THE ENVIRONMENTAL AND AGRONOMIC CONSEQUENCES OF GROWING HERBICIDE TOLERANT CROPS[1]

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Introduction

Over the last 15 years considerable research effort both commercial and governmental has been put into the acquisition of data about genetically modified (GM) crops. This was needed to satisfy the UK governmental and EU regulatory requirements of the benefits and potential risks of the technology before the crops could be commercialised.

Most interest was in oilseed rape (*Brassica napus*) but work was also carried out on sugar beet (*Beta vulgaris*) and maize (*Zea mais*). EU funded studies explored the potential of gene flow to transfer genes to adjacent non-transgenic crops and particularly in the case of oilseed rape to related wild species (*e.g.* Crawley *et al.*, 1993; Scheffler *et al.*, 1993). Much of this work was done on small plot experiments and it became apparent that the consequences arising from the commercialisation of GM herbicide-tolerant crops were influenced by scale. For example, conclusions based on gene flow from 100 m^2 plots might not be relevant to 10-ha fields. Thus some scaling up of research was necessary to provide relevant answers. Work at NIAB and the Scottish Crop research Institute has explored the wider scale consequences of the introduction of these crops (Norris *et al.*, 1999; Timmons *et al.*, 1995; Wilkinson *et al.*, 1995).

By the end of the 1990s it was clear from UK trials and commercial use in North America that although the benefits of herbicide-tolerant crops to farmers could be substantial, there could also be agronomic and environmental risks. Questions, such as the following were raised:

- How would the farmer manage herbicide-resistant volunteer crop plants?
- Would the repeated use of the same herbicide result in a shift in the weed flora towards species that were not very sensitive to the herbicides?
- Was there a risk of the development of herbicide-resistant weed biotypes?
- Was it a good idea to mix different herbicide-tolerant crops in the same rotation?

Answers to such questions as these were not amenable to small plot trials and needed larger-scale, longer-term experiments. In autumn 1998 a SAPPIO LINK programme entitled 'Botanical and Rotational Implications of Genetically Modified Herbicide Tolerance' (BRIGHT), funded by the UK Ministry of Agriculture, Fisheries and Food (MAFF) and the Scottish Executive Rural Affairs Directorate (SERAD), was set up to conduct a 4-year experimental programme to explore the agronomic and botanical implications of growing herbicide tolerant crops.

At the same time as the BRIGHT project was in gestation, public concern over GM technology throughout Europe was increasing. The safety of GM food was questioned, as were the environmental implications of large scale introductions of herbicide tolerant crops. In the UK organic growers expressed concern about the risks of gene flow to adjacent organic crops (e.g. pollen movement from GM maize to organic sweet corn), which they perceived as a threat to their livelihood. In 1999 one of the UK government's advisory organisations on the natural environment (English Nature) suggested that the current regulatory procedures were ignoring potential secondary effects arising from herbicide tolerant crops. They were particularly concerned over decline in biodiversity, especially the dramatic decline in the numbers of farmland birds (Fuller *et al.*, 1995). Those supporting the technology, however, claimed that in some situations the use of herbicide tolerant crops could have beneficial effects on biodiversity, because of the greater flexibility in timing of herbicide treatments and the avoidance of persistent soil-acting pre-emergence products (e.g. Dewar *et al.*, 1999).

The UK government's response was to initiate a 4-year programme, funded by the Department of the Environment, Transport and the Regions (DETR) and SERAD, to explore the impact of the management of herbicide tolerant crops on biodiversity. A British commercial grouping aimed at the development of GM crops, the 'Supply Chain Initiative for Modified Agricultural Crops' (SCIMAC) is providing sites for the experiments and the research is being overseen by an independent expert Scientific Steering Committee. This 'Farmscale Evaluation' project was started in 1999, and the UK government reached a voluntary agreement with SCIMAC that commercialisation of GM herbicide tolerant crops will not proceed in the UK until the Farmscale programme is completed in 2003.

The BRIGHT project

Rotations

The core of the BRIGHT project is a series of large plot experiments to investigate the impact of GM glufosinate and

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Table 1. Rotations in the BRIGHT project.

	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5
Sites[1]	NIAB, RES, SAC	MOR, BB	All	NIAB, RES, SAC	MOR, BB
1998/99	w. rape	s. beet	w. rape	w cereals[2]	w. cereals[2]
1999/00	w.cereals	w. cereals	w. cereals	w. rape	w. cereals
2000/01	w. cereals	w. cereals	GM crop[3]	w. cereals	s. beet
2001/02	w./s. rape	s. beet	w. cereals/ fallow	w. cereals/ fallow	w. cereals/ fallow

[1] NIAB = National Institute of Agricultural Botany; RES = IACR-Rothamsted; BB = IACR-Broom's Barn; MOR = Morley Research Centre; SAC = Scottish Agricultural College, Aberdeen
[2] Winter cereals undersown with volunteer rape
[3] This will vary across sites – rape or sugar beet

glyphosate tolerant oilseed rape and sugar beet, together with 'conventionally' bred rape tolerant to the herbicide imazamox, over a series of five, 4-year rotations (Lutman & Sweet, 2000) (Table 1). All herbicide-tolerant crops are grown alongside a standard 'conventional' crop and are managed, as far as possible, as normal arable crops. Most sites run three rotations, Rotations 1 and 2 represent normal farm practice for oilseed rape and sugar beet, respectively, whilst Rotation 3 will explore what might occur if more than one GM crop was grown in the same rotation. Rotations 4 and 5 were set up to examine what could happen if a large seed bank of sugar beet or oilseed rape was inherited from a previous GMHT crop. Each 4-year rotation includes two treatment years, when the broad-leaved crops are grown, and two years when the plots are cropped uniformly with cereals.

