Health and environmental impacts of glyphosate:

The implications of increased use of glyphosate in association with genetically modified crops

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Executive summary

The introduction of genetically modified crops tolerant to glyphosate will lead to a significant increase in the use of this herbicide. Monsanto, the company producing these crops, claims that their introduction will be of benefit because of the low toxicity and environmental safety of the herbicide. Monsanto, it should be noted, also manufactures glyphosate, marketing it as ‘Round up’, and so is able to sell seeds and herbicide as a commercial package. Independent research indicates that glyphosate may not be as safe as previously thought and may pose a threat to human health and the environment. It is essential that questions relating to the safety of this product are answered before its use is scaled up with the introduction of genetically modified crops. The following table provides a comparison of Monsanto’s claims and the findings of independent research.

Monsanto*s claims	**Independent research findings**
Roundup has a low irritation potential for eye and skin and otherwise is not a risk to human health.	C Roundup is amongst the top most-reported pesticides causing poisoning incidents in several countries. C Roundup causes a range of acute symptoms including recurrent eczema, respiratory problems, elevated blood pressure and allergic reactions.
Roundup does not cause any adverse reproductive effects.	C In laboratory tests on rabbits glyphosate caused long-lasting, harmful effects on semen quality and sperm counts.
Roundup is not mutagenic in mammals.	C DNA damage has been observed in laboratory experiments in mice organs and tissue.
Roundup is environmentally safe.	C In the agricultural environment, glyphosate is toxic to beneficial soil organisms and beneficial arthropod predators, and increases crops* susceptibility to diseases. C The use of glyphosate in forestry and agriculture has indirect harmful effects on birds and small mammals by damaging their food supplies and habitat. C Roundup containing POEA is lethal to the tadpoles of three species of tree and ground frogs in Australia. The Australian government has banned the use of these products near water. C Sub-lethal doses of glyphosate from spray-drift damages wildflower communities and can affect some species up to 20 metres away from the sprayer. C The use of glyphosate in arable areas causes dieback in hedgerow trees. C Glyphosate promotes population growth of a water snail that is the intermediate host of liver fluke in mammals. C The breakdown of glyphosate by micro-organisms in water may stimulate eutrophication effects.

Roundup is rapidly inactivated in the soil and water.	C Glyphosate is very persistent in soils and sediments. C Glyphosate inhibited the formation of nitrogen-fixing nodules on clover for 120 days after treatment. C Glyphosate residues were found in lettuce, carrot and barley when they were planted a year after glyphosate was applied. C Phosphate fertilisers may inhibit breakdown in soil.
Roundup is immobile and does not leach from soils.	C Glyphosate can readily desorb from soil particles in a range of soil types. It can be extensively mobile and leach to lower soil layers. C Glyphosate can be carried by soil particles suspended in run off.
Roundup does not contaminate drinking water when used by local authorities on hard surfaces.	C In the UK, levels of glyphosate above the EU limit have been detected by the Welsh Water Company every year since 1993. The Drinking Water Inspectorate recommends that glyphosate be monitored, particularly in areas where it is used by local authorities on hard surfaces.
It is nearly impossible for glyphosate resistance to evolve in weeds.	C In 1996, glyphosate-resistant ryegrass was discovered in Australia.
Outcrossing from GM crops and the transfer of novel genes occurs over a short distance and can be easily managed.	C In those crops which have been examined, the densities of pollen are much higher and their dispersal patterns differ from large fields compared to those found in experimental plots. Wind dispersal of pollen occurs over much greater distances and at higher concentrations than predicted by experimental plots. Gene flow from transgenic oil seed crops is inevitable.
Roundup Ready crops will reduce levels of herbicide use.	C Herbicide-tolerant crops will intensify and increase dependency on herbicide use in agriculture rather than lead to any significant reductions. A variety of herbicides will have to be reintroduced to control glyphosate-tolerant volunteers, feral populations of crops and resistant weeds.

Sources: Monsanto Company, 1985, *Toxicology of Glyphosate and Roundup Herbicide.* Monsanto Company, Department of Medicine and Environmental Health, Missouri, USA; Monsanto Company, Web Site: www.monsanto.com., 18th January 1998; Monsanto Advertising Supplements in Farmers*s Weekly, *Roundup 91,* 7 June 1991, and *Roundup 92,* 5th June 1992; Pesticide Outlook, Dec. 1997, Royal Society of chemistry, Vol. 8, No. 6, pp3-4.

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Introduction

In the last 50 years, UK agriculture has become increasingly dependent on artificial chemicals to control weeds, pests and diseases. The chemical revolution in agriculture of the 1950s was heralded as the panacea to any farming problems. The weeds and pests which had plagued farming for centuries would be eliminated and food would be cheap and plentiful for all. Fifty years later, we see the situation is not so simple. Many of the chemicals have proved to be toxic to humans and the environment, and the pests they were designed to kill soon developed resistance to them. This has led to a seemingly endless demand for new, more powerful chemicals. In developing countries, the agro-chemicals and hybrid seeds on offer initially were often inappropriate to local conditions or too expensive for poor farmers. The need to reduce agricultural reliance on chemicals around the world, and move towards less damaging systems of farming, is finally being recognised.

Now we are faced with another revolution in agriculture: biotechnology, or genetic engineering. The same companies behind the chemical revolution are now manipulating the genetic make-up of crop plants. Not surprisingly, the most well-advanced developments from the genetic engineering companies focused on herbicide (weedkiller) resistance. The chemicals and biotechnology company Monsanto, which produces the market-leading herbicide glyphosate (‘Roundup’), has started producing crop plants which have been engineered to resist this herbicide. A gene from a soil bacterium is spliced into the plant enabling the crops to be sprayed with glyphosate without being affected. The weeds under and around the the crop are killed, leaving the crop to grow on free from competition.

Which sounds wonderful. Monsanto claims its ‘Roundup Ready’ crops offer the prospect of higher yields, reduced use of herbicides, bigger profits for farmers and a route towards a sustainable system of farming. However, Roundup-tolerant crops will also bring Monsanto great rewards. Not only has Monsanto been able to move into the seeds market but the company has the potential to gain an increased share of the global herbicide market. Glyphosate is already the world’s most-used herbicide and Monsanto is using genetically modified (GM) crops to tie farmers to Roundup, rather than other brands of this chemical.

Friends of the Earth asked the Pesticides Action Network UK to review the safety of glyphosate for human health and the environment, and to look at the implications of its widespread use in agriculture due to the introduction of genetically modified crops. The Network’s report shows that the widespread use of glyphosate on these crops could have significant implications. Glyphosate is a broad-spectrum herbicide and if applied widely to GM Roundup-tolerant crops, it could leave fields almost devoid of wild plant species. This would have a serious impact on the wild creatures which depend on those plants for food and cover. The UK is a heavily farmed island. We do not have the space to create huge wilderness areas for wildlife conservation, as in the US. Even our national parks are heavily managed. Our agricultural land is, therefore, our nature reserve. The massive change in farming practice which the introduction of herbicide-tolerant crops represents could wreak havoc with wildlife in arable areas. Wildlife is already suffering under the current regime of intensive chemical farming.

The UK countryside is used as a giant outdoor laboratory to test herbicide-tolerant crops. Monsanto alone has more than 100 test sites growing glyphosate-tolerant oilseed rape and sugar beet scattered around the country and is now involved in the government-sponsored farm-scale trials.

