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A report on the farm scale evaluations of GM herbicide tolerant crops

Friends of the Earth

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Executive summary

The Farm Scale Evaluations (FSE) may provide a significant contribution to the field of agricultural ecology, both in terms of basic understanding of the crops being examined, and in terms of the development of monitoring techniques and methodology for measuring agricultural biodiversity. But this does not mean that they will be able to determine whether the introduction of genetically-modified herbicide tolerant (GMHT) crops will lead to ecologically important reductions in biodiversity.

In fact, it seems likely that the conclusions of the FSEs will be uncertain and may simply raise further questions. It is vital that this is acknowledged, and that equivocal results are not used as a smokescreen for Government decisions that are motivated by a political desire to proceed with the commercialisation of GM crops.

The following executive summary considers:
- **Key issues**
- **Can the FSEs detect differences in biodiversity?**
- **Are the FSEs relevant to wider agriculture?**
- **Relevance to the wider context**

Key issues

1. The FSEs have been motivated by the needs of Government and industry to avoid a formal moratorium on GM crops while at the same time showing that something was being done about the concerns of the Conservation Agencies and wider society. They are not driven by a coherent strategy for the future of agriculture, nor a desire to find the best technologies for enhancing wildlife in the UK. Furthermore, it appears that the taxpayer is funding research, which under the requirements of Directive 2001/18, is the responsibility of Monsanto and Bayer CropScience.

2. The outcomes of the FSEs should be weighted in favour of protecting biodiversity. In the case of GM crops, the precautionary principle underpins European legislation (Article 4.1 of EU Directive 2001/18). This principle means that mistakenly accepting the safety of GM crops when they could be harmful is a serious error. Changes to biodiversity may be serious and possibly irreversible and so fall within the scope of precautionary action.

3. The basic design for the FSEs of GMHT crops is to compare GMHT crops with equivalent non-GM crops under conventional pesticide regimes. The objectives and outline design, including timescale and maximum number of sites, were drawn up by Government in advance of the research consortium becoming involved. These were:

- Paired comparison of GMHT winter oilseed rape, spring oilseed rape and fodder maize with comparable non GM crops
- Paired fields or split fields on a commercial scale, ie around 10 hectares
- A four-year programme, with the first year as a pilot
- Two sites per crop in the first year and up to 25 sites per crop in following years

- The null hypothesis that there are no significant differences between the biodiversity associated with the management of the GMHT crop and the comparable non-GM crop at the farm scale

4. Many failings of the FSEs stem, at least in part, from the fact the contractors have been working within an experiment that was politically motivated and designed.

Can the FSEs detect differences in biodiversity?

1. The first objective of the ecological monitoring in the FSEs was to test the null hypothesis that there are no significant differences between the biodiversity associated with the management of the GMHT crop and the comparable non-GM crop at the farm scale. The results will be used to justify political actions, which could have huge impacts on biodiversity. However, for a number of reasons differences can exist between the GM and non-GM crops, but not be detected in the experiment.

- Based on published power analyses, the FSEs may simply not be powerful enough to detect differences of less than 1.5 fold in biodiversity between the GM and non-GM crops. If the experiment fails to detect differences, they may still be present.

- The power of the FSEs to detect differences in the various biodiversity indicators is not consistent. For some indicators, regardless of their importance, it may not be possible to detect meaningful results.

- A vital consideration for the FSEs is whether they are able to detect changes that are of ecological importance. Comparison with long-term research suggests that small, incremental changes in plant and insect populations cause ecological shifts in the long term. The assumption is made in the FSEs that detection of 50 per cent to 100 per cent difference in biodiversity indicator species between GM and non-GM crops is an acceptable sensitivity. However, evidence suggests that ecologically important differences may in fact be at levels as low as 13 per cent.

- Publicly available information on the power analysis indicates that it has been based on making comparisons between GM and non-GM treatments over the whole experiment, and not on subsets within it. Any comparisons between subsets will be made with greatly reduced power.

To sum up: the theoretical calculations conducted by the Scientific Steering Committee (SSC) overseeing the FSEs and the consortium undertaking the research indicate that the power of the FSEs to detect a 1.5-fold difference will be 80 per cent. However, it would appear that the ability of the FSEs to detect ecologically important differences is likely to be considerably lower for the following reasons:

- Observed co-efficients of variation for some biodiversity indicators are greater than the 50 per cent assumption in the calculations
- The calculations assume a difference of 1.5-fold (50 per cent), whereas ecologically important difference may be as little as 13 per cent.

Any further complications including the interaction of covariates or systematic error such as cultivar differences, could further reduce the power of the experiment to detect ecologically important changes.

2. While there is no doubt that the consultants who were charged with carrying out the fieldwork and analysis of the data collected in the FSEs are of the highest integrity and have been scrupulous in their work within the constraints imposed upon them, the FSEs have presented serious practical difficulties that are likely to affect the quality of results.

- The research consortium has faced difficulties in terms of the indicators chosen for monitoring and the methodology used. In essence, the quality of the monitoring has been limited by current status of scientific knowledge, budget, and the limited timescale of the FSEs.

- The FSEs have been used to develop techniques for agro-ecological monitoring. This has value in terms of advancing knowledge in the field but leads to questions as to how comparable the data sets from the first full year will be with subsequent years, at least for some of the indicator species used.

- The interactions and relationships between the organisms that make up the biodiversity of agricultural ecosystems are very complex and poorly understood. This means that extrapolating from results will be very difficult.

- There is some anecdotal evidence that the GM and non-GM varieties used in the trials are not similar. This could–introduce a further difficulty, because as the growth and development of the crop cultivars go out of phase, the presence of biodiversity indicator organisms will also go out of phase between the two halves. Agricultural activities, such as fertiliser application, might also have to be taken at times that are not appropriate for one or other of the cultivars. This would result in a bias one way or the other.

To sum up: one of the most significant outputs of the FSEs is likely to be a greater understanding of the relationships between organisms and their environment within farmland ecosystems. In addition, the FSE could provide an important source of basic information on the biodiversity associated with intensive agriculture at this point in agricultural history.

While this is very valuable in terms of increasing scientific understanding of agricultural ecosystems, it is essential to retain a realistic perspective on the ability of the results and modelling to predict the impact of GMHT crops on wider biodiversity in agricultural areas. The model will be used to extrapolate beyond the range of the data, and will probably be used as a basis for policy decisions and possibly as a justification for the commercialisation of GM crops. Yet, in the face of this level of complexity, such models are notoriously unreliable and dangerous to use; they are often little more than an educated guess about what may or may not happen.

Are the FSEs relevant to wider agriculture?

The secondary objective of the research was: "to contribute to an assessment of the wider question of whether the commercial use of GMHT crops will change the management of farming systems and the agricultural landscape".

The ability to fulfil this second objective rests in large part on how representative the trial sites are. If the farms used do not accurately reflect the rest of the farms found in UK agriculture, the relevance of any results will be much weaker.

It is worth noting that:

1. The FSEs have been drawn from a small pool of farmers who were willing to take part in the farms and as a result there are clear biases in the geographical spread and range of farm types included. The farms used for the FSEs show a large number of repeats in individual parishes and farms. Thus the intentions of the SSC to obtain a representative sample have been compromised by the limited number of farmers offered by SCIMAC.

2. Failure to measure yield in the FSEs, in combination with the control of GM herbicide applications being given to the biotech industry, has created the potential for management decisions to be manipulated in order to provide an unrealistically favourable impression of GM crops. These basic oversights could compromise the ability of the FSEs to meet their secondary objective and, more crucially, could call into question the relevance of their results.

3. The FSEs: "will not undertake an economic analysis of the take-up of GMHT crops; rather we will adopt MAFF or SCIMAC figures of take-up when scaling up to the national level".[1] To take an estimate of farmer take-up from SCIMAC, which is a proponent of GMHT crops, indicates a certain naivety on the part of the research consortium. Furthermore, it is unclear on what basis either the government or SCIMAC will estimate GMHT crop take-up in the absence of economic data from the FSEs, which has been the only large scale growing of such crops in the UK.

4. Establishing the impacts of GMHT on the wider agricultural environment may prove to be a difficult task on the basis of the data likely to be provided by the FSEs. The FSEs are looking at changes within a single year (in most cases) and in a relatively small area. This means that the results will have to be scaled up, both quantatively and timewise, in order to make assessments about the impacts at a larger scale.

Relevance to the wider context

1. It appears that the experiment is likely to throw up further questions that will be difficult to answer because they have not been addressed in the design. Most importantly, there has been no attempt to establish what level of difference is of ecological importance and whether or not the FSEs are sufficiently sensitive to detect this. Furthermore, the experiment will not allow comparison with the biodiversity inherent in more sustainable farming systems, such as organic. It will not even be able to address the value of the GMHT system in comparison with other developing technologies in weed control, such as mechanical weed control in maize or the use of good establishment to control weed development in oilseed crops.

2. In this context, the question arises as to why there has been such emphasis on GMHT crops, despite the environmental concerns that surround them. The answer lies in the fact that the modification of agricultural crops is dominated by companies that have a history of pesticide production, so herbicide-tolerant crops are viewed, both by Monsanto and Bayer CropScience, as a means to continue sales of their core agro-chemicals; respectively glyphosate (Roundup) and glufosinate ammonium (Liberty). Both Bayer and Monsanto have

invested in greater manufacturing capacity of these core herbicides in anticipation of the introduction of GMHT crops.

3. Herbicide-tolerant crops are a key part of these companies' strategies to maintain market share, not least by tying the sale of the GM seed to purchase of the proprietary version of the herbicides. The fact that large multinational companies, such as Monsanto and Bayer, are behind GMHT crops goes a long way to explaining the emphasis that has been placed on their development, and why such a large research effort has been provided and funded by Government.

1. Introduction

In 2003-04, the Government will decide whether the first generation of genetically modified herbicide tolerant (GMHT) crops will be grown commercially in the UK. This decision will follow the completion of the Government-sponsored Farm Scale Evaluations (FSEs) of these crops and the publication of the results and recommendations in July 2003.

It is fair to say that the FSEs have not been universally welcomed and that the science behind them has been questioned. Whatever the results of the trials, they will influence the Government's final decision on whether or not to license the first generation of GM crops. Other factors, such as pressure from industry, the competitiveness of UK-grown crops in world markets, the UK's relationship with the USA, the potential market for GM crops and public opinion will also weigh heavily on the Government's mind when it makes the final decision.

As with all scientific experiments, the value of the results of the FSEs hinges on the experimental design, the quality of the data gathered and the interpretation of that data. It is important therefore that politicians fully understand any limitations in experiments and the results they are presented with. Those limitations must also be made transparent to the electorate. Friends of the Earth firmly believes that sound science should be used to inform political decisions on matters such as the commercialisation of GM crops, but equivocal scientific information should not be used to justify decisions that are largely political.

Friends of the Earth has no doubt that the consultants who were charged with carrying out the fieldwork and analysis of the data collected in the FSEs are of the highest integrity and have been scrupulous in their work within the constraints imposed upon them. However, the FSEs were conceived for political rather than scientific reasons and therefore it is essential that whatever results emerge from the trials in July 2003 should not be used inappropriately to legitimise decisions which go beyond those supported by the science.

This report examines the limitations of the scientific methods used by looking at the background to the decision to conduct the FSEs, the scientific methods used in them, the way the research and farm management was conducted and the errors inherent in the whole process. We publish it in the hope that it will add to the public debate on GM crops and analysis of the results of the FSEs and, thereby, prevent any abuse of those results for politically motivated reasons.

2. The context of the farm scale evaluations

The FSEs are examining the impacts on biodiversity of growing five GMHT crops:

- Fodder maize tolerant to the herbicide glufosinate ammonium, produced by Bayer CropScience[1]
- Spring oilseed rape tolerant to the herbicide glufosinate ammonium, produced by Bayer CropScience
- Winter oilseed rape tolerant to the herbicide glufosinate ammonium, produced by Bayer CropScience
- Fodder beet tolerant to the herbicide glyphosate, produced by Monsanto
- Sugar beet tolerant to the herbicide glyphosate, produced by Monsanto

Before considering the science of the FSEs it is essential to examine the political and regulatory context in which they were carried out because this is important for an understanding of the pressures and constraints which have been placed on the experimental design, control and conduct of the experiments. It also helps clarify the political expectations placed on the science and may give some insight into how politicians, who commissioned the research, hope to use the outcomes.

The regulatory background

In order to get to commercial approval, GM crops must have a number of regulatory approvals. Under the EU's GMO Deliberate Release Directive 2001/18 (replacing Directive 90/220) crops need a "Part C" marketing approval to be sold commercially in the EU. If the crop is to be used for food it also needs to be approved under the Novel Foods Regulation 258/97. In addition, the seeds derived from the GM organism need individual acceptance onto the National List of Agricultural Plant Varieties (the National List), which assesses the value of the variety for "cultivation and use". Finally, the herbicides used in conjunction with the GMHT crops need approval for this use under the EU's Plant Protection Products Directive 91/414.

In 1998, Bayer's GM maize gained Part C approval, but none of the GM crops being examined in the FSEs had all the necessary approvals to be grown commercially (see table 1). They were still several years from commercial introduction and, in fact, the plantings of GM oilseed rape and sugar beet have been carried out under experimental (Part B) licenses.

