Plant Biotechnology: Potential Impact for Improving Pest Management in European Agriculture

Maize Case Study
June 2003

Leonard Gianessi
Sujatha Sankula
Nathan Reigner

The National Center for Food and Agricultural Policy
1616 P Street, NW Suite 100
Washington, DC 20036

Full Report: www.ncfap.org

History of maize and its use in Europe

Corn is the domesticated form of a wild grass that originated in Mexico. Columbus brought some corn seeds to Spain from his first exploration in 1493. Thereafter, the plant was spread throughout Europe. Corn is mainly grown as fodder/field corn in Europe. Cultivation of silage corn and sweet corn only takes place at a modest scale.

Field corn (maize) is an important crop in the EU accounting for 4.5 million hectares of production for grain with a value of €5.3 billion/yr. Four countries (France, Italy, Spain, and Germany) account for 88 % of the field corn production in the EU. 72% of the European maize harvest is used as animal feed (for cattle, swine, poultry) while the remainder is used for human consumption (oil, starch, flour). Corn acreage and yields increased dramatically in the four countries in recent decades. Corn acreage increases occurred as growers abandoned traditional rotations with cereals. As a result, corn has become the only cultivated crop in large areas being grown continuously on the same land year after year. In France, 50% of corn is grown continuously. European corn yield increases have resulted from increased use of irrigation, fertilizers, pesticides and new hybrids. The increase in corn production has meant that the EU is substantially self sufficient for corn with minimal imports from other producing regions of the world. However, nearly 3 million tonnes of corn are annually imported by Portugal and Spain from third countries under a preferential trade agreement.

Table 1 summarizes field corn production statistics for the major EU countries and for the U.S. for 2001.

Approximately 1% of Germany's grain corn acreage is grown organically [4]. Approximately 1000 Ha (0.2%) of Spain's maize hectares are organic.

History of the corn borer as pest in Europe

Among the insect pests that cause damage to corn, two species of corn borers are of particular importance in Europe: European corn borer (ECB) and Mediterranean corn borer (MCB).The MCB is also referred to as the pink stem borer. ECB is the major pest in France, Germany, Italy and Spain while the MCB is a second pest problem in the Mediterranean regions of Southern France, Italy and Spain. The ECB, as its name implies, is a native of Europe. First reports of ECB damage to corn in Europe date back to the late 1800s. In addition to corn, other plants that serve as ECB hosts in Europe include hops, hemp, millet and a weed species (mugwort). Although the ECB was known to infest all major European corn producing areas in the early 1900s, it caused only minor damage to corn due to extensive natural control by parasites, predators and other environmental factors [18]. ECB infestations were initially limited to the climatically favorable Mediterranean countries only. The insect moved northward eventually and adapted itself to less favorable regions such as Germany [19].

The ECB was accidentally introduced into the US from Europe in the early 1900s, probably on imported brooms made of corn leaves. Without the parasites and predators that controlled its population in Europe, the ECB spread rapidly in the U.S. resulting in large reductions in corn yields. In the 1920s and 1930s the USDA conducted the single greatest attempt in history to try and control a pest with biological means by importing ECB predators and parasites from Europe. However, none of the imported species became established in the US and losses to the corn borer remained high in the U.S. The USDA issued annual reports for 1942-1974 in which estimates were made of the yearly corn production losses from European corn borer damage. [33]. The annual losses varied from a low of 33 million bushels (838,000 tonnes in 1952) to over 300 million bushels (7.6 million tonnes in 1949, 1971).

Damage to corn from the ECB has increased in Europe in the last several decades. This increase may be due to environmental changes, the significant increase in monoculture corn acreage, the introduction of more susceptible hybrids, and the increased use of pesticides, which could be reducing predator/parasite populations [17] [22].

Mating between adult borer moths occurs in the late spring. Each female lays about 15 to 20 masses of 500 to 600 fertilized eggs on corn leaves. Eggs hatch into larva, which feed on the corn plant. Following a brief feeding period in the whorl of developing corn leaves, the larva bore into stalks and excavate tunnels in which they complete development. The tunnels produced by borers interfere with the movement of nutrients and water in the plant. The tunnels also reduce the strength of the stalk, thereby predisposing the corn plants to stalk breakage. The feeding of the borers results in reduced plant growth, malformed ears, reduced kernel size, and harvest losses due to broken plants [9] [14] [19]. Research has shown that in Europe corn yields are reduced 6% for one ECB larvae per plant [8]. Similar to ECB, MCB-infested maize is characterized by the presence of tunnels throughout the stem.