This review of glyphosate raises many questions about what the long-term impact of a huge increase in glyphosate use will be; at the very least it could lead to a significant increase in the residues of this herbicide found in food and animal feed. These questions must be answered before glyphosate-tolerant crops are given commercial approval.

Given the lack of a complete picture of the impact of herbicide-tolerant crops on the environment and food quality, Friends of the Earth believes the only option for the Government is to impose a five-year moratorium on all commercial releases of herbicide-tolerant crops. This will give the necessary breathing space to allow the farming community and the public to assess whether or not herbicide-tolerant crops are worth the risk.

We hope this report will contribute to that debate.

2

Background

Glyphosate is the world*s best selling ‘total’ herbicide, representing 60 per cent of global ‘broad-spectrum’ herbicide sales. It was developed by the US chemical company, Monsanto, in the early 1970s. Glyphosate was first registered in the US and the UK in 1974. Monsanto is believed to have 95 per cent of world sales. Its major formulation is Roundup but it also produces a number of other formulations including Vision, Rodeo, Ranger and Sting. Zeneca, a rival agrochemical and biotech company, markets another glyphosate product called Touchdown.

By any commercial yardstick, glyphosate is a very successful product. Worldwide sales of glyphosate products are worth more than US$1,500m annually and account for about 50 per cent of Monsanto*s total agricultural sales[1]. Growth in sales is expected to increase to $2,000m over the next five years, equivalent to more than 40,000 tonnes of active ingredient. Use of glyphosate in the EU increased by 129 per cent between 1991 and 1995[2]. In the UK, 487.21 tonnes of glyphosate (active ingredient) were used on arable crops and set-aside land in 1996, making glyphosate the eighth most-used pesticide by weight. Over half a million hectares (571,673 ha) of arable crops were sprayed[3].

The patent for glyphosate expired in most of the world in 1991 and expired in the US in 2000. Once a product’s patent expires, other companies can produce it and the original manufacturing company*s market share diminishes. Monsanto has developed a strategy to protect its glyphosate market and in recent years has cut the sale price by half [4]. Increased sale volumes have compensated for the price cut and enable Monsanto to develop major markets in India and China. Monsanto has also greatly increased its manufacturing and formulation capacity for glyphosate in a number of countries, investing $200m in Roundup manufacturing technology since 1995[5]. Zeneca is expanding its glyphosate production in the UK at a new plant in Huddersfield.

In the near future, Monsanto expects that most expansion in sales of Roundup will come from the increased adoption of conservation tillage practices around the world. Conservation tillage - no-till farming systems - depend on herbicides rather than mechanical tillage to control weeds and reduce soil erosion. Already, more than 40 per cent of the volume growth in Roundup sales in recent years has come from expanded use of these farming practices. Monsanto says that Latin America and south-east Asia offer the greatest potential for expansion in conservation tillage.

Another key component of Monsanto*s strategy has been investment in genetic engineering and the development of glyphosate-tolerant crops. Known as Roundup Ready crops, these include Roundup Ready soya, cotton, maize, oilseed rape and canola, sugar beet, wheat, rice, alfalfa and sugar cane[6]. Tests of European glyphosate-tolerant oilseed rape are already underway, mainly in Germany. Similarly, Monsanto has made applications to the EU for commercial-approval permission to commercialise varieties of Roundup tolerant maize, fodder beet and cotton.

Environmental exposure to glyphosate is extensive, due to the vast quantities used annually all over the world. Exposure may occur from direct application, accidental releases or spray drift. Monsanto claims that once glyphosate is introduced into the environment it is inactivated through adsorption to soil or sediment particles and is rapidly degraded by microbial activity. In its own experimental tests on laboratory animals, Monsanto found glyphosate to have low acute toxicity and few long-term chronic effects. Most of the early tests were done on technical-grade glyphosate. More recently it has been discovered that an added ingredient, polyoxyethylene amine (POEA), added to most formulations, is more acutely toxic than glyphosate itself and is likely to be a cause of human death through suicide and also have adverse impacts on other organisms.

In spite of its extensive use, relatively few studies have been done on the environmental and health impacts of glyphosate. No data has been found on the environmental or health impacts of the production process or of disposal of unwanted glyphosate. The lack of interest in glyphosate is compounded by the fact that detecting it in the environment is laborious and costly. There is, however, a slow but increasing understanding of the complex impacts that agro-chemicals have in the human body and environment and, increasingly, more elaborate studies are being conducted to address the lack of data on glyphosate. Some key studies reviewed below raise serious concerns over the safety of glyphosate. These concerns are particularly significant in view of the development of glyphosate-tolerant crops and anticipated increase in environmental and human exposure to glyphosate formulations.

2.1 *What is glyphosate?*

Glyphosate is a post-emergent, systemic and non-selective (or broad-spectrum) herbicide used in both agricultural and non-agricultural areas. Recommended application rates do not exceed 5.8 kg active ingredient per hectare (a.i./ha)[7]. It is used to kill all plant types including grasses, perennials, and woody plants. It is mainly absorbed into the plant through the leaves and then transported throughout the plant where it acts on the plant's enzyme system. The exact mode of action is not known, but it is thought that glyphosate inhibits amino acid metabolism in what is known as the shikimic acid pathway. This pathway exists in higher plants and micro-organisms but not in animals.

Glyphosate is a weak organic acid. Its chemical name is N-(phosphonomethyl)glycine. It is usually formulated as the isopropylamine or trimethylsulfonium salt of glyphosate. Other ingredients known as inerts or additives are also added to the formulation. A surfactant (wetting agent) known as polyoxyethylene amine (or POEA), which helps the active ingredient penetrate the plant surface, is usually added to glyphosate formulations. Other additives include sulphuric and phosphoric acids[7]. The main breakdown product or metabolite of glyphosate is aminomethyl phosphonic acid (AMPA).

3

Health impacts

Monsanto claims that extensive testing of glyphosate has shown that it has a low order of toxicity and exhibits no unusual toxicological effects in animals[8]. The company also claims that studies in animals have determined that glyphosate does not cause cancer, birth defects, mutagenic effects, neurotoxic effects or reproductive problems[9]. Most of the toxicological tests carried out for the approval authorities have been done on glyphosate alone. Tests on the formulated products containing surfactants and other additives have been limited to only a few selected acute toxicity and sub-chronic studies[8 10].

Much of the available data published before 1995 on the toxicology and ecological effects of glyphosate has been reviewed by Caroline Cox of the Northwest Coalition for Alternatives to Pesticides (NCAP) in the US [10, 11,12]. Some studies have been made to assess the toxicological impacts of glyphosate formulations on laboratory animals and humans. Much of this research has identified the surfactant, POEA, as a major cause of some of the acute and chronic toxic effects observed. Some studies have also found that the combination of glyphosate and POEA is more toxic than POEA alone.

Being aware of these problems with the surfactant, Monsanto has developed a glyphosate product, Roundup Pro Bioactive, with a different but unnamed surfactant. The company claims that the new product has improved efficacy and safety[13]. In the UK, the new formulations are recognised by the approval authorities as being a non-irritant and they carry no hazard symbols[13,14]. All garden products contain the new surfactant and most local authorities are using it. Although the new formulations are available for agricultural uses, they are more expensive.

