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An introduction to the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops

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Summary

1. Several genetically modified herbicide-tolerant (GMHT) crops have cleared most of the regulatory hurdles required for commercial growing in the United Kingdom. However, concerns have been expressed that their management will have negative impacts on farmland biodiversity as a result of improved control given by the new herbicide regimes of the arable plants that support farmland birds and other species of conservation value.
2. The Farm-Scale Evaluations (FSE) project is testing the null hypothesis that there is no difference between the management of GMHT varieties of beet, oilseed rape and maize and that of comparable conventional varieties in their effect on the abundance and diversity of arable plants and invertebrates. The FSE also aims to estimate the magnitude and consider the implications of any differences that are found.
3. The experimental design of the FSE is a randomized block, with two treatments allocated at random to half-fields. The target sample is around 60–75 fields for each crop, selected to represent variation of geography and intensity of management across Britain. The experimental crops are managed by commercial farmers as if under commercial conditions.
4. Biodiversity indicators have been selected from plants and terrestrial invertebrates to identify differences between crop management regimes that may result in important ecological changes over larger scales of space and time. Field sampling is at fixed points, mainly along transects from the field boundary, starting before the crop is sown and continuing into following crops.
5. *Synthesis and applications.* The FSE is best considered as an investigation into the effects of contrasting crop management regimes on farmland biodiversity, rather than a study of the effects of genetic modification. It could become a model for future studies of ecological effects of the way we use and manage agricultural land.

Key-words: agro-ecology, biodiversity, biodiversity indicators, experimental method, public understanding of science, trophic interactions

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Introduction

By October 1998, the first genetically modified herbicide-tolerant (GMHT) crops had cleared most of the regulatory hurdles needed before commercial growing could be permitted in the UK. Varieties of these crops, maize *Zea mays* L., beet *Beta vulgaris* L., spring oilseed rape and winter oilseed rape, or canola *Brassica napus* L., have been modified to make them tolerant to broad-spectrum herbicides. Maize and oilseed rape varieties were made resistant to glufosinate-ammonium and the beet to glyphosate. Such varieties have the potential to allow greater flexibility in the timing of herbicide use (Dewar *et al.* 2000; Firbank & Forcella 2000; Elmegaard & Bruus Pedersen 2001), to facilitate the control of herbicide-resistant weeds (Gressel & Rotteveel 2000) and to reduce reliance on persistent and relatively hazardous chemicals (Phipps & Park 2002). The regimes differ in timing and specificity; the herbicides glyphosate and glufosinate-ammonium are broad-spectrum and can be applied later in the development of tolerant crops than herbicides applied to non-tolerant crops. However, concerns were raised (DEFRA 2002) that this change in weed management might exacerbate the recent declines in biodiversity of arable fields, especially by reducing food resources for farmland birds (Krebs *et al.* 1999). This indirect risk to the environment of using such herbicides on crops had not been considered specifically under the existing regulatory system, but was potentially of great public concern. In response, the UK government introduced the concept of the 'managed development' of GMHT crops, which involved a voluntary delay in their commercial use to allow time for research into the effects of the management of these crops on farmland biodiversity (DEFRA 2002).

The background to this concern about farmland biodiversity is the considerable evidence of declines in abundance of many species groups associated with lowland farmland in Great Britain (Barr *et al.* 1993; Gibbons, Reid & Chapman 1993; Firbank *et al.* 1994; Robertson & Sutherland 2002); there is little arable farming in Northern Ireland. In particular, the abundance of some farmland birds has declined dramatically in recent decades (Fuller *et al.* 1995; Noble, Bashford & Baillie 2000). Many plants of arable habitats have also declined in frequency, more than any other major group of the British flora (Preston *et al.* 2002). These declines are associated with changes in farming practice, especially a switch from spring to winter cropping, and increases in fertilizer and pesticide use (Evans 1997; Chamberlain *et al.* 2000). It was suggested that GMHT crops might exacerbate these declines, not because of any direct effect of the genetically modified (GM) technology on other species but because farmers would be able to control weeds more effectively (Hails 2000). Reduced weed densities may result in fewer weed seeds being available as food for wintering birds (Watkinson *et al.* 2000) and may reduce numbers of invertebrates that feed on the weeds, together with their predators (ACRE 1999a; Beringer

2000). These effects would be particularly pronounced if farmers used the crops to reduce weed burdens from the weediest fields that are currently rich in plant and invertebrate food resources (Watkinson *et al.* 2000). However, other research suggests that the use of GMHT varieties might benefit farmland biodiversity during the growing season, because such crops facilitate later applications of herbicide compared with conventional weed treatments. Thus, the weeds may be allowed to persist longer than in conventional varieties, providing food resources and habitat structure for animals during the breeding season (Buckelew *et al.* 2000; Elmegaard & Bruus Pedersen 2001). The overall balance of these potentially positive and negative effects of GMHT crops on farmland biodiversity remains uncertain (Firbank & Forcella 2000): despite the large areas used to grow GMHT crops commercially world-wide there remains a global paucity of appropriate large-scale experiments and relevant research on field plantings (Committee on Environmental Impacts associated with Commercialization of Transgenic Plants 2002).

The Farm-Scale Evaluations (FSE) project was established to test whether GMHT varieties influence farmland biodiversity relative to the management of non-GMHT varieties and, more importantly, to examine what the implications to farmland biodiversity might be if GMHT crops were introduced to Great Britain on a commercial scale (Firbank *et al.* 1999; DEFRA 2002). The FSE research programme, conducted by a consortium of public sector research institutes, began with a series of pilot studies in April 1999. It was immediately one of the most controversial agro-ecological studies ever undertaken because of the background of public concern about genetic modification (Krebs 2000). It has become the focus of intense media attention and public debate, as well as the target for direct action by groups opposed to growing GM crops.