Secondary infections of fungi and bacteria are other risks associated with corn borer feeding. Corn borer larvae carry spores of pathogens in the genus *Fusarium* thereby increasing the incidence of stalk, ear and root rots. Additionally, the feeding holes left on corn kernels by corn borer larvae serve as a preferential site for penetration of fungi. Close associations have been noted between susceptibility of corn hybrids to ECB larvae and the appearance of stalk rot. *Fusarium* species that infect corn produce toxins in the plant tissue called fumonisins. In general, a high correlation exists between ECB damage and mycotoxin concentration in corn kernels [31]. Mycotoxins are carcinogenic and can cause fatal diseases in livestock and humans. Research has shown the natural occurrence of fumonisins in field corn from France, Germany and Spain and in several samples of corn-based feeds and foods collected in Italy and Spain [26] [23] [25]. The latter include different feeds for chickens, cattle and pigs and food products from retail markets such as corn meal for polenta [23]. Samples taken of corn-based human food in retail outlets showed positive fumonisin concentrations in corn semolina/polenta imported into Germany from Italy. Research has shown that the occurrence of fumonisins in corn is considerably higher in Mediterranean countries than in central Europe or the U.S. [24].

Potential damage from the ECB is greater in the Mediterranean region of southern France, Italy and Spain where it produces 2-3 generations of larva each summer due to the warm climate while in northern France and Germany only one generation of larva is produced. The MCB also completes 2-3 generations of larva in the Mediterranean countries. Research in France indicated that yield losses due to borers can be as high as 15% while in Spain research has determined that yield losses can be as high as 30% [15] [20].

About 25% of corn acreage in Spain is in high corn borer pressure areas while 40% is in medium pressure areas [40]. In Germany approximately 25% of the maize acreage is infested with ECB [42]. In France approximately 40% of maize acreage have an average of one or more ECB per corn plant [42]. In Italy, corn borers infest nearly all of the maize acreage every year with yield losses of 7-15% [41]. It is estimated that 5-7% of potential European corn production is lost annually due to borers depending on the intensity of the infestation [36][16].

However, in North-Western European and Scandinavian countries, corn borers have so far not been a pest in (fodder) corn cultivation.

Conventional strategies for corn borer control

Corn borer control (both ECB and MCB) is extremely difficult. Larvae can only be effectively controlled while they are feeding within the whorl of corn leaves. Once they enter the stalk, they cannot be controlled with the currently used management techniques, which include the release of parasitic wasps and the use of chemical insecticides [14].

Chemical control

Under European conditions, chemical insecticides provide approximately 75% control of corn borers [42]. Evaluation of the efficacy of one insecticide treatment against the second generation of the MCB was carried out in France from 1995 to 1997 with variable results: 71%, 80%, and 41% respectively [10]. This reduced level of efficacy is due to the difficulty of timing sprays to the narrow time frame before the larvae bore into maize stalks. Once the larvae are inside the plants, chemical applications are futile due to the hidden nature of the borers. The height of the corn plants at the time of treatment generally requires special high clearance tractors capable of driving through a field of grown, tall corn-which most farmers do not own [14][41]. Spray applications from airplanes are not always possible because many European corn fields are small and scattered, often abutting buildings and towns [41]. Chemical insecticides are seldom used for corn borer control in the water conservation areas of the Rhine Valley in Germany due to laws restricting their use. Many farmers do not realize the level of yield damage

inflicted by borers; many farmers do not have the time to scout fields to time the spray at the optimal time for borer control [40].

After 2003 in Germany, there will be no registered insecticide available for corn borer control [4].

So, insecticides are typically used on only a fraction of the corn borer infested acreage in Europe. In Italy, only 5% (55,000 hectares) of the acreage is treated typically for corn borers [41]. In Spain, typically 6-20% of the corn acreage is treated annually for borers (approximately 78,000 hectares, 15%) [40]. Insecticide treatments for corn borers in France and Germany total approximately 275,000 (14%) and 40,000 (10%) hectares respectively [5]. In total, 448,000 hectares are thus sprayed with chemicals for corn borer control, representing about 11 % of the total corn acreage in these four countries.

In Spain, the most commonly used insecticide for corn borers is the organophosphate chlorpyrifos (67,500 hectares) followed by synthetic pyrethroids (11,000 hectares). The average use rate per treated hectare in Spain is 0.58 kg active ingredient (AI) per hectare [40]. In France, Germany, and Italy, no organopposphate is used, whereas pyrethroids are used for borer control with an average use rate of 0.02 kg per ha [48].

Table 2 shows estimates of the cost and use amounts of insecticides used for corn borer control in Europe. It is estimated that 448,000 hectares are treated with 52,600 kilograms of active ingredient (115,700 lbs) at a cost of 13 million euros per year. Also shown in Table 2 are estimates of the cost of *trichogramma* releases for biological control of borers, which is estimated to total 2 million euros per year.