3.1 *Acute toxic effects in humans*

Glyphosate is poorly absorbed in the gut or through the skin. After oral intake, 30-36 per cent of glyphosate is absorbed in most test animals. Most of the absorbed glyphosate is excreted in the urine[7]. The acute toxicity of glyphosate, measured by the LD_{50} test (the oral dose required to kill 50 per cent of the test animals) is relatively low and in the US, glyphosate itself is classified in Toxicity Category III (Caution)[11].

Recent advances in toxicity tests mean that cell culture tests can determine the toxicity of low levels of pesticides, including glyphosate, with much higher sensitivity than tests based on using animals[15]. The tests may provide more information on glyphosate in the future.

In spite of animal tests showing a low mammalian toxicity, significant poisoning effects caused by both intentional and accidental exposure to glyphosate have been recorded in humans and laboratory animals.

Doctors in Japan first exposed the acute hazards of surfactants in glyphosate products in a study of 56 cases of Roundup poisoning, mostly resulting from suicides or attempted suicides, which included nine fatalities[16]. They found that the fatalities occurred after ingestion of about 200 ml (three quarters of a cup) of glyphosate formulation. A variety of symptoms have been noted from acute poisoning incidents[17].

3.2 Poisoning reports

Exposure to smaller amounts of glyphosate products in the work environment or through accidental contact has been shown to cause acute poisoning symptoms. Few studies have been made to monitor the exposure of workers to glyphosate products[7,18]. In the US, one such study was requested by the US Department of Agriculture (USDA) Forest Service which uses Roundup to kill weeds in its conifer seedling nurseries[19]. The study found that the dilution and use of Roundup with hand applicators or tractor sprayers resulted in a range of exposure to glyphosate despite the use of special protective clothing.

Reported poisoning incidents with glyphosate are frequent. For example, glyphosate is the most frequent cause of complaints and poisoning incidents recorded by the UK Health and Safety Executive*s Pesticides Incidents Appraisal Panel (PIAP)[4]. A variety of symptoms have been reported from various incidents and occupational exposures, including eye and skin irritation, contact dermatitis, eczema, cardiac and respiratory problems and allergic reactions[10,14,20,21,22,23].

3.3 Reproductive effects

Monsanto claims that glyphosate does not cause reproductive problems[9]. However, tests with rabbits have shown adverse dose-dependent effects on semen and sperm quality[24], and other studies at high dosages have reported effects such as decreased litter size and reduced sperm counts in rats [7,25].

3.4 Chronic toxicity

Some literature suggests that glyphosate can cause chronic health effects in laboratory animals. Lifetime glyphosate feeding studies have shown reduced weight gain, liver and kidney effects and degradation of the eye lens. These effects were significant only at the higher doses tested. At lower doses inflammation of the stomach*s mucus membrane was observed[7].

3.5 *Carcinogenicity*

The US EPA classifies glyphosate in ‘Group E’- non-carcinogenic for humans. The EPA based its decision on three lifetime studies, conducted between 1979 and 1990, of laboratory animals fed varying doses of glyphosate. Increases in testicular interstitial tumours in males, an increase in thyroid cancers in females, increases in kidney tumours in male mice, and an increase in pancreatic and liver tumours in male rats were observed, but all discounted for various reasons[11].

Nevertheless, a recent Swedish study found that increased rates of non-Hodgkin’s lymphoma were associated with exposure to the pesticides Roundup and MCPA[26]. The researchers stated that “glyphosate deserves further epidemiologic studies”.

3.6 *Genotoxicity (mutagenic effects)*

The genotoxicity of glyphosate has been studied in different test systems. A review of these studies suggest that there is no genotoxicity for glyphosate alone and a weak effect for formulated products[27]. A recent study testing the genotoxicity of glyphosate and Roundup in vivo recorded cytogenic damage in mouse bone marrow which was more pronounced for Roundup. A DNA-damaging activity of glyphosate and Roundup was also observed in the mice’s liver and kidneys[27].

3.7 *Residues in food*

The use of glyphosate may result in residues in crops and animal tissue or drinking water destined for human consumption[7]. The World Health Organisation (WHO) found that pre-harvest use of glyphosate (for late season weed control or as a pre-harvest desiccant) results in significant residues in the grain and plant material[28]. The WHO also found that glyphosate residues in animal feeds arising from pre-harvest glyphosate treatment of cereals may result in low residues in meat, milk and eggs. In storage, residues of glyphosate are reported to be stable for one year in plant material and for two years in animal products[29].

Generally, glyphosate residues are not monitored in food since methods of analysis are complex and costly. Likewise, measurement of glyphosate exposure in the general population through diet has not been conducted. The WHO recommends that “a market-basket survey would be useful to determine the possible exposure of the general population”[7].

The maximum residue limits (MRLs) for glyphosate have been set by the Food and Agriculture Organisation (FAO)/WHO Joint Meeting on Pesticide Residues, and varies for different crops. The level set is based on the maximum residue levels that are likely to occur when glyphosate is used in good agricultural practice and not on the basis of any likely health impacts. The acceptable daily intake (ADI) has been set by the FAO/WHO*s Codex Alimentarius Commission at 0.3 mg/kg/day for an average 60 kg man[18]. In general, there is concern that ADIs do not take account of the risks to children, the old or people with immune disorders. In the early 1990s, the US National Research Council*s Committee on Pesticides in Diets of Infants and Children concluded that infants and children might be more vulnerable to pesticide residues and emphasised the need for more data and information on exposure. The British Medical Association (BMA) also raised concerns over the susceptibility of children to pesticide residues in food[30]. The US and the UK authorities have since announced initiatives to accommodate these sorts of differences, but the process is still at an early stage.

In Canada, the decision to register glyphosate for pre-harvest use on cereals, beans and oil seeds raised questions about residues in flour. The milling and baking industries expressed concern that the possibility of residues of glyphosate in cereal and grain products could result in a lack of consumer confidence[31]. In Sweden, glyphosate cannot be used 10-14 days before harvest, and in Denmark, some leading bread manufacturers will not buy flour made from grain treated with glyphosate close to harvest[32].

Information on glyphosate residues in food comes mainly from controlled studies[7]:

- Research by Monsanto showed the presence of glyphosate (up to 14.6 parts per million (ppm)) in most samples of all grains harvested from treated plots. The metabolite, AMPA, was detected at relatively low levels[31].
- Studies showing the fate of glyphosate residues in wheat found that levels in white flour were 10-20 per cent of the levels in wheat, and the bran residues were two to four times higher than those in wheat. The residues were not lost during baking[7]. Levels of glyphosate residues in the final bread product depend on how much glyphosate-contaminated flour is diluted with uncontaminated flour.
- In a two year study in Canada, residues of glyphosate in wheat after pre-harvest treatment increased with the rate of application and decreased with seed moisture content at time of application. When the maximum application rate of 1.7 kg/ha was sprayed at seed moisture content of 40 per cent or less, glyphosate residues were found at the MRL (5 mg/kg) established by Health Canada[33].
- Glyphosate residues in malt and beer derived from barley were 25 per cent and four per cent respectively of the original level in the barley[7].
- Levels of glyphosate in processed oats were found to be 50 per cent of the levels in the pre-harvest treated oats[7].
- Cattle, pig and poultry fed a diet of 100mg/kg of glyphosate resulted in significant residues in pig liver and kidney (up to 1.6 and 0.19 mg/kg respectively) and in cattle kidney (up to 1.4 mg/kg). Levels of glyphosate in milk, eggs and meat were very low[7].
- Field studies on the uptake and persistence of glyphosate on wild blueberry and raspberry in a forest in Canada found that residues in the fruit after spraying remained above the Canadian maximum permissible residue level (0.01 mg/kg) throughout the 61 days of the study period. The berries of the two species absorbed

the glyphosate at different rates. The initial mean residue value in blueberry was 7.94 ppm and in raspberry was 19.49 ppm. These fruit are typically sprayed in late summer when the fruit is ripe. Contaminated fruit may be eaten by wildlife species or picked for human consumption (including for commercial sale)[34].