In 1998, the European Commission published a proposal for amendments to the GMO Deliberate Release Directive as a result of an emerging consensus within the EU that the safety provisions of that directive were inadequate. In December 1998, at the EU Council of Environment Ministers, it was agreed that procedures to make the risk assessment of GM crops more rigorous should be adopted immediately, and in advance of any new legislation. The new procedures, which have since been incorporated into the new Deliberate Release Directive 2001/18, required a consideration of the indirect as well as the direct effects of GM crops, such as those caused by changes in crop management.

During the negotiations to revise the GMO Deliberate Release Directive EC 90/220 (which was replaced by Directive 2001/18 in October 2002) a more rigorous environmental risk assessment was proposed. As a result of various EU member states refusing to give agreement to any more marketing

[1] In 2002 Bayer bought out Aventis CropScience to form Bayer CropScience. Prior to the formation of Aventis CropScience in 1999, the company was called AgrEvo. AgrEvo bought the company Plant Genetic Systems, which was the originator of the GM oilseed rape being used in the FSEs.

approvals for GM crops until the more rigorous procedures were in place, a de facto moratorium on new approvals came into force. Applications for approval covered by the moratorium included those for the GM oilseed rape and GM fodder beet being examined in the FSEs. It became clear that no further GM crops would be approved until the new legislation was in place, and then only if companies could supply enough data to satisfy the new, more rigorous environmental risk assessment.

Table 1. Approvals status of GM crops being used in the farm scale evaluations

Crop	Approvals under 2001/18	Novel Foods Approval	National List Decision	Pesticide approval
GM 'T25' maize	Part C marketing approval granted 1998	Approval for processed products only	Varieties Chardon LL and Sheridan both proposed for addition to the NL	Experimental approval for use in FSEs. Application for full approval made in 2000
GM spring oilseed rape 'MS8xRF3'	Part B experimental approval only Part C application forwarded to European Commission in 2003	Approval for processed oil only	Applications for 2 varieties made 1997. Decision awaiting Part C consent	Experimental approval for use in FSEs. Application for full approval made in 2000
GM winter oilseed rape 'MS8xRF3'	Part B experimental approval only Part C application forwarded to European Commission in 2003	Approval for processed oil only	Applications for 4 varieties made in 2000/2001. 2 varieties withdrawn, trials ongoing for 2 remaining	Experimental approval for use in FSEs. Application for full approval made in 2000
GM fodder beet	Part B approval only. Part C application rejected by UK authorities	Not applicable	Application withdrawn	Experimental approval for use in FSEs
GM sugar beet	Part B experimental approval only. Part C application forwarded to European Commission in 2003	Application for approval made	Application made by Syngenta, 1997	Experimental approval for use in FSEs

GM crop varieties cannot be placed on the National List in advance of gaining a Part C marketing approval. When a variety of Bayer's T25 was proposed for addition onto the UK's National List in April 2000, some 227 organisations and individuals (representing several thousand people) objected, creating the need for a public hearing. Evidence was presented at the hearing addressing a range of environmental, animal and human health, economic and ethical issues. In addition evidence was presented which pointed out serious deficiencies and procedural irregularities in the safety assessments for the GM maize.[2] The hearing was adjourned in November 2000 following the admission that the testing of the variety for distinctiveness, uniformity and stability by the French authorities did not comply with EU law. The report of the chairman of the hearing was published in December 2002.

Key finding: The four-year timescale of the FSEs has not significantly delayed the commercial introduction of the GM maize, as the regulatory procedures would have taken several years. In addition, time would be needed for seed certification and to build up seed stocks. In the case of the sugar beet, fodder beet and oilseed crops, the FSEs have generated data which otherwise, under the requirements of 2001/18, would have had to be generated and paid for by the companies themselves.

Why biodiversity?

Concern about the introduction of GMHT crops goes back to at least 1990[3], and has come from a wide range of non-governmental organisations and scientists. Initially it focused on issues such as the increased use of herbicides, the spread of herbicide tolerance to related weeds, the development of multiple herbicide tolerance in volunteers and damage to habitats adjacent to crops. These issues have yet to be resolved[4]. Regrettably, these concerns do not appear to have greatly exercised the regulatory authorities at the time. The Government's Advisory Committee on Releases to the Environment (ACRE) is charged with examining the environmental safety of GM crops. In their 1996-97 Annual Report, the committee gave consideration to the risks posed by herbicide-tolerant crops and concluded that "we consider that the current regulatory regimes cover most of the concerns raised regarding the safety of GM herbicide tolerant crops."[5] No mention was made of the possible effects on farmland biodiversity from growing GMHT crops.

In contrast to this complacency, concerns were raised by the Government's advisors on nature conservation. This occurred as a result of a consultation in the summer of 1997 by the Ministry of Agriculture Fisheries and Food (MAFF) into the use of GMHT in UK agriculture. In their response to this consultation,[6] the statutory conservation agencies (English Nature, Joint Nature Conservation Council, Scottish Natural Heritage and the Countryside Council for Wales) challenged MAFF's interpretation of the benefits of GMHT crops, and raised concern that the use of these crops would cause a further decline in biodiversity in agricultural areas. They stated that

"…the broad spectrum GMHT candidate herbicides are usually far more damaging to farmland ecosystems than some of the selective herbicides they might replace. There is every possibility that the use of GMHT crops would also lead to increased herbicide use overall and would certainly lead to 'weed-free' cultivation systems over large areas of arable cropping. Coupled with a change to broad spectrum herbicides, this would have a severely detrimental effect on wild plants, insect and bird populations using farm fields and their margins."

The conservation agencies recommended a moratorium on the growing of GM crops in the UK for a period of five years. In 1998, English Nature published a position paper on GM organisms in which it stated that "there should be careful assessment of the risks to, and implications for, biodiversity and for the environment generally before decisions are made on the commercial release of genetically modified organisms."[7] Pressure for a moratorium on the growing of GM crops continued to mount, and through the Five Year Freeze organisation, was eventually supported by over 120 national organisations, representing the full range of civil society, 50 local authorities, and many food companies.

Prior to the intervention of English Nature, industry representatives and agronomists had been promoting the new GM crops to farmers as an advance in weed control. For example, it was claimed that "GMHT varieties...could be extremely valuable where weed problems exist," highlighting "their value in strategic plans to minimise weed burdens across the whole rotation."[8] No mention was made of the impact of total weed control on farmland biodiversity. But afterwards, the arguments from industry changed significantly and a series of initiatives to support their products were launched, such as Monsanto's high-profile advertising campaign. Industry spokespeople started claiming that GMHT crops, instead of wiping out weeds, could be used to manage weed populations to the benefit of biodiversity. During the public meetings about the FSEs organised by the then Department of the Environment, an industry spokesperson even claimed that GM sugar beet could be marketed as "skylark friendly".[9]

While the biotech companies were rushing to reposition their products, the question for wider society was whether these were needed at all. Public antagonism to their introduction has remained consistently high, and in addition to fears about their impact on biodiversity, concerns have been raised about the ethical status of GM crops, their safety as foods and their potential economic impacts on other farming sectors. However, the impact on biodiversity remained the only societal concern that could be readily examined within the regulatory regime and this may explain why it became central to the Government's response.

In late 1998, the Government commissioned a report by the Pesticide Safety Directorate (PSD) to look at the issue. Unfortunately, this provided little clarification, pointing out that "[t]he current status of biodiversity in arable crops is poorly understood. There is at present little independent research to allow an accurate prediction of the potential impacts on wildlife of the introduction of GMHT crops."[10] It was apparent that an immediate assessment of the likely impact of GMHT crops on agricultural biodiversity by the Government's advisory committees would be impossible, because essential information was lacking on existing biodiversity and the functioning of agricultural ecosystems within specific crops.

It was against this background of growing public concern and increasing pressure from industry that in 1998 the Government sidestepped a moratorium. The Environment Minister Michael Meacher announced that the Government had instead "reached agreement in principle with the plant breeding industry for a programme of managed development of herbicide-tolerant GM crops" in which "farm-scale plantings" would be "monitored for ecological effects along with comparable plantings of conventional crops."[11] The cost of this programme to the public purse would rise to £5.1 million by 2002.[12]

In an age-old response to public concern, the industry proposed self-regulation. It set up an organisation to manage the commercial development of GM crops, called the Supply Chain Initiative on Modified Agricultural Crops (SCIMAC), which put forward a voluntary code of practice for farmers on the management of GMHT crops. The members of SCIMAC are the British Society of Plant Breeders (BSPB), the National Farmers' Union (NFU), the British Agrochemicals Association (BAA), the United Kingdom Agricultural Supply Trade Association (UKASTA) and British Sugar Beet Seed Producers' Association (BSBSPA). None of these bodies can be said to represent the interests of consumers, smaller farmers or the rural communities who will be affected by GM crops.

In relation to similar research, the time-span of the FSEs is short. Comparable systems research looking at the environmental impacts of changing agricultural inputs, such as the TALISMAN (Towards A Lower Input System Minimising Agrochemicals) and SCARAB (Seeking Confirmation About Results At Boxworth) projects, have been of six years' duration. However, it seems reasonable to assume that the Government would have found it difficult to obtain industry agreement to defer commercialisation of GM crops for six years, regardless of the needs of scientific rigour.

The beet crops

The crops originally chosen for the FSEs were those considered to be closest to gaining full commercial approval for the UK. Bayer's T25 maize had already received Part C approval from the European Union and was undergoing trials for assessment under the UK's National Seed Listing process. Bayer's GMHT oilseed rape, called SeedLink, also had Part C consent (for seed production only) and an application had been made for a full marketing consent. It was also undergoing trials for assessment under the UK's National List process. These were the crops closest to commercial growing, but even they were still going through the regulatory procedures.

In the first year of the FSEs, SCIMAC funded parallel studies of GM sugar and fodder beet. Beet was not initially included in Government-funded research because it was "some way behind the other crops in completing the necessary regulatory procedures".[13] However, by the beginning of 2000 the Government had agreed to include both sugar and fodder beet in the FSEs,[14] at an additional cost to the taxpayer of £445,000 per year.[15] The rationale for including these crops in the FSEs is unclear, especially as nothing had changed in their distance from commercial introduction. An application for marketing consent had been made to the EU for GM fodder beet late in 1997, but both the UK's Advisory Committee on Novel foods and Processes (ACNFP) and MAFF had objected on the grounds that insufficient data had been provided on its safety for animal feed.[16] It does seem somewhat perverse to include a crop in the FSEs which the Government's own advisors had refused to approve on safety grounds.

In the case of GM sugar beet, no application for marketing consent for GM sugar beet had even been made by Monsanto (and still has not). Its completion of the regulatory procedures remains, even now, many years away. Conveniently for Monsanto, it will benefit from the data provided by the publicly funded FSEs if it does decide to make an application for marketing consent in the future. This is because the new Deliberate Release Directive, 2001/18/EC, requires the company to provide data on the indirect effects of the crop on biodiversity.

Key finding: The FSEs have been motivated by the needs of Government and industry to avoid a moratorium on GM crops while at the same time showing that something was being done about the concerns of the conservation agencies and wider society. They are not driven by a coherent strategy for the future of agriculture, nor a desire to find the best technologies for enhancing wildlife in the UK. Furthermore, it appears that the taxpayer is funding research, which under the requirements of Directive 2001/18, is the responsibility of Monsanto and Bayer CropScience.

3. Detecting differences in biodiversity

The basic design for the FSEs of GMHT crops is to compare GMHT crops with equivalent non-GM crops under conventional pesticide regimes. The outline of the design was given in Environment Minister Michael Meacher's original announcement of the managed development of GM crops. More detailed specifications for the project were drawn up later through a process of informal consultation by the then Department of the Environment. Discussions were held with other government departments, members of ACRE and wildlife and research advisors,[17] acting as an ad hoc steering committee. It was at this stage that the objectives, scope and parameters of the research that would accompany the industry's managed development of GM crops were developed. These were:

- Paired comparison of GMHT winter oilseed rape, spring oilseed rape and fodder maize with comparable non-GM crops
- Paired fields or split fields on a commercial scale, ie around 10 hectares
- A four-year programme, with the first year as a pilot
- Two sites per crop in the first year and up to 25 sites per crop in following years

In February 1999, there was a formal consultation on the FSEs (outside of the ad hoc group) and an official steering committee was appointed in April 1999, though by then the fundamentals of the research had already been established.

The responsibilities of the different groups involved in the FSEs were made clear in the tender documents for the monitoring. SCIMAC would be responsible for finding willing farmers to grow the GM crops, while the Government would be responsible for funding the research.[18] The successful applicant for the Government's research tender for the monitoring of all the GM crops was a consortium made up of the Scottish Crops Research Institute (SCRI), the Institute of Terrestrial Ecology (ITE) and the Institute of Arable Crops Research (IACR).

As laid out in the initial tender documents sent out in February 1999, the first objective of the monitoring by the research consortium was to test the experiment's null hypothesis. In the tender for the monitoring of spring oilseed rape, this was set out as follows:[19]

> "that there are no significant differences between the biodiversity associated with the management of GM spring oilseed rape tolerant to the herbicide gluphosinate ammonium and comparable non-GM oilseed rape at the farm scale."

Unless the results of the experiment clearly demonstrate that this is not the case, the theory that, in biodiversity terms, GM crops are the same as non-GM will stand. It is important, therefore, to understand whether there are any ways in which differences may exist between the GM and non-GM crops but not be detected in the experiment, and also to understand where any errors might arise and why. The quality of the testing of the null hypothesis rests with the power of the experiment, in other words the ability of the experimental design and analysis to detect changes.

