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

Sugarbeet Case Study
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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 sugarbeet and its use in Europe

Beet has been grown for food and fodder since ancient times. Its sweetness was reported in the 1500s but beet did not become a source of refined sugar until 1747 when a German scientist extracted crystalline sugar and another 40 years before other German scientists selected types of beets that had sufficient sugar for profitable extraction of sucrose. The first factory to produce sugar from sugarbeet began operating in Silesia in 1802 [3]. During the Napoleonic Wars, the British Navy blockaded French ports preventing sugarcane from being imported, which resulted in extensive planting of sugarbeets in mainland Europe. By 1880, beet was the main source of sugar in Europe and the consumption of beet sugar exceeded the consumption of cane sugar. The first successful beet sugar operation in the U.S. was established in 1879. The sugarbeet industry expanded dramatically in the UK in the 1920s for two main reasons: first, to make Britain more self sufficient in sugar production after severe shortages during World War I and after it lost most of its colonies in the early years of the 20th century; and second, to boost the depressed agricultural industry by giving farmers the opportunity to grow a valuable cash crop [4]. In the 20th century sugarbeets were cultivated with higher sugar contents due to improvement of cultivation and breeding techniques. Also, processing improved. In the 1970s the Common Organisation of the Market (COM) was established in Europe for a steady supply of sugar at a (relatively) constant price, as well as to protect the European sugarbeet growers from cane sugar from Africa and Middle and South America.

Sugarbeets are harvested for their roots. As a result of plant breeding, the sugar content of the roots was increased from 1-4% to 15-20%. Sugarbeets are biennial and have a two-year life cycle. For sugar production, sugarbeets are grown for only the first year of the life cycle. During this time, the crop is in a non-reproductive stage and does not produce seed. Sugarbeets that are grown specifically for seed are allowed to grow for the second year when seeds are produced by the plant. European sugarbeet seed production is located in specialized areas in France and Italy.

Sugarbeet roots are processed in factories to remove the sugar. The roots are soaked in hot water and the sugar of the beet passes from the plant cells into the water. The resulting brown liquid is boiled to produce a thick syrup in which crystals appear. The crystals are separated from the syrup in a centrifuge, producing granulated sugar. Because sugarbeet is a heavy and bulky crop, transport distances between field and factories are kept as short as possible to reduce costs. The sugar factories have been built in the beet growing areas [4].

In recent years, the number of EU sugar factories has fallen sharply, as the industry has undergone major changes to improve efficiency. This development has also been made in response to the significant fall in the real value of the sugar price support since the mid-

1980s. The number of factories has been reduced from 213 in 1992, to 135 in 2002. The number of employees has followed suit. In 2002, they numbered 33,600, a fall of 45% since 1992 [2].

Eight countries (Denmark, France, Germany, Italy, Netherlands, Spain, Belgium, and UK) each have more than 60,000 hectares of sugarbeets and account for 88% of the EU's production. EU growers produce 115 billion kilograms of sugarbeets, which are processed into 15 billion kilograms of white sugar. The value of sugarbeet production to EU farmers is approximately €4.7 billion/yr.

Table 1 summarizes EU and US sugarbeet production and processing statistics. European sugarbeet production , acreage and value is 3-4 times higher than the US. European sugarbeet yields are approximately 25% higher than in the US.

Approximately 5-6 million tonnes of sugar is exported from the EU, while 1.7 million tonnes is imported annually at a guaranteed price from African, Caribbean and Pacific countries [5].

In the UK, the government offers payments to farmers to aid them in their conversion to organic farming. In 2001, British Sugar contracted for 10,000 tonnes of organically produced sugar; in 2002 this figure increased to 20,000 tonnes [11]. Approximately 300 ha of sugarbeets are grown organically in the UK, representing 0.2 % of the total UK sugarbeet acreage. Similar initiatives on a comparable scale have also been taken by the Dutch sugar companies. Since 1998 sugarbeet is organically grown on an acreage of 360 hectares in the Netherlands, which is 0.3 % of the total sugarbeet acreage [47].

Each of the major European sugarbeet countries has a research station that specializes in sugarbeet research: Institut Technique de la Betterave (ITB) in France, Agronomica S.r.l Consortile in Italy, Institut fur Zuckerruben-forschung (IfZ) in Germany, Asociacion de Investigacion para la Mejora del Cultivo de la Remolacha Azucarera (AIMCRA) in Spain, Institut Royal Belge pour l'Amelioration de la Betterave (IRBAB) in Belgium, Broom's Barn Research Station in the UK and Institute for Sugar Beet Research (IRS) in the Netherlands.