- Residues of glyphosate have been found in strawberries[35], lettuce, carrots, and barley following applications. Glyphosate residues were found in some of these food items when they were planted a year after glyphosate was applied[36].

Genetically engineered glyphosate-tolerant crops could result in more glyphosate residues in some food crops. For example, the Australian Food Authority requested that the tolerance for glyphosate in soya beans be raised from the domestic level of 0.01 mg/kg to the recommended Codex level of 20 mg/kg so that Roundup Ready soya beans could be imported from the US[37]. The UK tolerance level for soya has also been raised to 20 mg/kg[38].

.8 Residues in drinking water

Monsanto advertises that glyphosate is not considered a threat to drinking water since it is bound by soil and sediment and is rapidly biodegraded[39].However, glyphosate has the potential to contaminate surface water if it is carried by soil particles suspended in run off[7]. Glyphosate has also, on rare occasions, been detected in groundwater. Once in water, glyphosate is not readily broken down by water or sunlight[11]. Dissipation from water is usually due to sorption to sediment or suspended particles or uptake by plants and biodegradation[7].

Generally, glyphosate residues in water are not monitored because they are extremely difficult to isolate and many authorities (the Department of the Environment, Transport and the Regions in the UK for example[40]) do not consider glyphosate to be of major concern as a water contaminant. There are occasional reports of water contamination by glyphosate[7]. According to the WHO, most conventional plants for processing drinking water would not remove glyphosate unless an ozone treatment was involved[41]. The WHO has not set a guideline value for glyphosate in drinking water. The EU limit for any pesticide in drinking water is 0.1 mg/l.

In 1995, ten water companies in the UK monitored for glyphosate, seven reported adequate limits of detection (defined as 0.02 mg/litre or less) and two detected glyphosate at levels greater than the EU limit of 0.1 mg/litre. One of the samples was derived from groundwater and one from a mixture of sources. In 1996, eight companies monitored for glyphosate, only one reported an adequate limit of detection and one company detected glyphosate above the EU limit[42]. The Drinking Water Inspectorate recently recommended that water companies should include glyphosate in their monitoring programmes wherever appropriate and particularly where glyphosate is used as a non-agricultural herbicide such as on hard surfaces[42].

Recent reports of ground and surface water contamination by glyphosate include:

- The Welsh water company, Dwr Cymru Cyfyngedig, has occasionally detected glyphosate residues in drinking water, with at least one sample recorded over the EU limit every year between 1993 and 1996[43]. In Wales, local councils have largely replaced atrazine with glyphosate in many areas of non-agricultural use.

- In the US, routine monitoring for glyphosate in groundwater is infrequent. Glyphosate has been found in seven US wells (one in Texas, six in Virginia)[44].

In 1994, the Mexican government suspended plans to spray 18,500 hectares of Lake Chapala with glyphosate to control water hyacinths because of concerns over the health risks. The Inter-secretarial Commission for the Control of Production and Use of Pesticides and Fertilisers made regulatory changes to prohibit the use of glyphosate in any water intended for human consumption until it has been demonstrated that there are no harmful effects on human health. People in the region depend on the lake for fishing and for drinking water[45].

3.9 *Occupational exposure during manufacture, formulation and disposal*

Despite an extensive review of the literature, no data has been found on occupational exposure to glyphosate during manufacture.

4

Environmental fate

When glyphosate is introduced into the environment a number of processes appear to determine its fate. The most important include:

- the formation of complexes in water with ions such as Ca2+, Mg2+
- sorption to sediment or suspended particles
- suspended particles in water and soil
- uptake and metabolism by plants
- biodegradation by micro-organisms.

A range of bacterial strains can degrade glyphosate using the compound as a source of phosphorus, carbon, or nitrogen. The major breakdown product or metabolite of glyphosate is aminomethylphosphonic acid (AMPA). Carbon dioxide is also a breakdown product[7].

4.1 Persistence in soil and water

The agrochemical company Zeneca claims that its product, Touchdown, a herbicide containing glyphosate trimesium, is “rapidly inactivated and broken down in the soil”[46]. Monsanto has measured the half life of glyphosate (the time required for half the amount to biodegrade or dissipate) and determined it to vary between three and 141 days.

In the field, long persistence of glyphosate has been observed in a number of studies. AMPA has been found to be even more persistent than glyphosate, with a half life in soil between 119 and 958 days[7]. In water, glyphosate has a long persistence in sediments. Records of glyphosate persistence include[47]:

- 249 days on Finnish agricultural soils.
- between 259 and 296 days on eight Finnish forestry sites.
- between one and three years on 11 Swedish forestry sites.
- 335 days on a Canadian forestry site.
- 360 days on three Canadian forestry sites.
- two Canadian studies found glyphosate persisted 12 to 60 days in pond water following direct application

- glyphosate residues in pond sediment were found 400 days after direct application with the formulation Accord
- glyphosate was found to persist for more than one year in studies of pond sediments in the US
- studies in Norway have detected glyphosate in surface and ground waters[48].

.2 *Mobility in soil*

Monsanto claims glyphosate is essentially immobile in soil[9]. The belief that glyphosate readily and permanently binds to soil particles and remains in the upper few centimetres of soil has greatly increased its popularity and use. In reality, there is very little information available on the behaviour of glyphosate in soils[49]. The mechanism of sorption to soil is not fully understood, although it is believed that metal complexes with humic acid in soil may be the main binding mechanism[7].

Recent studies have cast important questions over the extent to which glyphosate is immobile in soil. One such study has shown that glyphosate can readily desorb from soil particles in some soil types and can be highly mobile in the soil environment (see below)[50]. Four soils, chosen to represent the most widespread soil types in the EU, were used in the study. The key findings included:

- Levels of adsorption of glyphosate varied in the different soils according to their composition. Least adsorption occurred in the soils containing lower levels of iron oxide. The clay mineral content was also found to be important. Soils containing higher levels of clay minerals adsorbed more glyphosate. However, desorption readily occurred in soil with a high clay mineral but low iron oxide content.
- Large parts of the fixed herbicide can be easily returned to the soil solution.
- The least adsorbing soils desorbed up to 80 per cent of the adsorbed herbicide and the high adsorbing soils released between 15 and 35 per cent of the glyphosate adsorbed.
- In soils that are unable to bind with glyphosate long enough for microbial degradation to take place, the herbicide can be extensively mobile in the soil environment.
- Desorbed glyphosate can leach to lower soil layers.
- Glyphosate can bond with water soluble humic substances found in soil solution. Humic substances are the soil components primarily responsible for the mobility of pesticides in soil. Glyphosate can be transported with humic substances to lower soil depths[50].