Despite the undoubted expertise of the research consortium of ITE, IACR and SCRI, the extent of their research proposal was limited by parameters that had already been laid down, including the period of the research, the maximum number of sites, the objectives and the null hypothesis. In fact, the contractors were only to "design and implement a monitoring programme" within the existing experimental design.[20] Many failings of the FSEs stem, at least in part, from the fact the contractors have been working within an experiment that was politically motivated and designed.

The null hypothesis

Perhaps because it was drawn up prior to the involvement of organisations specialising in this type of research, the null hypothesis is itself problematic. The function of the null hypothesis is to act as a testable starting premise; it is not a statement of what you do or do not want to find, it simply sets out what is to be measured. With experiments of comparison, such as the FSEs, it is normal practice to start with the premise that there is no difference between what is being compared. In the case of the FSEs, the null hypothesis should be that the GM and the non-GM cultivars have equal biodiversity, or no difference. The actual null hypothesis is somewhat curious, in that it does not state that the starting point is no difference, but no *significant* difference. The use of the word significant would imply a null hypothesis in which the GM and non-GM crops have *nearly* the same biodiversity.

This is perhaps a minor point, and the statisticians involved in the FSEs have acted as if the null hypothesis was correctly phrased, but the fact that the experimental design contains such a basic error certainly adds to the poor perception of the FSEs.

Practicalities

There are also problems with the null hypothesis in relation to the ecology of agricultural ecosystems. In their bid for the research contract,[21] the consortium points out that testing the null hypothesis would be…difficult to achieve within in [sic] practice, for several reasons:

- a full characterisation of biodiversity requires the complete characterisation of the range and relative abundances of species *and* genes present in the system, including groups that are difficult to assess
- effects of crop management on biodiversity are frequently small but cumulative, making them difficult to detect in a short time period
- it can be difficult to assess the effects of localised changes in crop management on more mobile organisms."

The power of the farm scale evaluations

The power of the experiment is its ability to detect changes and this rests upon the level of certainty, or significance, that is required and the variation in the data being measured. Generally, the more variation is found in the data – in this case the results of ecological monitoring – the less sensitive is the experiment and larger the change that must occur before it can be detected with any confidence. Broadly speaking, the power depends on:

- the sample size
- how variable the data is on the organism being collected
- the size of the difference between the two treatments
- the size of the test – ie the probability of rejecting the null hypothesis when it is actually true (often set at 5%).

In the case of the FSEs, consideration should also be given to whether the experiment is able to detect changes (however small) that are of *ecological* significance.

In preliminary papers from the researchers, using a standard coefficient of variance (CV) of 50% for all indicators, the power of the experiment to detect a 1.5-fold difference (R=1.5) at a confidence level of 95% has been suggested to be 80%.[22] These calculations are based on various values of 'R', which is the difference that might be detectable.[2] The test is two-tailed, meaning that both increases and decreases in the indicator are considered significant; so if 'R'=1.5, the difference between treatments

[2] The relationships between counts of the biodiversity being monitored are considered on a logarithmic scale, so that it is the ratio between counts that is measured.

could be a decrease from, for example, 100 to 67 or equally an increase from 100 to 150. So, a statement that the power of the test is 80% means that if there *is* a difference between treatments (either increasing or decreasing) the chance of the experiment successfully detecting it is 80%. In other words, there is a 20% (one in five) chance of failing to detect the difference. If there is an actual difference between the treatments but it is smaller than 1.5, the power of the test to detect that difference will be still lower.

Another point that should be examined is the way in which the findings are presented. Differences between the GM and non-GM treatments should not be presented as merely a statement of "significant difference" or "no significant difference". Instead, it would be better if the observed differences are presented in the results as confidence intervals. For example, a non-significant difference for one of the indicators of 20% between treatments could be interpreted as no difference because the result is not significant (ie it could be a chance finding). However, this approach is equivalent to stating that the GM crops had *no impact* on biodiversity when in fact there was an *uncertain impact*.

An alternative approach would be to express the observed difference between treatments as a range of possibilities within which the actual difference lies, such as, –1% to 41%. Note that, in this case, the null hypothesis could still be accepted because a difference of 0% is a possibility. But rather than to conclude, as in the first approach, that there is no difference in biodiversity between the GM and non-GM crops because the difference cannot be detected with sufficient certainty, it is much better to say that the plausible values are between –1% and 41%. It would then be an ecological and a political decision as to whether, on the basis of this plausible range, such a change in biodiversity was acceptable.

Key finding: It is highly likely that differences between the GM and non-GM crops will go undetected. The FSEs may simply not be powerful enough to detect differences of less than 1.5-fold in biodiversity between the GM and non-GM crops. It should be made clear that if the experiment fails to detect differences, they may still be present.

Precaution

There is always a trade-off relationship between the power of a test and the significance level selected for it. The stricter the significance, the less is the sensitivity of the experiment to detect differences, although there can be greater confidence in any differences that are detected. In their power calculations, the research consortium has used the widely accepted significance level of 5%. This means that there is only a 5% chance of wrongly concluding that there is a difference between the GM and non-GM crops when there is none in reality. However, at this level of certainty only large differences can be detected. The use of a less stringent significance level (eg 10%) would increase the ability of the test to detect smaller differences (although there would of course be a decrease in the certainty).

A less stringent significance level increases the chance that the FSEs will conclude that there is a difference between the treatments when in fact there is none. If such a difference could constitute harm to the environment, then this might lead to the GM crops failing to be approved when in fact they are harmless. On the other hand, a stringent significance level increases the likelihood that a real difference between the GM and non-GM crops will go undetected. This in its turn might mean approval being given for GM crops that do, in fact, cause considerable harm to biodiversity.

In the case of the FSEs a question arises. Is it more important to be certain about your results but fail to detect actual differences, or to increase the ability of the experiment to detect impacts on biodiversity resulting from the use of GM crops? The answer depends, not on the science, but on the policy framework within which the FSEs are to be used. The company in whose interest it is to win licensing approval for the crop may favour a higher significance level, allowing them to argue that no definite harm has been proved. In contrast, a reasonable approach for Government would be one that gave greater weight to detecting a difference, in order that approval cannot be given unless a high standard of proof is achieved, and the safety of the technology has been proved beyond reasonable doubt.

Key finding: In the case of GM crops, the precautionary principle underpins European Union legislation on their approval (Article 4.1 of EU Directive 2001/18). The precautionary principle would imply that mistakenly accepting the safety of GM crops when they are in fact harmful is the more serious error.

Variation and sample size

Generally, the more variation is found in the data – in this case the results of ecological monitoring – the less sensitive is the experiment and larger the change that must occur before it can be detected with any confidence. As the variation of the data goes up, so the sample size must go up. In the case of the FSEs it is essential that the power of the experiment be sufficient to detect ecologically important differences, and so the number of sites used is crucial. The appropriate sample size is usually determined in advance of the experiment using a power analysis. Although this analysis was done in the first (pilot) year of trials, a *maximum* number of test sites (25) appears to have been decided very early on. In fact, the tender document itself restricts the number of sites that could be used, asking applicants to "specify the level of statistical significance that can be obtained for monitoring the plants and invertebrates in 10, 15, 20 and 25 paired comparisons in the second and subsequent years".[23]

At the very first meeting of the Scientific Steering Committee (SSC) in June 1999, it was noted that while "20 sites is considered sufficient" this was an "assumption" that needed to be "fully investigated before the evaluations are scaled up next year".[24] Later that year, at the SSC's meeting of 12 October 1999, it was noted that, based on a power analysis conducted by members of both the research consortium and the SSC, it had been "unanimously agreed to seek 25 fields, per crop, per year, for three years (75 fields per crop total)".[25]

The research consortium asked that SCIMAC provide a "very wide choice of potential sites"[26] in order that a representative sample could be chosen. However, the FSEs came up against fierce local opposition both from inside and outside the farming community. Consequently, SCIMAC found it difficult to find farmers willing to take part in the trial, and this has impacted on the number of sites that could be used. For example, in 2000 only 12 maize sites and 12 spring oilseed rape sites were actually brought to harvest.[27] This may partly explain a later change in the requirements of the sample size. In a paper published in 2002,[28] it was stated that the research consortium had used power analysis to determine that only 20 sites per crop per year was necessary instead of 25. However, this calculation was done because in 2001 the SSC specifically asked what the power of the experiment would be to detect a 1.5-fold difference (at the 5% level) if only 60 sites were used.[29]

As previously explained, the ability of the experiment to detect changes rests on the variance of the data. The power analysis to determine the number of sites used a CV of 50% for all indicators. However, data from the first year of the farm scale trials indicates that the CV for several of the indicators may in fact be somewhat higher than this. Estimates of variability based on the first year's data produced the following CVs greater than 50%:[30]

Biodiversity indicator	CV
Pre-herbicide broad-leaved weed seedling count	68 %
Vortis counts – detritivores	82 %
Vortis counts – phytophagous insects	68 %
Pitfall trap of carabid species *Harpalus rufipes*	82%
Pitfall trap of carabid species *Calanthus fuscipes*	61%
Pitfall trap of carabid species *Pterostichus madidus*	72%

In addition, data presented in the tender documents suggest that for some indicators the variance can be much higher. The tender suggests that the variation in butterfly transect counts ranges between 42% and 100%[31] while that for bee transect counts ranges between 100% and 268%.[32] In the first year results of seed bank counts, it was found that these varied by 13-fold[33] and at the second meeting of the SSC, "some reservations were voiced regarding the power to detect differences in the seed bank between treatments".[34]

The difficulty of using a one size fits all approach to determine sample size when using a range of indicators with very different levels of variation is thus clear. It is probable that changes will be estimated with some certainty for some of the indicators, while for others the level of certainty will be much lower. The power of the experiment is likely to be weakened in cases where the CV is much higher than the 50% value chosen by the research consortium. This is born out by the power analysis conducted by the research consortium at the behest of the SSC on data collected in 2000. In the January 2001 Interim Report they list the results of this analysis for a small selection of the biodiversity indicators used. It is stated that, even from a limited selection of the biodiversity indicators, the power to detect a 1.5-fold difference is less than 80% for:

- *Poa annua* in spring oilseed rape
- dicotyledonous weed seedling density in maize
- weed biomass across all crops
- Collembola in the field verge[35]

Key finding: In the light of the differences in the power of the FSEs to detect changes for the various biodiversity indicators, the question arises as to how to judge the results. For some indicators, regardless of their importance, it may not be possible to detect meaningful results.

Ecologically significant change

In the final analysis, the crucial question for the FSEs will be whether measured changes in biodiversity are important in ecological terms. In terms of what can actually be determined with the methodology applied in the FSEs, the consortium has pointed out that, given the complexity of the task and the highly variable abundance of the chosen indicators, "even given effective sampling, it will remain possible that even quite large effects are not detected".[36] The SSC appears to have settled for the detection of really quite large differences between treatments with the power calculations based on the detection of differences of 1.5-fold between GM and non-GM crops for most of the biodiversity indicators, and two-fold in the case of seedbank density.[37]

However, it is questionable whether these thresholds of difference are really justified. In a study conducted in Sussex examining the change in biodiversity across a number of farms from 1970 to 1995, the levels of change were lower than those which the SSC has accepted as measurable within the FSEs, and yet ecological changes were evident. So, for example, over the 25-year study comparisons were made in weed abundance between those fields treated with herbicide and those not treated; after taking account of yearly variation, it was found that difference in weed abundance was –13% ($P < 0.001$).[38] It seems reasonable to suggest that a treatment difference of herbicide/no herbicide constitutes a comparable treatment difference to GM/non-GM, but the level of change actually found in the Sussex study was much lower than, as is suggested from preliminary papers, will be detected with any certainty in the FSEs. That small, incremental change is of ecological significance is born out by examination of bird species dependent upon broad-leaved weeds and invertebrates. The Sussex study found that the density of male grey partridges was significantly negatively related to the mean number of herbicide applications per field in 1995 and significantly positively related to the mean number of broad-leaved weed species present per field in 1995.

In the same 25-year study, a comparison was made in abundance of invertebrates between fields treated with insecticides and those not treated. Based on a within-crop analysis, it was found that the densities of Symphyta (sawflies) and Lepidoptera (butterflies and moths) were 15% lower in fields treated with insecticides, while non-aphid Hemiptera (bugs) densities were 26% lower.[39] While the Sussex study lacked some of the elements of control used within the FSEs, there is no doubt that it provides a useful comparison of the level of change to be expected.

Key finding: The assumption is made in the FSEs that detection of 50% to 100% difference in biodiversity indicator species between GM and non-GM crops is an acceptable sensitivity. However, evidence suggests that ecologically important differences may in fact be at levels as low as 13%.

Further complications

Covariates

As well as the treatment difference of GM/non-GM, there are other variables in the FSEs which can be controlled to varying extents and will have different effects on the results. These other factors which influence the outcome of the experiment are known as covariates. It is clear from various documents produced by the consortium and the SSC that the FSEs in fact contain a number of these covariates which form subsets for analysis. As the researchers themselves say, the "sites were selected to include a range of factors related to the commercial growing conditions". Those listed as being considered include:[40]

- region
- soil type
- field size
- agronomic methods
- adjoining features, eg woodland or amount of hedge
- for beet crops, whether the crop is sugar or fodder beet
- management and site history
- intensity of the farm

Some of these will apply to both halves of the sites while some, such as boundary type, are recorded separately for each half.[41] These factors may themselves explain differences in biodiversity observed between sites, or they may contribute to or ameliorate differences between the non-GM and GM crops.