In Europe, sugarbeets are grown under a quota system governed by the EU. There is no incentive for farmers to grow much more sugarbeet than they require to meet or maintain their contracted tonnage [7].

History of weeds in European sugarbeet cultivation

Weeds have been a major problem in sugarbeet since the crop was first cultivated in the late 1700s. In 1799, German scientists published articles stressing the need to control weeds before the crop was sown. They also noted that once sugarbeet was clear of competition from early-emerging weeds, it would grow vigorously and smother weeds

that germinated later. Modern weed control recommendations for sugarbeets are still based on these early observations that sugarbeet plants need to gain an advantage over weeds early in the season [6].

Weeds occur in all European sugarbeet fields every year at population levels that would cause crop failure unless they are controlled [6]. Weeds compete with the sugarbeet crop for light, nutrients and water. The yield of roots and sucrose can be severely decreased by weeds. Competition from uncontrolled annual weeds that emerge within eight weeks of planting can reduce root yields by 26-100% [6]. Broadleaf weeds often grow to a height two to three times that of sugarbeet by mid-summer [6]. In a four-year study in the UK, uncontrolled weeds reduced sugarbeet yield 96%, 61%, 78% and 90% [10].

The main weeds found in sugarbeets in Europe include the perennial species, common couch (quackgrass) and creeping thistle, while common annual weeds include fat-hen (lambsquarters), knotgrass (prostrate knotweed), cleavers, black bindweed, charlock(wild mustard), and common chickweed [7]. Crop volunteers of potatoes and oilseed rape are present in many countries including the UK, and weed beet (an annual form of sugarbeet) is a problem in many countries, especially the UK, where it is present in approximately 60% of sugarbeet fields [7].

Sugarbeet is grown as a biennial. Any beet plants which become reproductive in the first year (bolters) may produce viable seeds which are returned to the soil. These in turn germinate and produce weed beets. Successive generations of weed beet tend to become progressively more annual in habit, and as such, they produce small highly lignified roots with little sugar [14]. The weed beet problem got out of control before the Europeans reacted. In the U.S., weed beet is not a problem due to seed companies' long-standing practice of screening their seed for the presence of weed beet or easy bolters before it is planted for seed production [15].

Because the beet has a long-lived seed bank and can shed thousands of seeds, weed beets reappear each spring. Because weed beets belong to the same species as cropped sugarbeets, they are insensitive to the selective herbicides used in sugarbeet fields [19]. In the UK, low populations of weed beet (< 1,000/ha) are pulled by hand; moderate populations (< 10,000/ha) are controlled by wiping with glyphosate through a selected height applicator; dense populations are cut by machine [49]. Tractor hoeing is also used to control weed beet growing between the rows.

Conventional weed control in European sugarbeet production

When the first manuals were written for growing sugarbeets in 1799, the main methods used for weed control were hand pulling and hand hoeing. In the mid-nineteenth century, German researchers referred to the use of mechanical hoes for cultivating sugarbeet. These were horse-drawn or ox-drawn implements, which tilled the soil between the rows.

Hand hoeing between sugarbeet plants in the row and hand pulling weeds that grew too close to sugarbeet plants was still necessary. However, the introduction of the mechanical hoes made it possible to reduce the labor requirements at a time in the late 1880s when using hand labor on large areas of sugarbeet in Europe was a problem due to labor being in short supply [6]. Weeding in France required 120 hours of labor per hectare [27].

As growers found it increasingly difficult to obtain hand labor in the late nineteenth century, research began in Europe with chemicals to kill weeds. One of the earliest recorded uses of chemicals for weed control in sugarbeets was the application of sulphuric acid in France during the 1890s. German scientists reported successful trials in Silesia using iron sulphate for weed control, although research showed that this chemical damaged sugarbeet [6].

The use of organic chemical herbicides, which could be applied to the soil for residual control of germinating weed seeds in sugarbeet fields, was researched in Europe beginning in the 1930s. In the 1960s-1970s, a number of new herbicides were developed by European chemical companies and evaluated for controlling weeds in sugarbeets. These herbicides (ethofumesate, phenmedipham, desmedipham) were applied in post-emergence combinations to kill emerged weeds. Many herbicides that were developed for sugarbeets in Europe were also registered in the U.S. and have been extensively used.