Other recent studies have found:

- Adsorption of glyphosate on clay minerals decreased in the presence of copper, due to the formation of glyphosate-copper complexes. The study concluded that in relation to glyphosate release and mobility in soil, it is necessary to take into account both the soil type and any element in the soil capable of forming complexes with glyphosate[51].
- A study of sandy soils in Western Australia found that adsorption of glyphosate and

AMPA increased strongly with iron and aluminium content of the soils, while soil organic matter competed for adsorption sites and inhibited adsorption[52].

In addition, there is some evidence that the presence of inorganic phosphate inhibits degradation of glyphosate by some bacteria. The WHO recommends that the effects of phosphate fertilisers on the binding of glyphosate to soils should be investigated[7].

!.3 *Effects on soil micro- and macro-organisms*

There is little available information on the biological effects of glyphosate in soil[7]. Experimental research suggests that some important beneficial soil bacteria and fungi, including nitrogen-fixing bacteria and fungi responsible for breaking down organic matter, are affected by glyphosate. Examples of these are included in Part 5. Some studies have shown the impacts of glyphosate treatment can last for several months. This suggests glyphosate can remain active and may be released from soil and taken up by organisms.

C As well as affecting nitrogen-fixing bacteria, glyphosate has been found to inhibit mycorrhizal fungi. Mycorrhizal fungi grow in a symbiotic relationship in or on the roots of higher plants, such as pine trees. They help plants absorb nutrients and help protect from cold or drought. The presence of the fungi is vital for the establishment and growth of seedling trees of a number of species[53].

Glyphosate has also been found to adversely affect earthworms:

C A study in New Zealand found that repeated biweekly applications of low rates of glyphosate (1/20 of typical rates) caused a reduction in growth, an increase in time to maturity and an increase in mortality of the most common earthworm found in agricultural soils[54].
C Other studies have found that glyphosate is toxic to earthworms[7]. Earthworms exposed to glyphosate-treated soils were soft, slack and lethargic at concentrations greater than 500 mg Roundup/kg dry soil weight. The response was dose related.

!.4 *Effects on aquatic organisms*

Glyphosate can contaminate surface water either directly as a result of aquatic weed control or indirectly when glyphosate bound to soil particles is washed into rivers or streams[7]. Glyphosate and commercially formulated products containing POEA surfactant are toxic to fish and to some aquatic invertebrates[7,12]. POEA is about 30 times more toxic to fish than glyphosate[55]. Studies have shown that the acute toxicity of glyphosate varies according to species and age of fish and under different environmental conditions, such as water hardness, pH and temperature[12].

Very little research has been performed on the effects of glyphosate on aquatic micro-organisms or invertebrates[56,57,58,59]. Similarly, few ecotoxicity studies have been performed with pond or river sediment and sediment-living organisms[7]. The WHO recommends the biological activity of sediment- and soil-bound glyphosate in the environment should be studied. The WHO also recommends that further toxicity studies of sediment-living organisms are needed[7].

The authors of one recent study were concerned that the lack of long-term exposure studies with sub-lethal levels of glyphosate has hindered the establishment of guidelines for levels of glyphosate for freshwater organisms[58]. The Australian National Registration Authority recently banned most formulations of glyphosate from use near water after tests found that surfactants used in most formulations are harmful to tadpoles. Monsanto*s new formulation Roundup Bioactive, which does not contain POEA, surfactants is excluded from the ban.

Recent studies that have tried to address the lack of information include:

- A study to determine the effects of sub-lethal glyphosate concentrations on carp. It found that sub-acute toxic effects included changes in some enzyme activity in serum, liver and kidneys and morphological changes in gills, liver and kidneys [59].
- A study in Louisiana, US, tested the effect of sub-lethal concentrations of glyphosate on an aquatic snail species, *Pseudosuccinea columella.* The study found that low levels of glyphosate adversely affect snail reproduction and development. It also found that, at different concentrations, glyphosate can stimulate growth and development and increase the number of eggs laid containing more than one embryo with the potential to increase the snail population. The snail is an intermediate host of sheep liver fluke and the study concluded that low levels of glyphosate could ultimately promote increased liver fluke infections in mammals[58].
- A study examined the DNA damage caused by five commercial pesticides, including Roundup, on bullfrog tadpoles. Significant increases in DNA damage were observed for two out of the three concentrations tested (both of which were well below the recommended application rates). There was a strong linear correlation between DNA damage and dose. The study concluded that Roundup is clastogenic (causes DNA damage) in tadpoles[60].
- A study to test the toxicity of 23 different pesticides on aquatic plant life found that diatoms and one cyanobacterium were sensitive to glyphosate. The study concluded that there are considerable differences in sensitivity among species and that the use of an uncertainty factor is needed to provide an acceptable margin of safety when evaluating the hazard of pesticides to the aquatic ecosystem[61].
- Another study found that glyphosate can potentially stimulate undesirable eutrophication effects if primary producers (diatoms, etc) use glyphosate as an alternative source of phosphorus. The study raised concerns that ‘below detectable level* glyphosate induced eutrophication of waterways, could indirectly affect fish habitats, and have other aquatic resource management effects [57] . However, such an effect may not be significant in all cases as high levels of phosphorus can enter aquatic environments from other sources.

!.5 *Effects on terrestrial organisms*

Adverse effects of glyphosate and glyphosate-containing formulations have been recorded in a variety of terrestrial animal and plant species. Damage can result from direct toxicity effects, through damage to food supplies or habitat destruction.

Invertebrates

Studies have shown that glyphosate can have both a direct toxic effect and an indirect impact due to habitat change on forest-dwelling invertebrates:

- In the US, a three-year study found that herbivorous insects and ground invertebrates were significantly reduced up to three years after treatment with Roundup in a four-to-five-year-old clear-cut planted with spruce seedlings. The vegetation did not recover over the study period and the authors concluded that the effects on the forest organisms were mainly due to habitat change[62].
- A laboratory study found that Roundup exposure caused a decrease in the survival and a decrease in body weight of woodlice[63].

In the agricultural environment, the use of glyphosate has been found to adversely affect a number of species that are beneficial predators of crop pests. As early as the 1970s, the decrease in numbers of predatory arthropods and weed density following the use of herbicides was suggested as a cause for the increased frequency of cereal aphid outbreaks in treated fields[64]. Glyphosate and its commercial formulations have been found to have direct toxicity effects and indirect habitat impacts on both test and field populations of beneficial insects, mites and spiders:

- A study found that exposure to glyphosate killed more than 80 per cent of a test population of predatory beetle and 50 per cent of parasitoid wasp, lacewing, ladybird and predatory mite[65].
- A study of winter wheat fields in North Carolina, US, found that populations of large carabid beetles declined after treatment with a glyphosate formulation and did not recover for 28 days[66].
- A study of Roundup treatment of pasture hedgerows in the UK found a similar effect on carabid beetles. The study also found that Roundup treatment reduced the numbers of spiders, probably by killing the plants they preferred for web-spinning[67].
- A comparison of arthropod populations in sprayed and unsprayed headland plots in spring wheat fields in the UK, found that female carabid beetle species contained more eggs in unsprayed areas than in sprayed areas. The reduction in prey species in sprayed areas may have been affecting beetle fecundity and hence recruitment to beetle populations, with a corresponding decline in overall pest predation rates in the crop[68].