With such a range of stratification categories, given the relatively small sample size and the probability of interaction between covariates, the complexity and power of the final analyses may be problematic. In a paper to the Agriculture and Environment Biotechnology Commission, the head of the research group, Dr Les Firbank stated that

"…any 'blocking' factor, such as farming intensity, that is thought a priori to have a substantial interaction with the main treatment, should occur in the sample in sufficient numbers so as to be able to estimate the interaction reasonably accurately."

As far as we can ascertain, there is no indication in published materials as to what these sufficient numbers are, or what is considered to be reasonable accuracy.

Key finding: Publicly available information on the power analysis indicates that it has been based on making comparisons between GM and non-GM treatments over the whole experiment, and not on subsets within it. Any comparisons between subsets will be made with greatly reduced power.

Cultivars

According to the original research tender, the FSEs make comparison between GM and non-GM crops as they would be grown in commercial practice, and therefore differences in rotation or field margin management should reflect these two regimes. However, the consortium stressed that, in order to make an accurate comparison between the crops it is important that "the two varieties being considered are as similar as possible in traits other than the herbicide tolerance, especially phenology and crop structure".[42] This is because factors such as the flowering time of the crop, structure of the plants, canopy development and so on will affect invertebrate abundance and weed interactions. They further specified that non-herbicide treatments (such as insecticides or fertiliser applications) should be applied at the same time to each half of the field. This was later reiterated by the SSC.[43]

However, Friends of the Earth was informed by representatives of the then Department of the Environment, Transport and the Regions (DETR) that "varietal association" varieties of winter oilseed rape had been planted in the non-GM half of some of the FSEs in 1999/2000, in order to monitor for cross pollination between the two halves.[44] Varietal associations are made up of two types of oilseed rape, one of which is male sterile (not producing pollen) with the other acting as pollinator. No information has been made available on whether these have the same phenology and crop structure as the open pollinated GM oilseed rape but it is unlikely. For example, there would be less pollen produced in the non-GM half of the field, as 80% of the varietal association does not produce pollen, and this might affect insect abundance.

Furthermore, anecdotal evidence suggests that the cultivars used may not be similar. For example, the early vigour of the GM and non-GM varieties used at the Munlochy FSEs of winter oilseed rape (2001/2002) was substantially different and the GM variety was stunted in comparison with the non-GM variety.[45] The farmer attempted to even out this growth difference by applying nitrogen fertiliser only to the GM half of the field, and it was not until local campaigners raised concerns about this biasing the treatments that the non-GM crop also received the fertiliser application.[46] Similarly, local people have reported that at an FSE at Newport-on-Tay, oilseed rape crops in the GM and non-GM halves flowered at different times[47].

If the GM and non-GM varieties used in the trials are not similar, this could to introduce a further interaction to contend with. As the development of the crop cultivars go out of phase, activities such as fertiliser application, which need to be carried out during the crop season, will have to be performed at times that are not appropriate for one or other of the cultivars. This would result in a bias one way or the other. Friends of the Earth has only anecdotal evidence, but if it is in fact repeated across the FSEs, then this could represent a systematic error across the trials.

Key finding: The theoretical calculations conducted by the SSC and the research consortium indicate that the power of the FSEs to detect a 1.5-fold difference will be 80%. However, it would appear that the ability of the FSEs to detect ecologically important differences is likely to be considerably lower for the following reasons:

- **Observed coefficients of variation for some biodiversity indicators are greater than the 50% assumption in the calculations**
- **The calculations assume a difference of 1.5 fold (50%), whereas ecologically importance difference may be as little as 13%**

Any further complications including the interaction of covariates or systematic error such as cultivar differences, could further reduce the power of the experiment to detect ecologically important changes.

4. The problems with monitoring biodiversity

The purpose of the FSEs is to compare the biodiversity associated with GM and non-GM crops. However, as the research consortium has acknowledged, "a full characterisation of biodiversity requires the complete characterisation of the range and relative abundances of species *and* genes present in the system, including groups that are difficult to assess." In particular, bird and mammal species that are of social and cultural concern are difficult to assess within the limited scale of the FSEs, as any changes would be likely to occur at the landscape level. As a result, the monitoring is focused on a range of plant and invertebrate indicators, from which it is hoped that impacts on the wider ecosystem can be extrapolated.

Farmland biodiversity

There have been concerns about the wildlife impacts of chemical intensive agriculture for decades. Declines in biodiversity associated with changes in farming practice include the loss of specific habitats, such as hedgerows, and crucially a more general decline in the abundance of species associated with agricultural ecosystems. This is exemplified by the plight of farmland birds, 24 species of which are in decline.[48] While there has been remarkably little monitoring of biodiversity in agricultural areas, what data there is suggests an overall reduction in the abundance of invertebrates and a wide range of plant species, some of which are no longer classed as weeds but are now considered to have rare status. Further, the evidence suggests that invertebrates are important in the diets of those bird species in decline while woodland plants feature more in the diets of those bird species with stable or increasing populations.[49] While the biodiversity associated with farmland has intrinsic value, it also provides a range of biological functions of value to agriculture. Nutrient cycling and pest outbreaks are essentially aspects of the ecological system of which farming is part. The benefits afforded by increased agricultural diversity can include enhanced natural control of pest outbreaks,[50] prevention of diseases, and better weed suppression in margins.[51]

In several respects arable weeds form the linchpin of agricultural ecosystems, providing habitat and food to the invertebrates upon which many birds and mammals depend. They are also a food source to many birds and mammals at important stages of their life cycles. For this reason the changing use of herbicides has come under scrutiny as being a primary driver in biodiversity decline. In a recent review, the impact of herbicides on 32 selected arable plant species was examined for the PSD,[52] focusing on winter wheat, the largest arable crop by area. It was found that the spectrum of activity of commonly used herbicides had widened, with more arable plants susceptible to herbicides used now than those used in the 1970s. In terms of the products used, there had been a shift in cereal herbicides from selective to broad spectrum active ingredients. In fact, the report noted that a "factor in the development of new herbicides has been the desire of companies to market herbicides that control a wide range of species".[53] So while farmers are primarily interested in controlling economically important weeds such as black grass, cleavers and wild oats, the type of herbicides being promoted by agro-chemical companies has led to increasing effects on non-target plants. In contrast, this widening of activity has not yet occurred to the same extent in broad-leaved crops, such as oilseed rape.

Both sugar and fodder beet are important for biodiversity within the arable system as they act as spring break crops in the predominantly winter-sown cereals production. A number of farmland bird species, including stone curlew, skylarks and lapwings use sugar beet more than other crops, attracted by the winter stubbles, the open vegetation structure in the late spring and the post-harvest sugar beet stubble. Skylarks also often graze on beet seedlings. Broad-leaved weed control is difficult in these crops and these weeds are associated with a higher number of invertebrates than grass weeds and also produce seeds eaten by birds.[54]

Modelling complexity

In a paper for the Agriculture and Environment Biotechnology Commission, the chair of the SSC wrote of the monitoring research that

"The ideal endpoint is one in which models can be generated for each crop that suggest the long term and large-scale implications of growing GMHT crops."[55]

Clearly, the achievement of such a target requires sufficient monitoring to enable a model to be developed. It is questionable whether, in view of the timescale of the FSEs and resources available, this will be achieved. The consortium accepted from the start that it would be impossible to monitor all of the biodiversity present within the agricultural ecosystems being studied, and in order to stay within the defined parameters and funding available several simplifications were proposed by the consortium. Firstly, genetic variation was to be excluded. Secondly, indicator species were chosen to represent particular species groups. A further limitation for the monitoring is the fact that most of the sites were for one year and one crop only, making it difficult to monitor ecological shifts that would occur over a longer period.[56] Finally, birds and mammals tend to range too widely for effective monitoring within a single field and so the consortium gave priority to the monitoring of higher plants and invertebrates.[57]

Relating observed changes in the indicators chosen to longer-term and larger-scale impacts will be very difficult, primarily because the interactions between organisms at the various trophic levels are not straightforward and are only poorly understood. For example, in most cases the relative food value to birds of different invertebrate taxa is not known, nor are the relationships between availability and preference.[58] Similarly, the availability of weed seeds has not always been found to predict their use by birds, as use is mediated by factors such as the relative nutritional value of available food sources, spatial distribution and predation risk.[59] Although the indicators are to be classified by functional groups as well as taxonomy, there are still complications to be considered. The indicators chosen include ecologically diverse species whose niche differentiation will affect their interaction with other organisms; for example whether or not carabid beetles species are nocturnal will determine their availability to daytime foraging birds.

Issues such as the relative importance of different food sources at different life stages and times of year can also complicate interpretation – for example, summer weed abundance may be very important for invertebrates that form an important part of the diets of chicks of some bird species (eg grey partridge), while winter weed seed availability determines survival and therefore later breeding success of other bird species (eg skylark). Certain organisms may be critical in the diet to a range of other species over a very short window, for example snails are used as a calcium source by many bird species just prior to egg laying[60] while other organisms may exhibit a specific relationship, for example the seeds of fumitories are preferred by turtle doves but largely avoided by most other granivorous birds.

There are likely to be further conflicts of interpretation as certain species may play multiple and conflicting roles within the agricultural setting and the wider ecosystem. Two plant species which provide an illustration of this complexity are the weeds annual meadow grass *(Poa annua)* and knotgrass (*Polygonum aviculare).* These two plants are common and economically important weeds which can impact on yield and are therefore targets for weed control. They are also both important in the diets of farmland birds whose populations are in decline, including skylark, partridge, turtle dove, sparrows, finches, linnet and stone curlew.[61] The plants support five endangered (Red Data Book) invertebrate species as well as seven pest invertebrate species.[62] Relationships between indicators may also be counter-intuitive; for example, in the case of carnivorous carabid beetles, there is evidence to suggest that weed-free fields allow for less restricted movement and are therefore easier for the beetles to colonise,[63] thus an increase in carabid beetles could, paradoxically, be associated with a decline in weed numbers.

In the first Interim Report of the SSC it is stated that "the basic model is one that tests the null hypothesis of no effects of the treatment on each indicator individually".[64] This could mean that the final data will be expressed as a matrix of results, whose size is determined by the number of species included. It appears unclear how such complex results will be interpreted; this is likely to become a matter of socio-political and economic judgement. For example, how would a decline in butterflies be weighed against increases in other species? Any attempt to summarise all of the diversity measures into a single index, as is often done in ecological studies, would not be helpful in this instance. It would cloud the issue as to which species might be declining and which might not be.

Key finding: One of the most significant outputs of the FSEs is likely to be a greater understanding of the relationships between organisms, and between organisms and their environment, within farmland ecosystems. FSEs could also provide an important source of basic information on the biodiversity associated with intensive agriculture at this point in agricultural history. For example, it has been suggested that the results will provide useful baseline data on the soil seedbanks associated with oilseed rape, maize and sugar beet crops.[65] While such information is very valuable in terms of increasing scientific understanding of agricultural ecosystems, it is essential to retain a realistic perspective on the ability of the results and modelling to answer the second objective of the research tender, that is to predict the impact of GMHT crops on wider biodiversity in agricultural areas. The model will be used to extrapolate beyond the range of the data, and will probably be used as a basis for policy decisions and possibly as a justification for the commercialisation of GM crops. Yet, in the face of this level of complexity, such models are notoriously unreliable and dangerous to use – they are often little more than an educated guess about what may or may not happen.

Developing techniques

In their original tenders, the consortium presented monitoring protocols for a number of indicators.[66] However, over the course of the FSEs, some indicators were dropped, while others were added. The protocols for measurement finally agreed, as outlined in the Interim Reports of the SSC, are as follows:

Table 2. Biodiversity indicators used and protocols for measurement

Soil Seedbank	Weed seed abundance using 6-8 soil samples each in the GM and non-GM half
Seed rain	Measurement using "pot-type" seed traps
Vegetation in the crop	Measurement of either flowering species (9 sampling points); vegetation cover (3 sampling points); seeding species (9 sampling points)
Vegetation in the field verge and margin	Measurements as above if verge/margin is over 1m wide.
Vegetation in the following crop	Samples taken in April/May
Gastropods (slugs and snails)	Sampling using refuge traps; timed searches of snails in the field margins; identification to species level
Arthropods on vegetation	Vortis sampling in field margin, headland and in the crop; identification of plant bugs (*Heteroptera*), springtails (*Collembola*) and caterpillars of butterflies, moths and sawflies. Identified to species where possible. Other arthropods (spiders, flies, beetles etc) identified to family or group level. Functional group categorisation
Ground-dwelling arthropods	Standard pitfall traps set along transects through the field. Carabid beetles counted and identified to species level. Spiders (*Aranae*) and weevils (*Curculionidae*) also identified

Bees	Abundance and diversity of foraging bees identified by transect walks through the crop and field margins. Timed counts over a fixed area in maize
Butterflies	Abundance and diversity of butterflies identified by transect walks through the crop and field margins. Timed counts over a fixed area in maize
Crop Pests	Counts of numbers of pests on selected crop plants

Because the FSEs are an entirely new endeavour, many of the sampling techniques were developed during the pilot year and the first full year of the experiment. For example, at the end of the 2000 trials, the following changes were raised by the SSC with respect to the protocols:[67] [68]

Table 3. Changes to monitoring protocols

Biodiversity indicator	Changes to monitoring protocols
Weed seedling counts	Reduction by half in the area counted in each quadrat from $0.25m^2$ to $0.125m^2$ Addition of size categories for seedlings
Vegetation in following years	Samples were taken in late June, but it was found that "spring-sown cereal crops had sometimes lodged… reducing the accuracy of sampling" and so it was recommended this be done in April/May in subsequent years
Within-crop vegetation	Addition of measurement of over-winter survival of winter oilseed rape
Biomass sampling	Reduction of sample area from $1m^2$ to $50cm^2$ for very weedy samples Distinguish flowering/fruiting plants
Soil surface invertebrates – pitfall sampling	Increase in degree of identification – count of one species of carabid larvae; counts of wing morphs of 3 species of carabid; identification of spiders to 6 taxonomic groups
Invertebrates on vegetation	Reduction in sampling occasions from 3 to 2; reduction in transects from 9 to 3; Increase in identification to taxonomic and functional groups
Bees and butterflies	Reduction in site visits from 6 to 4 in beet and winter oilseed rape and from 6 to 3 in maize
Earthworms	Addition of worm cast counts
Within field gastropods	Addition of bait to traps and increase in trap intensity from 1 to 4 at each sampling point
Crop pests	Reduction by half in the number plants sampled for crop pests per half field from 90 to 45

Key finding: While the FSEs have thus been useful in the development of techniques for agro-ecological monitoring, the question arises as to how comparable the data sets from the first full year will be with subsequent years, at least for some of the indicator species used.

