Glufosinate-tolerant maize: Implications of the USA experience for weed control in forage maize in the UK

A report for Greenpeace UK

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Executive summary

Forage maize is the most important fodder crop in the UK. It is harvested for whole-crop silage and is now an important part of livestock farming, particularly for the intensive dairy sector. Nevertheless, the crop is of concern as a contributor to diffuse pollution from high fertiliser use and as a source of soil erosion and atrazine herbicide residues.

Approximately 120000 ha of forage maize are grown annually, mostly in the south and west of Britain, with a small amount of sweetcorn (c. 1500 ha). Crops are drilled in April and May and harvested from late September onwards. In 1997, the last year pesticide usage was assessed, more than half the crop was treated with the herbicide atrazine, with 20% treated with bromoxynil. About 50% of maize is grown continuously in the same field.

The weed flora of maize is dominated by spring and summer germinating weeds. A range of grasses and dicotyledonous weeds are found, including fat hen, mayweeds, Polygonaceae and meadow grasses. Problematic species include black nightshade and couch grass. Maize cropping favours late-germinating weeds; continuous use of atrazine selects for resistant weeds, such as nightshade, and contributes to the evolution of herbicide resistance.

Maize is very susceptible to competition from weeds early in the life of the crop. Therefore efficient weed control at the pre- and early post-emergence stages is essential. Once maize reaches approximately 0.5 m in height, weed control no longer affects yield.

In the USA, glufosinate-tolerant maize has been grown for many years. Susceptibility to early weed competition and extended weed germination have resulted in the continued use of residual herbicides, dominated by atrazine, in GMHT maize. Herbicide products that include atrazine and glufosinate are routinely used in Liberty Link maize.

In the UK, atrazine will be withdrawn from use in approximately 18 months. It has already been banned in seven EU countries. The crop will continue to be grown. A range of alternative herbicides are available, notably sulfonylurea compounds, with others like bromoxynil continuing to be available. These products are likely to be more expensive than atrazine.

Experience with GMHT maize in the UK is limited to the recent Field Scale Evaluation of GM crops, where conventional crops received two herbicides a year and the GM cultivar one application on average. Better weed control was achieved in the conventional crop. On balance, it seems likely that similar weed pressures operate in the USA and the UK, even if the cultivars of maize grown and the climates are different. On this basis, the behaviour of maize growers is likely to be similar. The FSE maize results are therefore misleading and the reality of GMHT maize in the UK would be that residual herbicides would probably be used.

1. Introduction

Food production is perhaps the most important occupation of most of the population of the globe. However, in the developed world, the population engaged in primary agriculture is declining rapidly. For example, in the UK, the population working on the land has declined by over 77% since 1945 (Robinson & Sutherland, 2002) and now involves much less than 1% of the population. This reflects profound changes in agriculture over the past three hundred years, dating from the agricultural revolution of the late 1700s. The commercialisation of artificial fertilisers in the 1850s has been followed by progress in mechanisation, plant breeding and the development of pesticides over the past fifty years (Stoate et al., 2002). The most recent advances have been made using molecular biology to genetically modify crops. The first generation of genetically modified (GM) crops is now grown on over 50 million ha round the world (James, 2001), the majority of which are in the developed world, but a fifth in the developing world. Two approaches have been taken initially, first to introduce pest and disease resistance into crops and secondly to introduce herbicide tolerance genes. Pest and disease resistance can result in reduced pesticide inputs, whilst herbicide tolerance may allow some simplification of weed control. Herbicides continue to be the largest part of pesticide sales across the globe, reflecting the major constraint on crop yield caused by weed species. So-called genetically modified herbicide-tolerant (GMHT) crops, whilst extensively grown elsewhere in the world, are subject to restrictions within Europe, not having achieved approval for general use. There are concerns in regard to the movement of transgenes (e.g. Desplanque et al., 2002) and on possible impacts on biodiversity (Firbank et al., 2003a). The technology remains contentious, with the need for thorough evaluation of the risks and benefits under different conditions (Marshall, 2003; Pretty, 2001; Tester, 2001). The reduction in pesticide use where crops have been engineered for resistance can be contrasted with herbicide-tolerant crops that require agrochemicals (Marshall, 2001; 2003).

The first large-scale experimental field evaluation of such GMHT crops has been the subject of recent research in the UK (Firbank et al., 2003a; Perry et al., 2003). The Field Scale Evaluation of GM crops has compared the biodiversity associated with four GMHT crops with conventionally grown cultivars, using split field treatments. As such, the comparison is between two approaches to crop management, rather than a test *per se* of the genetic component of the contrasted cultivars. Using GMHT cultivars, a broad spectrum herbicide is used to control most weed species, often at a later stage in the growth of the crop compared with conventional herbicides. The latter products often control only a limited number of weed species with sufficient safety to the crop. The development of GM crops is only the most recent example of technologies that intensify land management and the selection pressures on components of agroecosystems.

In the UK, agriculture is a key component of land use, with farming and forestry together amounting to over 75% of the land surface (Dalton & Brand-Hardy, 2003). Nevertheless, agriculture already has significant impacts on the environment, as noted by the UK Environment Agency:

Collectively, farming has the following impacts:

- Farmers have addressed the most acute problems associated with slurry and silage through investment in better infrastructure with government support. This has reduced the number of serious pollution incidents (Category 1) between 1989 and 2000 from 522 to 21. However, 27 per cent of Category 1 and 2 water pollution incidents still arise from agriculture.
- In 2000, more than 30 of the 50 pesticides found most frequently in surface waters, above the EU drinking water limit (0.1 micrograms per litre) were plant protection products predominantly used in agriculture.
- Livestock farming contributes about 85 per cent of the UK's ammonia emissions. This makes up about half of the nitrogen deposition, and leads to increased acidification of sensitive soils and waters.
- Phosphate leaching, and loss of soil containing phosphate, significantly contributes to the eutrophication of rivers and lakes. Excessive algal growth results in up to 200 freshwaters annually.
- There is increasing evidence that surface water run-off rates are increasing -as a result of the loss of woodland, pastureland, and changes in soil management. This increases the risk of flooding.
- Similarly, sedimentation of salmon and trout rivers damages spawning gravels and fish egg survival.
- Changes in land management linked to more intensive agriculture have been associated with the loss of habitat and biodiversity and notably the loss of certain key species of farmland birds. Taken from: http://www.environment-agency.gov.uk/business/444304/444312/306330/306360/?lang=_e

Pesticides residue levels are analysed regularly by the UK Environment Agency as an indicator of water quality. A number of pesticides are found in water samples above the target levels (Fig. 1). The data indicate a marked decline in atrazine residues after 1993; this probably reflects the restricted use of the product after that date. Prior to 1993, atrazine was widely used on railways, rights of way and industrial areas, often where hard surface runoff contributed to residues in surface waters. An increase in atrazine incidents in the mid to late 1990s may be associated with increased maize production.

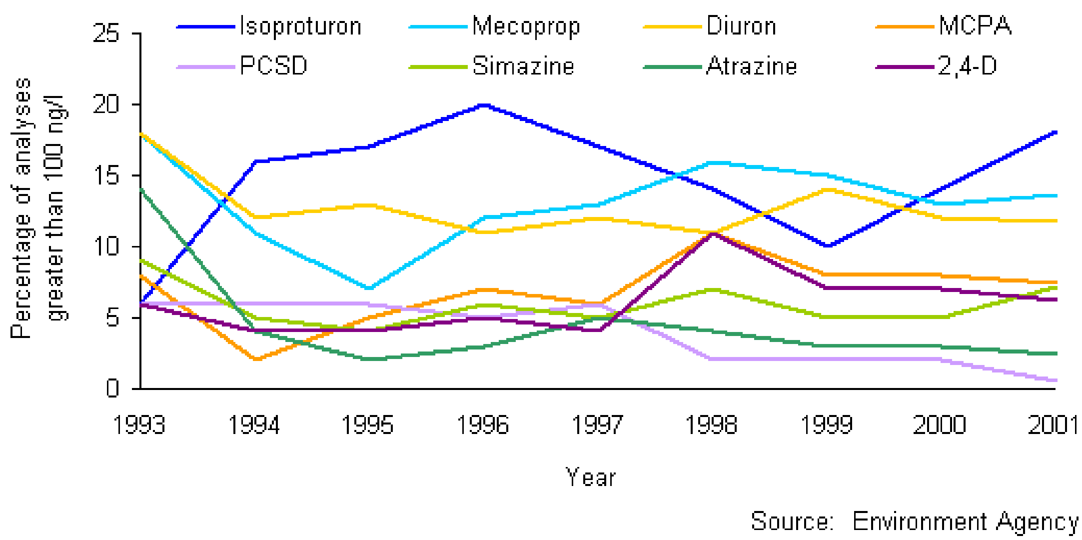

Fig 1. Percentages of water samples found with eight herbicides at concentrations above the 100 ng/l level between 1993 and 2001.