Birds and mammals

The toxicity of glyphosate to birds and mammals is generally low. Bird and mammal populations have been more severely affected by glyphosate-induced changes to their habitat and food sources. Studies on the effects of glyphosate on bird and mammal wildlife species have tended to focus on the effects of the use of glyphosate in forestry, particularly in North America, where glyphosate is used to remove plants that may compete for resources and light with conifer seedlings and trees. For example, in Canada, Monsanto*s Vision accounts for 81 per cent of all herbicide applications in forestry[69]. Deleterious impacts observed on small mammal populations in clear-cut forests sprayed with glyphosate are most probably due to habitat change and the decline in the availability of food (both plant and arthropod prey) and cover[62,70,71,72].

The following two studies show that small mammals exposed to glyphosate can be contaminated through their diet or direct contact and that exposure to glyphosate may affect behaviour.

C After aerial spraying of a forest in Oregon, US, with Roundup at a rate of 3.3 kg a.i./ha, concentrations of glyphosate in small mammals were of the same order of magnitude as the concentrations in litter and groundcover. The concentration of glyphosate in the internal organs of herbivorous small mammals decreased more slowly than in omnivorous and carnivorous small mammals. The highest concentration, 5 mg a.i./kg, was found in omnivorous deer mice immediately after spraying[73].

C Glyphosate and other environmental chemicals affected the taste and smell receptors in the gerbil. Glyphosate reduced responses to several taste solutions. Taste and smell are chemical responses that play a crucial role in food selection. Damage to taste and smell receptors can impair food intake, nutritional status and survival[74].

Another group of animals that has been studied for the effects of forest herbicides is songbirds. Changes to habitat diversity are also likely to be the cause of population-density reductions in song birds:

C A three-year study of four-to-five-year-old clear-cuts in Maine, US, planted with spruce seedlings and sprayed with glyphosate at a rate of 1.7 kg a.i./ha found that total bird densities decreased by 36 per cent. The most sensitive species were the insectivorous common yellowthroat, lincoln*s sparrows and alder flycatchers[75].

C A study in Nova Scotia found that the densities of two common species of birds, white-throated sparrow and common yellowthroat, declined for two years after clear-cuts were sprayed with glyphosate. Densities had returned to normal by the fourth year. However, it was observed that new species including warblers, vireos, and a hummingbird had colonised the unsprayed control plot. These species did not appear in the sprayed plots[76].

C In Norway, black grouse avoided clear-cuts for several years after spraying with glyphosate. The authors recommended that glyphosate not be used near grouse courtship areas[77].

In the UK, the indirect effects of pesticides on farmland bird populations has been a subject of concern for the Royal Society for the Protection of Birds (RSPB). Cereal herbicides are associated with the decline of 11 species of farmland birds[78].

Plants

Glyphosate is also a threat to terrestrial non-target plants as a result of spray drift from target areas. Measurement of the effects of herbicide spray drift on plant communities is very difficult. This is especially true when the amounts received are sub-lethal and the long-term damage is likely to be subtle[79]. In the US, for example, sub-lethal doses of herbicides have been blamed for reducing winter hardiness and resistance to fungal diseases in trees[80]. Studies of the impact of spray drift include:

- A study of the effects of spray drift of a glyphosate formulation on British species commonly found in nature reserves. The plant species were exposed to spray drift at different distances, wind speeds and application rates (0.5 and 2.2 kg a.i./ha). Death and severe growth suppression occurred at a distance of 2-6 metres from the sprayer. Sub-lethal effects could be detected up to 20 metres away for one species, *Prunella vulgaris* (self heal). Some species were consistently more sensitive including *Digitalis purpurea* (foxglove), *Centaurea nigra* (hard head), *Prunella vulgaris* (self heal) and *Lychnis flos-cuculi* (ragged robin). Epinasty (more rapid growth of the upper side of an organ causing for example curling in a leaf) was the most frequent symptom of damage[81].
- A recent study looked at species typical to UK woodland margins, hedgerows and field margins. The plant communities were exposed to glyphosate and other herbicides each year for at least three years. The effects of sub-lethal doses were measured on species yield, flowering performance, seed production, seed variability and invasion of new species. All species showed some effects within an eight-metre zone. One important result of this study was the finding that individual species respond to spray drift in different ways depending on the structure of the plant community in which they are growing. This means that it is extremely difficult to extrapolate the results of toxicology tests on single species to predict an outcome in the field[79].
- A UK Forestry Commission study into the decline of hedgerow ash found that 19 per cent of hedgerow ash showed symptoms of dieback (measured according to the proportion of foliage lost). Trees in rural areas were more badly affected than urban trees. In rural areas, dieback was strongly associated with arable land (38 per cent of trees associated with arable land suffered dieback compared to 10 per cent for trees surrounded by grassland). The Forestry Commission believes that hormone and glyphosate herbicides commonly affect hedgerow trees and may in part be responsible for the dieback in ash. Other factors may include plough damage to the trees' root system and soil compaction by farm vehicles[82].

The introduction of crops genetically engineered to tolerate glyphosate poses an additional threat to plant wildlife. Some crops have wild relatives with which they can cross pollinate. There is therefore a risk of introducing engineered genetic material into the wild population. The ecological implications of this genetic pollution in wild populations is unpredictable and may be similar to the introduction of foreign species. Most introduced non-indigenous plants do not survive. But those that do can cause massive economic damage. If the modified gene enhances the survival of the wild species it may give it an advantage over other wild species and ultimately affect the structure of local plant communities[83]. A number of studies have demonstrated the potential for transfer of tolerant genes to wild species and these are discussed later under the section on ‘Impacts of genetically modified glyphosate-tolerant crops’.

5

Agricultural impacts

The use of glyphosate herbicides has a number of impacts on the arable environment. It can inhibit some beneficial bacteria and fungi and increase the susceptibility of some crop plants to diseases. It may also increase pest attacks. Over long periods of continuous use, weeds may become tolerant to glyphosate. One possible consequence of these effects is increased applications of other agrochemicals including fertilisers, insecticides, fungicides and herbicides. The introduction of glyphosate-tolerant crops will increase the use of glyphosate and may enhance these adverse impacts. There are also new risks specific to genetically engineered crops which are discussed further later.

5.1 Nutrient cycles

Some studies have found that glyphosate reduces the nitrogen-fixing activity of soil but no data is available on the impacts of these findings on agricultural performance. As with the effects of glyphosate on higher plant communities, impacts of extensive glyphosate use on beneficial micro-organisms in the arable field may be long-term and subtle. The use of glyphosate in forests can also affect the long-term fertility of forest soils indirectly. Findings of studies include:

- The formation of nitrogen-fixing nodules on clover roots was inhibited at levels of between 2 and 2000 mg/kg glyphosate. The effect persisted 120 days after treatment[84].
- Nitrogen fixation by a species of nitrogen-fixing bacteria in roots of soybeans were inhibited after treatment with glyphosate[85].
- Glyphosate doses of more than 4 kg/ha resulted in an inhibitory effect on the nitrogen-fixing action of free-living bacteria. Glyphosate affected respiration and caused a decrease in cell size[86].
- Treatment with glyphosate of soil collected from tea plantations in India reduced strains of nitrogen-fixing species[87].
- An Egyptian study of the effects of glyphosate on soil fungi and the decay of organic matter found that treatment with Roundup influenced the soil fungal community structure, reducing some species while enhancing others, and affected soil respiration and rate of decay of organic matter[88].