Limitations of the monitoring

The techniques used for the ecological monitoring may be the best available, but that does not make them flawless. Limitations are generally inherent in the assessment of the target groups and are therefore not readily overcome. Furthermore, decisions about the intensity of sampling at each site have been made not just on a scientific basis, but also as a result of budgetary constraints.

Soil seedbank

The consortium acknowledges that "many authors have emphasised the spatial and temporal heterogeneity of seedbanks and the consequent problem of quantifying them…All practitioners agree that a very large number of samples – hundreds from a single field – are needed to capture most species and to estimate their frequency reliably."[69] The research consortium proposed instead a less intensive programme of sampling that could be used to examine changes in the composition and frequency of the commoner, dominant arable plant species pointing out that "detecting every last rare species is simply not feasible".

The approach is based on studies that consider seedbank differences in herbicide trials and, in the context of the FSEs (which are essentially comparisons of herbicide regimes), would seem a sensible approach. In the context of examining broadbrush differences in biodiversity, rare arable weeds can be overlooked as weed biomass, dominant species, and species of importance to other organisms will be more important. However, it is important to remember that if the results are scaled up to consider these crops at a regional scale, the impact on rare and endangered species, including those for which the Government has made specific conservation commitments under the biodiversity action plans, cannot be determined from the data available.

Soil organisms

In the original tender, it was proposed that soil organisms, including earthworms and micro-organisms, be monitored by taking samples from the soil. In the case of earthworms, this procedure was dropped by the SSC because firstly oilseed rape is harvested and sown during the inactive period of earthworms, secondly it was too resource-intensive and thirdly changes were unlikely to be detectable over the short period of the trials.[70] This is unfortunate, as the number of earthworms is very relevant to those bird species which predate them, such as pheasant, lapwing, little owl and starling.[71] Instead, earthworm casting counts were introduced. However, not all worm species are frequent casters and so this method will not give an accurate reflection of the numbers of all earthworms present.

In a paper to the Agriculture and Environment Biotechnology Commission, Dr Les Firbank noted that "soil fauna and micro-organisms may well be affected by GMHT cropping, especially if it entails a change in the methods of cultivation. However, such effects require at least five years before they can be readily detected, and even then high sample densities are required."[72] This statement clearly highlights the difficulties with the timescale chosen for the FSEs; changes that take longer than one year to become apparent cannot be monitored and therefore must be dropped.

Total invertebrate biomass

Total invertebrate biomass is considered to be an important aspect of the study since the diversity and bulk of invertebrates taken by farmland birds in arable fields is very important to bird populations. While the general approach, as laid out in the tender document, appears to be robust, the protocol only examines above ground invertebrates. This may be a cause for concern as some invertebrates are seasonally above ground or at the surface, and below ground at other times or at other stages of their lifecycle. There may also be diurnal patterns of behaviour that influence results too. It may therefore be necessary to show caution when extending any interpretation of the sampling data, in the absence of an evaluation of the interactions between above and below ground faunas.

Slugs and snails (gastropods)

A similar issue arises with the monitoring of gastropods, which is based on refuge traps. Many gastropods (including ecologically important species) do not necessarily lend themselves to surface or trap collection because they live primarily within the soil itself.

Bees

Bees are a very important group, both ecologically and economically. The proposed methodology for monitoring honey bees, bumble bees and solitary bees has some serious limitations. The method proposed is walking transect samples, and considering the size of the fields, the tender documents suggest that each transect could take 30 minutes.[73] As the research consortium note, in the case of the oilseed rape monitoring, “because oilseed rape flowers open early in the morning and produce most nectar at this time, bee activity can fluctuate greatly at this time and comparisons between sites will be difficult to make”.[74] Comparison and replication of transect samples of this sort are prone to externally imposed factors and variation that could potentially make interpretation difficult. The interpretation of these results will therefore have to be extremely cautious.

Butterflies

Some of the same cautionary notes apply to butterflies as to bees. Sampling butterflies by walked transects is an established approach but does have limitations. In particular, externalities of daily weather variations and between year weather trends may outweigh and confuse variation within the sites on the scale of the projects being undertaken. Adult butterflies are highly mobile and very much affected by weather both on the day of sampling and over the longer period before sampling. Micro-topography is also very influential and its importance on a particular site may change significantly during the day.

Crop management

Much of the data of relevance to the agronomy and activities of the farmers are being collected by the farmers themselves. Farmers are not primarily researchers and, therefore, data collection may not be their first priority. This appears to have led to problems with collection of this data; for example, in 2000 the SSC noted that in the case of field activities, such as application of pesticides, “in many cases farmers fail to appreciate the urgency of this information and are reluctant (or too busy) to send it immediately”. Similar difficulties were found in getting farmers to verify the season’s management activities at the end of the year.[75]

In the sugar and fodder beet trials, the GM halves have been prematurely harvested in order to avoid the risk of mix-ups with non-GM crops destined for British Sugar or to feed stock. This means that during the autumn and winter, a very important period in which to assess the biodiversity impact of GM sugar and fodder beet, accurate biodiversity monitoring cannot take place in the GM portion of the trial.

Key finding: The monitoring of biodiversity is the reason for the FSEs. However, there have been difficulties in terms of the indicators chosen and the methodology used. The FSEs seem likely to provide useful advances in methodology, but in essence, the quality of the monitoring has been limited by the status of current scientific knowledge, budget and the limited timescale of the FSEs. Further, some of the most significant groups in terms of policy decisions (the birds and mammals) could not have been meaningfully studied within the scale of the trials undertaken.

5. How relevant are the farm scale evaluations to UK agriculture?

The secondary objective of the FSEs, as set out in the tender specifications is

> "to contribute to an assessment of the wider question of whether the commercial use of GMHT crops will change the management of farming systems and the agricultural landscape."

The ability of the FSEs to fulfil this second objective rests in large part on how representative the trial sites are. If the farms used do not accurately reflect the rest of the farms found in UK agriculture, the relevance of any results will be much weaker.

Site selection

From the start, the SSC has consistently placed heavy emphasis on obtaining farms for the FSEs that "ensure representative ranges of size, intensity of management, geography and so on".[76] In fact, in the second Interim Report it is stated that the research group and SSC had agreed that "farm intensity and geographic location were among the most important factors in selecting farms".[77] While it is clear that the SSC has done its best to obtain this representative sample, and has devoted time to the consideration of relevant factors in deciding which farms to use, there is still a question as to whether they have been hampered by the very nature of the crops being examined. In a recent paper by members of the research consortium, it was noted that the "farms involved in the trial come from a limited, self-selected set of growers who were willing to grow GMHT crops"[78] and that as a result it had not been possible to obtain a representative sample through statistical sampling. In other words, the farms involved in the FSEs do not, by the very fact of being in the trials, provide a random and representative selection from UK agriculture.

It is apparent from the minutes of later meetings that this issue has dominated site selection, and that the unwillingness of most farmers to take part, and the consequent difficulty in obtaining sites, has led to problems of representation across all areas. In the October 2001 Interim Report, it was noted that the 180 study sites used up to that date had been cultivated by only 75 farmers. Concern was expressed that "should these same farmers contribute a high proportion of sites during 2002, there is concern that the study may become too dependent upon a relatively small base of farmers."[79]