Forage maize (*Zea mays* L.) is grown widely across southern Britain. It is harvested for whole-crop silage and is now an important part of livestock farming, particularly for the intensive dairy sector in the UK. A minor horticultural crop, sweetcorn, is also grown, particularly in the south-east of Britain, where summer temperatures are generally higher than elsewhere in the UK. The area of maize has grown fourfold since 1989 (Garthwaite & Thomas, 1999) and in 1997, six years ago, the acreage was estimated at 109,413 ha (Garthwaite et al., 1997). The maize acreage in 2002 was estimated as 121,000 ha (Nix, 2003), indicating that the rapid increase in area during the 1990s has now stabilised.

In the 1997 Pesticide Usage Survey, maize was the major fodder crop grown, amounting to 52% of the total area of fodder crops in Great Britain. The amounts of the crop grown in different regions of Great Britain are shown in Table 1. The south west of Britain grows the largest amount of maize, reflecting the predominance of dairy and beef enterprises in the region. The Midlands and south east also grow significant amounts of fodder maize.

Table 1. Acreages (ha) of maize and all fodder and grassland crops in Great Britain in 1997. Data from (Garthwaite et al., 1997).

	Northern	Midlands & Western	Eastern	South Eastern	South Western	Wales	Scotland	Great Britain
Maize	1873	23382	8768	21120	48818	5452	-	109413
All fodder and grassland	1299492	1104254	324762	469031	1226138	1353541	4355173	10132392

Maize crops have been of concern to those responsible for the environment, as the crop has been implicated in contributing to diffuse pollution. These concerns focus on soil erosion and increased sedimentation in rivers, the use of cattle slurry as a fertiliser on the crop (maize is capable of high nitrogen uptake) and the use of triazine herbicides for weed control. The impacts of farming systems on soil erosion and sedimentation in rivers and streams has become one focus of the UK Environment Agency. The wider growth of maize crops in southern and western Britain is implicated in increased sedimentation in some catchments with trout and salmon rivers, as a result of soil erosion.

Although it accounts for only 1.1% of the crop area of England and Wales, maize can cause problems in some areas. Pollution from maize production is due to the use of high levels of fertilisers and the use of atrazine as a pesticide. Erosion is often associated with this crop because soils are left bare in winter. From www.environment-agency.gov.uk.

Atrazine has been declared a “dangerous substance” by the North Sea Conferences, which consider the environmental health, management and exploitation of this marine area.

This report examines 1) the current management of forage maize and the closely related sweetcorn in the UK, 2) evaluates changes in management that may result from the deregistration of the herbicide atrazine, and 3) assesses the likely patterns of weed control that might arise from the introduction of genetically-modified herbicide-tolerant (GMHT) cultivars, especially Liberty Link glufosinate-ammonium (hereafter glufosinate)-tolerant maize, in the light of experiences in the USA (Owen, 2003).

2. Current management of fodder maize in the UK

As most maize cultivars benefit from high summer temperatures and reasonable moisture, crops are mainly grown in southern Britain. A significant proportion of maize is grown continuously in the same field; Knott (2002) estimated this at around 50% of the crop. This aspect of maize production enhances particular problems, particularly in regard to crop protection, as continued cropping encourages the build-up of resistant weeds, pests and diseases. The continued use of particular crop protection pesticide programmes also selects for resistance; a number of triazine herbicide-resistant weed biotypes occur in maize fields.

Crops are drilled in April and May, significantly later than other spring-sown arable crops. The crop is sown on wide rows, typically 0.75m apart, at a drilling rate of 100000 seeds/ha. A pre-cultivation herbicide, such as glyphosate is sometimes used. All seed is dressed, commonly with thiram to prevent damping off diseases that kill seedlings. The majority of maize crops were treated with the herbicide atrazine in 1997. The herbicide is soil-acting, killing seedlings as they emerge through treated soil, and is therefore usually applied at the early post-emergence stage, once maize has established, but sometimes pre-emergence. The herbicide is adsorbed onto soil particles, giving residual weed control, in comparison to foliar-acting herbicides, such as glyphosate and glufosinate-ammonium, which are absorbed only via leaves. The current estimated cost of atrazine application in maize is between £5 and £6.50 per ha (Nix, 2003), which is a relatively small part of the variable costs of the crop (Table 2).

The crop is usually harvested for whole-crop silage from late-September into October, with yields averaging 40 tonnes/ha at 30% dry matter. Chopped material is placed in silage clamps and fed to cattle after fermentation.

Table 2. The yield, variable costs and contractor costs (£/ha) of growing silage maize (Nix, 2003).

	£/ha
Yield	40 tonnes/ha
Seed	£120
Fertilizer	£55
Sprays	£35
Total variable costs	£210
Contract drilling	£40
Harvesting	£75 or £125 with carting & clamping
Area payment (CAP)	£69.53
Average sale (£25/tonne @ 30% dry matter)	£1000 (sold standing at £425-525/ha)

3. Sweetcorn, a minor crop

A small area of sweetcorn (1600 ha) is drilled or transplanted in the UK, in late April/May on wide rows 0.75m apart if grown for hand-picking (Knott, 2002). Sweetcorn is initially slow-growing when temperatures are low and it seldom forms a complete canopy before the end of July. Spring emerging annual weeds can smother sweetcorn at early growth stages and perennial species, particularly common couch, can cause crop suppression. Even when mature, the canopy allows light penetration and weeds grow beneath it. Sweetcorn is often grown continuously on the same sheltered field and repeated use of atrazine leads to a build-up of black nightshade (*Solanum nigrum*), a species that is poorly controlled by the herbicide. There are a number of weeds that have evolved resistance to triazine herbicides under such conditions, such as groundsel (*Senecio vulgaris*).

4. The weed flora of maize crops

Maize crops are grown either as part of a rotation in arable or grassland or as a continuous crop. In arable crop rotations, the weed flora reflects the soil type and the field cropping history, and is commonly a mixture of annual dicotyledonous and grass weeds. In grass rotations, the weed flora is more often a mixture of selected grassland annual weeds, notably chickweed (*Stellaria media*) and annual meadow grass (*Poa annua*), with other components of the previous swards.

It is well understood that the timing of final cultivations has a major impact on the weed flora of arable crops. Winter-sown crops support an autumn-germinating flora, while spring-sown crops are dominated by spring germinating species (Chancellor, 1985; Hald, 1999). Thus, maize, being late-spring sown, supports a particular weed flora of those species that either germinate in the late spring and early summer or all year round. One species of note is typical of maize fields, black nightshade (*Solanum nigrum*). This species germinates late in the year (Fig. 2), together with fat hen (*Chenopodium album*), the mayweeds (*Matricaria* and *Tripleurospermum* species) and greater plantain (*Plantago major*). Other spring-germinating weeds of the Polygonaceae are often also well-represented.

In continuous maize, where the crop is grown in the same field year after year, the selection pressure is such that the weed flora tends to become dominated by the later germinating weed species, especially black nightshade, which is poorly controlled by the standard herbicide programme applied. In addition, perennial weeds, particularly couch grass (*Elytrigia repens*) can become problematic in continuous maize fields. Some grass weeds, such as meadow grasses (*Poa* spp.), can also be difficult to control in this grass crop. A particular concern in continuous maize cropping is the encouragement of resistant weeds, such a black nightshade. Also, the evolution of herbicide resistance is promoted where the same herbicides are used year after year (Caseley et al., 1991).