;.2 *Susceptibility to plant diseases*

Glyphosate has been found to increase the susceptibility of crop plants to a number of diseases, for example:

- C Glyphosate increased the pathogenicity and survival of a disease causing fungi, *Gaemannomyces gramminis*. The fungus causes 'take-all disease' in wheat crops. In addition, the proportion of soil fungi which was antagonistic to the take-all fungus decreased[89].
- C Glyphosate increased the susceptibility of bean plants to the parasitic disease anthracnose[90].
- **C** It was found that spraying Roundup prior to planting barley increased Rhizoctonia root rot disease in the crop and decreased its yield[91].

;.3 *Impacts of genetically modified glyphosate-tolerant crops*

Some of the recognised implications of planting herbicide-tolerant crops include:

C the spread of genetically engineered herbicide-tolerant genes to related weed species and to neighbouring crops
C increased risks of weeds naturally developing resistance to the herbicide
C change in the use of herbicides
C transgenic crops as weeds
C potential loss of farmland biodiversity .

Cross pollination with related weeds

The transfer of glyphosate resistance genes to wild or weedy relatives of GM crop plants can take place by pollen dispersal (by insects or wind) or through vectors such as viruses or nematodes. The potential for transfer of the foreign gene depends on the local ecology in areas of transgenic crop production and will vary for each crop in different parts of the world.. For example in the US, where many of the transgenic crops are being developed, there are no wild relatives of maize, soybeans, wheat or cotton. In Spain, there are many wild relatives of crops, which could potentially harbour modified crop genes[92]. In the UK, the Government's Advisory Committee on Releases to the Environment has acknowledged that oilseed rape is likely to be able to cross breed with several related UK plant species[93].

Monsanto admits that oilseed rape can transfer novel genes to weeds but states that such outcropping can only occur over a short distance and can be prevented by sowing a border of unmodified rape around the transgenic crop[94]. However, monitoring carried out by the National Institute of Agricultural Botany (NIAB) in the UK has found that pollen was dispersed up to 400m from a nine-hectare field of GM oilseed rape, despite the field being surrounded by a 20m deep boundary of unmodified oilseed rape[95].

Studies of oilseed rape (Brassica Napus) have shown that pollen densities around large agricultural fields are very much higher and have dispersal characteristics unlike those of experimental plots[96]. Moreover, recent studies have shown that wind dispersal of oilseed rape pollen from agricultural fields occurs over much greater distances and at higher concentrations than originally predicted [97]. Feral and volunteer populations of GM oilseed rape further complicate the problem, as these can potentially act as additional sources of GM pollen. In a recent report examining existing patterns of gene flow in oilseed rape farming areas, it was concluded that "potential exists for a continuous network of cross-pollination of oilseed rape across any region growing the crop"[98].

Evidence that indicates the cross-pollination and transfer of herbicide-tolerant genes includes:

- Tests with experimental plots detected gene flow between neighbouring spring- and autumn-sown fields and between fields and feral populations. It was concluded that given the close proximity of fields and feral populations within the agricultural environment, significant levels of gene flow from transgenic oil seed rape fields is inevitable[97].
- A Danish study found that spontaneous hybridisation between oilseed rape and wild turnip (*Brassica rapa*) could occur under field conditions. The hybrid plants were highly fertile and carried a transgene from the oilseed rape. The researchers concluded that the rapid spread of genes from oilseed rape to the weedy relative *B. rapa* is possible[97].
- A report for the UK Advisory Committee on Releases to the Environment concluded that in the case of wild turnip "the production of herbicide-tolerant hybrids must be considered a realistic prospect"[93].
- Research in France demonstrated that hybridisation can occur in the field between oilseed rape and wild radish (*Raphanus raphanistrum*). The progeny of the hybrid exhibited characteristics of both parents and the authors of the study recommend further careful research before planting large areas of herbicide-tolerant crops[99].
- Other studies have shown that hybridisation occurs between oilseed rape and hoary mustard (*Hirschfeldia incana*). It was found that, under competitive conditions, the hybrid plants do better than the hoary mustard, suggesting that hybridisation may be an important avenue for gene escape for oilseed rape[100].
- In an experiment in which wild radish was crossed with oilseed rape carrying a gene for resistance to the herbicide glufosinate-ammonium, the tolerant gene persisted after the hybrids had been bred for four generations. The study also predicted that other transgenes in oilseed rape, such as antibiotic tolerant genes used as markers, will readily transfer to wild plants.
- A study in France found that gene flow occurred between GM herbicide-tolerant sugar beet and weed beet in a neighboring field within one growing season[101].
- In Africa, sorghum hybridises with weedy relatives producing a weed pest that looks very similar to the crop and is therefore very hard to control. ICI (now Zeneca) has ceased work on herbicide resistance in sorghum for this reason[102].
- The US Department of Agriculture has acknowledged that natural hybridisation is

known to occur between cultivated soya bean, *Glycine max,* and a wild relative, *Glycine soja*[103]. *G. max* is thought to be derived from *G. soja* and where the two species overlap, a number of intermediate forms are found[104]. *G. Soja* is a principle weed in Japan. It is also found in Australia, southern China, Taiwan, the Philippines and Papua New Guinea. Transfer of glyphosate-tolerant genes from Roundup Ready Soya could increase the problems with this weed in Japan and elsewhere.

The initial benefits manufacturers claim for herbicide-tolerant crops may be quickly eliminated by the impacts of cross breeding with weedy relatives. In particular, crops such as sugar beet, for which problem weeds are closely related to the crop, will rapidly lose the benefits of herbicide tolerance for weed control.

Weed resistance

Weed resistance is a major area of concern for farmers all over the world. It can have serious agronomic and economic impacts, especially when weeds gain multiple resistance to a range of herbicides. In a 1995/6 International Survey of Herbicide Resistant Weeds, 183 herbicide resistant weed biotypes were recorded in 42 countries[105]. A resistant weed biotype is a naturally occurring group of individual weeds with the same genetic predisposition to resist a herbicide. The study recorded 124 weed species with herbicide resistance. Most of the resistant biotypes were found in countries where herbicides are the primary weed control method. For example, there were 49 resistant weed biotypes in the US, 24 in France and Spain, 22 in Canada and 16 in the UK.

In 1996, a farmer in Australia found that rigid ryegrass (*Lolium rigidum*) had developed glyphosate resistance. Subsequent studies have confirmed his findings[105].

Before 1996, researchers argued that it was nearly impossible for weeds to become resistant to glyphosate, primarily because it has a long history of widespread use with no evidence of weed resistance and also due to its unique properties, including its mode of action, limited metabolism in plants, and lack of residual activity in soil. Other scientists now believe that there are few constraints to weeds evolving resistance to glyphosate[106]. The author of the 1995/6 International Weed Resistance Survey acknowledges that the appearance of weed resistance to glyphosate is a timely reminder that farmers cannot depend on herbicides alone to control weeds[105]. There is particular concern that multiple uses of glyphosate within a single crop season on glyphosate resistant crops could provide the ideal conditions for further weed resistance to evolve[106].