Figure 1: Comparison of FSE sites against UK area grown — Spring oilseed rape

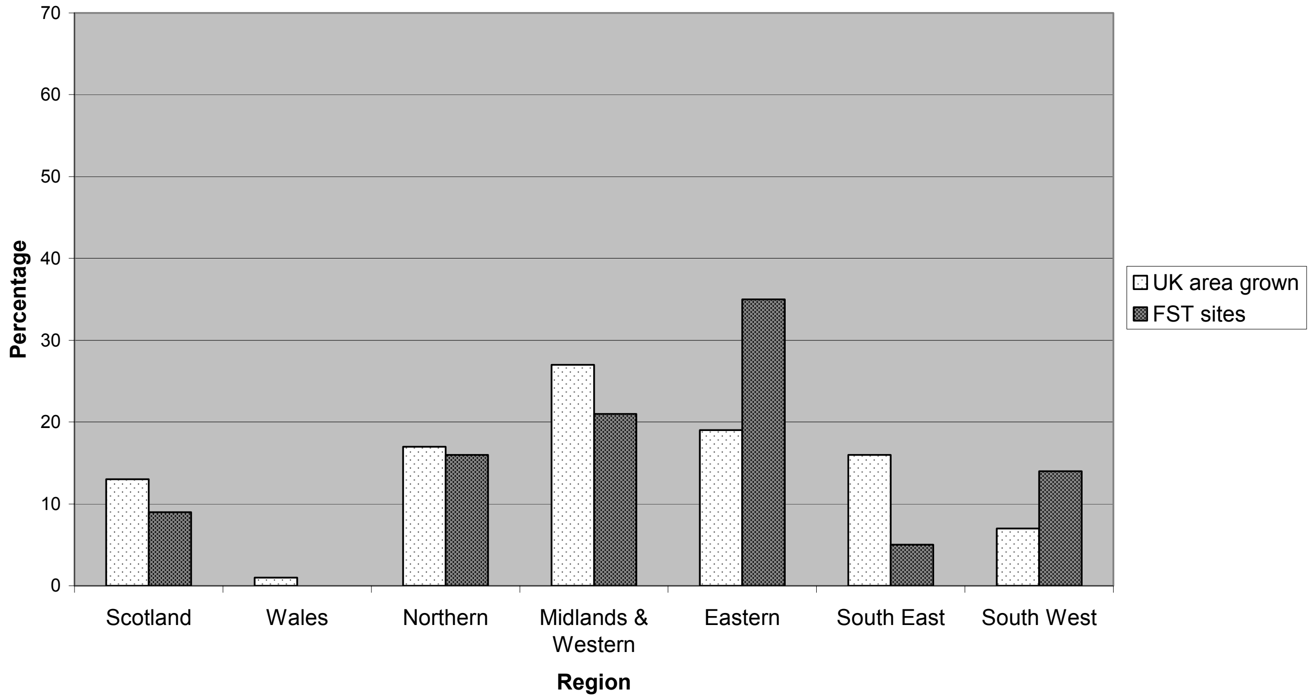


Figure 2: Comparison of FSE sites against UK area grown — Maize

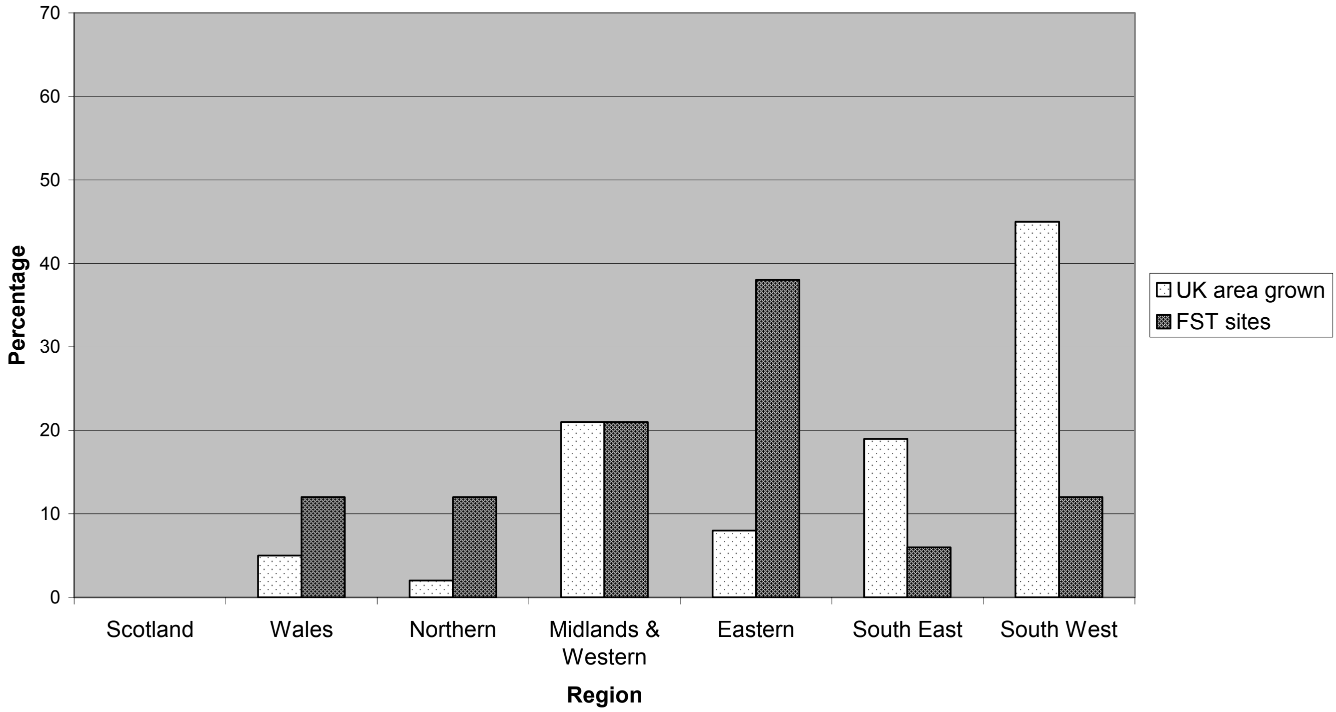


Figure 3: Comparison of FSE sites against UK area grown — Beet

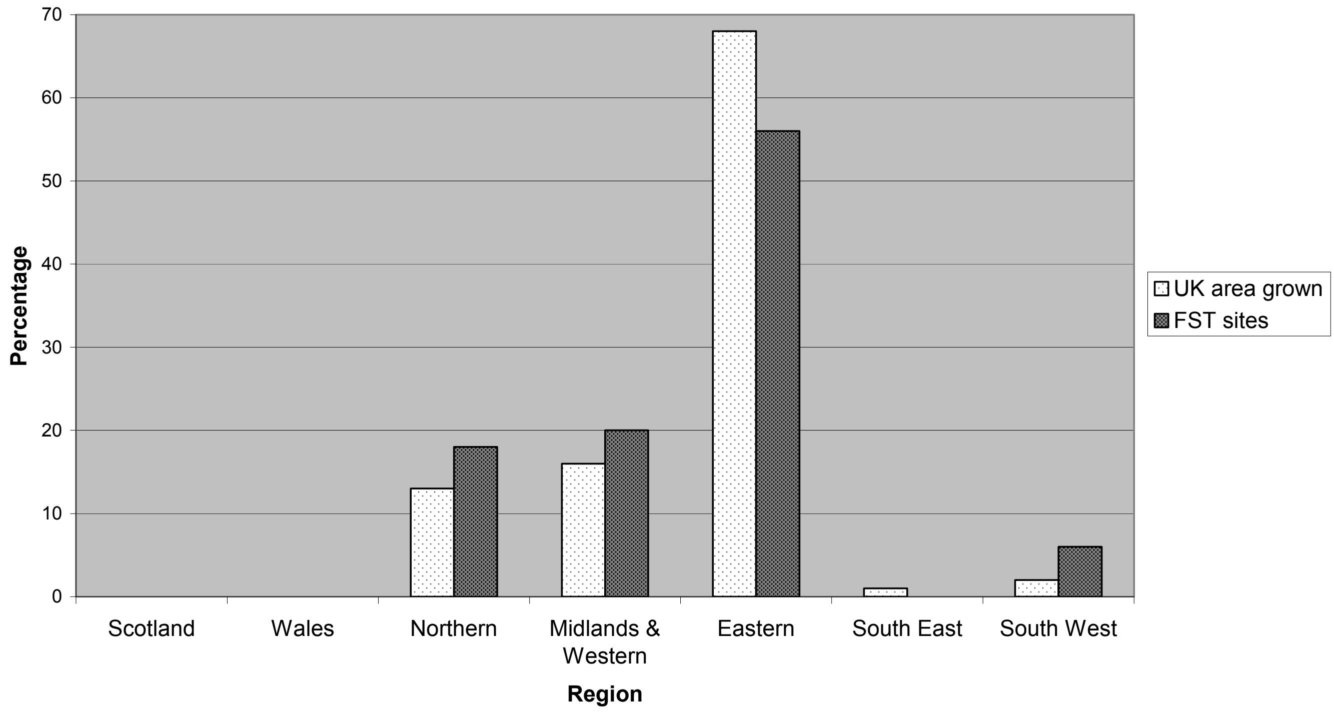
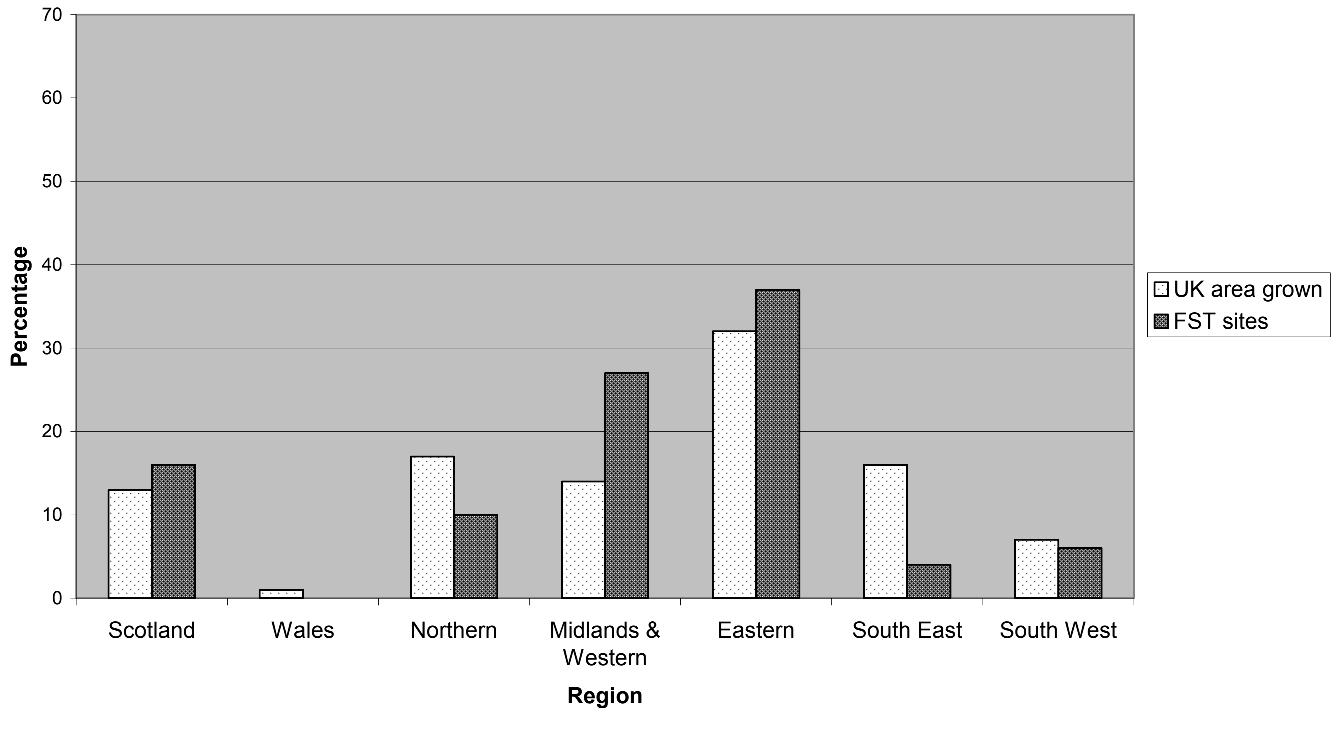


Figure 4: Comparison of FSE sites against UK area grown — Winter oilseed rape



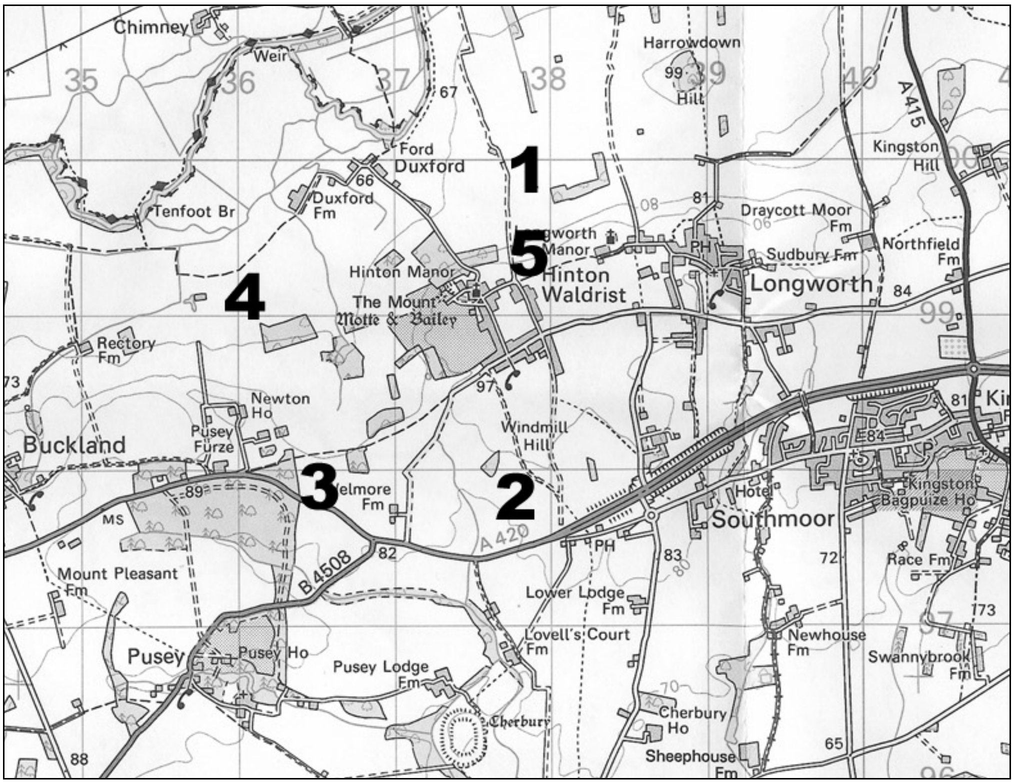
Geographical spread

The SSC attempted to get a good geographical distribution of sites. However, because the public and many farmers are opposed to GM crops there have been problems obtaining enough willing farmers, particularly in the southwest of England. As a result, it is questionable whether the final sites chosen truly represent the geographical distribution of oilseed, maize and beet crops (see Figures 1-4) in UK farming:

- In the case of spring oilseed rape the spread of sites under-represents the southeast of England (5% of sites against 16% of area grown) and over-represents in the eastern region (35% of FSE sites against 19% of area grown).
- In the case of maize, the spread of the maize trials is poor with the majority being in a band across the middle of England. In addition, the east/west distribution of the crop is reflected very poorly. Only 8% of the national crop is grown in the eastern region, but 38% of the maize FSE was grown there, and while 45% of the UK's maize is grown in the Southwest, only 12% of the FSE sites were located there.
- The beet crops are somewhat under-represented in the eastern region (68% of area grown, 56% of sites).
- In the case of winter oilseed rape, there is a shortage of sites in the Southeast (16% of area grown, 4% of FSE sites), and considerable over-representation in the Midlands (14% of area grown, 27% of FSE sites).

The farms used for the FSEs shows a large number of repeats in individual parishes and farms (Figure 5). Thus the intentions of the SSC to obtain a representative sample have been further compromised by the limited number of farmers offered by SCIMAC.

Figure 5: Location of farm scale evaluations of rape and maize near Hinton Waldrist, Oxfordshire, 2001-2002



Key

1: Rape Spring 2001
2: Maize Spring 2001
3: Rape Winter 2001
4: Maize Spring 2002
5: Rape Winter 2002

Scale: 2cm=1km

Credits
Figures 1 & 2 N.Mullen
Figures 3, 4 & 5 J.Saunders

Farming intensity

The importance of including farms with higher biodiversity and lower intensity has been highlighted by the SSC, as these may contribute disproportionately to the biodiversity in an area. Selection of farms for the FSEs is based on an evaluation of the intensity of the farm by means of self-assessment conducted by the farmers and on information provided by farmers about a checklist of biodiversity potential indicators such as the use, anywhere on the farm, of beetle banks, conservation headlands, wildflower strips or game cover and the use of Farming and Wildlife Advisory Group advisors, or Linking the Environment And Farming audits.[80] While the biodiversity potential indicators used for site selection are more objective than the intensity assessment, it is unclear whether the measures used across the whole farm are necessarily directly linked to biodiversity of the actual fields used in the FSEs.

These considerations are significant because a weedy field on a farm which has not undertaken conservation activities might be more important for local biodiversity than a very intensively managed field on a farm which undertakes conservation activities across the farm as a whole. This is reflected in the work of Watkinson et al, who modelled the impact of GMHT sugar beet on skylarks.[81] They found that the severity of the deleterious effect on the bird population was related to the abundance of the weed *Chenopodium album* (fat hen) in the field prior to the use of the GMHT crops. Weed burdens in fields are not necessarily related to the use of conservation measures on the farm.

The measure of farm intensity may address this issue. Yet this is clearly a subjective measurement by the farmers themselves. Asked to rate their farm's intensity as a score from one to five, over the first two full years of the trials more farmers rated their intensity as four than any other, indicating that most farmers included in the trials are at the more intensive end of farming. Of the 43 farms entered in the spring oilseed rape trials in 2000/2001, only one farm gave an intensity assessment at one or two. The same was true for the 34 farms entered in the maize trials in 2000/2001. (The beet crops were rated using a different scoring system.)