No single herbicide active ingredient controls all of the weeds found in Europe's sugarbeet fields. Growers in the individual countries use mixtures of chemicals to control the predominant weed species. Mixtures are also commonly used in the U.S. A widespread practice in the U.S. is to band the herbicides down the row of sugarbeet plants and use mechanical cultivation between the rows of plants. In Europe, common practice is to broadcast the herbicide over the entire sugarbeet field [9].
Most of the herbicides will only control weeds when they are small. Therefore, a sequence of herbicides is required to control the range of weeds that emerge in sequential flushes during the early spring. Typically, four to five applications of herbicide treatments are used each season [7]. Tractor hoeing between the rows is employed on approximately 30% of the UK crop [25]. Tractor hoes are estimated to provide approximately 70% control of weeds in sugarbeets [12]. Tractor hoeing is primarily targeted at weed beet; it does not replace any chemical use. Tractor hoeing has been reduced significantly in the UK since the 1980s when 66% of the acres were cultivated [25].

In the U.S., approximately 38% of the acres are typically band-treated and 98% of the acres receive at least one mechanical cultivation [28].

One trend in herbicide use in European and U.S. sugarbeets has been a significant reduction in the amount of chemical active ingredient applied per treated acre. This reduction has resulted from: (1) a movement away from the use of higher rate pre-emergence herbicides to the use of lower rate post-emergence herbicides, (2) the use of multiple low rates of post-emergence herbicides to each weed flush when the weeds are

small rather than waiting and applying fewer but higher dose mixtures to larger weeds, and (3) the introduction of new low rate post-emergence herbicides [7] [22].

A major reason for low doses and multiple applications of the currently used sugarbeet herbicides is that some of the herbicides are not completely safe for the sugarbeet [16]. Current herbicides used in Europe are estimated to cause between 5% and 15% yield reduction mainly as a result of phytotoxicity following application when the sugarbeet crop is under stress [24].

A 1998 pesticide use report in the UK reported that 555.39 tonnes of herbicides were applied to the nation's 171,000 hectares (3.2 kg/ha) [23]. In France, surveys indicate that approximately 2.7 kg of active ingredient are used per ha [27].

The average spent on sugarbeet herbicides in the UK in 2001 was around £105/ha (ca. 158 Euros/ha). The cost of each application was about £6/ha (9E/ha) [12]. In France, the national average cost for herbicides used in sugarbeets is approximately €130/ha [38].

The most common method of applying herbicides to sugarbeet fields in the Netherlands are: broadcast over entire field low dose (60%), and broadcast over entire field high dose (30%) [9]. The low dose strategy requires four trips across the field, while the high dose strategy requires two trips [9]. For the Dutch situation a typical herbicide program includes three post-emergence sprays with a combination of phenmedipham, metamitron and ethofumesate and one pre-emergence application of pyramin (in 50 % of the cases). This leads to a total amount of 2.4 kg active ingredient per hectare [48].

Table 2 shows estimates of the current use amounts of sugarbeet herbicides in individual European countries and the U.S. The herbicide use estimates for European countries are drawn from a recent article in which experts from each of the sugarbeet institutes profiled current herbicide use patterns [24] [40]-[45]. The average herbicide use rate in Europe is 3 times higher than the rate in the US due to more use of pre-emergence chemicals and less use of banded applications in Europe. Approximately 11.7 million lbs. (5.3 million kg) of herbicides are currently used in the EU's sugarbeet fields while in the U.S., 1.6 million lbs. (0.7 million kg) are used.

Table 3 summarizes the costs of weed control in sugarbeets in Europe and the U.S. The total cost of herbicides and their application is approximately €199/ha in Europe with 80% of the costs represented by the cost of the herbicides. Total costs of herbicides and their application in Europe is estimated at €331 million per year with €265 million per year representing the cost of herbicides.

In Europe, manual weed hoeing in organic sugarbeet production often accounts for up to 150 hours per hectare [8]. Organic sugarbeet growers in the Netherlands report that acceptable weed control can be achieved without the use of chemicals or excessive hand labor [13]. Reliance is made on numerous passes of mechanical weeders. It is believed that organic beet production in the Netherlands is concentrated on recent polders with consequently low weed seedbanks. A German organic operation reported yields of 44

tonnes of beets per hectare, which is approximately 21% lower than the conventional yield in Germany [34].