Here we present the structure and summary methodologies of the project, explaining how these have arisen from the objectives of the study and from our present state of knowledge about arable ecosystems. Details of the design, analysis and power of the experiment are presented elsewhere (Perry *et al.* 2003). We expect these studies to inform and stimulate the debate about FSE, and to provide a case study of the design of experimental studies on the ecological effects of changing agricultural practices.

THE RESEARCH OBJECTIVE

For each crop, the FSE aims to test the null hypothesis that there is no difference between the management of GMHT varieties and that of comparable conventional varieties in their effect on the abundance and diversity of arable plants and invertebrates.

The conditions of the experiment are intended to represent the ranges of soil types, weather conditions and management regimes expected during commercial cropping in Great Britain. The FSE also estimates the

magnitudes and considers the implications of any differences in biodiversity that are found.

The project does not constitute a complete environmental risk assessment (Walker & Lonsdale 2000). In particular, the project does not address any ecological effects arising from gene flow from the crops because these have already been addressed elsewhere (ACRE 1999b); gene flow monitoring is, nevertheless, taking place at the field sites. The experiment contrasts the effects of the management regimes rather than the risks of genetic modification *per se*; the approach would have been the same for herbicide-tolerant varieties bred using conventional means.

The null hypothesis considers each of the four crop types separately, asking the same question of each. Therefore the research methodology for each crop is the same, as far as possible, allowing the crop results to be presented separately and in combination. The hypothesis stresses direct comparisons between GMHT and non-GMHT varieties, leading to a paired experimental design. Testing the hypothesis requires measurable biodiversity indicators and data on species diversity, abundance and biomass of a wide range of biota, especially within the field containing the GMHT crop and in following crops. The hypothesis relates effects to management, and so crop management data are required in order to demonstrate that the experimental crops are grown appropriately. Finally, the hypothesis addresses effects at the farm scale, which encompasses the need to account for potential changes in management of the farming system as a whole.

The interpretation of any differences depends upon their magnitude, their timing and which taxa are affected. In particular, there may be combinations of differences that indicate changes in important ecological processes, such as altered predator–prey ratios. There may also be landscape-scale implications of any differences, including effects arising from altered proportions of crops and land uses on the farm and between regions; these cannot be detected directly within the experiment, but may be explored using mathematical modelling.

Project design and methods

EXPERIMENTAL DESIGN

As a result of the pilot year of field studies (1999–2000), the experimental design and methodology have developed substantially since the initial description of the study was published by Firbank *et al.* (1999; Firbank 1999-on). Full details of the experimental design and statistical analysis are given by Perry *et al.* (2003) and are summarized here.

The experiment uses a randomized block design with two treatments (GMHT and conventional varieties) per block. The blocks are represented by individual fields, on farms that represent the range of soil types, environmental conditions and crop management strategies employed for each crop within Great Britain. The fields are

split to try to keep ecological conditions as similar as possible between the two halves. For example, both halves should have roughly the same amount of adjacent hedge-row or woodland, and fields should be split parallel to obvious gradients of moisture or soil type. The allocation of treatments to field halves is strictly at random.

SITE SELECTION

The sites are selected from commercial farms in those areas of Great Britain where the crops are already grown. Organic farms are excluded, because their standards preclude the use of GM crops. In some cases, part-fields are used, reflecting commercial practice where larger fields are split into smaller management units. We assume that low-intensity high-biodiversity fields are of particular importance, because of their contribution to regional biodiversity (Watkinson *et al.* 2000) and because they may be valuable in establishing any effects of GMHT crop management on scarce species and diverse communities. Such sites are therefore being overrepresented in the sample. The desired sample size is 60–75 sites per crop, including provision for site wastage (Perry *et al.* 2003).

Site selection is intended to preserve the impartiality of the study by separating clearly the tasks of each body. Any farmer willing to take part in the study applies to the Supply Chain Initiative on Modified Agricultural Crops (SCIMAC), the industry body obliged to ensure the proper use of GMHT seed, crops and the herbicides applied to them. SCIMAC decides whether each volunteer farmer will be a suitable contractual partner, and forwards the pool of possible farms to the researchers.

The farmers are contacted to provide the details necessary to assess how well their fields would contribute to the overall sample of sites. Much of this information refers to the whole farm, including farm location, the source of agronomic advice, typical management practices, soil type, yield of the appropriate crop or average winter cereal yield and typical inputs on the crop under study. Farmers also provide a self-assessed score of how intensively they farm, on a scale of 1–5, and complete a checklist of indicators of conservation practices. These include beetle banks (Thomas, Wratten & Sotherton 1991), conservation headlands (Sotherton 1991), the use of the Linking Environment and Farming (LEAF) audit for environmentally sound farm management (Drummond 1995) or other integrated farm management system, and the use of a conservation adviser. Other information relates to the field or fields under offer to the project, such field size, soil type, crop yields, rotations and pesticide inputs.

This information is used to generate a sample of sites that represents the range of variation appropriate to each crop. The key elements are geographical location and ‘intensity’, assessed from responses on yield, previous inputs and the self-assessed intensity score; field size and conservation practices are also taken into account. The same farmer may offer different fields in the same year. Only one field is chosen, unless the fields

offered represent different environments or management systems (usually when the farmer owns or manages several farms). The farmer may, however, provide more than one crop type in the same year, because each crop is treated as a separate experiment.