A number of the spring germinating weeds are important components of the diet of farmland birds, especially in stubbles over winter (Vickery et al., 2002). It is possible that maize could be an important crop for farmland birds, as stubbles are often present over winter before the crop is sown, and spring germinating weeds are encouraged. However, maize is particularly susceptible to competition from weeds, especially early in the life of the crop, so the evidence is that following herbicide applications the crop is rather poor from a biodiversity perspective (Vickery et al., 2002). The Farm Scale Evaluation results also indicate that conventionally managed maize crops tend to have fewer weeds and associated invertebrates, compared with GMHT cultivars under the herbicide regime imposed (Heard et al., 2003a; Heard et al., 2003b).

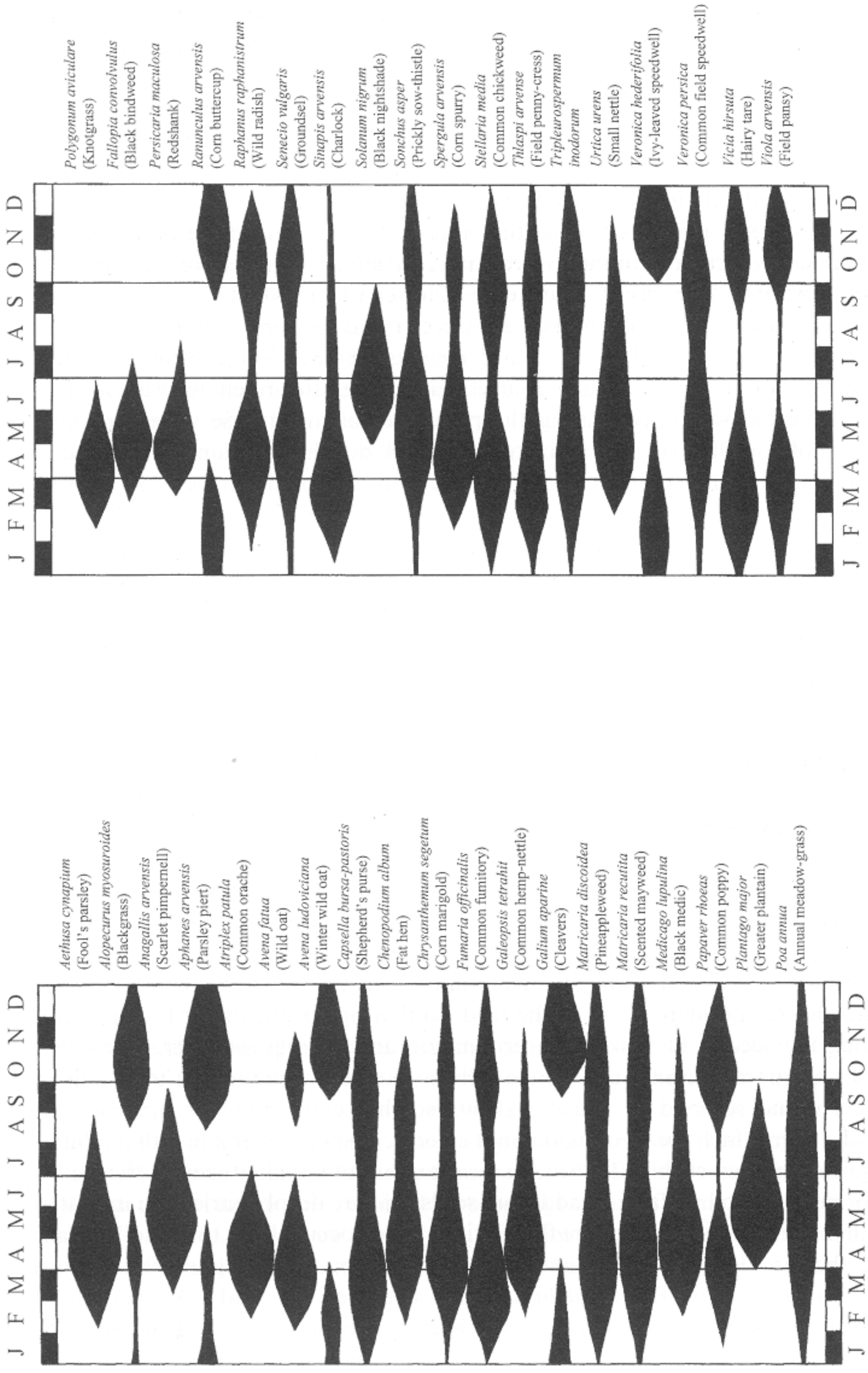

Fig. 2. Germination periodicity of common arable and horticultural weeds. From Grundy & Jones (2002) after Hance & Holly (1990).

5. Weed competition in maize and the critical weed-free period

Maize is highly susceptible to the effects of weed competition early in the life of the crop. As the crop is planted on wide rows, the canopy rarely closes. The plant, whilst it is generally robust, grows upright in its early stages. At this point, competition for light and nutrients from weeds causes highly significant yield losses. Without weed control, maize yield is significantly reduced (Table 3).

Table 3. Comparison of maize yield data from plots treated with atrazine (Conventional) or left untreated. Experimental data from Somerset (Vickery et al., 2002).

	Yield measure	Conventional	No herbicide	s.e.d.
Maize	t/ha fresh weight	40.85	25.75	2.458
	t/ha dry weight	12.54	8.02	1.057
	plant density No/m^2	104.44	109.91	ns

ns = not significant

The need to control weeds during the early stages of the crop is known to be critical, e.g. (Evans et al., 2003b). Weed control once maize plants have grown to 0.5m height does not radically affect yield. Thus maize growers pay particular attention to herbicide applications at drilling or shortly afterwards.

Maize is grown extensively in North America, where it is known as corn, and herbicide-tolerant cultivars have been grown there for more than seven years. There is a considerable literature on weed control in GMHT maize. The need for efficient weed control early in the life of GM crops requires residual herbicide use, especially atrazine (Hamill et al., 2000). Interactions between weed control and nitrogen are also documented. Increased nitrogen supply to the crop can result in the need for extended weed control (Evans et al., 2003a; Evans et al., 2003b).

A field study was conducted in 1998 and 1999 at over 30 locations throughout the North Central region of the USA to determine the effect of time of weed removal on weed control and yield of glyphosate-tolerant corn (Gower et al., 2002). Herbicide treatments were applied when the grass weed giant foxtail *(Setaria faberi* Herrm.) was 5, 10, 15, 23, or 30 cm tall. Average corn yield was 101, 99, 93, 93, and 80 % of the weed-free control, respectively. Average weed control for these treatments was greater than 90 % for grass and broadleaf weeds, but was occasionally as low as 70 % due to late emergence of annual grasses and *Amaranthus* species or difficulty in controlling *Ipomoea* species. Most effective and consistent annual grass control occurred when glyphosate was applied to grasses at least 15 cm in height. The problem of weed re-infestation after single applications of foliar-acting herbicides was significant.

6. Current weed control in UK maize

Typically, maize in the UK receives two herbicide applications per year, each a different product. On average, 100% of the crop receives a seed treatment, 98.1% receive herbicide sprays, 6.9% insecticide and 0.8% receive molluscicide or repellents. In terms of the herbicides used, the Pesticide Usage Survey indicates the treated area in GB in 1997 (ha) is approximately twice that planted, i.e. there are two applications on average per crop (Table 4).

Table 4. Pesticides used on maize (area treated with different products) in the UK in 1997.

Chemical group	Area (ha) treated out of 109413 ha planted in 1997
Fungicides	-
Growth regulators	-
Herbicides	208687
Insecticides	10307
Molluscicides & repellents	1172
All seed treatments	224427
All pesticides	444593

To quote the 1997 Pesticide Usage Survey: "*Seed treatments accounted for 50% of all applications to maize and the most extensively used seed treatments were of thiram (42%) and methiocarb (35%). Atrazine was applied to 53% of the herbicide treated area of maize and was used mainly for general weed control. Bromoxynil, applied to 23% of the same area, was used for the same reason but also to control nightshade (*Solanum nigrum*, black nightshade). Gamma-HCH was used on 85% of the insecticide treated area, the main reasons given for its use being the control of wireworm or a combination of wireworm and leatherjackets in maize crops grown after grass. There was no recorded use of fungicides or growth regulators on maize*." (Garthwaite et al., 1997).

