NOTE TO ACRE ON THE FARM SCALE EVALUATIONS BY THE GM SCIENCE REVIEW PANEL – DECEMBER 2003

1 Introduction

This note briefly describes the research and some of the findings reported by the Farm-scale Evaluation (FSE) research team. This is followed by the Panel's interpretation of the evidence, followed by commentary on the broad implications of this work.

2 The Issue

In Section 6.5 of the First Report of the Science Review, the Panel drew attention to a lack of detailed knowledge of the potential impacts on biodiversity following the introduction of GM herbicide tolerant (GMHT) crops. Studies that systematically compared the effects of GMHT and conventional management regimes were available, but usually confined to small-scale studies at research stations or observations in commercial fields. At least five studies had shown that using GMHT crops generally increased the efficiency and reliability of weed control in maize, beet, and oilseed rape (Read & Bush 1998, Strandberg & Pederson 2002, Wevers 1998, Read & Ball 1999a, Read & Ball 1999b). Only one commentary (Firbank & Forcella 2000) suggested that weed control was sometimes less efficient than conventional methods when GMHT varieties were used. The Panel also raised the possibility that the use of GMHT cropping systems could have an impact on spray damage to field boundary and hedgerow biodiversity.

The First Report also drew attention to potential impacts of GMHT cropping on taxa other than plants. In this case, there was little scientific information, although some research was available on possible impacts of delayed herbicide spraying of GMHT crops on insect populations. A modelling study had investigated potential impacts of changes in herbicide use associated with GMHT crops upon skylarks.

Section 6.5 of our First Report identified as an important issue whether GMHT management would be more or less harmful to wildlife than conventional cropping, and posed the key questions:

> "Will delayed herbicide applications in GMHT crops allow more weeds, more invertebrates and, for example, improved breeding productivity of birds? Or will the efficiency and reliability of weed control mean fewer resources for seed predators such as granivorous birds, and declining weed populations in the long term?"

In Section 6.5.4 of the First Report, we reported that there is general agreement that there have been substantial declines in biodiversity in the UK in recent decades and that the evidence is stronger for birds and plants than for invertebrates. However, there is growing scientific acceptance that these declines have been caused by agricultural intensification. We noted that there is less evidence (particularly environmental evidence), and therefore less general agreement, to indicate the relative contributions of herbicides *per se* in these declines;

but that there is, however, general agreement that declines in weed seed resources have played a major role in the dramatic declines of seed-eating farmland birds.

In Section 6.5.7, the Panel looked forward to the outcome of the UK government-funded FSEs of GMHT crops to help resolve this issue. This study has been running for four years, investigating the impacts on biodiversity of herbicide regimes associated with GMHT maize, beet and oilseed rape compared to herbicide application on non GM crops. The results of the studies on spring-sown varieties of these crops are now available; the results of research on winter-sown oilseed rape to follow next year.

3 The Research

The FSEs are the largest manipulative experiment ever carried out on farmland ecology anywhere in the world, exceeding by more than threefold any comparable experiment undertaken previously (Perry *et al*. 2003). The researchers, a consortium of experienced ecologists and statisticians overseen by an independent steering committee, organised the planting of 273 trial fields around England, Wales and Scotland. Data from 201 fields were eventually used in the final analyses. Each field was divided into two: half was sown with the GMHT crop and half with its conventional equivalent. To avoid experimental bias, treatments were allocated randomly to field halves. Farmers managed the fields using their normal herbicide regime on the conventional half, and a spray regime on the GMHT part that was consistent with cost-effective weed control, based on recommendations from agrochemical manufacturers and an industry body, SCIMAC. The researchers checked that these management practices were being carried out properly, and that herbicide applications on the conventional parts of fields represented normal farming practice.

Crops were grown as part of farmers' normal crop rotations. These three crops are 'break' crops, usually grown as part of a rotation that includes other crops such as wheat or barley. This means that the GM crop was often grown for only one year in a specific field, with the exception of a few maize sites where continuous cropping was practised.