Unfortunately, due to the way it has been measured, it is difficult to compare this subjective measure of intensity with any national data on input use, but it would seem that, despite the SSC's requirement that they be over-represented, only a very small number of low-intensity farms have actually taken part in the trials.

Many of the farms taking part in the FSEs are not commercial holdings but either company or institution research sites, such as Advanta's trial ground at Boothby Graffoe (Lincs), ADAS sites at Itchen Abbas (Hants), Meden Vale (Notts), Preston Wynne (Herefordshire) and IACR at Rothamsted. Previous management practices may differ at these sites from those followed on a commercial unit and there may well be different biodiversity on these research sites, which have different priorities, staffing and funds available, than ordinary farms.

Key finding: The FSEs have been drawn from a small pool of farmers who were willing to take part in the tests and as a result there are clear biases in the geographical spread and range of farm types included. The ability of the FSEs to fulfil the secondary research objective, that of assessing the impact of GMHT crops on wider agricultural management, may be compromised by the unrepresentative samples used.

Relevance to commercial farming practice

A crucial determinant of how successfully the FSEs fulfil the secondary objective, that is of determining whether the commercial use of GMHT crops will change the management of farming systems and the agricultural landscape, is how relevant the practices used in the FSEs are to commercial farming practice. In other words, do the FSEs reflect the real concerns of farmers, such as cost, quality and yield of the crops involved?

Yield

In the FSEs, the final assessment of crop yield is undertaken by the farmer and is an estimate, rather than an accurate measurement. This is a major flaw in the design of the FSEs as crop yield is a major determining factor in farmer choice and consequently will affect whether or not they adopt the technology. It also fundamentally devalues the relevance of the entire experiment as it is entirely possible to grow crops with a high level of biodiversity if yield is disregarded, but a low yielding crop has little use as far as farmers are concerned. In normal circumstances, farmers manage their crop for the maximum profitable yield and so high weed levels in the crop, which cause the yield of the crop to decline, are avoided. Failing to measure yield accurately allows potential for the crops to be managed to tolerate higher levels of weeds than would ever be acceptable in commercial practice.

The results of the BRIGHT (Botanical and Rotational Implications of Growing Herbicide Tolerant crops) research, will provide data on the optimum time to apply herbicides to GM crops from an agronomic perspective. But this research will not be completed until 2003 – after the FSE results are due to be published. So the optimum time for applying herbicides to GM crops in the UK is still under investigation. The absence of independent advice on crop management, combined with the fact that herbicide applications for the GM half of each site are effectively under the control of the biotech companies, can only fuel suspicions that the GM crop management could have been directed at maximising biodiversity, rather than reflecting realistic practice. However, if the GM crops are grown commercially, the main concern of farmers will be to maximise yields and they will seek to achieve the best weed control available through the use of herbicide-tolerant crops. Friends of the Earth has been informed that at one of the beet FSEs, the host farmer repeatedly expressed concern to Monsanto that the GM half of the crop was excessively weedy, and was repeatedly told to delay herbicide application.[82]

This potential for the results of the FSEs to be irrelevant is exemplified by sugar beet. In the case of sugar beet, competition from uncontrolled annual weeds that emerge before the eight leaf stage of sugar beet can reduce yield by between 26 to 100%, while season long weeds at densities as low as one to 12 weeds per 30m of row can reduce yield by 11 to 24%.[83] This means that manipulation of GM weed control in order to boost biodiversity will have an inevitable yield penalty. For example, trials conducted by the IACR-Broom's Barn for Monsanto and the BBSRC examined the impact of delayed control of weeds in GMHT sugar beet.[84] It was found that when herbicide treatment was delayed until the crop was at the eight leaf stage, final yield was reduced by 24% and when herbicide application was delayed until the 12-14 leaf stage of the crop, and the weeds were in flower, yield dropped by 32%. The relationship between yield and application of herbicide to the GM crop was confirmed by more recent results from this programme.[85] Clearly this delay in treatment was beneficial from a purely biodiversity perspective, but it is questionable whether such a yield penalty would be acceptable to most farmers. Similarly, research in Canada found that delaying the application of glyphosate to GM oilseed rape by two weeks reduced yield by between and 19% and 57%.[86]

In the case of glufosinate-tolerant maize, there is a real question as to how relevant the FSEs are to maize production as it will be practised commercially. This is because evidence from the United States clearly indicates that glufosinate on its own does not provide the level of weed control that farmers need to maintain yield. A report from the Texas Agricultural Extension Service[87] concludes that weed control with glufosinate used on its own is "poor to fair", and it is estimated[88] that between 75% and 90% of farmers growing GM maize in the United States use a product marketed by Bayer called 'Liberty ATZ', which is a mixture of glufosinate and the conventional herbicide atrizine. So the farm scale trials themselves may report that the GM maize produces a level of biodiversity in the experiment that is apparently very good, but will not be repeated in commercial practice because farmers need an adequate crop, as well as biodiversity.

As well as addressing the second research objective, measurement of yield would have provided a check against the agronomy used on the GM and non-GM halves of the fields, helping to confirm that the crops have been managed according to normal practice. Comparing both sides would be one way of ensuring there had not been differential treatment.

It is unclear why the research consortium and the SSC are so unconcerned with yield measurement, or why they are content for their research to be so irrelevant in this respect that they state that "we will not undertake an economic analysis of the take-up of GMHT crops; rather we will adopt MAFF or SCIMAC figures of take-up when scaling up to the national level".[89] To take an estimate of farmer take-up from SCIMAC, which is a proponent of GMHT crops, indicates a certain naivety on the part of the research consortium. This seems an abdication of the consortium's contractual obligation to fulfil the secondary objective of the research. Furthermore, it is unclear on what basis either the government or SCIMAC will estimate GMHT crop take-up in the absence of economic data from the only large-scale growing of GMHT crops in the UK.

Key finding: Failure to measure yield in the FSEs, in combination with the control of GM herbicide applications being given to the biotech industry, has created the potential for management decisions to be manipulated in order to provide an unrealistically favourable impression of GM crops. These basic oversights could compromise the ability of the FSEs to meet its secondary objective and, more crucially, could call into question the relevance of the results of the FSEs

6. The conduct of the trials

While there is no doubt that the scientists involved in the FSEs have applied best practice within the constraints imposed upon them, and have strived to conduct the experiments properly, questions remain over the actions of other participants in the FSEs and whether these could be detrimental to the reputation of the research. The responsibilities for the FSEs are divided among the various parties involved:

- The Government is responsible for funding the consultants and appointing the SSC, which has been given the task of overseeing the whole four-year programme
- The SSC was also, in part, responsible for the design of the experiment, overseeing the monitoring and analysis of the data and making a recommendation to the Government based on the final results. Members of the SSC include the RSPB, Game Conservancy Trust and English Nature and academics
- SCIMAC is responsible for finding farmers who are willing to take part in the FSEs. It also attends meetings of the SSC. SCIMAC and Aventis are also responsible for ensuring that the farmers have followed the SCIMAC guidelines for growing GMHT crops
- Individual biotechnology companies, such as Bayer CropScience and Monsanto assist in locating farmers (they are all members of SCIMAC), provide the GM seeds and herbicide, agree the contracts with individual farmers, pay the farmers for taking part and provide guidance on when to apply the herbicide to the GM crop
- The consultants ITE, IACR and SCRI are responsible for refining the experimental design and methodology, the field work, data logging, data analysis, reporting to the SSC and writing the final reports

Thus, important and potentially influential roles in the management of the FSEs have been placed by Government into the hands of the very companies who stand to profit if the results of the FSEs are favourable. This is a quite extraordinary decision by the Government, as from the outside it would seem an essential prerequisite of the FSEs that they were, and were seen to be, conducted free of any commercial influence. By allowing SCIMAC and the individual companies such a prominent role, the Government has opened up the FSEs to the accusation that they could be manipulated.

Key finding: The Department of Environment, Food and Rural Affairs (DEFRA) could easily have ensured that the task of locating farmers, shortlisting fields and providing agronomic advice was in the hands of an organisation without any vested interest in the outcome of the trials. For example, the National Institute for Agricultural Botany was already engaged in research into the agronomy of herbicide-tolerant crops (the BRIGHT project) and so could have been contracted to provide agronomic advice, although it would have been better to have delayed the FSEs until after the BRIGHT project ended in 2003. MAFF/DEFRA would have been well placed to recruit and contract farmers to take part in the trials, as they are in contact with all farmers in the UK through the annual farm census. This would have left only the supply of seeds and herbicides to the biotech companies.

Preventing GM contamination from the sites

From the start, it seemed to Friends of the Earth that there was a very real chance that the pollen produced by the GM crops in the FSEs would cross-pollinate with other crops, both organic and non-organic, in the surrounding areas. The numbers of the FSEs meant that the proposed releases of GM crops were on a far greater scale and geographic spread than had previously been seen.

SCIMAC produced a voluntary code of practice ostensibly designed to prevent cross-pollination. The Government endorsed this code of practice prior to the commencement of the FSEs in 1999. However, Friends of the Earth and others have criticised the SCIMAC code for the inadequacies of the voluntary separation distances between GM crops and neighbouring crops of the same species. For instance, the maximum separation distance between GM oilseed rape and neighbouring oilseed crops is 200 metres (for seed and organic crops). In contrast, the European Commission, when assessing the measures required to maintain a level of 0.3% GM contamination in first generation non-GM oilseed rape seed, recommended a separation distance of 5,000 metres between GM crops and non-GM seed crops.[90] This is 25 times SCIMAC's maximum distance.

In 1999 Friends of the Earth asked the National Pollen Research Unit to monitor pollen movement from the first FSEs oilseed rape crop in Oxfordshire. GM pollen was found to be travelling on the wind at least 475 metres from the edge of the crop[91] (the furthest point monitored). In addition, honey bees from hives 4.5km away from the field had been collecting pollen from the GM oilseed rape. Subsequently, in 2000, Friends of the Earth found GM pollen in honey purchased at retailers near a GM test site in England[92] and later similar findings were made in Fife in 2002.[93] Further evidence for the difficulties posed by GM contamination came in 2002, when DEFRA announced that seed lots used in 25 of the spring oilseed rape the FSEs over three years had contained unapproved GM material.[94]

There is concern that the separation distances used around FSE sites were not chosen to reduce the chance of any cross-pollination to below the level of detection for novel genes in crop plants (0.1%). In fact, they appear to have been based on existing practice in the seed industry where much higher levels of contamination in seed crops is pragmatically accepted (eg up to 10% for certified oilseed rape seed.[95]) GM crops have to be treated differently to non-GM seed crops because of the need to prevent genes escaping into the environment (where the consequences of such events are hard to predict, but potentially serious) and into non-GM crops (including organic crops). For these reasons, English Nature has already stated that the threshold of contamination for seed crops should be "near zero".[96]

Public consultation

Many people living near them did not welcome the FSEs. The anger of local people was increased by the method which the Government, in the shape of the Department of Environment Transport and the Regions (DETR) and then DEFRA, used to announce the trials. The Departments chose to consult local people after sites had been announced. In the early years of the FSEs, these consultation meetings took place a matter of days before the crops were sown and in the early years sometimes miles from the parishes affected. Later the period was extended to six weeks after the main research and demonstration centre of one of the UK's foremost organic research organisations, The Henry Doubleday Research Association, was threatened by potential contamination from a proposed FSE for fodder maize. The actions of Government departments may well have engendered further hostility to GMHT crops.

Several local authorities made representations to the Government concerning the undemocratic imposition of the trials in their areas, for example, West Lindsey in North Lincolnshire and Dorset. In a minority of cases, farmers who were planning to host the FSEs withdrew following massive local public outcries and in the case of the HDRA site, it was SCIMAC who, in advance of the General Election, withdrew the site as a gesture of goodwill. However, in most cases the FSEs were planted often against the wishes of local people and it is hardly surprising that some people were angry enough to take direct action against the crops.

7. Conclusions

Ability of the farm scale evaluations to test the null hypothesis

The outcomes of the FSEs should be weighted in favour of protecting biodiversity. In the case of GM crops, the precautionary principle underpins European legislation (Article 4.1 of EU Directive 2001/18). This principle means that mistakenly accepting the safety of GM crops when they could in fact be harmful is a serious error. Changes to biodiversity may be serious and possibly irreversible and so fall within the scope of precautionary action.

The first objective of the monitoring by the research consortium was to test the null hypothesis that there are no significant differences between the biodiversity associated with the management of the GMHT crop and the comparable non-GM crop at the farm scale. The results of this test will be used to justify political actions which could have huge impacts on biodiversity. However, for a number of reasons, differences can exist between the GM and non-GM crops, but not be detected in the experiment.

- Based on published power analyses, the FSEs may simply not be powerful enough to detect differences of less than 1.5-fold in biodiversity between the GM and non-GM crops. If the experiment fails to detect differences, they may still be present.

- The power of the FSEs to detect differences in the various biodiversity indicators is not consistent. For some indicators, regardless of their importance, it may not be possible to detect meaningful results.

- A vital consideration for the FSEs is whether they are able to detect changes that are of ecological importance. Comparison with long-term research suggests that small, incremental changes in plant and insect populations cause ecological shifts in the long term. The assumption is made in the FSEs that detection of 50% to 100% difference in biodiversity indicator species between GM and non-GM crops is an acceptable sensitivity. However, evidence suggests that ecologically important differences may in fact be at levels as low as 13%.