An analysis of the herbicides used in 1997 on maize indicates the commonest treatment was atrazine (Table 5). This triazine herbicide is very persistent in soils, lasting up to one year depending on applied dose. This can restrict the crops that can be grown following applications. Because of its persistence, there is a high risk of movement via surface and through-flow to both surface and ground waters. Residues have been recorded frequently in water samples across the globe where the product is used for agricultural, horticultural and industrial weed control. Restrictions in the use of the herbicide have been imposed during the period the chemical has been in use.

The second most frequently used herbicide in maize is bromoxynil. This herbicide controls broad leaved (dicotyledonous) weeds. Where late-germinating weeds or species that are resistant to atrazine are present, an application of this herbicide will control most of the non-grass weeds present.

Table 5. Usage of herbicides on maize and sweetcorn crops grown in Great Britain (spray hectares) taken from the CSL Pesticide Usage reports. Herbicides used on 10% of the crop or more in red; herbicides not supported in the EC Review in blue; herbicides no longer manufactured or withdrawn in green.

Herbicides	**Maize (1997)**	**Sweetcorn (1999)**
Crop area	**109413**	**1,690**
Herbicides Total weeds		
Diquat/paraquat		60
Glyphosate	18815	404
Paraquat	1325	14
Herbicides Broad-leaved & grass weeds		
2,4-D	214	
Atrazine	109579	2,085
Benazolin/2,4-DB/MCPA	138	
Bromoxynil	47117	
Clopyralid	2032	15
Cyanazine/pendimethalin	4839	
Fluroxypyr	3514	0
MCPA	83	
Mecoprop	264	
Metsulfuron-methyl	18	
Pendimethalin	5709	138
Pyridate	11929	738
Rimsulfuron	2385	
Simazine		4
Other herbicides	735	655
Herbicides area treated (ha)	**208687**	**4,112**
Herbicide as % area grown	**191**	**244**

A series of herbicides were cleared in 2000 by the UK Pesticide Safety Directorate (http://www.pesticides.gov.uk) for use in maize (Table 6):

Table 6. Herbicide active ingredients cleared for use in maize crops and the weed types they control. From: Whitehead (1999). Blue: herbicides being withdrawn

Weed type	Herbicide active ingredients
Annual Dicotyledons	atrazine, bromoxynil, bromoxynil + prosulfuron, clopyralid, cyanazine, cyanazine + pendimethalin, fluroxypyr, pendimethalin, pyridate, rimsulfuron, simazine
Annual grasses	atrazine, cyanazine, pendimethalin (off-label), simazine
Annual meadow grass (*Poa annua*)	cyanazine + pendimethalin, pendimethalin
Black bindweed (*Fallopia convolvulus*)	bromoxynil + prosulfuron, fluroxypyr
Black nightshade (*Solanum nigrum*)	pyridate
Chickweed (*Stellaria media*)	bromoxynil + prosulfuron, fluroxypyr
Cleavers (*Galium aparine*)	fluroxypyr, pyridate
Corn marigold (*Chrysanthemum segetum*)	clopyralid
Creeping thistle (*Cirsium arvense*)	clopyralid
Docks (*Rumex* spp.)	fluroxypyr
Fat-hen (*Chenopodium album*)	pyridate
Hemp-nettle (*Galeopsis* spp.)	bromoxynil + prosulfuron, fluroxypyr
Mayweeds (*Matricaria* spp.)	bromoxynil + prosulfuron, clopyralid
Perennial dicotyledons	clopyralid
Polygonum species	bromoxynil + prosulfuron
Rough meadow grass (*Poa trivialis*)	cyanazine + pendimethalin
Speedwells (*Veronica* spp.)	pendimethalin, pyridate
Volunteer oilseed rape	rimsulfuron
Volunteer potatoes	fluroxypyr
Wild oats (*Avena fatua* & spp.)	difenzoquat

Recent additions to the list of registered herbicides include nicosulfuron and prosulfuron, sulfonylurea herbicides, and other molecules may be released in future, such a flucetosulfuron.

7. The USA experience: weeds and weed control practice in GMHT maize

As noted previously and reported by Owen (2003), there is considerable experience of growing GMHT maize in the USA and Canada. It is apparent that while GM maize is a small proportion of the total US corn market, perhaps 10% of the total sown, of this the increasing part is glyphosate tolerant, rather than glufosinate-ammonium tolerant. Owen (2003) notes that with both GM cultivars, current weed control programmes usually include a residual herbicide, typically atrazine. The need for good weed control early in the life of the crop is paramount, irrespective of the cultivar type.

For Liberty Link glufosinate-ammonium-resistant maize, the addition of atrazine either pre-emergence or early post-emergence gives the grower greater flexibility in the timing of the second and final application of glufosinate-ammonium. Glufosinate-ammonium is less well translocated in comparison with glyphosate, so weeds need to be smaller or at an earlier growth stage for effective control. Timing of applications of foliar-acting herbicides under US conditions, where there is an extended germination period of weeds, is critical to protecting crop yield. Glufosinate-ammonium does not provide consistent control of velvetleaf (*Abutilon theophrasti*), fat hen (*Chenopodium album*) or *Amaranthus* spp. Of these, fat hen is a common weed in the UK.

The important conclusion for glufosinate-resistant corn in the USA is that:

"*The best agronomic fit for glufosinate-resistant maize and the greatest potential for weed control success require the addition of atrazine or another residual herbicide to glufosinate*."

Contacts with a small number of academics in Canada and the USA (Table 7) support the report by Owen (2003) and indicate that Liberty Link maize is planted by a minority of growers.

Table 7. Contacts in the USA and Canada who responded by email regarding herbicide use in Liberty Link maize.

Dr. Clarence Swanton, Professor and Chair, Plant Agriculture, Univ. of Guelph, Guelph, Ontario. N1G 2W1 Canada
Mark M. Loux, Extension Weed Specialist Horticulture and Crop Science, The Ohio State University, 021 Coffey Road, Columbus, OH 43210, USA
Dr. John Cardina, Ohio State University, 021 Coffey Road, Columbus, OH 43210, USA

Typically, weed control programmes are based on herbicide mixtures based on glufosinate-ammonium and atrazine. To quote Dr Cardina

"*There is a pre-mix product called 'Liberty ATZ' that is a mix of glufosinate-ammonium plus atrazine for use in postemergence applications. Glufosinate-ammonium works best in a combined preemergence plus postemergence sequence, using standard preemergence herbicides to kill weeds for several weeks after maize planting, followed by glufosinate plus atrazine postemergence*".

Atrazine is still used on Liberty Link maize, as early weed control is essential to guarantee high yields. In glufosinate-resistant maize, research studies indicate that the effects of weed competition early in the life of the crop are such that pre-emergent herbicide application as part of a spray programme still gives the best yield and economic return (Bradley et al., 2000; Hamill et al., 2000). Thus, in this instance reduced herbicide programmes have not resulted from the introduction of a GMHT crop.

Efforts to develop integrated weed management programmes for maize have been made in North America, for example by combining different row spacings and planting densities with GMHT crops and herbicide programmes (Shrestha et al., 2001). These are underpinned by research on crop and weed interactions based on resource use and growth characteristics (Rajcan & Swanton, 2001).

8. Weed control in maize in the UK after the deregistration of atrazine

The Plant Protection Products Directive 91/414/EEC is the Directive under which all pesticide products are examined for unified registration across the European Union. There is an on-going review process to harmonise registration that requires comprehensive data dossiers on active ingredients to be submitted. As a result of the review, a number of products and active ingredients are being withdrawn from use. Some of these may be due to lack of commercial support or because the active substance fails to gain inclusion on Annex I of Directive 91/414/EEC.

In October 2003, the UK Pesticides Safety Directorate reported that "*the Standing Committee on the Food Chain and Animal Health (SCFA) has supported the Commission proposal for non-inclusion of both atrazine and simazine on Annex I and withdrawal from the market. This proposal still has to be formally adopted but essentially the* *decision has been made*". In addition the applications for the UK "essential use" bids were successful and are as follows:

Atrazine	**Simazine**
Sweetcorn	Beans
Forestry	Rhubarb
	Asparagus
	Hardy ornamental nursery stock

"*Where essential use derogations have been granted, use can continue until the end of 2007. For those uses where there is no derogation the withdrawal timetable will be dependent on when the Commission adopt the decision but continued use is likely for the next 18 months*". From:
http://www.pesticides.gov.uk/farmers/minor%5Fuses/essential%5Fuse%5Fupdate1.htm

In other words, atrazine will not allowed to be used on forage maize beyond March 2005, so the 2004 harvest year will be the last that UK growers can use the herbicide. Limited use on sweetcorn will be allowed to 2007. The herbicide has already been banned in other parts of Europe, including Austria, Denmark, Finland, Germany, Italy, the Netherlands and Sweden, reflecting concerns over the level of residues measured in ground and surface waters. Other similar triazine herbicides, such as cyanazine, terbutryne and simazine, will also be lost from the growers' armoury.