Within the fields, researchers measured weed diversity and abundance, seed rain and weed seed banks. Assessments were also made of weed seed banks and weed seedlings in plots following the GMHT management. Within the crops, various standard methods were used to assess the relative abundance and diversity of invertebrates, including slugs and snails, insects and spiders. Bee and butterfly transects were also used to assess the foraging preferences of these insects. Plants and invertebrates were also assessed in field margins, field verges and in field boundaries such as hedges and ditches where these were present. Estimates of crop cover and development were also made to assess whether any differences between the characteristics of the GM and conventional crops *per se* could be affecting the results.

The strengths of this experimental design are:

- High statistical power derived from the large number of sites and split field design. This meant that the experiment was able to detect relative small changes in numbers of organisms affected by the different herbicide applications. The overall size of the trials was determined by a 'power analysis'. This used existing data on weed and invertebrate numbers and their variability to arrive at a target of 65 fields for each crop type. The targets were met over the duration of the experiment. The numbers of fields were set to detect over 80% of 1.5 fold differences in abundance between treatments at a statistically significant level; in the event 82% of such differences were significant, fully in line with the targets.

- The wide variety of organisms sampled and measured (1.5 million invertebrates and 0.5 million seeds). Statistical analyses were not only able to detect variation in different taxa between treatments, but could also be analysed by looking at the effects of treatments on species grouped by trophic (feeding) level, revealing impacts on food webs.

- Field management was carried out by a group of farmers representative of the range of cropping practices used in different regions of the UK. This was more likely to reflect the realities of any commercial introduction of GMHT crops than previous small-scale experiments confined to research stations.

- A wide variety of sites reflecting different farming intensities were selected over a wide geographic range, spread over several years with varying weather conditions.

4 The Results

The results were published in October 2003 as a series of papers in a theme issue of the *Philosophical Transactions of the Royal Society* (Squire *et al*. 2003; Champion *et al.* 2003; Heard *et al.* 2003a & 2003b; Brookes *et al.* 2003; Haughton *et al.* 2003; Roy *et al.* 2003; Hawes *et al.* 2003). This group has also published a commentary on the implications of their work (ISBN 0-85521-036-2).

The results were remarkably consistent and clear. The results showed overall, that animal and plant life was most abundant in conventional oilseed rape fields, with more butterflies, weeds and seeds in these fields than in those of GMHT rape, where a different herbicide was used. A similar picture emerged for biodiversity in beet fields, but here bees were significantly less abundant on the GMHT side. There were, however, more springtails, small insects feeding on plant debris, in GMHT beet and rape fields in summer than in the conventional fields. The research showed that these were feeding on dead weeds after the GM crops had been sprayed. A ground beetle that feeds on springtails was also more abundant in the GMHT beet and rape fields.

In maize fields a contrasting picture has emerged from the research. Conventional maize fields (where a powerful residual herbicide, atrazine, is commonly used) were found to be the least abundant in animal and plant life, with relatively more weeds, seeds, and insects occurring in the GMHT maize.

These results were consistent not only from year-to-year but also from area-to-area, indicating that how farmers manage their fields has a far greater effect on biodiversity than variations in weather or soil-type. The results showed that conventional beet and spring rape crops were in general, more abundant in plants, seeds and animals than the GMHT crops because the broad-spectrum herbicides used on the GM crops were more effective at controlling weeds than the selective herbicides used on conventional crops. Conversely, the residual herbicide regimes used in conventional maize are more effective, in general, at controlling weeds than the broad-spectrum herbicide applied over the GMHT maize.

Analysis of the impacts of the different herbicides on trophic levels within fields demonstrated that effects on weeds were reflected through food webs, with reductions in weeds causing, reductions in invertebrates feeding on plants and consequent reductions in predators, although not all the organisms sampled in these studies were studied declined. In maize and oilseed rape fields, the effects of GMHT management regimes on invertebrates were less marked than in beet.