Herbicide-tolerant sugar beet as a new approach to weed management

Glyphosate is a broad-spectrum non-selective herbicide that kills plants by binding to an enzyme (EPSPS), which prevents the production of essential amino acids in the plants. An EPSPS gene was isolated from a soil bacterium and it was determined that glyphosate would not bind to it. Through the use of genetic engineering (agrobacterium), the gene from the soil bacteria was inserted into the genome of sugarbeets. This transformation was performed in a European laboratory by Novartis [17]. When glyphosate is applied to the transgenic sugarbeet, it binds to the original EPSPS in the plant. However, it does not bind to the introduced EPSPS which continues to function and results in the production of the essential amino acids. Glyphosate applied to a field of transgenic sugarbeets kills the weeds because they have susceptible EPSPS, while the sugarbeet plants remain unaffected.

Field tests of transgenic sugarbeets began in the U.S. in 1993. Although approved for planting in the U.S. in 1999, the transgenic seed has not been planted on a single acre in the U.S. because no sugarbeet factory has listed transgenic varieties as acceptable for processing. Because of its broad-spectrum effectiveness on weeds infesting sugarbeets, the use of glyphosate would be expected to replace current herbicide use, hand weeding and cultivation in the U.S. with an associated cost savings of $60 per acre ($149 per hectare) [29].

Field research in each of the major European sugarbeet-growing countries indicates that glyphosate is highly effective in controlling the major weeds infesting sugarbeet fields. Two applications of glyphosate over the top of the transgenic crop provides just as effective control as the commonly used weed control program in each country [16] [27]. The European research showed that sugarbeet yields were equivalent or higher in the glyphosate-treated fields in comparison to conventional sugarbeets with current weed control practices.Increased crop safety with glyphosate resulted in yield increases of 3-5% [16].

The currently used herbicides in sugarbeets cannot distinguish between sugarbeet and weed beets. However, the seed bank of weed beets in European fields still are glyphosate–sensitive. Weed beets will therefore be fully controlled by an application of glyphosate, provided scrupulous care is taken to control the low population of bolters expected in the GM crop, otherwise a herbicide tolerant weed beet problem will arise [16] [19].

In a Danish experiment, two applications of Roundup (720 g/ha) provided equivalent weed control to three applications of currently used herbicides (3kg/ha) [18]. In Germany, two years of experimentation showed that sugarbeet yields with the glyphosate treatments were slightly higher than with the conventional herbicide treatments [20].

Research in the Netherlands showed that two applications of glyphosate resulted in sugarbeet yields that were 4% higher than the current standard practice of three to four applications [21]. In France, the glyphosate treatments resulted in a three to five percent yield increase due to improved control of weeds [27].

No transgenic herbicide tolerant sugarbeet varieties were approved for planting in Europe prior to the 1998 de facto moratorium, which stopped any new approvals of transgenic crops in Europe.

Potential for change of herbicide use and grower's income

Several studies have estimated the potential impacts of the adoption of the genetically modified (GM) sugarbeets in Europe. One study examined the current herbicide use patterns for each of the major sugarbeet growing countries and concluded that a switch to the GM crop would result in a reduction in herbicide use amounts in each country. This study estimated that a complete switch to glyphosate-tolerant sugarbeets would bring about an annual reduction of 1.9 million kg of herbicide active ingredient [24].

A study in the UK concluded that the average net savings in herbicide costs (including product, application and technology fees) that would result from planting the glyphosate tolerant varieties on 100% of the acreage in the UK would amount to £71/ha (106 euros per hectare) [25]. Current UK herbicide costs were estimated at £110/ha (165 euros per hectare) with a cost of £29/ha (44 euros per hectare) for 4.5 applications. The glyphosate-tolerant strategy was estimated to require 2 applications at a cost of £13/per hectare (19 euros/ha) for application and £20/ha (30 euros/ha) for herbicides plus a technology fee of £25/ha (37 euros/ha). The UK study estimated an additional 83 £ of gains to the average sugarbeet hectare (124 euros per hectare) from adoption of the glyphosate tolerant varieties. These additional gains include savings due to less nozzle replacements, less subsoiling following herbicide applications, less consultancy on spray decisions, less manual labor for weed beet control, less need for herbicides in rotation crops, less tillage, and less manganese and insecticide use. The most important additional gain is reducing phytotoxicity, giving increased yields (and consequently, reduction in area sown and hence costs when production is quota limited). Also included was an estimated 2 % increase in yield due to improved control of weed beet. The overall gain in UK sugarbeets was estimated at £154/hectare (231 euros/ha) or £23 million/year (34 million euro/yr) if the glyphosate technology were adopted on 100% of UK acreage.