Biological control

One of the parasites of the ECB in Europe identified in the 1920s by USDA researchers is a tiny parasitic wasp, *trichogramma.* The females of *trichogramma* need to deposit their eggs into the eggs of a specific host to advance its generation. *Trichogramma* females exhibit preference towards lepidopteran insects such as corn borers (both ECB and MCB) and codling moths. The female *trichogramma* upon coming into contact with a corn borer egg lays one or more eggs into the borer egg. The parasitic larvae, upon hatching, feed on the contents of the corn borer egg thereby killing it [28].

Commercial use of *trichogramma* first began in Germany in 1980 followed by France in 1986. The commercial availability of *trichogramma* to corn growers is the result of a collaborative effort between several private companies and government agencies. The method of application involves inundative releases of *trichogramma* eggs in capsules that are scattered by hand in corn fields. The release is initiated when the first corn borer moth is caught in light traps. Generally, a second release is made two weeks following the first for each generation of borers. Each release takes about 20 minutes per hectare. Each capsule contains about 500 flour moth eggs that have been parasitized with *trichogramma*

eggs. The capsules are released at the rate of 200 per hectare, which yields about 100,000 wasps per hectare per release. The parasitic wasps hatch and emerge from the capsules. Female and male wasps mate and the pregnant female wasps search the corn plants for borer eggs and deposit their eggs into the borer eggs. Research in Germany showed that parasitic wasps used at 150,000 to 200,000 eggs/ha resulted in a reduction in ECB larvae by 61 to 93% [27]. However, a long-term study in Italy suggested that the highest rate of parasitization by *trichogramma* was only 33% under Italian conditions. A major limitation to the use of *trichogramma* is reduced efficacy under conditions of heavy rainfall, sunshine and high temperature [30]. In addition to reducing the efficacy of parasitism by *trichogramma*, high temperatures cause male sterility and reductions in the rate of wasp emergence from the capsules. The presence of the MCB complicates the situation as *trichogramma* is species-specific which would necessitate the use of two species of *trichogramma* to control both the ECB and MCB [28]. Another limitation on the efficacy of *trichogramma* is timing. If the release is not made at the right time or if the wasps do not emerge in a timely manner, ECB parasitism is reduced if the ECB eggs hatch before the wasps deposit their eggs.

Trichogramma are released on about 50,000 hectares (2.6%) of French and 7,000 to 10,000 hectares of German corn acreage [11] [27]. In Germany, approximately half of the *trichogramma* releases are on seed corn acreage while the remainder are for grain corn [5]. In some parts of Germany, corn growers receive a subsidy of approximately 60 euros per hectare for using *trichogramma* [4].

Bt corn as a new approach to corn borer control

Through genetic engineering, genes encoding insecticidal proteins that were isolated from the soil bacterium *Bacillus thuringiensis* (Bt) have been inserted into the genetic makeup of corn plants [37]. Corn plants modified to contain Bt genes express crystal proteins (Cry proteins). When corn borer larvae feed on Bt corn plants, the insect's digestive enzymes activate the toxic form of the protein. The Cry proteins bind to the insect's intestinal lining and rupture the cells. Borers stop feeding within two hours of a first bite and die within two or three days. In addition, research also demonstrated that Bt corn varieties were significantly lower in mycotoxin levels in comparison to the conventional varieties. Research has shown in France and Spain that the fungal biomass formed on Bt corn grain was 4-18 times lower than on non-Bt corn [31]. Research with Bt corn in Italy resulted in a reduction of the fumonisin content by 90% (20 ppm to 2 ppm) [32].

Bt corn has been planted on 14.9 million acres (6.0 hectares) in the U.S. (21%). Table 3 shows estimates of the aggregate impacts on corn production, corn value, and pesticide use resulting from the planting of Bt corn in the U.S. In a typical year, adoption of Bt corn in the U.S. results in an increase of the net value of 125 million dollars and a decrease of pesticide use by 1.2 million kg.

In Europe, Bt corn varieties were approved for planting prior to the 1998 de facto moratorium, which stopped any new approvals of transgenic crops in Europe. Bt corn was planted on 22,000 hectares in Europe in 1998, primarily in Spain (20,000 ha) and France (2,000 ha) [34]. Bt corn plantings have been discontinued in France and except for a small number of hectares in Germany for research purposes (100 ha), Bt corn acreage in Europe is currently limited to Spain where 25,000 hectares (4-5%) are planted yearly. Further expansion in Spain has not occurred due to a voluntary arrangement of the seed supplier (Syngenta) [40]. Recently, five new Bt varieties have been approved for Spain, which will likely increase plantings to 10% of the crop.

