonnes/ha)	12.14 ± 2.00 (*n* = 40)	12.36 ± 1.77 (*n* = 29)	0.22 ns	12.01 ± 2.29 (*n* = 43)	11.85 ± 1.86 (*n* = 33)	–0.16 ns	12.53 ± 2.15 (*n* = 51)	12.59 ± 1.51 (*n* = 37)	0.06 ns
Revenues from yield (€/ha)	1,578.20 ± 260.19 (*n* = 40)	1,606.80 ± 229.77 (*n* = 29)	28.60 ns	1541.80 ± 297.18 (*n* = 43)	1540.50 ± 242.93 (*n* = 33)	–20.08 ns	1628.90 ± 286.74 (*n* = 51)	1636.70 ± 193.95 (*n* = 37)	7.80 ns
Cost of corn borer pest sprays(€/ha)	13.50 ± 15.42 (*n* = 61)	4.01 ± 9.60 (*n* = 42)	9.49**	13.50 ± 15.42 (*n* = 61)	4.01 ± 9.60 (*n* = 42)	9.49**	13.50 ± 15.42 (*n* = 61)	4.01 ± 9.60 (*n* = 42)	9.49**
Seed cost (€/ha)	163.62 ± 37.32 (*n* = 24)	174.92 ± 42.14 (*n* = 24)	–11.30 ns	177.43 ± 40.1 (*n* = 30)	180.97 ± 35.56 (*n* = 25)	–3.54 ns	176.78 ± 32.32 (*n* = 41)	182.84 ± 38.32 (*n* = 29)	–6.05 ns
Gross margin increase for *Bt* corn adopters (€/ha)			9.49			9.49			9.49
Lleida									
Yield (tons/ha)	11.51 ± 1.66 (*n* = 11)	12.66 ± 2.00 (*n* = 10)	1.15 ns	11.52 ± 1.60 (*n* = 14)	12.01 ± 1.64 (*n* = 20)	0.49 ns	11.75 ± 1.73 (*n* = 17)	12.18 ± 1.86 (*n* = 34)	0.43 ns
Revenues from yield (€/ha)	1,496.3 ± 216.41 (*n* = 11)	1645.8 ± 260.38 (*n* = 10)	149.50 ns	1497.6 ± 208.51 (*n* = 14)	1561.30 ± 213.39 (*n* = 20)	63.70 ns	1527.50 ± 224.58 (*n* = 17)	1563.90 ± 241.76 (*n* = 34)	55.9 ns
Cost of corn borer pest sprays (€/ha)	4.43 ± 10.51 (*n* = 52)	1.26 ± 5.07 (n = 66)	3.17*	4.43 ± 10.51 (*n* = 52)	1.26 ± 5.07 (*n* = 66)	3.17*	4.43 ± 10.51 (*n* = 52)	1.26 ± 5.07 (*n* = 66)	3.17*
Seed cost (€/ha)	164.88 ± 43.87 (*n* = 4)	193.67 ± 60.28 (*n* = 25)	–28.79 ns	164.88 ± 43.87 (*n* = 4)	193.67 ± 60.28 (*n* = 25)	–28.79 ns	164.88 ± 43.87 (*n* = 4)	193.67 ± 60.28 (*n* = 25)	–28.79 ns
Gross margin increase for *Bt* corn adopters (€/ha)			3.17			3.17			3.17
Zaragoza									
Yield (tonnes/ha)	9.87 ± 1.47 (*n* = 39)	11.06 ± 1.54 (*n* = 49)	1.19***	9.46 ± 1.10 (*n* = 55)	10.49 ± 1.66 (*n* = 63)	1.03***	9.53 ± 1.20 (*n* = 59)	10.64 ± 1.29 (*n* = 70)	1.11***
Revenues from yield (€/ha)	1,283.10 ± 190.95 (*n* = 39)	1,437.80 ± 199.63 (*n* = 49)	154.70***	1229.80 ± 142.54 (*n* = 55)	1363.70 ± 215.15 (*n* = 63)	133.9***	1238.90 ± 155.49 (*n* = 59)	1383.20 ± 167.53 (*n* = 70)	144.30***
Cost of corn borer pest sprays (€/ha)	32.07 ± 18.13 (*n* = 71)	12.03 ± 11.43 (*n* = 87)	20.04***	32.07 ± 18.13 (*n* = 71)	12.03 ± 11.43 (*n* = 87)	20.04***	32.07 ± 18.13 (*n* = 71)	12.03 ± 11.43 (*n* = 87)	20.04***
Seed cost (€/ha)	171.56 ± 44.43 (*n* = 55)	211.22 ± 34.18 (*n* = 49)	–39.66***	174.03 ± 42.33 (*n* = 57)	222.20 ± 35.91 (*n* = 61)	–48.17***	178.32 ± 40.43 (*n* = 61)	218.95 ± 51.18 (*n* = 72)	–40.64***
Gross margin increase for *Bt* corn adopters (€/ha)[a]			135.08			105.77			123.70