The most likely means of weed control in maize, once atrazine has gone, will be the use of newer and more expensive sulfonyl urea herbicides, notably nicosulfuron (Product name: Samson, Accent), but also prosulfuron (Tradename: Jester, Peak) and rimsulfuron (Tradename: Titus, Dragster). These products are typically applied shortly after maize plants have emerged and have a contact and some limited residual effect on weeds, controlling germinating seedlings. It is also likely that pendimethalin, which is soil acting, may also be used. This herbicide was cleared for use on maize as a mixture with cyanazine, but the latter herbicide, like atrazine, will be deregistered. As the spectrum of weeds controlled by these products is not comprehensive, herbicides such as bromoxynil and fluroxypyr, herbicides that control a range of broadleaved weeds, including black nightshade, are usually necessary as well.

The weed species controlled by sulfonylurea herbicides is limited. For example, rimsulfuron gives poor control of the spring-germinating species of the Polygonaceae, such as knotgrass (*Polygonum aviculare*), black bindweed (*Fallopia convolvulus*) and redshank (*Persicaria maculosa*). Often, an application of bromoxynil or fluroxypyr will be required to control those species that are missed by the sulfonylurea or other residual herbicide. Under these conditions, growers may consider that GMHT varieties of maize offer advantages in simplifying weed control programmes.

It has been possible to contact the French maize growers association, l'Association générale des producteurs de maïs (AGPM) (Tel: 0033 559 126768), to ascertain their approach to weed control in maize after the withdrawal of atrazine (Table 8; Appendix 1). Producers concentrate on pre-emergence weed control using a range of products, the majority of which are not cleared for use in the UK and most are mixtures. Post-emergence treatments are less popular, but also used. Residual herbicides are the norm.

Table 8. Herbicides used in France in maize after the withdrawal of atrazine (from AGPM). Some spellings are not recognised in the UK. Blue: herbicides being withdrawn

Pre-emergence treatments	**Post-emergence treatments**
Grass weeds	*Grass weeds*
acetochlor + dichlomid	cycloxydim
alachlor	
dimethenamid	
dmta-p	
s-metolachlor	
s-metolachlor + benoxacor	
Broad-leaved weeds	*Broad-leaved weeds*
isoxaflutole	bentazone
isoxaflutole + aclonifen	bromoxynil
pendimethalin	prosulfuron + bromoxynil
	pyridate
Broad spectrum herbicides	*Broad spectrum herbicides*
isoxaflutole + flufenacet	foramsulfuron + isoxadifen
metosulam + flufenacet	mesotrione
metosulam + metolachlor	nicosulfuron
pendimethalin + alachlor	rimsulfuron
pendimethalin + dimethenamid	rimsulfron + thifensulfuron
pendimethalin + imazamox	sulcotrione

It is feasible that a number of these products would become available for use in the UK in the future, augmenting the limited number of herbicide products currently cleared for use. This would offer more residual herbicides, which would seem to be favoured by growers.

9. Crop consultant and farmer opinions

A small number of telephone interviews of crop consultants and farmers have been made, together with a number of email contacts, introducing the idea that atrazine will be lost from the grower's armoury and seeking views on what will be the result.

A consistent view is that forage maize will continue to be grown. One farmer noted that if atrazine is lost, then GM maize becomes a more interesting prospect. Herbicides to replace atrazine are available but are likely to be expensive, as they are unlikely to be out-of-patent materials. Products containing the herbicides pendimethalin, bromoxynil, prosulfuron, rimsulfuron, nicosulfuron and fluroxypyr were most frequently mentioned as replacements for atrazine. Of these, only pendimethalin is used primarily pre-emergence.

Glyphosate is now made by many manufacturers and is less expensive than it used to be. Product costs of £6.00 to £10.00 per ha for glyphosate compare well with atrazine at £5.00 to £6.50 per ha (Nix, 2003). The same is likely to be the case for glufosinate-ammonium. However, GM crops are likely to cleared for use with only named herbicide products, i.e. the cultivar will be sold as a package together with particular herbicide products.

10. Fitting glufosinate-tolerant maize into UK practice

From a grower's perspective, the most important drivers affecting farm practice are economics and the quality requirements of the retail trade for milk, milk products and meat. Considering the economic perspective first, the newer herbicides that will have to be used in conventional maize will be more expensive than atrazine. If glufosinate-tolerant maize were available, its uptake, from an economic perspective, will be dependent on the balance of costs. These costs will include the seed (presumably more expensive for GMHT) and the herbicide costs, compared with conventional cultivars. A simple comparison is made in Table 9.

Table 9. A comparison of seed and herbicide input costs (£ per hectare) in conventional, glufosinate-resistant and glyphosate-resistant maize in the UK, after atrazine is withdrawn.

	Conventional 1	Conventional 2	Glufosinate-tolerant maize	Glyphosate-tolerant maize
Seed costs	£120	£120	? more expensive	? more expensive
Herbicide 1 - residual	£22 – sulfonyl urea	?£5 - pendimethalin	? £5 – 22 residual	? £5 – 22 residual
Herbicide 2	£2 – 17 bromoxynil or fluroxypyr	£2 – 17 bromoxynil or fluroxypyr	£6 – 10 glufosinate-ammonium	£6 –10 glyphosate
Herbicide 3		£2 – 17 bromoxynil or fluroxypyr	£6 – 10 glufosinate-ammonium	£6 –10 glyphosate

There are a number of uncertainties in the likely patterns of use that might develop in both conventional and GMHT maize in the UK. For example, it is unclear how effective pendimethalin used alone will be. The likely use of herbicides in GMHT maize under UK conditions requires further evaluation. However, the experiences from the USA and UK Field Scale Evaluations should inform this debate.

In the Field Scale Evaluations, growers followed weed control advice from SCIMAC representatives for the GMHT cultivar and their own crop consultants for the conventional cultivar. On average, two herbicide applications were made to the conventional cultivar and one to the GMHT cultivar (Champion et al., 2003; Firbank et al., 2003b). The conventional crops, where atrazine was typically used for residual weed control, gave cleaner crops with fewer weeds. The glufosinate-tolerant maize was treated later and was weedier for longer, compared with the conventional atrazine-treated crop. A comparison of weed dry weights in the two cultivars showing higher values in the GM fields is given in Fig. 3.

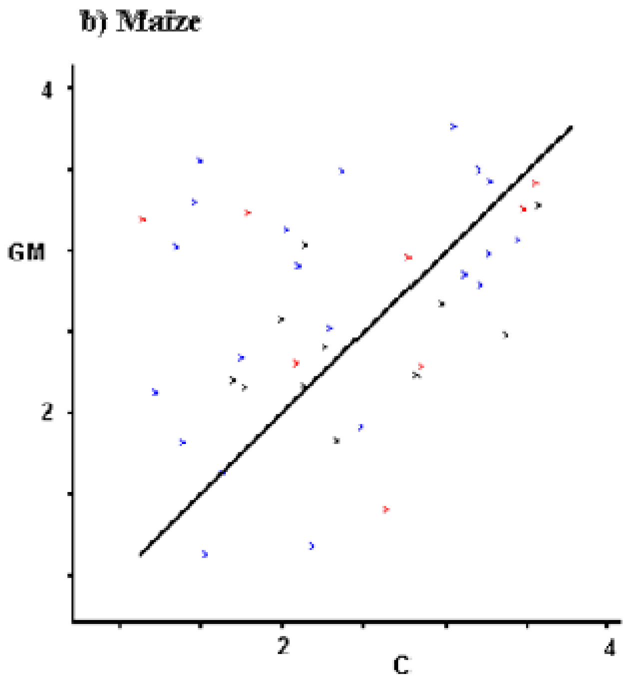

Fig. 3. Logarithmically transformed weight of total weed biomass in GMHT (GM) half-fields plotted against the same variable in conventional (C) half-fields, in maize crops. From: (Firbank et al., 2003b) http://www.defra.gov.uk/environment/gm/fse/results/fse-commentary.pdf

The valid question is: would UK farmers follow the advice given by SCIMAC and limit applications to a single application of the herbicide the crop is tolerant to? Would a residual herbicide be used and/or would several applications be required? With the future removal of atrazine, the relevance of the conventional results from the FSE project may also be questioned.