Field margins can support a high diversity of plant species and are important for conservation within farmed landscapes in Europe. Margin vegetation was recorded in three components of the field margin. No marked effects of GMHT crops were found on plants and invertebrates living in the field verge or boundary. Effects in the tilled margins of fields were similar to those recorded within the crop, as they were subject to the same herbicide regimes. There was a significant reduction in seed-producing weeds, flowering plants and butterflies (in July) in the tilled margins of GMHT beet and oilseed rape. The effect was reversed in maize fields, where significant increases in weeds and flowering plants were recorded in the margins of GMHT fields. Effects on butterflies mirrored the effects on vegetation. The likely cause is the lower nectar supply in GMHT field margins and cropped edges. Few large differences were found for bees, gastropods or other invertebrates. Scorching of vegetation by herbicide spray drift was significantly higher on field verges adjacent to all three GMHT crops, although the areas affected were very small in relation to the total length of verge.

Figure 1 provides a star plot containing mean values of major biodiversity indicators across conventional and GMHT of beet, maize and spring oilseed rape.

5 The Panel's View on the Quality of the Evidence from the FSEs

The FSEs are one of the largest ecological experiments that have taken place on farmland. The Panel agrees that the data sets produced by this research are unusually large and that the statistical methods used both for design and analyses were valid and robust. The FSEs give a clear picture of the changes in biodiversity caused by the different herbicide regimes used on GMHT and conventional crops of maize, beet and spring oilseed rape.

The design of the FSE experiments attempted to capture the current range and intensities of farming practices across the UK. Given that the sites used in these experiments varied greatly in species composition, geographic location and crop management, the Panel agrees that the effects of GMHT management on biodiversity are a fair representation of what would actually happen if widespread adoption of GMHT crops and weed management regimes were to take place as set out in the FSEs.

The researchers conclude that because there were significant differences between treatments for each crop, but the effects were not the same for each crop, there was no evidence that treatment effects had arisen because the crops had been produced using transgenic technology. In addition, there were no significant effects on crop pests (rather than those that lived on weeds) suggesting that the crop itself had no effect on invertebrates. They showed that the differences could be explained entirely by the effects of contrasting herbicide regimes used on GMHT and conventional crops. The Panel agrees with this. It therefore notes that the conclusions of the experiment would apply equally if herbicide tolerance were to be introduced into these crops using other forms of plant breeding, such as mutation breeding or marker-assisted breeding that are not regulated in the same way as transgenic technologies.

6 Implications for Farmland Biodiversity

What we know

The results show that the adoption of GMHT beet and oilseed rape, if managed as they were in the FSEs, would result in fewer weeds, seeds, butterflies and bees (bee activity was only significantly lower in beet) in and around these fields. Not only was there a significant reduction in weeds in these crops, but also a large reduction in weed seed production and return of seeds to the soil, especially seeds from broad-leaved plants. These differences, if compounded over time, could result in a large decrease in population densities of arable weeds. On the basis of the available seed bank data, Heard *et al. (2003b)* conclude that there is the potential for an accelerated decline in the abundance of weed seed species under GMHT beet and spring oilseed rape management, in the order of an additional 7% per year for arable rotations[1], over and above the current generally accepted annual 3% decline in weed seed banks in the UK since the 1940s.

The results are clear and show that overall, GMHT beet and spring oilseed rape crops, if managed as they were in the FSEs, would provide fewer nectar resources for pollinating insects (bees and butterflies) and fewer weed seed resources for granivorous birds.

By contrast, GMHT maize resulted in more weeds in this crop in summer. This could result in more food resources for birds in and around GMHT maize fields, and raises the prospect of leaving weedy stubbles following maize cultivation, with potential benefits to wintering wildlife. Weedy stubbles do not usually result from our current atrazine-based weed control in conventional maize.