Two multi-location field trials were conducted in Germany for two consecutive years to compare the performance of Bt with non-Bt corn. Grain yield from Bt plots were 17% higher than untreated plots, 6% higher than insecticide-treated plots, and 14% higher than *trichogramma*-treated plots [4] [46]. Eight years of experiments in Germany demonstrated that Bt corn was more efficacious (95%) in controlling borers than were chemicals (75%) or *trichogramma* (55%) [39]. The AGPM (Maize Growers General Association) in France assessed the effect of Bt corn on the MCB. An efficacy over 99% was found against the first and second generation of that pest. French research with Bt corn for ECB control resulted in 100% control in 5 out of 8 trials [37]. Research in Italy demonstrated significant improvements in corn borer control with Bt corn in comparison to conventional corn treated with insecticides [44]. Research in the Rhine River Valley of Germany showed that ECB larvae caused nearly no grain yield reduction in Bt corn plots [35]. Bt corn yields were 15% higher than conventional corn treated with insecticides [35].

A recent study estimated the impacts of Bt corn planting in Spain [40]. The cost of the Bt corn technology was estimated at an increase of 18-19 euros per hectare relative to conventional seed. This cost is based on the purchase of seed through cooperatives. In regions of high borer infestation, it was estimated that Bt corn yields were 10% greater than when treated with insecticides and 15% greater in comparison to when insecticides were not previously used. Overall, a yield improvement of 6% was estimated for Bt corn based on trials conducted in 1997 [47]. Factoring in savings of not making insecticide treatments and the value of the increased yield, it was estimated that Bt corn improved profitability of corn production by 13%. The study estimated that if the voluntary limitation on planting Bt corn were lifted, that it would make economic sense to plant Bt corn on 36% of Spain's corn hectares. Table 4 summarizes the aggregate projected impacts for Spain from the study.

An analysis of the economic comparison of Bt corn in Germany indicated a gain of 61 euros per hectare in comparison to insecticide use and a gain of 154 euros per hectare in comparison to *trichogramma* use [4].

Potential for change of pesticide use and grower income due to Bt corn adoption in Europe

Table 5 estimates the potential impact of planting Bt corn in Europe on hectares that are highly infested with corn borers. Bt corn is projected for adoption as follows: France (40%), Italy (50%), Spain (36%), and Germany (25%) [42] [40] [41]. Total adoption area

is projected at 1.599 million hectares. Table 5 estimates the impact on production volume and value of the hectares in each country according to their current treatment status. Approximately 448,000 hectares are currently treated with insecticides. On these hectares, a yield increase of 10% is assumed as a result of planting Bt corn. 59,000 hectares are currently treated with *trichogramma.* On these hectares a yield increase of 14% is assumed as a result of planting Bt corn. 1.092 million hectares are currently untreated for corn borers and the production and value increase is estimated at 15%. Table 5 also shows estimates of the potential aggregate cost of Bt corn relative to conventional seed, which is estimated at 18.5 euros per hectare for a total of 29.58 million euros.

Table 6 sums the impacts of the adoption of Bt corn by country from the subtotals derived based on the current treatment status in each country as shown in Table 5.

Table 7 provides an overall summary of the potential impacts of Bt corn in Europe. Bt corn is projected for adoption on 1.599 million hectares (41% of corn hectares). The adoption of Bt corn is projected to increase production costs by 14.4 million euros. By increasing production by 1.9 billion kilograms per year, it is estimated that corn value would increase by 263 million euros, which would result in a net increase of farm income of 248 million euros. Insecticide use is projected to decline by 52,600 kilograms.

The improvement in profitability of corn production afforded by Bt corn may be of particular importance in offsetting the potential adverse effect on maize crop margins that are expected to result from the EU Commissions Mid Term Review Proposals to reform its current agricultural policy.

Table 1a: Grain Maize (Corn) Production			
	Production (billion Kg/yr)	***Hectares (000)***	***Value (billion €/yr)***
France	16.3	1914	2.0
Italy	10.4	1109	1.6
Spain	4.9	504	0.7
Germany	3.5	397	0.4
Total	35.1	3924	4.7
EU-15	40.1	4527	5.3
U.S.	331.2	30300	19.2

Table 1b: Grain Maize (Corn) Production			
	Production (billion Lbs/yr)	***Acres (millions)***	***Value (billion $/yr)***
France	36.2	4.8	2.0
Italy	23.2	2.8	1.6
Spain	10.9	1.3	0.7
Germany	7.7	1.0	0.4
Total	78.0	9.9	4.7
EU-15	89.1	11.3	5.3
U.S.	736.0	75.7	19.2