In order to take into account variation due to effects of weather on species abundance and crop management, batches of new sites are introduced into the FSE in 3 successive years. These are selected in order to maintain the representativeness (especially geographical) of the overall sample, using a combination of new farms and new fields in farms already taking part in the study; this helps distinguish between crop management by farmers new to GM cropping and those with more experience. In general, commercial rotations ensure that the experimental crops are followed with cereals. However, it is sometimes appropriate to grow maize continuously, in which case the treatment and observation schedules are repeated, with the same allocation of treatment to field half as in the first year.

CROP MANAGEMENT

Because of the emphasis on crops being managed under commercial conditions, farmers are allowed maximum flexibility to manage both GMHT and non-GMHT varieties in the manner they consider consistent with cost-effectiveness. For example, zero herbicide regimes are allowed on either treatment if appropriate. The conventional crop variety is selected by the farmer according to local conditions, and can vary between farms. The statistical implications of variable management regimes are discussed by Perry *et al.* (2003).

There are regulations and guidelines governing the management of the GMHT crops, addressing issues such as separation distances from other crops, the prevention of flowering of beet crops, the appropriate use of herbicides and appropriate crop disposal (SCIMAC undated). However, within these guidelines there remains substantial flexibility. Because GMHT crops are new to Great Britain, farmers may not have the experience to manage them appropriately. At such an early stage in the development cycle of agricultural products, advice is often given to farmers by the company developing the product. Therefore, advice from the companies in SCIMAC is being allowed on the herbicide regimes on the GM varieties, to ensure that the farmer or adviser understands the guidelines and the product label. SCIMAC is making every effort to channel this advice through the growers' usual agronomic consultants. SCIMAC is not allowed to provide advice for managing the non-GM varieties.

All advice to farmers (whether from SCIMAC or agronomists) is recorded in writing, all management activities on the crops noted, and a sample of farms is visited by an agronomist. These data are used to establish whether the management is 'typical' of the wider population of farmers and that advice is appropriate. The GMHT herbicide regimes are compared with

those developed in smaller scale experiments in Great Britain (Lutman, Berry & Sweet 2000) and practice in other countries (Bradley *et al.* 2000), checking that the crop management is consistent with cost-effective weed control. Other aspects of crop management can be compared with contemporary farming practice.

While the main differences in crop management between treatments are mostly restricted to herbicide regimes, differences in rotations, field margin management or cultivation are allowed between the two half-fields if there are good agronomic reasons. Thus different levels of pesticides are permitted if there are more insect pests on one treatment than the other.

THE CHOICE OF INDICATORS OF FARMLAND BIODIVERSITY

It is not possible to measure changes in abundance of all species. Therefore indicators were chosen to represent larger groups of organisms or to identify ecological processes that may result in important changes over larger scales of time and space (Table 1). The indicators need to respond to differences in crop management at scales appropriate to the experimental design. Sample sizes and levels of variability need to be adequate to test the null hypothesis. Identification to a common standard must be feasible for large numbers of samples.

We assume that the major ecological effects of GMHT varieties result from the effects of the herbicide regimes on the arable weeds and those species that are associated with them (Firbank *et al.* 1999; Watkinson *et al.* 2000). The weeds are important for farmland biodiversity, partly in their own right (Firbank 1999) and partly for their contribution to food resources, cover and microclimate for other organisms (Potts 1997). The indicators of these weed populations must be sensitive to the differences in weed management and must be capable of providing data that can be related to resources for herbivores. Therefore, the FSE records data on the weed seed bank, seedlings (before and after post-emergence herbicide application), adult plants, seed set and dissemination (Fig. 1; Harper 1977). Such data can be used to generate population models of individual species (Firbank & Watkinson 1986; Lintell-Smith *et al.* 1999). The biomass of mature arable plants is also recorded, as this is correlated with seed set and provides a measure of food resources available to herbivores within the crop towards the end of the growing season.

Selected indicators also include a wide range of invertebrates. Many invertebrates are primary consumers of plant material and their short generation times and high fecundity might amplify any changes in vegetation quality or quantity, thus making it easier to detect significant changes as they occur. They provide recognized indicator groups for environmental change (Woiwod & Thomas 1993). Invertebrates account for the largest diversity of species within the farmland ecosystem. Finally, any modelling of effects of GMHT cropping on breeding bird and mammal populations is

Table 1. The biodiversity indicators measured directly during the FSE. Note that 'abundance' refers to the density of individual species; such data can be used to generate diversity indicators. The 'survey title' refers to the actual fieldwork protocol for collecting the data, see Table 2. Studies of gene flow and birds are also undertaken on the sites under other research contracts, and are not reported here