Uncertainty

The main uncertainties that remain concerning the impact of these GMHT crops on farmland biodiversity (were they to be given commercial approval in the EU) are the degree of uptake of the crops by farmers (acreage and distribution); the nature of the farms involved (e.g. would participating farmers tend to be from farms with current high or low weed burdens?); and how closely any future management of these crops mimic those studied in the FSEs (e.g. in particular, the similarity or otherwise of herbicide regimes). The significance of the impact on wildlife will also be dependent upon the wider landscape setting.

It is therefore not possible to predict the scale of potential effects at the current time. However, the evidence from the FSEs suggest that the herbicide regime associated with the large scale cropping of GMHT maize, compared with conventional maize, could be of benefit to farmland wildlife, with increased levels of weeds that may be of value to granivorous birds, whereas those associated with GMHT cropping of beet and spring oilseed rape will be of disbenefit compared with the conventional crops, providing fewer nectar resources for pollinators and fewer weed seed resources for granivorous birds.

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[1] In a five course cereal rotation with a break crop grown every 5 years (e.g. *Watkinson et al.* 2000).

It would be useful to develop ecological models using the raw data from the FSEs to investigate these issues further.

7 Looking to the Future (What are the Potential Developments in this Area and Do They Affect the Panel's Conclusions?)

The interpretation of the maize results has been complicated somewhat by the recent announcement that atrazine will be banned within the EU because of its unfavourable environmental profile. Atrazine, a residual herbicide, was the most commonly used weed killer on conventional maize in the FSEs. It is possible that the herbicides that replace atrazine in maize will be as effective in weed control, but it is also possible that they will not. Further analysis to compare the biodiversity impacts of the GMHT maize management with the few conventionally cropped fields where atrazine was not used might be informative but, because of the low numbers of these fields, this may not be statistically sufficient.

The FSEs not only gave a clear and consistent answer to the important issue of impacts on biodiversity of GMHT cropping identified in our First Report, but also gave a deep insight into the wildlife that lives in and around the crops tested (Figure 1). This experiment was the first time that the impact on biodiversity of a novel cropping system has been assessed *before* large-scale commercial use of the system. The experimental protocol could be used not only to assess the wildlife impacts of future cropping systems but could also be used to look at the long-term impacts of existing systems such as winter cropping and general agrochemical applications on farmed land. The methods used in the FSEs could be used for example to assess the indirect impacts of herbicides and other agrochemicals used in conventional cropping, or to compare the biodiversity associated with conventional cropping to that in organic systems or other farming approaches such as integrated pest management (IPM). Analysis of the FSE data may suggest some alternative smaller-scale approaches for the future.

There have been vast changes to agricultural practice over the last 50 years – changes in crops, in, farm management, rotations, change to autumn sown and spring sown crops. It is important to place GMHT crops in the context of past and future changes. The FSE data, and more that will follow, offer modelling opportunities to assess the longer term and large-scale implications of this work, and will contribute to informing debate on broader agricultural issues related to societal choices and the balance of natural resources.

Looking at the broad context, the results underscore how crop production and wildlife are irrevocably linked in farming. These trials give numerical possibilities in allowing us to measure, interpret and manipulate the balance between resources for human beings and for wildlife. Striking the balance between the landscapes we want and the food we need is a much broader issue that is beyond the immediate context of this review and would need to consider changes in crop rotation practice, hedge and headland management and a broad range of wildlife stewardship objectives.

8 Conclusions

If all else remains constant and the three crops are introduced and managed in the way they were in the trials, then for GMHT beet and spring oilseed rape a significant reduction would be expected in weed biomass and weed seed return resulting in fewer nectar resources for pollinators and fewer weed seed resources for granivorous birds. For GMHT maize the opposite is expected. These effects arise from the crop management regimes associated with these GMHT crops (i.e. the herbicide application) and are not a direct consequence of the way the crops have been bred.

These data, and more that will follow, offer modelling opportunities to assess the longer-term and large-scale implications of this work, and will contribute to inform debate on broader agricultural issues related to societal choices and the balance of natural resources.