Treatments

Herbicide treatments are imposed whenever a broad-leaved crop is grown. In the oilseed rape there are 4 treatments: glyphosate tolerant, glufosinate-ammonium tolerant, imazamox tolerant and conventional. The imazamox resistance is not available in the sugar beet, so there are only 3 treatments in this crop. When the second herbicide tolerant crop is grown the 3 or 4 treatments are applied at 90° to the first set of treatments. As a result all combinations of sequences of treatments can be created, enabling a check on whether it is better to retain the same herbicide tolerance in one rotation or to mix up different ones. The 'conventional' plots receive the normal weed control treatments employed by the farm manager on the sites concerned.

Assessments

Weed infestation levels are being assessed before and after herbicide treatment in all crops, along with a weed biomass assessment in mid-summer. Visual assessments of herbicide performance are being made 6 weeks after application. Crop yields are being recorded. In the rape plots we are also assessing seed losses at harvest and soil cores have been taken after the rape harvest in autumn 1999 and 2000 to record numbers of volunteer rape seeds. Further soil cores have been taken at the beginning of the project to determine the weed seed bank; this will be repeated in year 4. Finally, some rape samples were collected in summer 1999 across all plots and these are being tested to identify the level of gene flow between plots. At the end of the rotations the project intends to release guidelines for farmers to help them grow GM crops successfully and in as environmentally safe a way as possible.

The Farmscale Project

Following a pilot year to develop protocols and resolve details with experimental design, the Farmscale project started in spring 2000 and will run for 3 cropping years (Firbank *et al.*, 1999). In this research the effects of the herbicide management in GM and non-GM parts of experimental fields on farmland wildlife biodiversity are being assessed. The programme is aimed to see how the change in weed control from conventional practice to the use of broad-spectrum herbicides (glyphosate, glufosinate) impacts first on the plants within the fields and secondly on invertebrate species that could be influenced by this change in the plant flora (slugs and snails, plant-living and ground-living arthropods, plant bugs, bees and butterflies). The effect on birds and mammals are also being investigated, but not so intensively, in a separate research contract.

Each experiment consists of a field divided into 2 parts (each up to 10 ha); one part is sown with a conventional crop and the other with the herbicide tolerant crop. Replication is achieved by replicating trials at different sites over the 3 years. The programme includes 4 crops, each tolerant to one herbicide (Table 2). The first sites of spring rape, beet and maize were established in spring 2000 and the first winter rape sites in autumn 2000. Sites are being located on farms with differing farming intensities (intensive arable crop production, mixed crop and animal farming *etc.*). When they are split into 2 halves, environmental aspects of the sites are, as far as possible, balanced between each half. The herbicide tolerant and conventional treatments are allocated at random to each half. With the exception of the herbicide treatments, both halves are treated similarly. The farmer makes his normal commercial

Table 2. Crops and herbicide tolerances included in the Farmscale programme.

Crop	Herbicide
Spring oilseed rape	glufosinate
Winter oilseed rape	glufosinate
Maize	glufosinate
sugar/fodder beet	glyphosate

decisions about weed control on the conventional half of the experiment and the members of SCIMAC advise solely on the herbicide use on the herbicide tolerant half of the field.

Comparison between the two projects

The BRIGHT Project has a limited number of sites, has up to 4 herbicide treatments (3 herbicide tolerant varieties + conventional) and continues for several years on the same sites. The Farmscale Project, on the other hand, consists of a large number of sites but has only 2 treatments, and each site continues in essence for only one year. The Farmscale plots are much larger than those on BRIGHT, to accommodate assessment of mobile animal species, rather than simply plants (weeds).

The two programmes are complementary – Farmscale concerned with single year effects on a wide range of organisms, while BRIGHT, less intensively monitored, concentrating on plants, but including rotational effects and comparisons of different herbicide tolerant crops in the same experiments. Between them they will provide a huge data set on the botanical and invertebrate diversity currently present in UK arable agriculture and on the effects that different herbicide treatments have on this diversity.

Progress so far

Both programmes are in their early stages. The BRIGHT programme is a rotational experiment and the full picture will only be apparent after the fourth year of the experiment. The full statistical power of the Farmscale comparisons between herbicide tolerant and conventional treatments will only be reached once the third season is completed.

No commercialisation of GM crops in the UK will occur until these trials are complete and then only if the outcome indicates no significant impact of the herbicide management associated with the technology, on biodiversity. This is not a legal requirement, as it could conflict with EU legislation, but is a voluntary agreement between those developing the technology and the UK government.

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Dr Jeremy Sweet is head of the Environmental Research Group at the National Institute of Agricultural Botany at Cambridge, UK. He has been leading the research programme on GM crops at NIAB for several years which has been monitoring the cultivation of the first GM crops in Britain. His team are conducting research for Department of the Environment, MAFF and biotech companies on the environmental and agronomic impact of GM crops. He is co-ordinator of the BRIGHT project, looking at a range of herbicide tolerant crops grown in rotation at several centres, and is co-ordinator of a European Science Foundation Programme on the Impact of GM plants.