Some personal remarks on the Farm Scale Evaluations of GMHT crops

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The continued increase in the yield of crops during the 20th century was not without effect on other organisms of the field. The move from spring-sown to autumn-sown cereals in the 1970s had claimed a large fraction of the annual solar energy, while the increase in number, type and broadening specificity of herbicides had even further reduced variety and abundance in the primary producers. By the late 1990s, many informed commentators felt things had gone too far. Long-term resident species were being lost from vice-counties and animals high in the food chain were declining. Definitive experimental evidence relating cause to effect was difficult to collect at the landscape-scale, but the consensus was that too many fields had become much degraded as biological systems[1, 2], to the extent that continued depletion of diversity must lead to major loss of function in soils.

The ecological debate in the 1990s was about rehabilitating and sustaining the functioning of fields with whatever form of cropping was used. At this time, seed companies notified their intent to commercialise GM herbicide-tolerant (GMHT) crops in the UK. The response had ethical and geopolitical as well as ecological overtones[3]. Arguments on ecological benefit or harm centred on change in pesticide profile, the effect of the GMHT package - the crop variety and herbicide – on the declining, in-field biodiversity and the movement of GM traits into other plants. Purely ecological concerns were raised by English Nature, the Royal Society for the Protection of Birds and concerned ecologists, who felt GMHT cropping used during the 'breaks' between cereals might be a step too far. The break crops, of which oilseed rape was the most widespread, gave probably the last general opportunity for broadleaved weeds to regenerate their populations, which in turn diversified the food web and sustained functions beyond those of the crop plants. In response to these calls, the UK government, through what was to become Defra, asked for tenders for research to examine the effect on farmland biodiversity of GMHT cropping. SCRI joined the Centre for Ecology and Hydrology (CEH) and Rothamsted Research as a bidding consortium. We won and began work in April 1999. The research consortium had to maintain its independence as part of a larger grouping of farmers, seed and agrochemical companies, a Steering Committee and government departments[4, 5].

Methods and experimental design No ecological studies of harm and benefit had been done at a large scale in countries where GMHT had already been grown, but plot-scale comparisons in the UK and overseas all pointed to very small or negligible ecological effects of plants having the GM herbicide-tolerant trait itself [6]. Any ecological impact would likely be through the package of the GM plant and a herbicide (glyphosate or glufosinate ammonium) which was able to target larger and more mature weeds growing when the crop was well developed. It could kill the weeds other herbicides could not reach. It was essential to compare this package with the existing, widespread form of cropping. The comparison was therefore between GMHT cropping as recommended by the manufacturers and the conventional ways of growing the beet, maize or oilseed rape[6]. The experiment was unique in that it would work with the variability among sites and years and not try to constrain it. Having argued that experimenters should be more prepared to relax the boundaries of their system[7], here was a chance to for me work with a group that expressly wished to probe an open system, not just some of its parts in isolation. The greatest challenge nevertheless was whether the comparison could be made successfully - whether a consistent shift, or absence of one, in populations or biological mass could be detected above the noise of weather and the general unpredictability of arable cropping.

In the first year, 1999, an extensive review, re-analysis of past data and collection of specific new information led us to propose a split-field experimental design and the need to repeat the comparison at 60-75 sites to detect an effect above the noise[8]. The statisticians Joe Perry and Peter Rothery led this phase of the work, but the whole team was convinced. The design withstood scrutiny by the Steering Committee and was eventually formalised and made public through the Defra web site. It became the target of anyone with a case against GM field trials. You would share a public debate with a partizan or political activist, who would

open with 'I'm no statistician but ....'. Such was the temporary success of this campaign that even some professionals you would meet followed the reluctant handshake with a 'pity about the experimental design'. But our conviction was and is still unswayable – based on the most thorough analysis of arable populations – the design was the best for the purpose, and our rationale was proved correct.

The comparison for the spring-sown beet, maize and oilseed rape was made in the seasons of 2000, 2001 and 2002. The consortium's research centres had access to all parts of GB and shared taking the measurements at sites. Les Firbank and the team at CEH Merlewood coordinated the study, mainly through a dedicated web site and many meetings of the group, while certain tasks, in taxonomy for instance, were allotted to specialists in the consortium. The main effort fell to a group of post-doctoral researchers, whose great ecological strengths were matched by their ability to drive and integrate our activities among all the target organisms, the four types of crop and the varied habitats in which the work was done. The final field measurements were made around September 2002, and the massive collection of data double-punched, checked and audited late that year. The work had become the most comprehensive study anywhere of the cropped habitat. Papers were reviewed by the Steering Committee, sent early in 2003 for peer review to a scientific journal - *Philosophical Transactions of the Royal Society, London* - and published in October 2003[9].