Taxonomic group	Abundance	Diversity	Activity	Other	In-field	Boundary	Following crop	Survey title
Higher plants (excluding crop)	X				X		X	Seed bank
	X				X			Seedlings
	X				X		X	Seedlings in following crops
	X			Biomass	X			Weed biomass
	X			Cover, flowers	X			Edge vegetation
	X			Crop growth	X			Crop assessment
Gastropods				Shed seeds	X			Seed rain
				Seeds on plants	X			Edge vegetation
	X	X	X		X	X		Within-field gastropods, field-margin gastropods
	X	X			X			Crop pests
	X	X			X			Soil-surface arthropods
	X	X			X			Crop pests
			X		X	X		Bees and butterflies
			X		X	X		Soil-surface arthropods, crop pests, invertebrates on vegetation
		X	X	Biomass		X		Crop pests
		X	X			X		Crop pests
Beetles	X	X	X		X			Soil-surface arthropods
	X	X			X			Crop pests
	X	X			X			Soil-surface arthropods
Bugs	X	X			X			Crop pests
	X	X	X		X			Invertebrates on vegetation
	X	X	X		X	X		Bees and butterflies
Butterflies	X	X	X		X	X		Crop pests, invertebrates on vegetation
	X	X			X	X		Soil-surface arthropods
	X	X			X	X		Invertebrates on vegetation
Collembola	X	X			X			Crop pests
	X	X			X			Soil-surface arthropods
	X	X			X			Invertebrates on vegetation
Hoverflies	X	X			X			Crop pests
	X	X			X			Crop pests
	X	X			X			Invertebrates on vegetation
Flies	X	X			X			Crop pests
	X	X			X			Crop pests
	X	X			X			Invertebrates on vegetation
Lacewings	X	X			X			Crop pests
	X	X			X			Crop pests, invertebrates on vegetation
	X	X			X			Crop pests
Moths	X	X			X			Crop pests, invertebrates on vegetation
	X	X			X			Crop pests
	X	X			X			Crop pests
Thrips	X	X			X			Crop pests
	X	X			X			Crop pests
	X	X			X			Crop pests

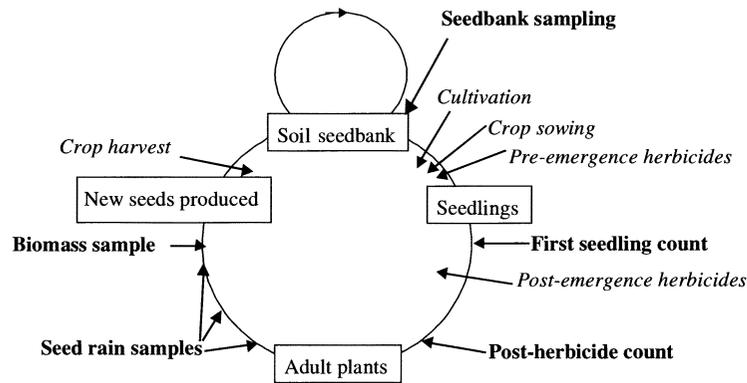


Fig. 1. Life cycle of an annual plant species in a field within the FSE in relation to agricultural operations and vegetation and seed bank sampling. The programme of sampling (in bold) is designed to monitor the whole life cycle.

likely to require data on representative invertebrate groups because of their importance as food items (Wilson *et al.* 1999).

Effects on field boundary flora and fauna of events such as herbicide spray drift and interactions between field boundary and crop species (Marshall 1988; Thomas & Marshall 1999) are identified using assessments of vegetation and invertebrates in the field boundaries. Plant species composition and availability of flower and seed heads are recorded, along with numbers of gastropods and selected arthropods.

Birds, small mammals and some insects have territories and foraging areas too large for population effects to be detected at the scale of the experiment, and so were largely excluded from the set of indicators. In general, potential effects on these wide-ranging species will have to be inferred from changes further down the food webs (Watkinson *et al.* 2000), using data on species biomass as well as abundance. Bees and butterflies are being monitored, quantifying foraging behaviour rather than effects on populations, because of their role as pollinators. Also, a pilot study was undertaken to consider the power of the FSE to detect treatment differences in bird numbers.

While soil organisms may also be influenced by GMHT cropping, especially through associated changes in cultivation regime, these were largely excluded from the FSE. This is partly because differences due to cultivation regimes need several years to become apparent (Mele & Carter 1999). Moreover, the small-scale patchy nature of soil communities would require very large sample sizes to test the null hypothesis adequately, and the phenology of the crops makes appropriate sampling very difficult. Studies in the pilot phase of the project led us to conclude that effects of GMHT cropping on most soil biota are better studied under more controlled experimental conditions (Griffiths, Geoghehan & Robertson 2000), with the exception of more mobile surface-active organisms such as some Collembola.

eties are in the ground, and continues through into the second crop following the experimental crops (Table 2 and Fig. 2). At each sample event, data are collected from a set, or (more usually) a subset of sample locations, and pooled to provide total values for each half-field. Each half of the field is sampled at the same time. Differences in sample times between fields are not important, as long as the overall schedule is maintained. Crop growth is assessed at every visit, or every 10 days during peak survey periods.

Sample points are located along transects from the edge of the crop area into the field centre, thus including the potentially greater variability in biodiversity at the crop edge. The transects are arranged around the three field edges not adjacent to the other crop, positioned using rules that include a random offset. The sample points on each transect are located 2, 4, 8, 16 and 32 m into the crop. This set of distances is derived from research on set-aside land, which showed that the vegetation at 32 m into a field is similar to that at 64 m, and therefore represents the vegetation well away from the field boundary (Critchley & Fowbert 2000). Sample areas in the field margin are centred on these transect locations. This approach (Figs 3 and 4) allows us to be confident that we are able to monitor changes in species groups over time, and the relationships among them.