9 Relevance to Other Parts of Our First Report

Herbicide applications, loads and effects

As mentioned in the First Report, there is no clear relationship between amounts of herbicide and biodiversity impact (Section 6.5.3). The FSE results provide an example where less herbicide was added to the GMHT beet and oilseed rape compared with the non-GM counterparts yet the impacts on certain classes of wildlife were greater.

In Section 6.5.6, of the First Report, we identified a gap in knowledge in terms of information on number of applications; the number of active ingredients used and the number of tractor passes needed, in comparison to conventional weed control systems. Evidence from North America was equivocal. For example, a review of various studies on glyphosate-resistant soybean cropping showed results varying between a 7% increase and a 40% decrease in total herbicide use with the HT crop (Hin *et. al.* 2001). The fewer passes over fields brings with it other potential environmental benefits such as reduced energy costs and emissions. The Panel noted that the herbicide cropping regimes for the GM HT varieties in the FSEs required lower inputs to achieve similar or greater levels of weed reduction in terms of numbers of active ingredients and tractor passes. The reductions in the application of these chemicals may have advantages[2].

Relationship to other studies

In the First Report the potential benefits of the GMHT herbicide regimes in terms of simplicity of weed control, the flexibility of weed control and potential benefits and biodiversity gains were discussed (Section 6.5.3). Two separate studies (Strandberg & Pedersen 2002; Dewar *et al.* 2003) considered in our First Report (Section 6.5.3) suggested that by using GMHT beet, applications of broad spectrum herbicides could be delayed, leaving weeds in the fields for longer. It was suggested that this might benefit farmland birds because more weeds would yield more invertebrates for them to eat. The FSEs did not test this, because farmers were managing the GM parts of the fields to optimise crop yield, not biodiversity, and applied the herbicides earlier in the season. In these parts of the FSE fields, compared to the conventional parts, there were more springtails and their predators feeding on decaying weeds, but these occurred in late summer when breeding birds' chicks would be unlikely to be feeding in the fields. There was also very little weed seed available for

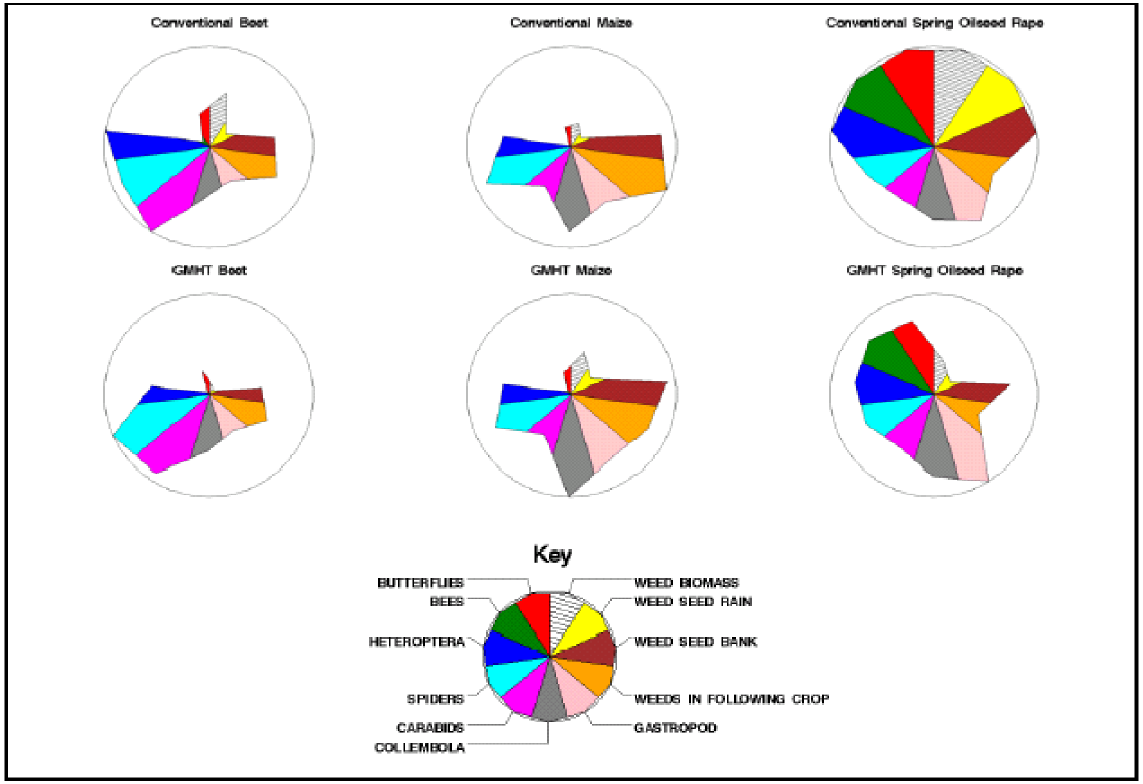
[2] E.g. environmental life cycle analyses might show energy savings, for example, in herbicide production, or fuel usage in tractor passes, or emissions. Organic farming may offer similar advantages over conventional systems.