First results The results for the spring-sown crops were clear. If farming used the technology as the companies recommended in the FSE, the last common refuge for in-field arable plants would be accessible to broad-spectrum herbicides. In beet and spring oilseed rape, this would accelerate the decline in arable biodiversity; in maize it would impede the decline, because the existing herbicides – the triazines – were already so effective. The precise results depended on <u>when</u> herbicide and competition affected the extended flush of emergence that began after sowing and decelerated as the crop developed. In conventional crops, the herbicides were given mostly near sowing and got rid of the peak of emergence but not generally the later population, which would then grow to plants of moderate size, mostly below the crop canopy, but still capable of re-seeding. In beet and oilseed rape, GMHT knocked out this later population. Any plants that survived, or germinated even later in the crop, were smaller at harvest and produced no or less seed. The reverse was true of maize, but whether this will hold when the triazine herbicides are no longer used is the subject of further study.

The most general lesson from the FSE is that measurements systematically targeted and applied can detect shifts in the food web caused by change in crop variety or management. Equally instructive was that the primary effect on the weed flora was transmitted to primary consumers, the herbivores and detritus feeders, and their consumers[10]. The FSE was unique in examining and detecting such changes on a large scale before a technology was deployed commercially. The published papers stressed that the effects of GMHT cropping were small compared to the difference in biodiversity between the crop species, and that the overall impact of GMHT cropping on food webs would depend on the rotation, the landscape and other changes in management. Proponents of the technology said that other field practice could readily change to compensate, or that using GMHT crops could lessen or reverse intensification in other parts of the cropping cycle. That may be, but such a contention could not be examined by hypothesis-driven experiment. Nor does recent history support the view that farming is likely to compensate voluntarily to balance the requirements of yield and food webs. 'Winter' cropping was adopted over most of GB, as were the many new types of herbicide and their increasing usage. More likely is that a cheap and effective remedy would be used to despatch the last remnants of the weed flora. Except in a few pockets, the decline of the in-field food web would accelerate. This notwithstanding, matters of predictive up-scaling are as important as the primary result and are still being examined.

GMOs in the environment The FSE also heightened attention on geneflow and the persistence of crop-derived traits in the field. This mattered most for oilseed rape, which persists as seed in fields and waysides, and is outcrossing, so exchanges genes over distance. Two main issues had to be resolved – the movement of genes from a crop to a feral or wild relative (e.g. herbicide tolerance in a weed population) and the occurrence of a GM trait in seed as an impurity in yield.

Comprehensive studies of cross pollination and its effects are rare over large scales in rural environments. From exploratory research in the UK, some biotechnologist and policy advisers had tended to understate,

and some activists to overstate, the distance that pollen moves and the time seeds and populations persist in the soil. Hard facts from realistic environments were needed to inform the debate and SCRI was able to provide these through combining its expertise in genetics, statistics, physiology and modelling. By the mid-1990s, SCRI had established itself in this area through competitive contracts on the transmission and persistence of genetic material in oilseed rape. Our approach was to measure the decline of the pollen and seed over distance and time and report the results without favouring any particular stance. Notably, the recent comprehensive studies of geneflow by Gavin Ramsay and Caroline Thompson have set standards in regional or large-scale estimates[11]. It was necessary in this work to establish a zero-point (for example, the distance from a large pollen source at which no geneflow is detected) in order to be able to confirm that low frequencies of pollination were in fact real (and not false positives). However, a zero point was not found even after several kilometres, and it is likely that zero cross-pollination (one field to another) will be rare among oilseed rape fields in the arable regions of the UK. Despite careful wording in reports to emphasise the uncertainties in measuring rare events, it is inevitable that some of the press and various protagonists will latch on to particular distances and persistence times and display them out of context. SCRI's uncompromising stance has nevertheless been appreciated by serious commentators. In response to results in the mid-1990s, the MP and writer on science, Tam Dalyell, asked whether a particular enquiry had taken account of the long-distance outcrossing found by SCRI. Our more recent studies are influencing debate and legislation in the UK and Europe.