The evidence from the USA in regard to weed control programmes with glufosinate-tolerant maize is clear. Growers continue to use residual herbicides, especially atrazine, together with the herbicides the crop is engineered to be tolerant to. The reasons are 1) that maize is very susceptible to weed competition early in crop growth and 2) weeds germinate over an extended period. Do these conditions apply in the UK? The susceptibility of maize to early weed competition is well-understood and applies in the

UK. The question as to extended weed germination is perhaps less clear. From Fig. 2, it is clear that weed species can germinate over most of the year and late-germinating black nightshade is a particular threat in UK maize crops. On balance, therefore, it seems likely that similar weed pressures operate in the USA and the UK, even if the cultivars of maize grown and the climates are different. On this basis, the behaviour of growers is likely to be similar and the reality of GMHT maize in the UK would be that residual herbicides would probably be used.

Returning to the economic considerations, the data outlined in Table 8 indicate possibly only minor cost differences between the GM and conventional cultivars. This may depend on the actual seed costs and the efficacy of weed control programmes. One may speculate that most growers will favour programmes that only require two herbicide applications, as in Conventional 1 (Table 9). Glufosinate-tolerant maize is treated with glufosinate + residual herbicide in the USA at the early post emergence stage, with a repeat application two to four weeks later. Glyphosate, although having no residual activity, is well-translocated and controls a wider range of weeds than glufosinate. There may be less need for residual herbicides with GMHT cultivars engineered for tolerance to this herbicide. For glufosinate-tolerant maize, the economic arguments for its use in the UK are not overwhelming.

Turning to aspects of crop quality and retail requirements, growers are very sensitive to the needs of the market. Currently, there is high awareness that buyers may not wish to purchase products that have GM uses within their supply chain. Together with the economic prospects, these factors indicate that glufosinate-tolerant maize is unlikely to be an attractive option for UK growers.

11. Conclusions

Maize is an important crop for the dairy industry. It is will continue to be grown in the UK, especially for the intensive dairy sector. A number of new dairy units of 1000 head of cattle housed mainly indoors have been constructed and others are planned across southern and western England. Maize silage forms an important part of the feeding programme of such units. Nevertheless, the crop can contribute to diffuse pollution from fertiliser use, soil erosion and the movement of atrazine to water.

Atrazine will cease to be available from the end of 2004 in the UK. It is likely to be replaced with more expensive sulfonylurea herbicides, which currently need supplementary herbicides, such as bromoxynil, to control the range of maize weeds. Other residual herbicides used in France may also become available for use in the UK.

There is little reason to expect there to be any difference in patterns of herbicide use in glufosinate-tolerant maize in the UK compared with that in the USA, should the crop be licensed here. Susceptibility of maize to early weed competition requires efficient early herbicide use. A single application of glufosinate-ammonium alone, as it has no residual weed control properties and affects only the plants sprayed, is likely to give insufficient weed control. Growers will either apply several times and/or use a residual herbicide with GM maize.

With concerns over costs of newer herbicides and for seed, as well as public concerns in regard to GM-free foods, it seems unlikely that Liberty Link maize will be favoured in the UK.

Acknowledgements

I should like to thank those with whom I have had informal discussions regarding maize production, GM crops and the replacement of atrazine. Organisations who have kindly given their time include the Maize Growers Association, AGPM, United Agri Products, the Farmed Environment Company and a number of individual farmers and crop consultants.

12. References

Bradley, P.R., Johnson, W.G., Hart, S.E., Buesinger, M.L. & Massey, R.E. (2000) Economics of weed management in glufosinate-resistant corn (Zea mays L.). Weed Technology, 14, 495-501.

Caseley, J.C., Cussans, G.W. & Atkin, R.K., eds. (1991) Herbicide resistance in Weeds and Crops. Butterworth-Heinemann, Oxford.

Champion, G.T., May, M.J., Bennett, S., Brooks, D.R., Clark, S.J., Daniels, R.E., Firbank, L.G., Haughton, A.J., Hawes, C., Heard, M.S., Perry, J.N., Randle, Z., Rossall, M.J., Rothery, P., Skellern, M.P., Scott, R.J., Squire, G.R. & Thomas, M.R. (2003) Crop management and agronomic context of the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. Philosophical Transactions Royal Society London: Biological Sciences Series B, 358, 1801–1818.

Chancellor, R.J. (1985) Changes in the weed flora of an arable field cultivated for 20 years. Journal of Applied Ecology, 22, 491-501.

Dalton, H. & Brand-Hardy, R. (2003) Nitrogen: the essential public enemy. J Appl Ecology, 40, 771-781.

Desplanque, B., Hautekeete, N. & Van Dijk, H. (2002) Transgenic weed beets: possible, probable, avoidable? Journal of Applied Ecology, 39, 561-571.

Evans, S.P., Knezevic, S.Z., Lindquist, J.L. & Shapiro, C.A. (2003a) Influence of nitrogen and duration of weed interference on corn growth and development. Weed Science, 51, 546-556.

Evans, S.P., Knezevic, S.Z., Lindquist, J.L., Shapiro, C.A. & Blankenship, E.E. (2003b) Nitrogen application influences the critical period for weed control in corn. Weed Science, 51, 408-417.

Firbank, L.G., Heard, M.S., Woiwod, I.P., Hawes, C., Haughton, A.J., Champion, G.T., Scott, R.J., Hill, M.O., Dewar, A.M., Squire, G.R., May, M.J., Brooks, D.R., Bohan, D.A., Daniels, R.E., Osborne, J.L., Roy, D.B., Black, H.I.J., Rothery, P. & Perry, J.N. (2003a) An introduction to the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. J Appl Ecology, 40, 2-16.

Firbank, L.G., Perry, J.N., Squire, G.R., Bohan, D.A., Brooks, D.R., Champion, G.T., Clark, S.J., Daniels, R.E., Dewar, A.M., Haughton, A.J., Hawes, C., Heard, M.S., Hill, M.O., May, M.J., Osborne, J.L., Rothery, P., Roy, D.B., Scott, R.J. & Woiwod, I.P. (2003b) The implications of spring-sown genetically modified herbicide-tolerant crops for farmland biodiversity: A commentary on the Farm Scale Evaluations of Spring Sown Crops. Defra. http://www.defra.gov.uk/environment/gm/fse/results/fse-commentary.pdf

Garthwaite, D.G. & Thomas, M.R. (1999). Pesticide Usage Survey Report 159. Arable Farm Crops in Great Britain 1998. CSL, York, UK.

Garthwaite, D.G., Thomas, M.R., Banham, A.R. & De'Ath, A. (1997). Pesticide Usage Survey Report 151. Grassland & Fodder Crops in Great Britain 1997. CSL, York, UK.

Gower, S.A., Loux, M.M., Cardina, J. & Harrison, S.K. (2002) Effect of planting date, residual herbicide, and postemergence application timing on weed control and grain yield in glyphosate-tolerant corn (Zea mays). Weed Technology, 16, 488-494.