Source [1][2][3]
Euros and Dollars are assumed equivalent

Table 2a: Maize for Grain: Corn Borer Treatments							
	Insecticides					*Trichogramma*	
	Hectares treated (000)	*Kg Ai/Ha*	*Total Kg Ai (000)*	*Cost*		*Hectares treated (000)*	*Total Cost (€000)*
				€/Ha	*Total (€000)*		
France	275	0.02	5.5	30	8250	50	1900
Italy	55	0.02	1.1	30	1650	0	0
Spain	78	0.58	45.2	21	1638	0	0
Germany	40	0.02	0.8	38	1520	5	190
Total	448		52.6		13058	55	2090

Table 2b: Maize for Grain: Corn Borer Treatments							
	Insecticides					*Trichogramma*	
	Acres treated (000)	*Lbs Ai/A*	*Total Kg Ai (000)*	*Cost*		*Acres treated (000)*	*Total Cost ($000)*
				$/A	*Total ($000)*		
France	688	0.02	12.1	75	8250	125	1900
Italy	138	0.02	2.4	75	1650	0	0
Spain	195	0.52	99.4	53	1638	0	0
Germany	100	0.02	1.8	95	1520	13	190
Total	1121		115.7		13058	138	2090

Trichogramma data from: [11][27][5]; Trichogramma releases estimated to cost €38/Ha [39]
Insecticide area data from [27][41][40][5]; insecticide cost and rate data from [40][43][39][42]
Euros and Dollars are assumed equivalent

Table 3a: Impacts of Adoption of Bt Corn in the U.S. (Typical Year)	
Hectares	6.0 million (21%)
Production	
Volume	+1.6 billion Kg/yr
Value	+ €126 million /yr
Costs	+ €1 million /yr
Net Value	+ €125 million /yr
Pesticide Use	-1.2 million kg/yr

Table 3b: Impacts of Adoption of Bt Corn in the U.S. (Typical Year)	
Acreage	14.9 million (21%)
Production	
Volume	+3.5 billion Lbs/yr
Value	+ $126 million /yr
Costs	+ $1 million /yr
Net Value	+ $125 million /yr
Pesticide Use	-2.6 million lbs/yr

Source: [6]
Euros and Dollars are assumed equivalent

Table 4a: Potential Aggregate Impacts of Planting Bt Corn in Spain	
% Hectares Adopting	36% (173,000 Ha)
Avg Yield Impact	+5-7 %
Production Volume	+88,000-124,000 tonne
Production Value	+ €11-15 million
Insecticide Use	
Hectares Sprayed	-59,000 to -98,000 Ha
Volume	-35,000 to -56,400 Kg

Table 4b: Potential Aggregate Impacts of Planting Bt Corn in Spain	
% Acres Adopting	36% (432,500 A)
Avg Yield Impact	+5-7 %
Production Volume	+194 to 273 million Lbs.
Production Value	+$11 to 15 million
Insecticide Use	
Acres Sprayed	-147500 to -245000 A
Volume	-77000 to -124000 Lbs.

Source: [40]
Euros and Dollars are assumed equivalent

Table 5a: Potential Impact of Planting Bt Corn in Europe

(1) Total Adoption Area

	%[1]	*Ha (000)*	*Current*		*Bt Corn Cost (€ 000)*[2]
			Production (billion Kg)	*Value (€ million)*	
France	40	765	6.5	800	14152
Italy	50	554	4.2	800	10249
Spain	36	181	2.0	252	3348
Germany	25	99	1.4	100	1831
Total		1599	14.1	1952	29580

(2) Adoption Acreage Currently Treated with Insecticides

	%[1]	*Ha (000)*	**Increase**[3]	
			Production (million Kg)	*Value (€ million)*
France	36	275	235	28.8
Italy	10	55	42	8.0
Spain	43	78	85	9.1
Germany	40	40	56	4.0
Total		448	418	49.9

(3) Adoption Acreage Currently Treated with Trichogramma

	%[1]	*Ha (000)*	**Increase**[4]	
			Production (million Kg)	*Value (€ million)*
France	7	54	64	7.8
Germany	5	5	10	0.7
Total		59	74	8.5

(4) Adoption Acreage Currently Not Treated

	%[5]	*Ha (000)*	**Increase**[6]	
			Production (million Kg)	*Value (€ million)*
France	57	436	558	68
Italy	90	499	565	108
Spain	57	103	169	21
Germany	55	54	115	8
Total		1092	1407	205

Dollars and Euros are assumed as equivalent

[1] Sources: [40][41][42][5][11][27]
[2] Calculated at €18.50/Ha [40]
[3] Calculated at 10% increase
[4] Calculated as a 14% increase
[5] Calculated by subtraction
[6] Calculated as a 15% increase

Table 5b: Potential Impact of Planting Bt Corn in Europe

(1) Total Adoption Area

	%[7]	A (000)	Current		Bt Corn Cost ($ 000)[8]
			Production (billion Lbs.)	Value ($ million)	
France	40	1913	14.5	800	14152
Italy	50	1386	9.3	800	10249
Spain	36	453	4.4	252	3348
Germany	25	248	3.1	100	1831
Total		4000	31.3	1952	29580