The persistence of oilseed rape as seed and feral populations will probably have more effect and consequences than will outcrossing through pollination. The rise of oilseed rape as a break crop since the 1970s is providing a rare opportunity to observe these new genotypes and phenotypes entering and diversifying in a cropped habitat. Even in winter here, feral seedlings emerge and second-year plants flower and fruit in local field-margins and waysides, in contrast to those established Cruciferae of similar architecture, *Sinapis* and *Sisymbrium*, that usually stay dormant for the winter. That feral oilseed rape can persist over ten years in disturbed habitats and waysides should not now be seriously questioned. Their effect on other plant populations is probably going to be slight: they will not be 'superweeds'. The difficulty for farmers is that the populations persisting in fields typically occur at around 100 m^{-2}, which (though a small fraction of the whole seedbank) is close to the stand-density of the crop, so even if 1 m^{-2} emerges in any future crop, it could cause impurity of 1%[12]. What is very uncertain is why its persistence is so variable between sites. The contributions of the genetics of the founder variety, the management and the local physical conditions have to be unravelled, and some progress will be possible by assessing persistence at the FSE sites.

Is coexistence between GM and non-GM feasible? While giving evidence to a committee of the Scottish Parliament[13], David Robinson of SCRI emphasised the argument that a type of crop or food can never be judged absolutely safe, since it is judged safe for practical purposes by showing the absence of harm under the conditions of the tests. People could go on for ever arguing that a foodstuff is unsafe. I do not believe that, for example, cooking-oil made from GMHT food-grade oilseed rape is harmful to eat. And I believe the same is largely true for other GM crops grown for food: at least, it is not their GM-ness that influences whether they are safe or not. To my mind, setting, and buying to, a threshold of impurity is mostly therefore for choice, not necessity, and the implications are economic, not environmental. If a farmer markets non-GM oilseed rape but their crop gets an impurity, then they lose money if they can't sell the crop.

We had direct experience of measuring and modelling impurities through traits that were introduced to both conventional and GMHT crops sown in the FSE. In the first instance, glyphosate-tolerance was introduced at low frequency in conventional oilseed rape. There was no issue of harm or benefit to environment or health. One of our crops on the research farm at SCRI contained the impurity, and we gained unique knowledge of its spatial distribution (mostly clumped around the GM mother plants) and its population dynamics. There was the usual clamour to disband the FSE after this impurity was announced and even more strident protestations after small amounts of seed with antibiotic resistance were discovered in GMHT seed lots by routine testing of GM trial seed. The impurities would have very minor ecological effects in these circumstances. The knowledge lost would have been considerable and detrimental to the debate. There were no logical reasons for disbanding the experiment.

Science meets reality In mid-2003, we were asked to advise on the real matter of sowing oilseed rape in fields used previously as FSE sites. We had been reporting to Defra on the decline rates of feral (volunteer) oilseed rape in fields[12]. An exhaustive review of existing data and thousands of simulations all indicated that sowing oilseed rape only two years after the GMHT crops could not guarantee meeting a threshold of around 1%, and certainly not the proposed threshold of 0.5% which the EU was considering for plants used in experiments such as the FSE. To meet the threshold of 0.5%, for instance, the feral weeds would have to emerge at less than 1 plant in 2 square metres of the rapeseed crop. This was unlikely at many sites after only two years, but we could not predict then which sites would meet the threshold and which not. Defra accepted our advice and asked the companies and the FSE farmers not to sow oilseed rape that year. I accept that we stuck our necks out on this one, and despite the ear-bashings from various interests, we had the confidence of having examined and re-worked all available knowledge. The question will be asked again.

Research over many years, and very much within the rough and tumble of the arable scene, leads us to conclude that (generally) outcrossing is too low between fields to prevent coexistence between GM and non-GM oilseed rape if the industry works to some reasonable threshold around 1%. In contrast, persistence of feral (volunteer) populations in fields is too great to allow rapid switching between GM and non-GM cropping in a field and achieve the same threshold with any certainty. It is not that impurities from volunteers cannot be reduced below 1% - they certainly can - but that a farmer should have doubt that it could be done within a reasonable time, say 5 years. This only applies to oilseed rape, and judgements have to be made by crop: maize, for instance, leaves no feral populations in GB. Our studies in coexistence will now be taken forward as a partner in a EU project, which aims to bring together similar work on outcrossing and persistence across Europe, and includes countries having a wide range of environments, crops and cropping patterns.