Grundy, A.C. & Jones, N.E. (2002). What is the weed seed bank? In Weed Management Handbook (ed R.E.L. Naylor), pp. 39-62. Blackwell Science and BCPC, Oxford.
Hald, A.B. (1999) The impact of changing the season in which cereals are sown on the diversity of the weed flora in rotational fields in Denmark. Journal of Applied Ecology, 36, 24-32.
Hamill, A.S., Knezevic, S.Z., Chandler, K., Sikkema, P.H., Tardif, F.J., Shrestha, A. & Swanton, C.J. (2000) Weed control in glufosinate-resistant corn (Zea mays). Weed Technology, 14, 578-585.
Hance, R.J. & Holly, K. (1990) Weed Control Handbook. 8th edn. Blackwell Science, Oxford. pp.
Heard, M.S., Hawes, C., Champion, G.T., Clark, S.J., Firbank, L.G., Haughton, A.J., Parish, A.M., Perry, J.N., Rothery, P., Roy, D.B., Scott, R.J., Skellern, M.P., Squire, G.R. & Hill, M.O. (2003a) Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. II. Effects on individual species. Philosophical Transactions: Biological Sciences Series B, 358, 1833-.
Heard, M.S., Hawes, C., Champion, G.T., Clark, S.J., Firbank, L.G., Haughton, A.J., Parish, A.M., Perry, J.N., Rothery, P., Scott, R.J., Skellern, M.P., Squire, G.R. & Hill, M.O. (2003b) Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. I. Effects on abundance and diversity. Philosophical Transactions: Biological Sciences Series B, 358, 1819-1832.
James, C. (2001) Global Review of Commercialised Transgenic Crops: 2001. ISAAA Briefs no. 24: Preview. Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications. (http://www.isaaa.org/publications/briefs/Brief_24.htm).
Knott, C.M. (2002). Weed control in other arable and field vegetable crops. In Weed Management Handbook (ed R.E.L. Naylor), pp. 359-398. Blackwell Science and BCPC, Oxford.
Marshall, E.J.P. (2001) Biodiversity, herbicides and non-target plants. In BCPC Conference Weeds 2001, pp. 855-862. BCPC, Farnham, UK, Brighton.
Marshall, E.J.P. (2003) Managing the ecological impacts of genetically-modified agricultural crops: changing patterns of agrochemical use, non-target effects and gene flow. In Assessing and Rational Management of the Agro-Ecosystem for Clean and Friendly Future Environment (eds H.-M. Ro & Y.-H. Park), pp. 321-359. Seoul National University, Korea.
Nix, J. (2003) Farm Management Pocketbook 2004. 34 edn. The Pocketbook, Melton Mowbray. 256 pp.
Owen, M.D.K. (2003). Report to Greenpeace: Glufosinate-tolerant maize in the United States of America. Michael D. K. Owen Consulting. 25 pp.
Perry, J.N., Rothery, P., Clark, S.J., Heard, M.S. & Hawes, C. (2003) Design, analysis and statistical power of the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. J Appl Ecology, 40, 17-31.
Pretty, J. (2001) The rapid emergence of genetic modification in world agriculture: contested risks and benefits. Environmental Conservation, 28, 248-262.
Rajcan, I. & Swanton, C.J. (2001) Understanding maize-weed competition: resource competition, light quality and the whole plant. Field Crops Research, 71, 139-150.

Robinson, R.A. & Sutherland, W.J. (2002) Post-war changes in arable farming and biodiversity in Great Britain. Journal of Applied Ecology, 39, 157-176.
Shrestha, A., Rajcan, I., Chandler, K. & Swanton, C.J. (2001) An integrated weed management strategy for glufosinate- resistant corn (Zea mays). Weed Technology, 15, 517-522.
Stoate, C., Boatman, N.D., Borralho, R.J., Carvalho, C.R., Snoo, G.R.de & Eden, P. (2002) Ecological impacts of arable intensification in Europe. Journal of Environmental Management, 63, 337-365.
Tester, M. (2001) Depolarizing the GM debate. New Phytol, 149, 9-12.
Vickery, J., Atkinson, P. & Marshall, E.J.P. (2002). The effects of different crop stubbles and straw disposal methods on wintering birds and arable plants. Project BD1610. BTO, Marshall Agroecology Ltd.
Whitehead, R. (Ed) (1999) The UK Pesticide Guide. BCPC and CABI Publishing. 736 pp.

Appendix 1. Herbicides used in France in maize after the withdrawal of atrazine:

RÉUSSIR L'APRÈS ATRAZINE

RAPPEL : Toute utilisation d'herbicide contenant de l'atrazine sera interdite au 30 septembre 2003, sauf dispositions réglementaires différentes. Pour l'évaluation de l'efficacité des produits concernés, se reporter à la version 2002 du dépliant «Protection du maïs» édité par SPV-AGPM.TECHNIQUE.

Code de Bonnes Pratiques Agricoles

Pour votre sécurité

Lire très attentivement l'étiquette, et se conformer aux précautions qui y sont mentionnées.

Ne pas manger, boire ni fumer pendant toute l'opération de préparation de la bouillie.

Porter des équipements de protection individuelle : gants, masque, bottes, côte réservé à cet usage.

Ne jamais déboucher une buse avec la bouche ; utiliser une brosse.

Pour le respect du milieu

- lors du remplissage de la cuve

Utiliser une cuve intermédiaire ou un dispositif permettant de maintenir le tuyau hors de la cuve.

Vider correctement les emballages, les rincer 3 fois et verser les eaux de rinçage dans la cuve.

- pendant le traitement

Ne pas traiter sur les fossés et les cours d'eau.

Prévoir une distance de sécurité non traitée en bord de cours d'eau telle qu'indiquée sur l'étiquette, ou de 3 à 10 m de largeur selon la pente et le vent.

- après le traitement

Diluer le fond de cuve et le pulvériser sur la parcelle traitée à grande vitesse pour éviter le sur-dosage.

Rincer le pulvérisateur et appliquer l'eau de rinçage sur la parcelle traitée.

- gestion des emballages vides

Rendre inutilisables les bidons préalablement rincés.

Les éliminer par le biais de filières spécialisées.

Pour assurer une meilleure efficacité

Se conformer aux précautions d'utilisation des produits figurant sur l'étiquette.

Respecter les conditions optimales d'utilisations précisées pour chaque stratégie.

1. Désherbage avant la levée du maïs

Pour assurer une meilleure efficacité...

- Les applications de post-semis pré-levée seront réalisées le plus tôt possible après semis de façon à bénéficier des conditions favorables de la préparation du lit de semences ; celui-ci ne devant pas être trop motteux. La dose de produit à appliquer varie en fonction de la teneur en matière organique du sol.
- Pour des raisons de sélectivité, mieux vaut éviter de traiter sur un maïs pointant.
- Afin de réduire les risques de transfert, il est conseillé dans la mesure du possible, de décaler l'application de quelques heures lorsqu'une pluie importante est annoncée.
- Le volume de bouillie peut être réduit dans la limite permise par le matériel utilisé.

❐ Herbicides à spectre anti-graminées

Matières actives (concentration % ou g/l) (formulation)	Produits commerciaux	Dose homologuée (/ha)	Risque de phytotoxicité	Efficacité globale en conditions sèches	Efficacité sur GRAMINÉES en conditions normales					Efficacité sur DICOTYLEDONES en conditions normales							
					Maîtrise des relevées	Panic pied de coq	Sétaire sp.	Digitaire sanguine	Pâturin annuel	Amarante réfléchie	Morelle noire	Chénopode blanc	Renouée persicaire	Arroche étalée	Mercuriale annuelle	Renouée liseron	Renouée des oiseaux
Acétochlore 400 g/l + Dichlormid (CS)	HARNESS MT[1] TROPHÉE[1]	5 l															
Alachlore 480 g/l (EC)	Nombreux produits[2]	5 l															
Alachlore 480 g/l (CS)	Nombreux produits[2][3]	5 l															
Diméthénamid 900 g/l (EC)	FRONTIERE[4] SYNTAXE[4]	1,6 l															
Dmta-p 720 g/l (EC)	ISARD[1][4] SPECTRUM[1][4]	1,4 l		★													
S-métolachlore 960 g/l (EC)	MERCANTOR GOLD	2 l															
S-métolachlore 915 g/l + Bénoxacor 45 g/l (EC)	ALISEO GOLD SAFENEUR[1] DUAL GOLD SAFENEUR[1]	2,1 l															

❐ Herbicides à spectre anti-dicotylédones

Matières actives (concentration % ou g/l) (formulation)	Produits commerciaux	Dose homologuée (/ha)	Risque de phytotoxicité	Efficacité globale en conditions sèches	Efficacité sur GRAMINÉES en conditions normales				Efficacité sur DICOTYLEDONES en conditions normales								
					Panic pied de coq	Sétaire sp.	Digitaire sanguine	Pâturin annuel	Maîtrise des relevées	Amarante réfléchie	Morelle noire	Chénopode blanc	Renouée persicaire	Arroche étalée	Mercuriale annuelle	Renouée liseron	Renouée des oiseaux
Isoxaflutole 75 % (WG)	MERLIN[5] EMERODE[6]	0,133 kg															
Isoxaflutole 75 g/l + Aclonifen 500 g/l (SC)	LAGON[6] ACAJOU[5]	1 l													★		
Pendiméthaline 400 g/l (SC)	PROWL 400[4][6][7]	2,5 l						•									