A study by INRA in France estimated that the glyphosate tolerant sugarbeet would be planted on 72% of the nations sugarbeet hectares based on a comparison of its cost in comparison to current programs [38].

Table 4 summarizes estimates of impacts on herbicide use amounts assuming the adoption of the herbicide tolerant varieties on 100% of European acreage. The current use of herbicides is estimated at 3.2kg AI/ha while the herbicide tolerant acre would receive

1.9kg/ha. An overall reduction of 2.1 million kilograms of herbicide active ingredient is projected. This estimate is consistent with a recent study which projected a reduction of 1.9 million kg [24]. In the U.S., potential adoption of the herbicide tolerant sugarbeet would result in an increase in herbicide use of 931,000 pounds (343,000 Kg) of herbicide active ingredient.

The cost savings estimated in Table 5 include only the costs of herbicides and their application. No estimates are made of additional cost savings due to less nozzle replacements, etc or yield increase that may result from the herbicide tolerant crop planting in Europe. As estimated in the UK study, these additional economic benefits could double the economic benefits of planting the herbicide-tolerant GM sugarbeets [25].

Table 5 summarizes estimates of cost savings for herbicides and their application that would result from the planting of herbicide tolerant GM sugarbeets in individual European countries on 100% of the acreage. Two applications of glyphosate are assumed to substitute for the current 3.5-4.5 applications. A technology fee of €38/ha is assumed. Glyphosate use rates of 1.5-2.2 kgs AI/ha are assigned to each country based on estimates provided by weed experts from each of the sugarbeet research institutes [24]. The average current cost of €197/ha for herbicides and their application would be replaced with a herbicide tolerant crop system costing approximately €86/ha for a savings of €111/ha which is equivalent to a total savings of €181 million/yr.

Table 5 estimates the aggregate cost savings for herbicides and their application for UK sugarbeet growers at €20 million from planting the herbicide tolerant sugarbeets which is roughly equivalent to £13 million which, in turn, is approximately equal to a recent estimate made in a UK study [25]. The UK study estimated that the total economic benefit to UK sugarbeet growers would be £23 million of which 46% (£11 million) would consist of savings on herbicides and their application taking into account the cost of the herbicide tolerant technology fee and herbicide cost.

Table 6 includes estimates of net income changes for EU sugarbeet growers assuming the adoption of the herbicide tolerant varieties on 100% of the acreage. In addition to the savings in weed control costs delineated in Table 5, Table 6 also includes estimates of increased income as a result of a 5% increase in production due to reduced damage to the crop.

However, it may be the case that growers would reduce the area that they plant to sugarbeets since they are contracted for a fixed amount of beets [25]. Thus, instead of an overall 5% increase in production, there may be a 5% reduction in land devoted to sugarbeet production.

Although European sugarbeet farmers could achieve even higher yields with early overall applications of glyphosate than with conventional herbicides, they may instead choose to use banded glyphosate applications early in the season followed by late broadcast

applications which would result in yields equivalent to conventional herbicides [32]. Weedy sugarbeet fields provide habitat and insect food for migrating bird species.

The improvement in profitability of sugarbeet production afforded by the biotech sugarbeet may be of particular importance in offsetting the potential adverse effects on sugarbeet crop margins that are expected to result from the EU Commissions Mid Term Review Proposals, to reform its current agricultural policy [25].