(2) Adoption Acreage Currently Treated with Insecticides

	%[7]	A (000)	Increase[9]	
			Production (million Lbs.)	Value ($ million)
France	36	688	522	28.8
Italy	10	138	93	8.0
Spain	43	195	189	9.1
Germany	40	100	124	4.0
Total		1121	928	49.9

(3) Adoption Acreage Currently Treated with Trichogramma

	%[7]	A (000)	Increase[10]	
			Production (million Lbs.)	Value ($ million)
France	7	135	142	7.8
Germany	5	13	22	0.7
Total		148	164	8.5

(4) Adoption Acreage Currently Not Treated

	%[11]	A (000)	Increase[12]	
			Production (million Lbs.)	Value ($ million)
France	57	1090	1239	68
Italy	90	1248	1255	108
Spain	57	258	376	21
Germany	55	135	256	8
Total		2731	3126	205

Dollars and Euros are assumed as equivalent

[7] Sources: [40][41][42][5][11][27]
[8] Calculated at $7.40/A
[9] Calculated at 10% increase
[10] Calculated as a 14% increase
[11] Calculated by subtraction
[12] Calculated as a 15% increase

Table 6a: Potential Impact of Bt Corn in Europe				
Production Costs (€000)				
	Current Treatment		***BT Corn***	***Net Cost***
	Insecticides	***Trichogramma***		
France	-8250	-1900	+14152	+4002
Italy	-1650	0	+10249	+8599
Spain	-1638	0	+3348	+1710
Germany	-1520	-190	+1831	+121
Total	-13058	-2090	+29580	+14432
Production Value (€000)				
	Current Treatment			***Total***
	Insecticides	***Trichogramma***	***None***	
France	+28800	+7800	+68000	+104600
Italy	+8000	0	+108000	+116000
Spain	+9100	0	+21000	+30100
Germany	+4000	+700	+8000	+12700
Total	+49900	+8500	+205000	+263400
Production Volume (million Kg)				
	Current Treatment			***Total***
	Insecticides	***Trichogramma***	***None***	
France	+235	+64	+558	+857
Italy	+42	0	+565	+607
Spain	+85	0	+169	+254
Germany	+56	+10	+115	+181
Total	+418	+74	+1407	+1899

Production costs: see Tables 2 & 5
Production value and volume: see Table 5

Table 6b: Potential Impact of Bt Corn in Europe				
Production Costs ($000)				
	Current Treatment		***BT Corn***	***Net Cost***
	Insecticides	***Trichogramma***		
France	-8250	-1900	+14152	+4002
Italy	-1650	0	+10249	+8599
Spain	-1638	0	+3348	+1710
Germany	-1520	-190	+1831	+121
Total	-13058	-2090	+29580	+14432
Production Value ($000)				
	Current Treatment			***Total***
	Insecticides	***Trichogramma***	***None***	
France	+28800	+7800	+68000	+104600
Italy	+8000	0	+108000	+116000
Spain	+9100	0	+21000	+30100
Germany	+4000	+700	+8000	+12700
Total	+49900	+8500	+205000	+263400
Production Volume (million Lbs.)				
	Current Treatment			***Total***
	Insecticides	***Trichogramma***	***None***	
France	+522	+142	+1239	+1903
Italy	+93	0	+1255	+1348
Spain	+189	0	+376	+565
Germany	+124	+22	+256	+402
Total	+928	+164	+3126	+4218

Production costs: see Tables 2 & 5
Production value and volume: see Table 5

Table 7a: Summary of Bt Corn Potential Impacts in Europe							
	Ha Adopted (000)	*% Ha Adopted*	*Production (€000)*			*Prod. Increase (million Kg)*	*Insecticide Use Kg*
			Costs	*Value*	*Net*		
France	765	40	+4002	+104600	+100598	+857	-5500
Italy	554	50	+8599	+116000	+107401	+607	-1100
Spain	181	36	+1710	+30100	+28390	+254	-45200
Germany	99	25	+121	+12700	+12579	+181	-800
Total	1599	(41)	+14432	+263400	+248968	+1899	-52600

Table 7b: Summary of Bt Corn Potential Impacts in Europe							
	A Adopted (000)	*% A Adopted*	*Production ($000)*			*Prod. Increase (million Lbs.)*	*Insecticide Use Lbs*
			Costs	**Value**	*Net*		
France	1913	40	+4002	+104600	+100598	+1903	-12100
Italy	1386	50	+8599	+116000	+107401	+1348	-2420
Spain	453	36	+1710	+30100	+28390	+565	-99440
Germany	248	25	+121	+12700	+12579	+402	-1760
Total	4000	(41)	+14432	+263400	+248968	+4218	-115720

Reference List

1. USDA, Crop Production 2001 Summary, National Agricultural Statistics Service, January 2002.

2. USDA, Crop Values 2001 Summary, National Agricultural Statistics Service, February 2002.

3. EU, Agriculture Statistical Yearbook, 2002 Edition, ISSN 1681-4711.

4. Heitz, Volker, "A Multiyear Comparison of European Corn Borer Control Methods," Amt fur Landwirtschaft, Landschafts – und Bodenkultur Offenburg.