- Publicly available information on the power analysis indicates that it has been based on making comparisons between GM and non-GM treatments over the whole experiment, and not on subsets within it. Any comparisons between subsets will be made with greatly reduced power.

Key finding: The theoretical calculations conducted by the SSC and the research consortium indicate that the power of the FSEs to detect a 1.5-fold difference will be 80%. However, it would appear that the ability of the FSEs to detect ecologically important differences is likely to be considerably lower for the following reasons:

- **Observed coefficients of variations for some biodiversity indicators are greater than the 50% assumption in the calculations**
- **The calculations assume a difference of 1.5-fold (50%), whereas ecologically important difference may be as little as 13%**

Any further complications, including the interaction of covariates or systematic error such as cultivar differences, could further reduce the power of the experiment to detect ecologically important changes.

While there is no doubt that the consultants who were charged with carrying out the field work and analysis of the data collected in the FSEs are of the highest integrity and have been scrupulous in their work within the constraints imposed upon them, the FSEs have presented serious practical difficulties that are likely to affect the quality of results.

- The research consortium has faced difficulties in terms of the indicators chosen for monitoring and the methodology used. In essence, the quality of the monitoring has been limited by current status of scientific knowledge, budget and the limited timescale of the FSEs.

- The FSEs have been used to develop techniques for agro-ecological monitoring. This has value in terms of advancing knowledge in the field but leads to questions as to how comparable the data sets from the first full year will be with subsequent years, at least for some of the indicator species used.

- The interactions and relationships between the organisms that make up the biodiversity of agricultural ecosystems are complex and poorly understood. This means that extrapolating from results will be difficult.

- There is some anecdotal evidence that the GM and non-GM varieties used in the trials are not similar. This could introduce a further difficulty, because as the growth and development of the crop cultivars go out of phase, the presence of biodiversity indicator organisms will also go out of phase between the two halves. Agricultural activities, such as fertiliser application, which need to be carried out during the crop season, would have to be performed at times that are not appropriate for one or other of the cultivars. This would result in a bias one way or the other.

One of the most significant outputs of the FSEs is likely to be a greater understanding of the relationships between organisms and their environment within farmland ecosystems. In addition, the FSEs could provide an important source of basic information on the biodiversity associated with intensive agriculture at this point in agricultural history. For example, it has been suggested that the results will provide useful baseline data on the soil seedbanks associated with oilseed rape, maize and sugar beet crops.[97]

While this is very valuable in terms of increasing scientific understanding of agricultural ecosystems, it is essential to retain a realistic perspective on the ability of the results and modelling to predict the impact of GMHT crops on wider biodiversity in agricultural areas. The model will be used to extrapolate beyond the range of the data, and will probably be used as a basis for policy decisions and possibly as a justification for the commercialisation of GM crops. Yet, in the face of this level of complexity, such models are notoriously unreliable and dangerous to use; they are often little more than an educated guess about what may or may not happen.

The relevance of the FSEs to wider agriculture

The secondary objective of the research was

> "to contribute to an assessment of the wider question of whether the commercial use of GMHT crops will change the management of farming systems and the agricultural landscape".

The ability to fulfil this second objective rests in large part on how representative the trial sites are. If the farms used do not accurate reflect the rest of the farms found in UK agriculture, the relevance of any results will be much weaker.

The FSEs have been drawn from a small pool of farmers who were willing to take part in the farms and as a result there are clear biases in the geographical spread and range of farm types included. The farms used for the FSEs show a large number of repeats in individual parishes and farms. Thus the intentions of the SSC to obtain a representative sample have been compromised by the limited number of farmers offered by SCIMAC.

The FSEs "will not undertake an economic analysis of the take-up of GMHT crops; rather we will adopt MAFF or SCIMAC figures of take-up when scaling up to the national level".[98] To take an estimate of farmer take-up from SCIMAC, which is a proponent of GMHT crops, indicates a certain naivety on the part of the research consortium. Furthermore, it is unclear on what basis either the Government or SCIMAC will estimate GMHT crop take-up in the absence of economic data from the only large-scale growing of GMHT crops in the UK.

Failure to measure yield in the FSEs, in combination with the control of GM herbicide applications being given to the biotech industry, has created the potential for management decisions to be manipulated in order to provide an unrealistically favourable impression of GM crops. These basic oversights could compromise the ability of the FSEs to meet their secondary objective and, more crucially, could call into question the relevance of the results of the FSEs.

Establishing the impacts of GMHT on the wider agricultural environment may prove to be a difficult task on the basis of the data likely to be provided by the FSEs. The FSEs are looking at changes within a single year (in most cases) and in a relatively small area. This means that the results will have to be scaled up, both in terms of scale and time period, in order to make assessments about the impacts at the larger commercial scale. It is questionable whether the measurements being taken will be relevant to a discussion about changes to the management of farming systems and the agricultural landscape, as the consortium have not made any assessment of the viability of the GM crops.

The wider context

The FSEs have been motivated by the needs of Government and industry to avoid a formal moratorium on GM crops and also to show that something was being done about the concerns of the Conservation Agencies and wider society. They are not driven by a coherent strategy for the future of agriculture, nor a desire to find the best technologies for enhancing wildlife in the UK. Furthermore, it appears that the taxpayer is funding research, which under the requirements of Directive 2001/18, is the responsibility of Monsanto and Bayer CropScience.

It appears that the experiment is likely to throw up further questions that will be difficult to answer because they have not been addressed in the experimental design. Most importantly, there has been no attempt to establish what level of difference is of ecological importance and whether or not the FSEs are sufficiently sensitive to detect this. Furthermore, the experiment will not allow comparison with the biodiversity inherent in more sustainable farming systems, such as organic. It will not even be able to address the value of the GMHT system in comparison with other developing technologies in weed control, such as mechanical weeding in maize or band and low dose spraying in beet crops.

It is a serious oversight that GMHT crops have not been examined in comparison with all the emerging technologies in conventional farming, when such alternatives exist for all the crops. For example:

- Due to its upright structure, maize is ideally suited to non-chemical methods of weed control such as brush weeding, and research has shown that effectiveness of mechanical weed control can be equivalent to herbicide use in terms of effectiveness and cost.[99]

- Herbicide use may often be unnecessary in oilseed rape because it can be very competitive and will smother many weeds. In fact, except for very aggressive weeds such as cleavers, the level of weed competition appears to be more related more to the quality of the establishment of the oilseed rape crop than the weeds themselves.[100] In the case of winter oilseed rape, this establishment can be enhanced by early sowing dates, while for spring oilseed rape herbicides may not need to be applied at all; in 1998, 16% of the cropped area was not treated with any herbicide or desiccant.[101]

- In the case of beet crops, research is continuing to reduce the amount of conventional pesticide used, eg by adopting band spraying.

In this context, the question arises as to why there has been such emphasis on GMHT crops, despite the environmental concerns that surround them. The answer lies in the fact that the modification of agricultural crops is dominated by companies that have a history of pesticide production, so herbicide-tolerant crops are viewed, both by Monsanto and Bayer CropScience, as a means to continue sales of their core agro-chemicals; respectively glyphosate (Roundup) and glufosinate ammonium (Liberty). At the German plant where glufosinate ammonium is produced, work began in 1995 to double production capacity in anticipation of the launch of GM glufosinate-tolerant crops.[102] 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.[103]

Herbicide-tolerant crops are a key part of these companies' strategies to maintain market share, not least by tying the sale of the GM seed to purchase of the proprietary version of the herbicides. The fact that large multinational companies, such as Monsanto and Bayer, are behind GMHT crops goes a long way to explaining the emphasis that has been placed on their development, and why such a large research effort has been provided by Government.

Summary

The FSEs are likely to provide a significant contribution to the field of agricultural ecology, both in terms of basic understanding of the crops being examined, and in terms of the development of monitoring techniques and methodology for agricultural biodiversity.

This does not mean that they will be able to answer the real question about the introduction of GMHT crops – namely, will the use of GMHT crops lead to ecologically important reductions in biodiversity in agricultural areas?

In fact, it seems very likely that the conclusions of the FSEs will be uncertain and may simply raise further questions. It is vital that this is acknowledged, and that equivocal results are not used as a smokescreen for Government decisions that are motivated by a political desire to proceed with the commercialisation of GM crops.

Finally, if the decision on GMHT crops is really going to be influenced by their impact on biodiversity, their performance should be examined against that of other farming systems and techniques which are proven to benefit biodiversity, such as organic farming or low input systems. This is particularly relevant given that there is likely to be an increase in these more environmentally friendly farming practices over the coming years as a result of changes in agricultural subsidies.

Abbreviations

ACNFP	Advisory Committee on Novel Foods and Processes
ACRE	Advisory Committee on Releases to the Environment
ADAS	Agricultural consultancy and research company (formerly the Agricultural Development and Advisory Service)
BBSRC	Biotechnology and Biological Sciences Research Council
BRIGHT	Research project: Botanical and Rotational Implications of Growing Herbicide Tolerant crops
BSPB	British Society of Plant Breeders
BSBSPA	British Sugar Beet Seed Producers' Association
CV	Coefficient of Variance
DEFRA	Department of the Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Region (now part of DEFRA)
GMHT	Genetically-modified herbicide tolerant
GMO	Genetically-modified organism
HDRA	Henry Doubleday Research Association
IACR	Institute of Arable Crop Research (now Rothamsted Research)
ITE	Institute of Terrestrial Ecology (now part of the Centre for Ecology and Hydrology)
MAFF	Ministry of Agriculture Fisheries and Food (now part of DEFRA)
NFU	National Farmers' Union
NGO	Non-governmental organisation
PSD	Pesticides Safety Directorate
SCARAB	Research project: Seeking Confirmation About Results At Boxworth
SCIMAC	Supply Chain Initiative on Modified Agricultural Crops
SCRI	Scottish Crop Research Institute
SSC	Scientific Steering Committee
TALISMAN	Research project: Towards A Lower Input System Minimising Agrochemicals
UKASTA	United Kingdom Agricultural Supply Trade Association
WOSR	Winter oilseed rape

Glossary

Agronomic	Relating to the science of crop production
Band spraying	Application of herbicide to the crop row only, rather than the entire field. This leaves untreated weedy gaps between the crop rows.
Beetle bank	Grass strip adjacent to the crop which provides cover to beetles and other invertebrates
Biodiversity	The variety of life in all its forms, levels and combinations, such as ecosystem diversity, species diversity, and genetic diversity.
Biomass	The amount of living organic matter in all, or part of, an ecosystem. Measured in dry weight of material.
Broad-spectrum herbicide	Weedkiller effective against a wide range of weeds, including grasses and broad-leaved weeds.
Brush weeding	Mechanical weeding techniques using brushes to remove weeds from the soil
Carabid	Beetle family, commonly referred to as ground beetles
Coefficient of variance	A measure of the variability of a population, defined as the standard deviation divided by the mean
Collembola	Primitive wingless insects, mainly living in soil or leaf litter
Confidence interval	A range given for an estimated quantity, within which the true value can be said to fall, within a given level of confidence
Confidence level	A statistical standard of confidence in accepting or rejecting the null hypothesis
Conservation headland	Area at the edge of cereal crops to which reduced herbicides are applied, in order to allow the development of small populations of broad-leaved weeds and their associated insects
Covariates	Factors that may have an influence on the measured results of an experiment but which are not the focus of study
Cultivar	Named crop variety
Detritivore	Organism that relies on dead tissues of other organisms for nutrients
Dicotyledonous	Broad-leaved plants
Fumitories	Small annual plants, commonly weeds, including *Corydalis* species and *Fumaria* species in the UK
Functional group	The function that a group of organisms play within an ecosystem, such as predator, primary producer, decomposer
Granivorous	Grain and seed eating
Hempitera	Plant bugs
Indicator species	Organisms chosen for study in order to represent a wider group of species
Inter-row cultivation	Mechanical weeding between the crop rows
Lepidoptera	Moths and butterflies
Niche differentiation	Differences in resource usage patterns between two or more competing species, such that each species utilises only part of the resources which it would use if the other were absent.
Null hypothesis	Formal premise upon which to base the statistical analysis of an experiment
Phenology	The response of living organisms to seasonal and climatic changes in their environment
Phytophagous	Feeding on plants
Pitfall trap	A trap for catching ground walking insects, such as beetles, made out of a cuplike container buried in the ground into which the insects fall

Power	A measure of the ability of an experiment to detect difference between treatments
Power analysis	Statistical calculation which predicts the power of the experiment
Precautionary principle	The principle that, when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.
Quadrat	An area used as a sample unit
Refuge trap	A trap for monitoring slugs and snails by providing a covered daytime refuge
Seed rain	Fall of seeds from plants to the soil
Selective herbicide	A weed killer that acts only on selected weeds or weed types (eg grasses)
Significance level	The level of certainty at which the null hypothesis is rejected or accepted
Symphyta	Sawflies
Taxonomy	Biological classification of organisms
Transect walk	A fixed route across a sampling area which is walked by researchers undertaking monitoring of butterflies and bees
Trophic level	Position in the food chain
Varietal association	Combination of two varieties of oilseed rape, only one of which produces pollen, sown together as one crop.
Volunteer	Crop plant, such as oilseed rape, growing in a following crop as a weed
Vortis sampling	Portable sampler designed to suck up invertebrates from a sampling area.

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