Table 1a: Sugarbeet Production and Processing					
	Area (000 HA)	***Beet Production (billion kg)***	***Sugar Production (billion kg)***	***# of Factories***	***Beet Value (€ million)***
Denmark	60	3	0.5	3	113
France	437	32	3.7	34	1261
Germany	461	26	3.7	30	902
Italy	242	11	1.3	20	475
Netherlands	110	7	1.0	5	381
Spain	109	7	0.9	13	365
UK	171	9	1.2	6	424
Belgium	98	6	0.8	8	253
Other EU	213	14	1.5	15	526
Total EU	1901	115	14.6	134	4700
U.S.	618	30	4.0	28	1243

Table 1b: Sugarbeet Production and Processing					
	Area (000 A)	***Beet Production (billion Lbs)***	***Sugar Production (billion Lbs)***	***# of Factories***	***Beet Value ($ million)***
Denmark	148	6.6	1.10	3	113
France	1079	70.4	8.14	34	1261
Germany	1138	57.2	8.14	30	902
Italy	597	24.2	2.86	20	475
Netherlands	272	15.4	2.20	5	381
Spain	269	15.4	1.98	13	365
UK	422	19.8	2.64	6	424
Belgium	242	13.2	1.76	8	253
Other EU	526	30.8	3.30	15	526
Total EU	4693	253.0	32.12	134	4700
U.S.	1527	66.0	8.80	28	1243

Source [1] [2] [35] [36] [37]
Euros and dollars are assumed equivalent.

Table 2a: Sugarbeet Herbicide Use			
	Rate (Kg/Ha)	***Area (000 Ha)***	***AI Total (000 Kg)***
Denmark	2.5	60	150
France	2.7	437	1180
Germany	3.7	461	1705
Italy	3.1	242	750
Netherlands	2.4	110	264
Spain	3.1	109	338
UK	3.2	171	547
Belgium	4.1	98	402
Total	(3.2)	1688	5336
U.S.	1.1	618	708

Table 2b: Sugarbeet Herbicide Use			
	Rate (Lb/A)	***Area (000 A)***	***AI Total (000 Lbs)***
Denmark	2.22	148	329
France	2.41	1079	2600
Germany	3.30	1138	3755
Italy	2.76	597	1648
Netherlands	2.14	272	582
Spain	2.76	269	742
UK	2.85	422	1203
Belgium	3.65	242	883
Total	(2.84)	4167	11742
U.S.	.89	1527	1559

EU herbicide use rates from [24] [46]
U.S. statistics from [29]

Table 3a: Sugarbeet Weed Control Costs						
	EUROS/Ha					
	Herbicides	***Applications***	***Total***	***Ha (000)***	***Total Costs (Millions E)***	**Herbicide Cost** ***(Million E)***
Denmark	138	40	178	60	10.7	8.3
France	130	40	170	437	74.3	56.8
Germany	200	40	240	461	110.6	92.2
Italy	100	40	140	242	33.9	24.2
Netherlands	195	31	226	110	24.9	21.4
Spain	160	40	200	109	21.8	17.4
UK	165	40	205	171	35.1	28.2
Belgium	170	31	201	98	19.7	16.7
Total	(157)	(39)	(199)	1688	331.0	265.2
U.S.	182	54	336	618	208	113.0

Table 3b: Sugarbeet Weed Control Costs						
	$/A					
	Herbicides	***Applications***	***Total***	**Acres** ***(000)***	***Total Costs (Million $)***	***Herbicide Cost (Million $)***
Denmark	56	16	72	148	10.7	8.3
France	53	16	69	1079	74.3	56.8
Germany	81	16	97	1138	110.6	92.2
Italy	41	16	57	597	33.9	24.2
Netherlands	79	13	92	272	24.9	21.4
Spain	65	16	81	269	21.8	17.4
UK	66	16	82	422	35.1	28.2
Belgium	87	13	81	242	19.7	16.7
Total	(64)	(15)	(79)	4167	331.0	265.2
U.S.	74	22	136	1527	208	113.0

Source of EU herbicide costs: [25] [38] [39]
A herbicide application is estimated to cost 9 euros/ha in Europe. Average of 3.5 applications in Netherlands and Belgium; 4.5 applications in all other countries.
U.S. total includes handweeding costs ($26/A) and cultivation ($14/A). U.S. application cost estimated at $6/A/application.
Cultivation and handweeding costs not included in European estimates.
Euros and dollars are assumed equivalent.