Arable plants within the cropped area

Our model for the possible effects of GMHT crop management is through the influence of the herbicide regimes on arable plant assemblages, and so these plants are closely monitored both within the season and in subsequent seasons. Higher plants are sampled from the soil seed bank prior to sowing, from seedling numbers before and after herbicide applications (with a mezzanine count between the application of herbicides on the conventional and on the GMHT treatments for beet and winter oilseed rape), from numbers and biomass of adult plants prior to harvest, and from seed rain from anthesis until harvest (Fig. 1). The seed bank is resampled up to 2 years after the initial sample, and seedlings are assessed in June in the two following

THE PROGRAMME OF FIELD SAMPLING

In the FSE, field sampling begins before the crop is sown, is most intense when the GM and control vari-

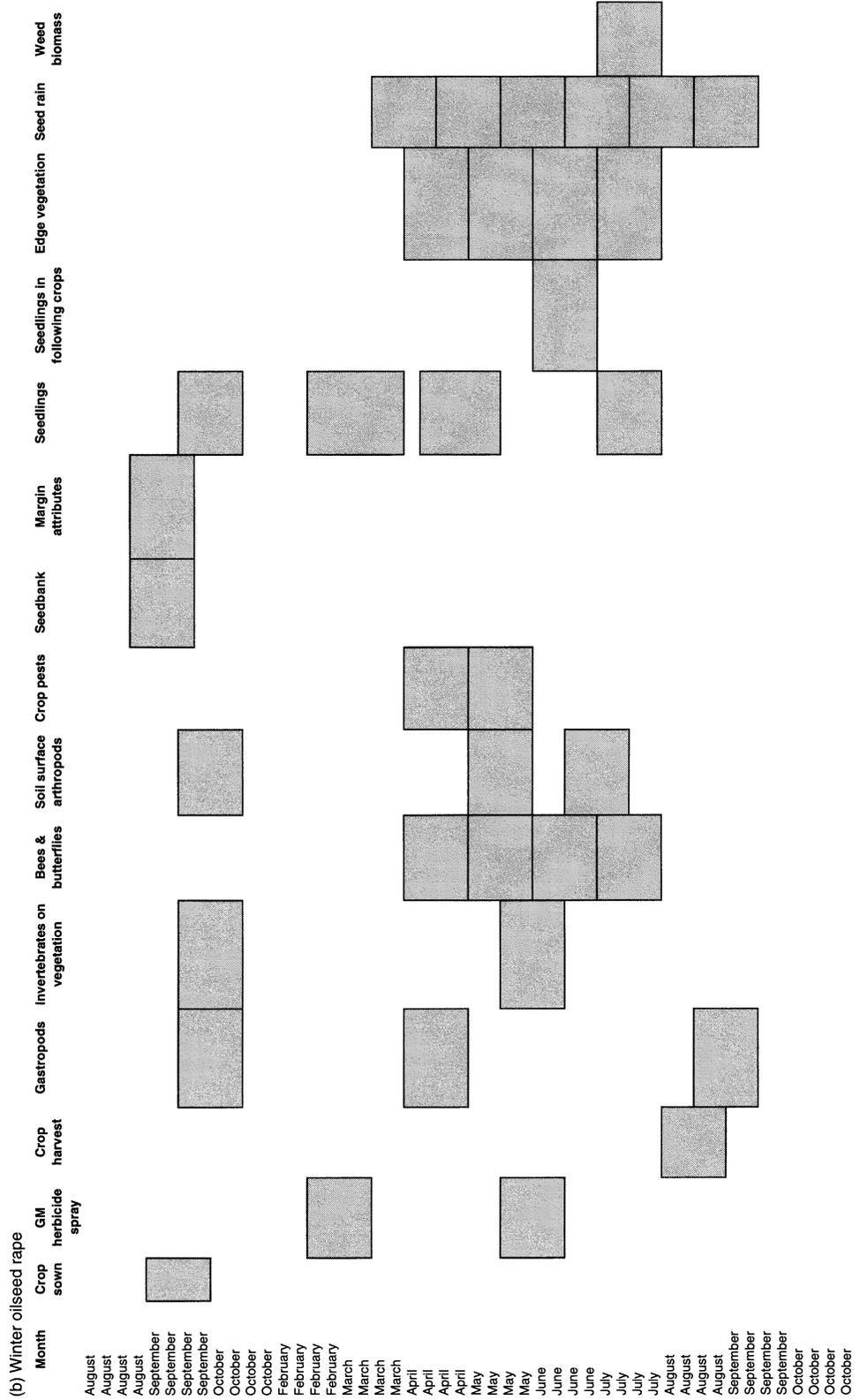


Fig. 2. Continued

Table 2. Summary of the field assessment programme; see text for details. Mezzanine weed seedling counts are made when there is a substantial difference in timing of herbicide applications between treatments in the same field; this only applies to beet and winter oilseed rape

Survey	Purpose (over and above contribution to overall biodiversity)	Timing and frequency
Crop assessment	To quantify crop growth and development	At every biodiversity assessment or every 10 days
Margin attributes	To give context for biodiversity data	Once, at site marking out
Seed bank	To integrate effects of past management and identify year-on-year changes in potential weed populations	Before sowing, and one and two years later
Seedlings	To estimate starting weed infestations and impacts of early weed control	Pre-herbicide, late winter (winter oilseed rape only), mezzanine, post-herbicide on both treatments
Weed biomass	To estimate food resource for animals, and correlate with seed production	Once, before crop harvest
Seed rain	To estimate seed return	Continuously from late May until harvest
Seedlings in following crops	To record effects in following crops	Twice, the first two summers after harvest
Edge vegetation	To estimate habitat and food resources for invertebrates and birds	3 for spring crops, 4 for winter oilseed rape
Gastropods (within crop and field margin)		2 for spring crops, 3 for winter oilseed rape
Bees and butterflies	To assess any choice between treatments	3 for spring crops, 4 for winter oilseed rape, coincidental with edge vegetation
Crop pests	To estimate the contribution of the crop itself to other biodiversity	2 per year
Invertebrates on vegetation	To estimate food resource for other animals	2 during spring/summer
Soil-surface arthropods	To estimate predator activity	3 per year

crops. In all cases, counts are made to species level and seedlings are allocated to size classes (excluding sites sown in 2000). Data are taken using soil cores (the seeds are germinated for assessment), seed traps and quadrats, and are analysed by species diversity, species number and abundances by species and species groups, e.g. broad-leaved weeds or food plants for farmland birds (Smart *et al.* 2000), and by size category.