Activism and damage to sites The FSE team was often asked what effect damage through protest had on the results and their interpretation. The simplest answer is very little, in terms of data lost. Intentional damage reduced the base of knowledge, but nowhere near to the point where replication was compromised.

Activism during the FSE was broad and varied in its intent and methods. We met groups and individuals who were highly committed to environmentalist causes, felt strongly about the creation of transgenic organisms or about the increased pressure on ecosystems, and tried to influence government policy rather than take direct action. There was also a "toffs with machetes" element to protest, a branch of activism that will fade, having no ideological or material base, much as mods and rockers no longer torment seaside towns in England. More widely, the national and multi-national activist groups did little to advance the causes of environmentalism. There was much posturing and position-taking among their representatives in GB but little of the environmental rationales of Fraser Darling[14] or Schumacher[15], of the political realism of Brandt[16] or the spiritual logic of Tenzin Gyatso[17]. Activism's establishment achieved little more than deflecting the public's attention from the important matter that, here for the first time, was an attempt to examine potential ecological impacts before a technology was introduced commercially. Activism also targeted many of the wrong people – family farms and young scientists included, many of whom are now dismissive of its tactics.

None of the FSE consortium suffered physical attacks (to my knowledge), or attacks on personal property, though some farmers did. The senior members of the consortium had their share of verbal abuse at public meetings, but even then I do not think the attacks were personal – in that you might be called a liar, mealy-mouthed, a cheat and so on, but it was mostly part of the activist game and not directed at you standing there. They would have said the same things whether you were there or not. Did the constant ridiculing through the media and internet affect morale in the FSE team? In some instances it did, but they were few. My younger colleagues at SCRI have a robust attitude to insult. At the few sites that did sustain repetitive damage, the plan was always to continue the sequence of measurements. It supported the farmers and gave least satisfaction to the damagers. By the end of the trials, many in the research group viewed routine, activist damaged much the same as they would bad weather – just another layer of environmental noise. As I have said, some of the farmers had a much harder time.

Peer review and reception of the first results The matter of peer review was also brought before the public and the media – that scientific papers are sub-

mitted to a journal, which has them scrutinised by experts in the subject, then rejects or accepts them. The Royal Society issued an explanation of the process of peer review[18], but while it stated that rejection did not necessarily mean that a work was inherently flawed, it was clear that collectively we had to achieve the standard for acceptance.

Peer review takes time. It was much faster for the media, working with activism, to fund some measurements and put out the results to greatest effect without any independent, critical review. This happened near the beginning of the experiments, when a national television news programme led on a story they had commissioned on pollen moving out from one of the FSE fields. The revelations were mostly existing knowledge, repackaged and sensationalised. If any of the scientists had so published without peer review, they should have been severely reprimanded, at least. We learned that even what appear to be authoritative news programmes take a line on issues!

How were the results of October 2003 received? In the UK, the GM Science Review[19] and the Advisory Committee on Releases to the Environment (ACRE)[20] endorsed the study and the findings. The response from EU member states has generally been constructive. Several countries have taken an interest in the results of both the food web and geneflow studies. Some states, notably Denmark, had considered all available information and put in place their own resolution to possible conflict[21]. We have advised commissions in other countries, including Sweden and France. Opinion from the UK's media on the conduct of the experiment and its findings was generally good: there was sufficient detail reported below the headlines to show that many journalists had taken the publication of results seriously. The headlines were mostly anti-GM, which distressed many biotechnologists. Some threw a few punches at the science of the FSE itself, but more reasoned reactions asked why the results had been so sensationally interpreted by the media[24]. The reasons for this are complex: biotechnology is still invisible and fearful to many people, and some of its proponents are dismissive when challenged. I support Joe Perry's reaction[22] to the 114 scientists who signed a letter to the Prime Minister deploring the headlines and asking for a rational response by government[23]. Where had such numbers been (we ask) while the FSE scientists were being thrashed in public, defending the right to do the field work on GMHT technology? If as scientists, we are not prepared to get out and talk to people, to convince them, then we should complain less when the public object.

