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

Maize – Herbicide-Tolerant Case Study
December 2003

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Introduction

Field corn (maize) is an important crop in the European Union, accounting for 4.5 million hectares of production for grain with a value of €5.3 billion/year. Four countries (France, Italy, Spain, and Germany) account for 88% of maize production in the E.U. 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).

Most of the maize crop grown in the U.K. is not grown for grain but for forage because the climate is not warm enough for the food varieties. It is typically fed as maize silage to cattle in the winter to complement grass silage.

Table 1 summarizes maize production statistics for the major E.U. countries and the U.S. for 2001.

Approximately 1% of Germany's grain maize acreage is grown organically [4]. Approximately 1,000 hectares (0.2%) of Spain's maize hectares are organic.

Weed Problems in European Maize

The maize growing areas in Europe are fertile, rain fed, and warm with large weed seed bank build up. As a result, 50-500 weed seedlings/m^2 emerge to compete with the young crop [9]. Maize is sown at a low seed rate (approx 8-10 plants/m^2) and young maize plants are especially intolerant of weed competition. Best yields are produced when weed competition is removed in the early phases of crop growth [9].

Maize crops in Europe are infested with a wide range of summer annual weeds. At least 14 separate weed species are estimated to infest at least one million hectares of maize in France, Italy, and Germany: fat hen, knotgrass, barnyardgrass, hairy fingergrass, bristlegrasses, black nightshade, common amaranth, common chickweed, mayweeds, annual mercury, velvetleaf, gallant soldier/shaggy soldier, couchgrass, and thorn apple [9].

Research in Italy determined that weed competition for seven weeks following crop emergence reduced maize yields 20-40% [10]. Experiments in Italy with mechanical weed control methods produced maize yields 12.5% lower than chemical spraying [5].

Maize Weed Management

Herbicides are used on 98% of European maize acreage [7]. In European maize fields, growers have traditionally relied on residual herbicides for weed control [6]. In France, surveys have shown that almost 100% of the maize hectares receive herbicide treatments [18].

In Spain, research has shown that without weed control corn yield losses were 34% but were just 4% when herbicides were used [16]. Because of the extensive use of herbicides, it is estimated that current maize losses to weeds are only 5% in the E.U. [16]. In Greece, herbicide treatments doubled maize yields in comparison with the weed-infested control [11].

Historically, weed management in European maize fields was based on the use of triazine compounds. Atrazine was a mainstay in European maize production since its introduction in the late 1950s, mainly due to its excellent crop safety, application options as soil or foliar treatment, residual action, and broad spectrum of activity on weeds. In 1999, French maize growers applied atrazine on 80% of the maize acreage [22].

Selective postemergence (POST) grass herbicides such as nicosulfuron were introduced for weed control in maize in 1980s. Before this, weed management in maize was based on soil applications of atrazine applied prior to crop emergence (PRE) followed by a POST application of atrazine in combination with herbicides such as bromoxynil. Use of atrazine in mixtures has been a common practice, as atrazine cannot control all weeds.

By 2003, seven EU countries, including France (2002), Italy (1990), and Germany (1991), had banned the use of atrazine in maize. Some E.U. countries that have not banned atrazine included Spain and the U.K. In Italy, terbuthylazine, linuron mixed with chloroacetanilides, or a mixture of chloroacetanilides and dinitroanilines (pendimethalin) were substituted for atrazine. Since the atrazine ban, the use of postemergence herbicides has increased [14].

French corn growers estimated that the ban of atrazine would result in the substitution of other herbicides at an increased cost of ₣150/ha (€23/ha) or ₣450 million (€69 million) in the aggregate [15]. French corn growers could not use atrazine in 2003.

In 2003, following a review, the E.U. decided not to reregister atrazine, which means that it will no longer be permitted for use in any E.U. country. Spain and Portugal will be permitted atrazine use for the next four years. The U.K. and Ireland will be permitted atrazine use through 2004.

A majority of German maize growers base their maize weed management on POST herbicide applications. About 70% of maize growers in Italy prefer a PRE herbicide program followed by either cultivation or a POST herbicide application, depending on soil conditions and weed pressure [25] [26].

A recent study profiled a typical herbicide program for the E.U. without atrazine, including flufenacet (0.6 kg/ha) + terbuthylazine (0.8 kg/ha) + nicosulfuron (0.04 kg/ha) + sulcotrione (0.3 kg/ha). The total active ingredient load for this program is 1.74 kg/ha [20].

A 1996 pesticide use survey indicated the main herbicides used in maize production in Germany and Italy. In German maize bromoxynil, metolachlor, pyridate, and

terbuthylazine were the main herbicides with a total of 6,000 metric tons of active ingredient applied to 1.7 million hectares (3.5 kg/ha). In Italy, the main herbicides were metolachlor, pendimethalin, and terbuthylazine, with a total use of 5,000 metric tons on 1.3 million hectares (3.75 kg/ha) [17].