wintering birds in the GMHT beet because although weeds were killed later than in conventional beet, mortality occurred before they had set seed.

Case-by-case assessment

Growing GMHT beet and oilseed rape had similar impacts on biodiversity despite the fact that they carried transgenes giving tolerance to two different herbicides, with beet tolerant to glyphosate, a translocated herbicide, and oilseed rape tolerant to glufosinate, a contact herbicide. That the conclusions of these experiments were different for different crops with GMHT traits reinforces our general conclusion in our First Report that impacts of GM crops must always be assessed case-by-case.

Figure 1[3]:
Star plots comparing mean values of major biodiversity indicators across conventional and GMHT treatments of beet, maize and spring oilseed rape crops. For each indicator, the length of the star corresponds to the value relative to the maximum value found in any of the six combinations of crop and treatment; for example, the most gastropods were found in GMHT spring oilseed rape. The key diagram shows which section of the star plots star relates to which indicator.



[3] Reproduced with kind permission from Les Firbank from: 'The implications of spring-sown genetically modified herbicide-tolerant crops for farmland biodiversity: A commentary on the Farm Scale Evaluations of Spring Sown Crops' by L.G. Firbank *et. al*.

References

Brooks DR, Bohan DA, Champion GT, Haughton AJ, Hawes C, Heard MS, Clark SJ, Dewar AM, Firbank LG, Perry JN, Rothery P, Scott RJ, Woiwod IP, Birchall C, Skellern MP, Walker JH, Baker P, Bell D, Browne EL, Dewar AJG, Fairfax CM, Garner BH, Haylock LA, Horne SL, Hulmes SE, Mason NS, Norton LR, Nuttall P, Randle Z, Rossall MJ, Sands RJN, Singer EJ & Walker MJ. 2003. Invertebrate responses to the management of genetically modified herbicide-tolerant and conventional spring crops. I. Soil-surface-active invertebrates. *Phil. Trans, R. Soc. Lond. B* **358**, 1847-1862.

Burke M. 2003. GM crops: Effects on wildlife. ISBN 0-85521-035-4

Champion GT, May MJ, Bennett S, Brooks DR, Clark SJ, Daniels RE, Firbank LG, Haughton AJ, Hawes C, Heard MS, Perry JN, Randle Z, Rossall MJ, Rothery P, Skellern MP, Scott RJ, Squire GR & Thomas MR. 2003. Crop management and agronomic context of the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Phil. Trans, R. Soc. Lond. B* **358**, 1801-1818.

Firbank LG & Forcella F. 2000. Genetically modified crops and farmland biodiversity. *Science*, **289**, 1481-1482.