Field edge habitat characteristics and vegetation

While the main effects of management for GMHT crops are expected in the cropped area of fields, field edges are an important resource for plants and animals in the arable landscape (Way & Greig-Smith 1987) and so need to be assessed, not least as covariates in analyses of treatment effects within the fields.

Margin attributes, such as verge, ditch and hedgerow dimensions, are recorded for a 10-m section of field margin at each transect position, and land adjacent to the trial field is classified into broad habitat categories (UK Biodiversity Steering Group 1998; Carey *et al.* 2002). Vegetation is sampled within the boundary, verge and field margin, using 10 × 1-m plots centred on the transects, recording flowering, total cover and seed production of forb species and for grass species combined. The timing of the samples coincides with margin invertebrate assessments as far as possible.

Soil surface arthropods

Pitfall traps are used to assess the activity, but not the population density, of carabid and staphylinid beetles,

selected taxa of spiders and Collembola. The traps are located on four of the sampling transects set at 2, 8 and 32 m in from the crop edge. Traps are set for 2 weeks in each of 3 months covering the period of crop growth.

Carabids are generally polyphagous predators and are likely to be good indicators of possible changes in populations at lower trophic levels (Thiele 1977; Luff & Woiwod 1995); they are good indicators of environmental change associated with agricultural management practices and anthropogenic perturbations generally (Luff & Woiwod 1995).

Individual species might indicate specific changes in food webs because of feeding specializations. For example, some *Harpalus* and *Amara* species are facultative herbivores that regularly climb herbaceous plants in search of seeds (Thiele 1977) and increase in the absence of herbicides (Raskin, Gluck & Pflug 1994) or with greater abundance of weeds (Lorenz 1995). Adult carabids are identified to species and macropterous and brachypterous morphs of some commonly trapped carabid species identified separately. Staphylinid beetles are identified to family, partly because further identification is difficult but also because functional response to habitat type has been demonstrated at this level (Moreby & Southway 1999).

Spiders are predators with a variety of habitat and dietary requirements, activity cycles and dispersal powers. Taxa selected for identification are known to be abundant within arable ecosystems and show good functional response to habitats with differing weed densities, notably individuals of Linyphiidae and, within this family, the species *Lepthyphantes tenuis* (Blackwall) and the genera *Erigone* and *Oedothorax*.

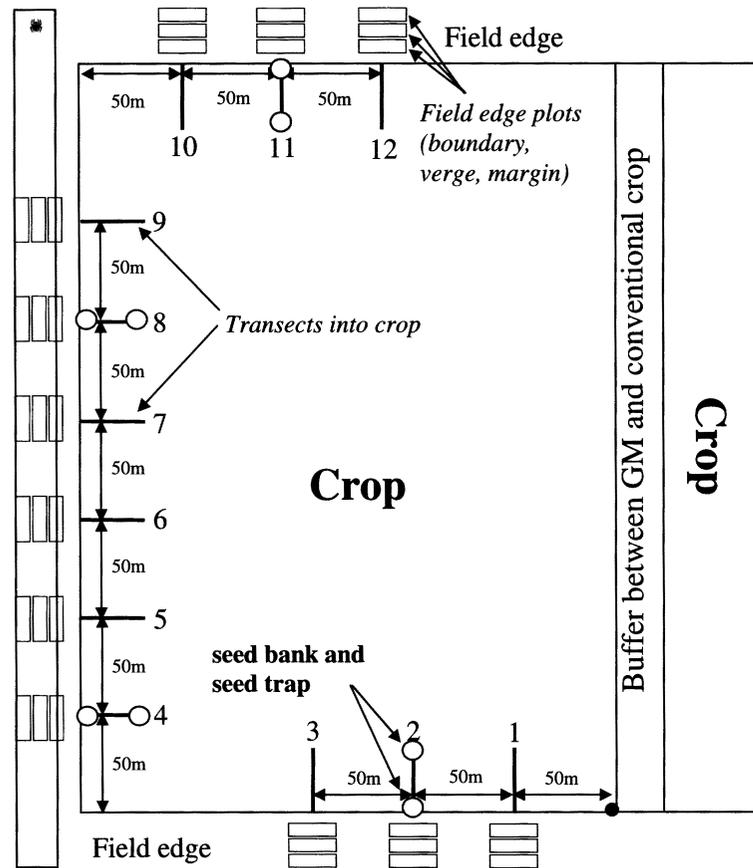


Fig. 3. Layout of the vegetation sampling of a half-field experiment unit of variable total area. Twelve transects extend 32 m into the crop, with sample locations at 2, 4, 8, 16 and 32 m. The distances between them are ideally located at 50-m intervals, and should be no less than 30 m apart. They are positioned along the field boundaries using random offsets, set on the basis of date. Vegetation counts and crop assessments take place at all locations, weed biomass samples taken at locations 2 and 32 m, as are seed bank samples and soil seed rain samples, but only on transects 2, 4, 8 and 11 (circles). Edge vegetation records are made at boundary, verge and margin locations, where the margin is a ploughed but unsown strip, the verge a grassy or herbaceous border between the ploughed edge, and the boundary defined as a physical feature that is an interface between the field and another land cover type. Not all of these are present at every field.