A 2003 survey in France identified the main maize herbicides as s-metolachlor, benoxacor, sulcotrione, nicosulfuron, alachlor, acetachlor, dimethanamid [21]. The average French maize hectare received 1.4 herbicide applications in 2003. The average chemical rate of application was 1.8 kg/ha [21]. 98% of the hectares were treated with herbicides. 60% of the hectares were treated once, 36% received two treatments, and the remaining 4% received three herbicide treatments [21].

A widely used herbicide program in German maize is a tank mix of nicosulfuron, flufenacet, and metsulam (0.532 kg ai/ha) [25]. In Italy, a widely used program includes terbuthylazine plus s-metolachlor (or alachlor) followed by nicosulfuron or rimsulfuron and sulcotrione or mesotrione [26]. The cost of this treatment is approximately €120/ha and involves 2.50 kg ai/ha [26]. A combination of metolachlor and terbuthylazine was estimated to cost €85/ha in Italy [8].

Transgenic Herbicide-Tolerant Maize

Two herbicide-tolerant maize systems have been developed, Roundup Ready (RR) and LibertyLink (LL). The Roundup Ready system facilitates the use of the nonselective herbicide glyphosate, which inhibits the synthesis of aromatic amino acids by blocking the enzyme 5-enolpyruvylshikimate-3-phosophate synthase (EPSPS). Herbicide-tolerant RR maize was developed by Monsanto through genetic substitution of EPSPS with an altered EPSPS enzyme, which is not affected by glyphosate. Liberty Link tolerance to glufosinate is due to introduction of a gene that codes for the enzyme phosphinothricin-N-acetyltransferase (PAT). The PAT enzyme catalyzes the acetylation of phosphinothricin thereby detoxifying glufosinate into an inactive compound.

In the U.S., herbicide tolerant varieties were planted on 15% of total maize acres in 2003 [27]. Adoption has been highest in states and areas where growers have particularly difficult weed control problems, including triazine-resistant weeds. It has been estimated that growers have saved approximately $10/A (€4.05/ha) in herbicide costs as a result of adopting the herbicide tolerant varieties [28]. Atrazine is still permitted in the U.S. and remains the most widely used herbicide due to its low cost and broad spectrum effectiveness.

A three-year study in the U.K. compared genetically modified herbicide tolerant (GMHT) maize varieties with conventional varieties. These Farm Scale Evaluations (FSE) compared the herbicides used with glufosinate-tolerant maize to the herbicides used with conventional varieties of forage maize. The primary herbicide used with the conventional maize was atrazine. The rate of herbicide application was lower with the glufosinate tolerant varieties (0.965 kg ai/ha) in comparison to herbicide use with conventional varieties (2.684 kg ai/ha) [23]. Higher weed biomass following glufosinate

treatments in the GMHT trials are credited to the greater effectiveness of atrazine, which persists longer in the soil than glufosinate [24].

The glufosinate applications reduced the number of weed seedlings to 48.9/m^2 (489,000/ha), while the conventional herbicide treatments reduced the number of weed seedlings to 15.7/m^2 (157,000/ha) [24].

No yield comparisons were made in the FSE experiments and no comparisons were made between glufosinate treatments and treatments which did not include atrazine.

Other experiments carried out since 1995 in U.K. have shown that glufosinate can achieve high levels of control of both grass and broad-leaved weeds in GM glufosinate-tolerant forage maize [19]. Glufosinate provided 87-100% control of individual weed species. The resulting maize yields were comparable to plots treated with the U.K. standard herbicide, atrazine [19]. Glufosinate performed well when two treatments were made at 0.4 kg ai/ha/treatment [19].

Roundup Ready maize has been experimented with in the Czech Republic and Germany. However, no yield comparisons have been released.

Impacts

It has been estimated that herbicide tolerant biotech maize would likely be planted on 40% of E.U. acreage due to limited effectiveness of conventional herbicides and/or the greater expense of the conventional herbicides in comparison to GM alternatives [12].

The substitution of two applications of glufosinate for the current herbicides used in maize would lower herbicide use by 55% (Table 2).

It is assumed that the cost of a glufosinate-tolerant program would be approximately €105/ha, which represents an average reduction of €15/ha or 12% from current costs (Table 3).

It is assumed that the biotech varieties would be planted on 40% of the maize area, implying an overall reduction in herbicide use of 1.7 million kg and an annual overall savings of €24 million/yr.

At this time, there is no information comparing yields of glufosinate or glyphosate treated maize in Europe to standard herbicide treatments that do not include atrazine.

It is assumed that maize yields would be unaffected with a substitution of glufosinate for the current herbicides used in European maize.

Glufosinate tolerant maize already has E.U. marketing approval [13].