More of substance to us was the criticism that the FSE had not measured everything or even not measured the right things[24]. It measured the things that were important for assessing GMHT cropping in GB at that time. Bulk offtake, as yield, was not measured. Rather, the mechanistic link between the crop and the food web was assessed through detailed measurements of the crop, its development, gross architecture, herbivores and their specialist consumers, all of which confirmed that the field management rather than the GM-ness of the crops affected the wider food web. The consortium nevertheless welcomed debate on what it had and had not measured: these are issues for the future.

Unintended outcomes The tactic by certain activist and media interests of attacking one or other senior members of the FSE group was not an effective means of deconstructing the research programme. Admittedly, it sometimes put great stress on the person, sometimes causing their wellbeing to suffer. The more general result of the pressures on the FSE was a strengthening of trust and dependence between colleagues and institutes. This in itself was good for the conduct of the science, since the work, and particularly the analysis of the results, was done in secrecy. There was no opportunity during the FSE to expose our thinking and early data in the semi-public arena of the scientific workshop. Not even the civil servants in Defra, nor the heads of the three research organisations knew the result. The scientists themselves, supported by members of the Steering Committee, simply had to get it right, and we were aided in this because circumstances had already forced us to rely on each other. We also demonstrated that a virtual project was feasible, where the science of the project, and the colleagues doing it, operated through web contact almost independently of the organisations. Of course, we relied on the infrastructure and expertise of the parent institutes, but once given the money and task, members of the groups got on with it, completed it and shared much more with each other than they would normally have done in a standard multi-partner project. More widely, the FSE and other studies in Europe have generated a research community which has a broad, holistic, agenda that combines many disciplines in basic and applied science. This community offers the potential to nurture young scientists and

technicians, challenging their intellects and manipulative skills by major problems that are not narrow in discipline or technique.

The outcome and launch of the results relieved the pressure from journalists and public. There has since been less of a tendency for enquirers to assume we are going to lie or obfuscate. The following quote from the *New Scientist* magazine is welcome: "The green groups claimed the experiment was biased and the researchers were in the pocket of the biotech industry. It wasn't, and they weren't." However, such comment should not simply be accepted because it is commendatory. I suspect that fewer positive comments on the conduct and competence of the researchers would have been made if the GMHT cropping had shown strong positive effects on the arable food web, yet the conduct of the study would have been the same. Publicly funded science still has a task to convince people that it is not swayed by this or that global interest. Independence and security of funding are essential.

Some conclusions and next steps Many commentators see the FSE as having ended with the launch of the results for the spring-sown crops. This is not so. The results for autumn-sown (winter) oilseed rape, by far the main break crop in the UK, are a year later than the spring-sown crops, and will be analysed and completed in 2004. Carry-over effects on plant populations, particularly of the buried seed, and decline rates of the GM and conventional seed residues will continue to be measured. Analysis is in progress on outcrossing from GMHT crops to surrounding populations and fields during 2002 and 2003. The FSE group is working on the important matter of up-scaling the results to address 'what if' questions (e.g. what would be the effect on arable biodiversity as a whole if most break crops were GMHT?).

The FSE has shown that major ecological questions are tractable; that well designed and well executed experiments can sift the background noise to leave quite small effects of treatment. Given this, it is feasible to define general and widespread features of a sustainable arable system and determine which biotechnology best fits the habitat. Moreover, all new technology should be considered before it is implemented – certainly not just GM technology - and we should be able to move forward with less confrontation and position-taking than has been the case around the FSE. This far, the ecological effects of cropping with GM herbicide-tolerant varieties appear small, but by no means negligible, compared to many other factors of intensification and global change affecting the habitat's capacity to hold and recycle energy and nutrients. Was it worth it? Certainly, for the science, for the good colleagues, for the experience of the farms and farmers! Perhaps most rewarding for me is the knowledge that arable field systems are still potentially biologically rich and could be managed to balance yield and food web.

Acknowledgements

The FSE research group publicly thanked the civil servants, the companies, the Steering Committee, and the farmers for their essential contributions[25]. I personally thank my FSE colleagues at SCRI (particularly Dr Cathy Hawes), CEH and Rothamsted Research, and the Director of SCRI, Professor John Hillman, who from inception of the study in 1999 to the first publication in October 2003 gave undiminished trust and support (without pressing me to tell him the results in advance of the launch!).

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