Collembola are sampled because of their importance as detritivores and possible food sources for predatory arthropods (Hopkin 1997; Bilde, Axelsen & Toft 2000). Their populations may be affected by differences in the amount of decaying vegetation at particular times of the season under the contrasting herbicide regimes. As this group has an intractable taxonomy, recording is limited to those families previously recognized by Fjellberg (1980).

Suction sampling of invertebrates on vegetation (Vortis)

Suction sampling from vegetation is used to collect samples of invertebrates that cover a range of functional and taxonomic groups. Samples are taken within the crop (but not directly from crop plants) and in the field edge using Vortis suction samplers (Arnold 1994) at positions and timings coincidental, as far as possible, with vegetation assessments. Arthropods are separated from other organic matter and soil particles by repeated flotation prior to being counted and identified.

Among the organisms collected in the Vortis samples, true bugs (Hemiptera: Heteroptera) comprise a

diverse group of insects encompassing a wide variety of ecological strategies and life histories (Southwood & Leston 1959). Duelli & Obrist (1998) have shown that true bugs provide one of the best single correlates for total biodiversity in agricultural areas. Moreover, they respond to botanical changes due to herbicide applications within the crop (Chiverton & Sotherton 1991) and to grassy field margins (Haughton *et al.* 1999) and are therefore likely to be good indicators of changes caused by different herbicide regimes. The group is a preferred prey type for some farmland birds, notably the grey partridge (Panek 1997). The characteristically high species richness:abundance ratio of plant bug communities means that data on community structure can be obtained very efficiently from samples.

Lepidoptera and sawfly (Hymenoptera: Symphyta) larvae are often abundant in agricultural systems and comprise largely non-pest species that feed mostly on non-crop plants. The larvae of both groups are plant feeders and are important prey for birds and mammals, and both have shown long-term declines in abundance (Potts 1991).

As with pitfall sampling, adult carabids are identified to species and Collembola to recognized families.

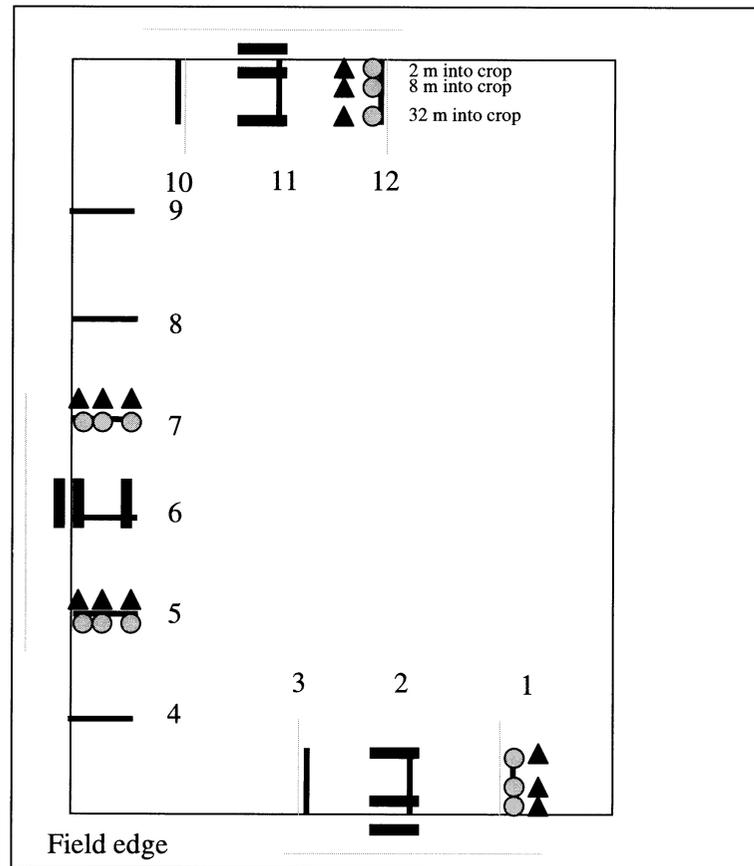


Fig. 4. Layout of the invertebrate sampling positions in a half-field experimental unit of variable total area. Pitfall traps (circles) are located at 2, 8 and 32 m into the crops, gastropod sample locations in all field edge plots and at 2, 8 and 32 m into the crops (triangles), Vortis sample areas (thick lines) at verge, 2 and 32 m into the crops, and bee and butterfly transects (grey lines) extending 100 m along the crop boundary and 50 m into the crop. Crop pests are assessed using a single plant at 2, 4, 8, 16 and 32-m locations at transects 1, 2, 3, 5, 6, 7, 10, 11, 12 (not indicated on the figure).

In addition, Coccinellidae are identified to species and any larvae counted. Counts are also made of total Curculionidae, Staphylinidae, other Coleoptera, Auchenorrhyncha, Aphididae, Neuroptera adults and larvae, parasitic wasps, Diptera adults and larvae, Orthoptera and spiders.

Insect pests and natural enemies on crops

Although insect pests on crops do not contribute much to species diversity within the crop canopy directly, they support parasites and predators and may be affected by the differing weed management programmes because of interactions with weed cover and pest levels (Buckelew *et al.* 2000). Insect pests and natural enemies are sampled without damaging the crop plants by selecting 45 plants across the half-fields, one per location at all sampling points within nine of the 12 transects. Plants are carefully searched, and the numbers of specific pests common to the crop being sampled (e.g. aphids on beet) are recorded along with any non-pest arthropods, such as spiders, coccinellid beetles, etc. Flowering oilseed rape is searched visually first, and then tapped over a tray to catch any weevils or pollen beetles. Sampling takes place twice per season at

times when specific pests may be present, which differ between crops (Fig. 2).