While industry is proclaiming that herbicide-tolerant crops will make weed control even simpler, weed scientists are calling for the adoption of longer term, more complex, non-chemical weed control strategies that reduce risks of resistance[105]. For instance, field experiments in the southern Canadian prairies looked at ways to reduce both the costs and the risks of herbicide resistance[107]. Conventional use of repeated applications of glyphosate and 2,4-D effectively controls weeds in fallow rotations with winter and spring wheat. However, methods involving a combination of herbicides and tillage gave the best results for all weed species and also minimised the risks of soil erosion. Soil water retention and succeeding wheat yields were similar to, or greater than, those attained with repeated herbicide use and no tillage.

Herbicide use

Monsanto claims that the use of glyphosate-tolerant crops will reduce the quantity of older, more toxic herbicides used by farmers. In the short term, the use of herbicides may appear to decline. In the long term, however, there are other considerations which will affect the levels of herbicides and possibly other pesticides used. These include:

- The development of glyphosate resistance in weeds or the use of practices to minimise the risks of weed resistance will perpetuate the practice of applying mixtures of herbicides that have a range of adverse environmental impacts.
- The presence of glyphosate-tolerant volunteers will require the use of additional applications of herbicides other than glyphosate. The Dutch Government has expressed concern that if herbicide-tolerant crops are commercialised, then the greater volumes and varieties of herbicides required in removing volunteer and feral plants will have impacts on soil and groundwater[108].
- The impact on pest insect populations and diseases after long-term use of glyphosate may mean that farmers increasing their use of insecticides and fungicides.

Rather than making significant reductions in pesticide use, in the long term herbicide-tolerant crops will intensify chemical dependence in agriculture. Other weed control strategies are being developed that aim to reduce dependency on herbicides and minimise the environmental impact significantly. For example, scientists working for DLO-NL, the Dutch Government-funded organisation for agricultural research, are assessing new systems of weed control that are drastically reducing the level of herbicide used in sugar beet and maize. The researchers have expressed their concern that widespread use of herbicide-tolerant plants will remove the incentives for farmers to adopt these non-chemical, more environmentally benign control systems[109].

Transgenic crops as weeds

Some crops appear as weeds in the next growing seasons and are a serious economic pest. Potato ‘volunteers’ or sugar beet ‘bolters’ are examples. Unharvested or spilled oilseed rape seeds can give rise to enormous quantities of volunteer plants growing in subsequent crops[96].

Some crop species have escaped from the field and are growing wild as feral populations. Oilseed rape, for example, is a roadside weed in many areas. Gene flow to these weed populations from transgenic crops or the spread of large numbers of transgenic crops themselves would reduce the efficacy of weed control and also of pre-harvest desiccation. Potato volunteers, for example, are currently controlled with glyphosate[110]. Glyphosate-tolerant potato volunteers would require the use of other herbicides. The accumulation of volunteers resistant to several herbicides would greatly exacerbate the problem.

The extent of the problem is difficult to assess from field trials. The OECD found that field monitoring after trials with transgenic crops varies between one year after the last volunteer is removed and five years during which the site is checked for surviving transformed plants[111]. However, in the UK the results of preliminary monitoring of GM oilseed rape grown at test sites did not show that the GM varieties produced more volunteer plants than the non GM varieties[112].

Loss of farmland biodiversity

At the present time, there is a great deal of controversy in the UK about whether herbicide-tolerant crops will pose a threat to the health of plants and animals. The Government has commissioned research to examine this issue, in particular farm-scale trials of herbicide-tolerant crops. These will not be complete until 2003. A paper produced by the UK Pesticide Safety Directorate said, in reference to the impact of herbicide-tolerant crops on biodiversity, that "there is currently a lack of independent research to allow an accurate prediction of the potential impacts"[113]. However, it has been widely suggested that the switch to broad-spectrum herbicides which are partnered to these crops could have significant impacts upon the biodiversity of UK arable farmland.

In July 1998, English Nature produced a position statement on genetically modified organisms. An accompanying press statement said: "More research is needed and existing research needs to be completed before we can have a better idea of the possible effects of GMOs on our already hard-pressed farmland wildlife ... Environmentally untested introduction of GMOs could be the final blow for species such as the skylark, corn bunting and the linnet."[114]

This position is backed up by other conservation organisations. In 1997, the Countryside Council for Wales supported an English Nature proposal that no commercial releases of herbicide-tolerant crops be approved for a five-year period[115]. Scottish Natural Heritage stated in response to a MAFF discussion paper on herbicide-tolerant crops that: "Genetically modified herbicide-tolerant varieties appear to offer the possibility of virtually weed-free crops, so removing the remaining food source for these [farmland] birds (many of which have already seriously declined in numbers during the past 20 years). Although the popular focus has been on skylarks and song thrushes, this is potentially serious for a far wider range of farmland birds."[116]

Similarly, the Royal Society for the Protection of Birds (RSPB) said: "The development of genetically modified herbicide-tolerant crops could lead to a massive increase in the use of broad-spectrum herbicides which would have a huge impact on biodiversity by increasing indirect effects of pesticides and further diminishing the food chain." Referring specifically to oilseed rape, the RSPB said: "Broadleaved crops, such as oilseed rape and sugar beet, support large populations of broadleaved weeds making them important in the arable rotation to wildlife. Genetically modified herbicide-tolerant crops could effectively be ‘sterilised’ of weeds by broad spectrum sprays”[117].

6

Conclusions

Glyphosate is already the world*s most-used herbicide. Its use is anticipated to increase even further with the introduction of genetically engineered, glyphosate-tolerant crops. The popularity of glyphosate has been encouraged by the claims of its primary producer, Monsanto, that it is not harmful to humans and is environmentally safe.

However, since glyphosate's introduction more than 25 years ago, scientists have developed a much greater understanding and appreciation of the complexity of the effects chemical contaminants have in the human body and ecological systems. Correspondingly, researchers have employed more elaborate and sensitive tests to evaluate the impacts of glyphosate. There is now a strong body of independent research that shows glyphosate to be a harmful chemical. In addition, the authors of the research studies reviewed in this report consistently remarked that there is an enormous lack of information on the effects of glyphosate in the environment and the difficulties in measuring subtle, long-term impacts.

A greatly increased and widespread use of glyphosate on genetically modified herbicide-tolerant crops is likely to effect wildlife directly, as well as have indirect effects caused by a reduction in weeds used by wildlife for food and cover. The farm-scale trials to investigate the impact of genetically modified herbicide-tolerant crops - begun in 1999 and due to be completed in 2003 - did not include any glyphosate-tolerant crops in the 1999 research programmes. But these trials are unlikely to be sensitive enough to pick up the long-term subtle effects of the genetically modified crops, even if glyphosate were being used.

Knowledge of the adverse impacts of herbicides has stimulated investment in research and development of weed-control practices that reduce reliance on herbicides dramatically.

The risks and benefits of glyphosate herbicides and the introduction of glyphosate-tolerant crops can no longer be evaluated in isolation, but must be evaluated in the light of other approaches that reduce herbicide use significantly. The perceived benefits of glyphosate-tolerant crops may prove nonessential where other, more environmentally beneficial, methods are applicable.

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