Haughton AJ, Champion GT, Hawes C, Heard MS, Brooks DR, Bohan DA, Clark SJ, Dewar AM, Firbank LG, Osborne JL, Perry JN, Rothery P, Roy DB, Scott RJ, Woiwod IP, Birchall C, Skellern MP, Walker JH, Baker P, Browne EL, Dewar AJG, Garner BH, Haylock LA, Horne SL & Mason NS. 2003. Invertebrate responses to the management of genetically modified herbicide-tolerant and conventional spring crops. II. Within-field epigeal and aerial arthropods. *Phil. Trans, R. Soc. Lond. B* **358**, 1863-1877.

Hawes C, Haughton AJ, Osborne JL, Roy DB, Clark SJ, Perry JN, Rothery P, Bohan DA, Brooks DR, Champion GT, Dewar AM, Heard MS, Woiwod IP, Daniels RE, Young MW, Parish AM, Scott RJ, Firbank LG & Squire GR. 2003. Responses of plants and invertebrate trophic groups to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Phil. Trans, R. Soc. Lond. B* **358**, 1899-1913.

Heard MS, Hawes C, Champion GT, Clark SJ, Firbank LG, Haughton AJ, Parish AM, Perry JN, Rothery P, Scott RJ, Skellern MP, Squire GR & Hill MO. 2003a. Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. I. Effects on abundance and diversity. *Phil. Trans, R. Soc. Lond. B* **358**, 1819-1832.

Heard MS, Hawes C, Champion GT, Clark SJ, Firbank LG, Haughton AJ, Parish AM, Perry JN, Rothery P, Roy DB, Scott RJ, Skellern MP, Squire GR & Hill MO. 2003b. Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. II. Effects on individual species. *Phil. Trans, R. Soc. Lond. B* **358**, 1833-1846.

Hin CJA, Schenkelaars P & Pak GA. 2001. *Agronomic and environmental impacts of the commercial cultivation of glyphosate tolerant soybean in the USA.* Utrecht: Centre for Agriculture and Environment (CLM).

Perry JN, Rothery P, Clark SJ, Heard MS & Hawes C. 2003. Design, analysis and statistical power of the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. *J. Appl. Ecol*. **40**, 17-31.

Read MA & Ball JG. 1999a. *The control of weeds with glufosinate ammonium in genetically modified crops of forage maize in the UK.* Proceedings of BCPC Conference, Weeds 1999, 847-852, British Crop Protection Council.

Read MA & Ball JG. 1999b. Control of weeds in genetically modified crops of winter and spring oilseed rape with glufosinate ammonium in the UK. *Aspects of Applied Biology*, **55***,* 27-33.

Read MA & Bush MN. 1998. Control of weeds in genetically modified sugar beet with glufosinate ammonium in the UK. *Aspects of Applied Biology*, **52**, 401-406.

Roy DB, Bohan DA, Haughton AJ, Hill MO, Osborne JL, Clark SJ, Perry JN, Rothery P, Scott RJ, Brooks DR, Champion GT, Hawes C, Heard MS & Firbank LG. 2003. Invertebrates and vegetation of field margins adjacent to crops subject to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Phil. Trans, R. Soc. Lond. B* **358**, 1879-1898.

Squire GR, Brooks DR, Bohan DA, Champion GT, Daniels RE, Haughton AJ, Hawes C, Heard MS, Hill MO, May MJ, Osborne JL, Perry JN, Roy DB, Woiwod IP & Firbank LG. 2003. On the rationale and interpretation of the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Phil. Trans, R. Soc. Lond. B* **358**, 1779-1799.

Strandberg B & Pedersen, MB. 2002. Biodiversity in glyphosate tolerant fodder beet fields - timing of herbicide application. Silkeborg: National Environmental Research Institute.

Watkinson AR, Freckleton RP, Robinson RA & Sutherland WJ. 2000. Predictions of biodiversity response to genetically modified herbicide-tolerant crops. *Science* **289**, 1554-1557.

Wevers JDA. 1998. Agronomic and environmental aspects of herbicide-resistant sugar beet in the Netherlands. *Aspects of Applied Biology*, **52**, 393-399.