Bees and butterflies

Farmland can support a substantial proportion of the UK butterfly fauna (Feber & Smith 1995) but its suitability as habitat depends upon management (Feber, Smith & Macdonald 1996). Honeybees, many solitary bees, and the majority of bumblebee species present in Great Britain can live in farmed landscapes provided that there are suitable, undisturbed, nesting sites and a seasonal succession of appropriate forage plants in field margins and crops (Corbet, Saville & Osborne 1994). Bees, and to a lesser extent butterflies, play an essential role in the maintenance of biodiversity within arable ecosystems because of their effectiveness in pollinating both wild and cultivated plants (Proctor, Yeo & Lack 1996). Any effect on flora due to the introduction of GMHT crops and the associated spraying regime may alter the nectar and pollen resources available to bees and butterflies. Investigations to date have shown no clear preferences by bees for either GMHT or conventional oilseed rape, even though differences

in quality or quantity of nectar and/or pollen between them are possible in principle (Picard-Nizou *et al.* 1995; Osborne, Carreck & Williams 2001).

Bees and butterflies travel considerable distances in search of resources (Pollard & Yates 1993; Osborne *et al.* 1999). Field counts therefore quantify the attractiveness of a location and do not give a direct measure of bee numbers or productivity. Standard transect walks, modified from Pollard & Yates (1993), are used to measure abundance and species richness of bees and butterflies on the field edges (3 × 100-m sections at the edge of the cropped area, incorporating margin, verge and boundary) and on the flowering crop itself, and on any flowering weeds in that crop (4 × 100-m sections). Bees flying across the transects are not recorded as they may be travelling over the field and not using any resource within it. Sampling takes place in appropriate weather four times for beet and winter rape and three for spring rape and maize, including a transect performed when each rape site and each maize site is in flower. Maize crops become too high for this method, and so counts are made by watching over a standard 5 × 5-m square of flowering crop from a stepladder for a 10-min period, four times in each half of the field. All samples coincide with collection of data on flowering of the edge vegetation.

Gastropod sampling

Gastropods are important components of biodiversity in agricultural situations. Some slug species are important pests of arable crops at establishment (especially winter wheat and oilseed rape) and damage levels may be influenced by the presence of palatable broad-leaved weed seedlings. Gastropods can profoundly influence the dynamics of vegetation communities through herbivory (Cottam 1985; Hanley, Fenner & Edwards 1995), and they are prey for a wide variety of invertebrate and vertebrate predators (Symondson & Liddell 1993). Some snails are of conservation value in their own right (UK Biodiversity Steering Group 1995).

Slugs in the crop are sampled using baited refuge trapping (Young *et al.* 1996), at three distances along four transects in each field half; four traps are set at each sample location. There are two visits for beet and maize, three for spring and winter oilseed rape. Visual searches are used to sample gastropods in the field boundaries, using a 4-min timed search on 2 × 1-m quadrats at the centre of the boundary vegetation plot. These searches are undertaken in moist conditions in spring and autumn.

Discussion

The FSE is best considered as an investigation into the effects of contrasting crop management regimes on farmland biodiversity, rather than a study of the effects of genetic modification. The overall approach involves a formal test of a two-tailed null hypothesis, coupled

with an experimental design based on power analyses and indicators selected on the basis of a general conceptual model of the ecology of temperate agro-ecosystems. The study represents the range of conditions under which the changing land management will apply, taking into account variation in behaviour of the land managers themselves. The replication is intended to detect differences at least of the order of 1.5-fold (Perry *et al.* 2003) and data are being collected over long enough time scales to infer trends in populations of at least some species under GMHT and conventional cropping regimes.

The FSE has proved very controversial. This is partly because it raises social, political and philosophical issues concerning the use of GM crops (Bruce & Bruce 1998; Babinard & Josling 2001) that are outwith the scientific scope of the study and because of risks to human health and of the effects of gene flow that had been addressed by the regulatory process before the FSE began (ACRE 1998–99, 1999a,b). It has been suggested that the use of large-scale open-air trials could be avoided by concentrating on modelling techniques or experiments in controlled conditions. We currently lack the data and understanding to model potential impacts of GMHT crops on biodiversity with any degree of confidence (Firbank & Forcella 2000), and while smaller-scale experiments are of value they cannot, in themselves, provide the necessary data to estimate larger-scale biodiversity impacts. An excellent example of this is the way that field studies of the effects of Bt maize on monarch butterfly *Danaus plexippus* L. populations has revealed that the risk to them is far less than appeared on the basis of laboratory studies (Sears *et al.* 2001).

Staff of the consortium have been heavily involved in meetings with the public and interested parties, and the progress of the research has been reported on a website. Despite our efforts, we remain concerned that the findings will be overinterpreted, that they will be used as arguments for the widespread adoption, or rejection, of GM crops in general (depending on our findings). Our experiment refers only to one effect of one crop trait. Our findings cannot be extrapolated to other crop traits, nor to other socio-environmental systems, and are unlikely to shed light on the philosophical and symbolic aspects of the debate on GM technology. They will, however, illuminate an issue of great policy and public concern.

We also envisage that the FSE will have a broader ecological relevance. Many of the issues that concern the interaction between land management and biodiversity are potentially suitable for experimentation along the lines adopted by the FSE. Indeed, we would like to think that the FSE could become a model case study for future studies of ecological effects of the way we use and manage agricultural land.

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Further details of the project are available on <http://www.defra.gov.uk/environment/fse/index.htm>.

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