5. Zellner, Michael, Institut Pflanzenschutz, Personal Communication, May 2003.

6. Gianessi, L.P., et al., Plant Biotechnology: Current and Potential Impact For Improving Pest Management In U.S. Agriculture: An Analysis of 40 Case Studies, National Center for Food and Agricultural Policy**,** June 2002.

7. Butron, A., et al., "Combining Abilities for Maize Stem Antibiosis, Yield Loss, and Yield Under Infestation and Non-infestation with Pink Stem Borer," Crop Science, 39:691-696, 1999.

8. Bohn, M., et al., "Damage and Grain Yield Losses Caused by European Corn Borer (Lepidoptera: Pyralidae) in Early Maturing European Maize Hybrids," Journal of Economic Entomology, 92:723-731, 1999.

9. Bohn, M., et al., "QTL Mapping for Resistance Against the European Corn Borer (*Ostrinia Nubilalis* H.) in Early Maturing European Dent Germplasm," Theoretical and Applied Genetics, 101:907-917, 2000.

10. Albajes, R., et al., "Mating Disruption of the Corn Borer using Sprayable Formulations of Pheromones," Crop Protection, 21:217-225, 2002.

11. Frandon, J. and F. Kabiri,. "La Lutte Biologique Contre la Pyrale du Mais avec les Trichogrammes Evolution de la Technique pour une Utilization A' grande E'chelle," Available at www.inra.fr/dpenv/frandc00.htm, 1998.

12. EU, "Opinion of the SCP on Bt – Resistance Monitoring," The European Commission, Health and Consumer Protection, Scientific Committee on Plants, Available at http://europa.eu.int/comm/food/fs/sc/scp/out35_en.html, March 1999.

13. Furlan, L., et al., "*Ostrinia Nubilalis* Population Levels in North Eastern Italy: Long Period Data and Practical Considerations," Proceedings of the XXI IWGO, 2001.

14. Melchinger, A. E., et al., "Evaluation of Early-maturing European Maize Inbreds for Resistance to the European Corn Borer," Euphytica, 99:115-125, 1998.

15. Anglade, P. and S. Rautou, Current Status of Breeding Corn in France for Resistance to the European Corn Borer (*Ostrinia Nubilalis* Hbn.), EPPO Public, No. 54: 45-55, 1970.

16. Labatte, Jean-Marc, et al., "Natural Mortality of European Corn Borer Larvae: Field Study and Modeling," Journal of Economic Entomology, Vol. 90, No. 3, 1997.

17. Eizaguirre, M. and R. Albajes, "Present Situation of Arthropod Pests in the Northeast of Spain," Acta Phytopathologica et Entomologica Hungarica, 24:77-80, 1989.

18. Thompson, W. R. and H. L. Parker, The European Corn Borer and its Controlling Factors in Europe, USDA Technical Bulletin No. 59, 1928.

19. Schulz, B., et al., "Genetic Variation Among European Maize Hybrids for Resistance to the European Corn Borer and Relation to Agronomic Traits," Plant Breeding, 116:415-421, 1997.

20. Butron, A., et al., "Resistance of Maize Inbreds to Pink Stem Borer," Crop Science, 39:102-107, 1999.

21. Giupponi, Carlo, The Environmental Impact of Maize Cultivation in the European Union: Practical Options for the Improvement of the Environmental Impact, Italian Case Study, Dipartimento di Agronomia Amientale e Produzioni Vegetali, Universita degli Studi di Padova, January 2000.

22. Cordero, A., et al., "Population Dynamics and Life-Cycle of Corn Borers in South Atlantic European Coast," Maydica, 43:5-12, 1998.

23. Visconti, Angelo, and M. Bruno Doko, "Survey of Fumonisin Production by *Fusarium* Isolated from Cereals in Europe," Journal of AOAC International, Vol. 77, No. 2, 1994.

24. Castella, Gemma, et al., "Surveillance of Fumonisins in Maize-Based Feeds and Cereals from Spain," Journal of Agricultural & Food Chemistry, October, 1999.

25. Sherphard, Gordon S., et al., "Worldwide Survey of Fumonisin Contamination of Corn and Corn-Based Products," Journal of AOAC International, Vol. 79, No. 3, 1996.