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
E.U.-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
E.U.-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 2. Potential impact of glufosinate-tolerant maize on herbicide use						
Country	**Area**	**Rate (kg ai/ha)**		**Total herbicide use (000 kg)**		
	(000 ha)	**Current**	**Biotech**	**Current**	**Biotech**	**Change**
France	1914	1.80	0.90	3445	1723	-1722
Germany	397	1.74	0.90	691	357	-334
Italy	1109	2.50	0.90	2772	998	-1774
Spain	504	1.74	0.90	877	454	-423
Total	3924			7785	3532	-4253

Source [20] [21] [26]

It is assumed that two applications of glufosinate at 0.45 kg ai/ha each would replace conventional herbicide programs in all countries. 100% adoption assumed.

Table 3. Potential impact of glufosinate-tolerant maize on weed control costs.

Country	Area (000 ha)	Weed control costs (€/ha)		Savings (€/ha)	Total savings (€ million /year)
		Conventional	Biotech		
France	1914	**120**	**105**	**15**	**28.7**
Germany	397	**120**	**105**	**15**	**6.0**
Italy	1109	**120**	**105**	**15**	**16.6**
Spain	504	**120**	**105**	**15**	**7.6**
Total	3924				**58.9**

Sources: see text
100% adoption assumed.

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. E.U., 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. Balsari, Paolo, and Gianfranco Airoldi, "Evaluation of the Mechanical Weed Control in Maize and Soybean," 8th EWRS Symposium: Quantitative Approaches in Weed and Herbicide Research and Their Practical Application, 1993.

6. Barberi, P. et al., "Structure of Weed Seedbank Communities Under Different Management Systems for Continuous Maize Crop," Aspects of Applied Biology, No. 51, 1998.

7. Fraga, M.I., et al., "Biological Characteristics of Maize Weed Flora in Galicia (NW Spain)," Second International Weed Control Congress, Copenhagen, 1996.

8. Zanin, G., et al., "Economics of Herbicide Use on Arable Crops in North-Central Italy," Crop Protection, April 1992.

9. Sutton, P.B., et al., "Integrated Weed Management Systems for Maize Using Mesotrione, Nicosulfuron, and Acetochlor," The 1999 Brighton Conference – Weeds.

10. Ferrero, A., et al., "Critical Period of Weed Interference in Maize," Second International Weed Control Congress, Copenhagen, 1996.

11. Eleftherohorinos, I.G., and Kotoula-Syka, E., "Influence of Herbicide Application Rate and Timings for Post-Emergence Control of *Sorghum Halepense* (L.) Pers. In Maize," Weed Research, Vol. 35, 1995.

12. PG Economics Ltd., GM Crops in Europe – Planning for the End of the Moratorium, available at http://www.bioportfolio.com/news/pg_2.htm, February 2003.

13. "Bayer Says GM Maize Ready for Planting in Britain," Reuters News, September 29, 2003.

14. Porceddu, E., et al., "Herbicide Resistance in Italy: Evolution and Current Situation," Agricoltura Mediterranea, Vol. 127, 1997.

15. UIPP, "Communique du 28 Septembre 2001," available at http://www.uipp.org/actualite.communiques/compeche_010928.htm, September 28, 2001.

16. Oerke, E.C., et al., Crop Production and Crop Protection – Estimated Losses in Major Food and Cash Crops, Elsevier, 1994.

17. Eurostat, Plant Protection in the E.U. – Consumption of Plant Protection Products in the European Union, Data 1992-1996, 2000 Edition.

18. SCEES, Traitements Phytosanitaires Mais-Grain, p. 22-26, 1990.

19. Read, M.A., and J.G. Ball, "The Control of Weeds with Glufosinate-Ammonium in Genetically Modified Crops of Forage Maize in the U.K.," The 1999 Brighton Conference – Weeds.

20. Phipps, R.H., and J.R. Park, "Environmental Benefits of Genetically Modified Crops: Global and European Perspectives on Their Ability to Reduce Pesticide Use," Journal of Animal and Feed Sciences, Vol. 11, 2002.

21. Valerie Bibard, ARVALIS-Institut du Vegital, Personal Communication.

22. "News Note: France Withdraws Trazines from Market," Global Pesticide Campaigner, Vol. 11, #3, 2001.

23. Champion, G.T., et al., "Crop Management and Agronomic Context of the Farm Scale Evaluations of Genetically Modified Herbicide-Tolerant Crops," Phil. Trans. R. Soc. Lond., Vol. 358, 2003, pp.1801-1818.

24. Heard, M.S., et al., "Weeds in Fields with Contrasting Conventional and Genetically Modified Herbicide-Tolerant Crops. I. Effects on Abundance and Diversity," Phil. Trans. R. Soc. Lond., Vol. 358, 2003, pp.1819-1832.

25. Karl Hurle, University of Hohenheim-Institute of Phytomedicine, Personal Communication.

26. Aldo Ferrero, University of Turino, Personal Communication.

27. USDA, Acreage, National Agricultural Statistics Service, June 2003.

28. 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, www.ncfap.org, June 2002.