Table 4a: Potential Impact on Herbicide Use of Herbicide Tolerant Sugarbeets						
	Ha (000)	*Rate Kg/Ha*		000 Kg		
		Current	*Herbicide Tolerant*	Current	Herbicide Tolerant	Change
Denmark	60	2.5	1.2	150	72	-78
France	437	2.7	1.9	1180	830	-350
Germany	461	3.7	1.7	1705	784	-921
Italy	242	3.1	2.2	750	532	-218
Netherlands	110	2.4	1.8	264	198	-66
Spain	109	3.1	2.2	338	240	-98
UK	171	3.2	1.9	547	325	-222
Belgium	98	4.1	1.5	402	147	-255
Total	1688	(3.2)	(1.9)	5336	3128	-2208
U.S.	618	1.1	1.7	708	1051	+343

Table 4b: Potential Impact on Herbicide Use of Herbicide Tolerant Sugarbeets						
	Acres (000)	*Rate Lbs/A*		000 Lbs		
		Current	*Herbicide Tolerant*	Current	Herbicide Tolerant	Change
Denmark	148	2.23	1.07	330	158	-172
France	1079	2.41	1.72	2600	1856	-744
Germany	1138	3.30	1.48	3755	1684	-2071
Italy	597	2.76	1.96	1648	1170	-478
Netherlands	272	2.14	1.61	582	438	-144
Spain	269	2.76	1.96	742	527	-215
UK	422	2.85	1.68	1203	709	-494
Belgium	242	3.65	1.37	883	331	-552
Total	4167	(2.82)	(1.65)	11743	6873	-4870
U.S.	1527	0.89	1.50	1359	2290	+931

Source of herbicide use rates: [24] [46]

Table 5a: Potential Impact on Production Costs of Herbicide Tolerant Sugarbeets						
		E/Ha		Savings		
	Ha (000)	*Current*	*Herbicide Tolerant*	*E/Ha*	*Total (million E/yr)*	*Use Rate: HT (Kg AI/Ha)*
Denmark	60	178	78	100	6	1.2
France	437	170	90	80	35	1.9
Germany	461	240	87	153	71	1.7
Italy	242	140	96	44	11	2.2
Netherlands	110	226	87	139	15	1.7
Spain	109	200	96	104	11	2.2
UK	171	205	90	115	20	1.9
Belgium	98	201	83	118	12	1.5
Total	1628	(197)	(86)	(111)	181	(1.9)
U.S.	618	336	187	149	92	1.7

Table 5b: Potential Impact on Production Costs of Herbicide Tolerant Sugarbeets						
		$/A		Savings		
	Acres (000)	*Current*	*Herbicide Tolerant*	*$/A*	*Total (million $/yr)*	*Use Rate: HT (Lbs AI/A)*
Denmark	148	72	32	40	6	1.07
France	1079	69	37	32	35	1.72
Germany	1138	97	35	62	71	1.48
Italy	597	57	39	18	11	1.96
Netherlands	272	92	35	57	15	1.61
Spain	269	81	39	42	11	1.96
UK	422	82	37	45	20	1.68
Belgium	242	81	34	47	12	1.37
Total	4019	(79)	(34)	(45)	181	
U.S.	1527	136	76	60	92	1.50

The herbicide tolerant simulation in Europe includes two applications at €9/ha/application, a technology fee of €38/ha and a cost of herbicide active ingredient (glyphosate) of €18/kg AI. These estimates are conversions of estimates made in £ [25].
European use rates from [24].
Includes technology fee of $49/a for the U.S.
Euros and dollars are assumed equivalent.
Includes herbicide plus application cost savings only.

Table 6a: Potential Impact on Production and Grower Income of Herbicide Tolerant Sugarbeets				
	Production Increase		Herbicide Savings (million E)	Net Income Increase (million E)
	(million kg)	*(million E)*		
Denmark	150	6	6	12
France	1600	63	35	98
Germany	1300	45	71	116
Italy	550	24	11	35
Netherlands	350	19	15	34
Spain	350	18	11	29
UK	450	21	20	41
Belgium	300	13	12	25
Total	5050	209	181	390

Table 6b: Potential Impact on Production and Grower Income of Herbicide Tolerant Sugarbeets				
	Production Increase		Herbicide Savings (million $)	Net Income Increase (million $)
	(million lb)	*(million $)*		
Denmark	330	6	6	12
France	3520	63	35	98
Germany	2860	45	71	116
Italy	1210	24	11	35
Netherlands	770	19	15	34
Spain	770	18	11	29
UK	990	21	20	41
Belgium	660	13	12	25
Total	11110	209	181	390

Production increase assumed as 5% of current production (Table 1)

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