❐ Herbicides à large spectre

Matières actives (concentration % ou g/l) (formulation)	Produits commerciaux	Dose homologuée (/ha)	Risque de phytotoxicité	Efficacité globale en conditions sèches	Efficacité sur GRAMINÉES en conditions normales					Efficacité sur DICOTYLEDONES en conditions normales								
					Maîtrise des relevées	Panic pied de coq	Sétaire sp.	Digitaire sanguine	Pâturin annuel	Maîtrise des relevées	Amarante réfléchie	Morelle noire	Chénopode blanc	Renouée persicaire	Arroche étalée	Mercuriale annuelle	Renouée liseron	Renouée des oiseaux
Isoxaflutole 10 % + Flufenacet 48 % (WG)	BOREAL[6]	0,85 kg													•			
Métosulam 2,5 % + Flufenacet 60 % (WG)	DIPLÔME[1] TERANO[1]	1 kg																
Métosulam 6,25 g/l + Métolachlore 500 g/l (SE)	GAO[1]	4 l							•	•					•	•	•	•

Matières actives (concentration % ou g/l) *(formulation)*	Produits commerciaux	Dose homologuée (/ha)	Risque de phytotoxicité	Efficacité globale en conditions sèches	Efficacité sur GRAMINÉES en conditions normales: Maîtrise des relevées	Panic pied de coq	Sétaire sp.	Digitaire sanguine	Pâturin annuel	Efficacité sur DICOTYLEDONES en conditions normales: Maîtrise des relevées	Amarante réfléchie	Morelle noire	Chénopode blanc	Renouée persicaire	Arroche étalée	Mercuriale annuelle	Renouée liseron	Renouée des oiseaux
Isoxaflutole 10 % + Flufenacet 48 % *(WG)*	BOREAL[8]	0,85 kg													•			
Métosulam 2,5 % + Flufenacet 60 % *(WG)*	DIPLÔME[1] TERANO[1]	1 kg																
Métosulam 6,25 g/l + Métolachlore 500 g/l *(SE)*	GAO[1]	4 l							•	•					•	•	•	•
Pendiméthaline 115 g/l + Alachlore 257 g/l *(EC)*	ARIZONA[4] [5]	7 l													•			
Pendiméthaline 150 g/l + Alachlore 225 g/l *(EC)*	INDIANA[4] [5]	7 l													•			
Pendiméthaline 250 g/l + Diméthénamide 250 g/l *(EC)*	WING[4] [6] BELOGA S[4] [6]	4 l																
Pendiméthaline 250 g/l + Imazamox 16,7 g/l *(EC)*	OKLAHOMA[4] [6] [8]	4,5 l		★	•		•		•	★					•	•	•	•

(1) Herbicides pouvant être appliqués en POST-LEVEE PRECOCE du maïs (stade 2-3 feuilles) avant la levée des graminées adventices.
(2) Adar Am, Alagan AM, Faeton EC, Lasso, Lasso 15 granulé, Lutoclor EC, Reneur, Swift AM, Tradiachlor EC
(3) Alagan ME, Lasso Microtech, Lariat Microtech, Swift MI
(4) Risque de phytotoxicité particulièrement en sol filtrant et semis mal recouvert
(5) Déconseillé en sol filtrant et sur semis superficiel
(6) Freine le développement en production de semences
(7) Ne pas utiliser en sol à plus de 6% de matière organique
(8) A n'utiliser que sur des variétés de maïs CLEARFIELD, naturellement tolérantes à l'imazamox

2. Désherbage après la levée du maïs

Pour assurer une meilleure efficacité ...

- L'application doit se faire avec une hygrométrie favorable, au-delà de 70%, avec des températures comprises entre 10 et 25°C garanties dans les 48h après le traitement et en évitant d'intervenir sur des maïs stressés.
- Les doses de produits à appliquer seront adaptées à la flore présente en tenant compte du stade et de l'espèce la plus difficile à contrôler. Toutefois, en limite d'efficacité des herbicides, traiter sur des adventices jeunes (moins de 3-4 feuilles) assure une meilleure efficacité, notamment pour les dicotylédones à problème.
- Intervenir avant 8-10 feuilles du maïs pour éviter l'effet parapluie. Pour les produits les moins sélectifs, éviter si possible de traiter en plein après 6-8 feuilles du maïs.
- Le volume de bouillie doit être adapté au matériel sans être trop réduit, l'optimum se situant entre 150 et 200 l/ha.

❒ *Herbicides à spectre anti-graminées*

Matières actives (concentration % ou g/l) *(formulation)*	Produits commerciaux	Dose homologuée (/ha)	Risque de phytotoxicité	Efficacité sur GRAMINÉES en conditions normales: Panic pied de coq	Sétaire sp.	Digitaire sanguine	Pâturin annuel
Cycloxydime 100 g/l (EC)	STRATOS ULTRA[9]	2 l					

(9) A n'utiliser que sur des variétés de maïs naturellement tolérantes à la cycloxydime.

❒ *Herbicides à spectre anti-dicotylédones*

Matières actives (concentration % ou g/l) *(formulation)*	Produits commerciaux	Dose homologuée (/ha)	Risque de phytotoxicité	Efficacité sur DICOTYLEDONES en conditions normales: Amarante réfléchie	Morelle noire	Chénopode blanc	Renouée persicaire	Arroche étalée	Mercuriale annuelle	Renouée liseron	Renouée des oiseaux
Bentazone 87 % *(SG)*	BASAGRAN SG ADAGIO SG	1,6 kg						★	★	★	
Bentazone 480 g/l *(SL)*	BASAMAÏS BENTER FIGHTER	2,5 l						★	★	★	
Bromoxynil phénol 250 g/l *(SC)*	Nombreux produits[10]	2,4 l						★	★	★	
Bromoxynil ester octanoïque 20 % *(WP)*	Nombreux produits[11]	2,25 kg						★	★	★	
Bromoxynil ester octanoïque 225 g/l *(EC)*	BROMOTRIL 225 CADELI	1,5 l						★	★	★	
Prosulfuron 3 % + Bromoxynil phénol 60 % *(WG)*	ECLAT[12] [13]	0,5 kg									
Pyridate 45 % *(WP)*	LENTAGRAN	2 kg						★	★		

(10) Bromotril P, Litarol M, Merit, Optimaïs, Peronev, Sabre, Toplan, Tramplin
(11) Emblem, Impérial, Norcel, Saxo, Stardom, Virgul
(12) S'utilise avec un mouillant non ionique tel que AGRAL 0,1%, Li700 0,5 à 0,75 l/ha, Héliosol 0,5 l/ha
(13) Action frénatrice sur Liseron des Haies

❒ *Herbicides à large spectre*

Matières actives (concentration % ou g/l) *(formulation)*	Produits commerciaux	Dose homologuée (/ha)	Risque de phytotoxicité	Efficacité sur GRAMINÉES en conditions normales: Panic pied de coq	Sétaire sp.	Digitaire sanguine	Pâturin annuel	Efficacité sur DICOTYLEDONES en conditions normales: Amarante réfléchie	Morelle noire	Chénopode blanc	Renouée persicaire	Arroche étalée	Mercuriale annuelle	Renouée liseron	Renouée des oiseaux
Foramsulfuron 22,5 g/l + Isoxadifen 22,5 g/l *(SC)*	EQUIP	2,66 l					•					•			
Mésotrione 100 g/l *(SC)*	CALLISTO	1,5 l					•						★		★
Nicosulfuron 40 g/l *(SC)*	MILAGRO[14] PAMPA[14]	1,5 l					•					•	★		
Rimsulfuron 25 % *(WG)*	CURSUS[14] [15]	60 g					•					•			
Rimsulfuron 50 % + Thifensulfuron 25 % *(WG)*	BASIS[14] [15]	30 g					•					★			
Sulcotrione 300 g/l *(SC)*	MIKADO	1,5 l					•					•	★	★	★

(14) Efficace sur Panic Faux Millet   (15) S'utilise avec un mouillant, Trend 90 0,25 l/ha