Data were obtained from a face-to-face survey conducted in 2005 among Spanish commercial corn farmers including 184 farmers growing only conventional corn and 195 farmers growing only *Bt* corn. The survey gathered data on yields, crop price, seed costs and applications of pesticide against corn borer for growing seasons (2002, 2003 and 2004). Results consist of mean values followed by s.d. and number of cases in parentheses. Number of cases varies between the variables due to missing data. One-way analysis of variance is used to test the differences among means. ns, not significant at 5%; *P < 0.05; **P < 0.01; ***P < 0.001. Seed costs for 2004 are used for the three years in Lleida due to missing data for 2002 and 2003.

[a]Gross margin increase is computed from adding the differences in revenues from yield, in cost of corn borer pest sprays and in seed costs when they are statistically significant.

Table 2 Average numbers of annual pesticide treatments against corn borer on surveyed farms[a]

Province	Conventional corn farmers	*Bt* corn farmers
Albacete	0.64 ± 0.73 (n = 61)	0.19** ± 0.50 (n = 42)
Lleida	0.21 ± 0.50 (n = 52)	0.06* ± 0.24 (n = 66)
Zaragoza	1.52 ± 0.86 (n = 71)	0.57*** ± 0.54 (n = 87)
Total average	0.86 ± 0.91 (n = 184)	0.32*** ± 0.50 (n = 195)

[a]All mean values for *Bt* corn farmers are different from those of conventional farmers at *P < 0.05; **P < 0.01; ***P < 0.001.

Table 3 Frequency distribution of number of pesticide treatments used by farmers cultivating conventional corn or *Bt* corn[a]

Number of treatments	Conventional corn farmers	*Bt* corn farmers
0	77 (42%)	136 (70%)
1	68 (37%)	56 (29%)
2	29 (16%)	3 (2%)
3	8 (4%)	0 (0%)
4	2 (1%)	0 (0%)
Total number of farmers	184 (100%)	195 (100%)

[a]For Pearson's Chi-square test applied to the frequency distributions of number of sprays against P < 0.001.

factors not analyzed in the survey (e.g., soil type, irrigation intensity, meteorological conditions) may vary between farms, we attribute the differences primarily to the introduction of *Bt* corn varieties.

There are very few reports on the economic performance of *Bt* corn in other parts of the world. For the United States, the largest grower of *Bt* corn, on-farm evidence is limited to the early years of adoption (1997–1999) and points to very variable economic effects resulting from large differences in geographical incidences of corn borers[10]. In South Africa, the *Bt* corn–yield advantage, together with reduced pesticide costs, increased income from €19.2 per hectare to €119 per hectare, a range similar to our findings in Spain[11].

Our data constitute the first large-scale, empirically based estimation of the economic impact of a GM crop for EU farmers. Future socioeconomic analyses of GM crops in EU agriculture need to consider a new element: the costs incurred by farmers adopting GM crops to ensure coexistence with non-GM crops. Most EU member states are now drafting specific coexistence measures for GM crop cultivation (http://ec.europa.eu/agriculture/coexistence/index_en.htm). Further socioeconomic research should evaluate the impact of these measures on the willingness of EU farmers to adopt GM crops and the extent to which coexistence costs will outweigh net gains in farmer's gross margin, as reported in this study.

Note: Supplementary information is available on the Nature Biotechnology website.

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Manuel Gómez-Barbero[1], Julio Berbel[2] & Emilio Rodríguez-Cerezo[1]

[1]European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), Edificio Expo, Avda. Inca Garcilaso s/n, 41092 Seville, Spain. [2]Departamento de Economía Agraria, Universidad de Córdoba, Spain.
e-mail: emilio.rodriguez-cerezo@ec.europa.eu

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