26. Tanaka, Toshitsugu, et al., "Worldwide Contamination of Cereals by the *Fusarium* Mycotoxins Nivalenol, Deoxynivalenol, and Zearalenone. Survey of 19 Countries," Journal of Agricultural & Food Chemistry, 1988.

27. Hassan, S. A. and W. Q. Zhang, "Variability in Quality of *Trichogramma Brassicae* (Hymenoptera: Trichogrammatidae) from Commercial Suppliers in Germany," Biological Control, 22:115-121, 2001.

28. Frandon, J., "Innovation Project – Biological Pest Control," Available at http://www.cordis.lu/itt/itt-en/98-1/ip-news.htm, 1998.

29. Neuffer, G., "The Use of *Trichogramma Evanescens* Westw. in Sweet Corn Fields. A Contribution to the Biological Control of the European Corn Borer *Ostrinia nubilalis Hbn* in Southwest Germany," in Les Trichogrammes, Les Colloques de l'INRA, no. 9, April, 1982.

30. Chihrane, J. and G. Lauge, "Loss of Parasitization Efficiency of *Trichogramma Brassicae* (Hym: Tricho Grammatidae) Under High Temperature Conditions," Biological Control, 7:95-99, 1996.

31. Bakan, B., et al., "Fungal Growth and *Fusarium Mycotoxin* Content in Isogenic Traditional Maize and Genetically Modified Maize Grown in France and Spain," Journal of Agricultural Food Chemistry, 50:728-731, 2002.

32. Masoero, F., et al., "Nutritive Value, Mycotoxin Contamination and *in Vitro* Rumen Fermentation of Normal and Genetically Modified Corn (CRY1A(B)) Grown in Northern Italy," Maydica, 44:205-209, 1999.

33. USDA, Cooperative Economic Insect Report, APHIS, Vol. 25, No. 32, August 1975.

34. Europabio, Europabio's Biotechnology Information Kit: Module 10, Genetically Modified Maize, Available at http://www.europabio.org/pages/module_10.asp, 2002.

35. Magg T., et al., "Comparison of Bt Hybrids with Their Non-transgenic Counterparts and Commercial Varieties for Resistance to European Corn Borer and for Agronomic Traits, Plant Breeding, 120:397-403, 2001.

36. Manachini, B., and G.C. Lozzia, "First Investigations into the Effects of Bt Corn Crop on Nematofauna," Bollettino di Zoologia Agraria e di Bachicoltura, April 2002.

37. Labatte, E-M., et al., "Field Evaluation of and Modeling the Impact of Three Control Methods on the Larval Dynamics of *Ostrinia Nubilalis* (Lepidoptera: Pyralidae)," Journal of Economic Entomology, 89:852-862, 1996.

38. Magg T., et al., "Relationship Between European Corn Borer Resistance and Concentration of Mycotoxins Produced by *Fusarium* Spp. in Grains of Transgenic Bt Maize Hybrids, Their Isogenic Counterparts, and Commercial Varieties," Plant Breeding, 121:146-154, 2002.

39. Zellner, M., "Control of European Corn Borer – What Possibilities Are There and What is to be Paid Attention to?," Available at http://www.stmlf.bayern.de/lbp/info/ps/ maiszuensler_eng.html, 2001.

40. Brookes, G., The Farm Level Impact of Using Bt Maize in Spain, Available http://www.europabio.org/upload/documents/gb_press_release/EuropaBio_btmaizeinspainreport_FINAL.pdf, 2002.

41. Manachinni, B., University of Milano, Personal communication, February, 2003.

42. Mitteilungen aus der Biologischen Bundesanstalt fur Land – und Forstwirtschaft, Heft 390, 96-97, 2002.

43. von der Heyde, Jurgen, "Biocontrolling the European Corn Borer in Western Europe," BASF Agricultural News, January 1990.

44. Lozzia, G.C., and I.E. Rigamonti, "Behaviour of the European Corn Borer, *Ostrina Nubilalis* Hb., on Transgenic Corn," Bollettino di Zoologia Agraria e di Bachicoltura, Vol. 28, No. 1, 51-69, 1996.

45. Bernd Hommel, Biologischen Bundesanstalt fur Land und Forstwirtschaft, personal communication, April, 2003.

46. Degenhardt, Heinz, "Bt-Mais in Deutschland; Erfahrungen mit dem Prazisanbau von 1998 bis 2002," Mais, vol. 2, 75-77, 2003.

47. Garcia-Olmedo, Francisco, "Transgenic Crops in Spain," in Nicholas Kalaitzandonakes ed., The Economic and Environmental Impacts of Agbiotech, Kluwer Academic/Plenum Publishers, 2002.

48. Naibo, Bernard, AGPM, Personal communication, June 2003.