THE ROYAL SOCIETY

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GM crops, modern agriculture and the environment

Report of a Royal Society Discussion Meeting held on 11 February 2003

Overview

The aim of this meeting was to explore the scientific evidence that exists about the potential impact of Genetically Modified (GM) crops on the UK environment. The ten papers presented at the meeting represent some of the evidence that scientists have collected to date on this subject. The meeting was arranged as a contribution to the UK-wide debate on GM crops, further details of which can be found on DEFRA's website at www.defra.gov.uk/environment/gm/debate/. The meeting was well attended, with over 300 participants and prompted a considerable amount of discussion and debate.

This document summarises the ideas expressed at the meeting and does not necessarily represent the views of the Royal Society. A transcript of the meeting and details of the Society's other activities in this area can be found on the Royal Society's website at www.royalsoc.ac.uk/gmplants.

Summary

The day's meeting was an attempt to put more of the scientific evidence about the potential impact of this technology on the environment into the public arena, so that an informed debate can take place and informed choices about GM can be made. Importantly, the presentations included a context in which to set the GM debate: the environment that modern agriculture has delivered already, described by one speaker as "a disaster for biodiversity". Speakers gave details of the impact modern agricultural practices have had on the British countryside in the last three decades, including the decline in wildflowers, invertebrates and farmland birds. This helped to establish a baseline against which GM agriculture can be compared. Evidence was presented about the likelihood of the spread of GM pollen into wild populations, the risk of superweeds being produced, the impact GM introductions might have on the colonies of micro organisms living in the soil and how such risks can be assessed and analysed. Finally, the potential of GM crops to promote environmentally sustainable agriculture was outlined as well as the potential of GM to deliver new industrial products and to provide increased yields.

An important part of the day was the time given to discussion. Views expressed covered a very broad spectrum of opinion; sometimes going beyond scientific facts and uncertainties and incorporating those who feel that GM is being unfairly demonised, those who are frustrated by the hurdles being put in the way of a technology which promises so much, and those whose fear is that GM will further deplete the UK's biodiversity. Issues that were raised included:

- Is genetic modification the way to meet the increased food needs of the world's burgeoning population? Will the developing world benefit, or will agribusiness in the developed world be the winners?
- Could GM crops become so genetically resilient to pests and disease that they reduce the need for the use of chemicals, so benefiting species like insects and birds? Or will they actually pose a threat to our environment, perhaps as yet unrecognised?

- Might the use of GMOs in agriculture prove so productive that we can actually leave parts of the countryside uncultivated as a haven for wildlife? And if so, would these be interspersed within our fields or in larger nature reserves, and is this what we want? Will GM technology deliver weed-free fields and bird-free skies, where profit is king and the only hum is that of distant tractors; a sterile vision of regimented monoculture and environmental poverty? Will planting GM crops in the fields unleash new breeds of super weeds, GM herbicide resistant invaders running amok across our fields and hillsides?
- Will GM crops offer opportunities for more flexible management such as insect resistant crops that are compatible with integrated pest management, or herbicide tolerant crops that may provide opportunities for leaving weeds in the field for longer?

The participants were in general agreement that the basic question that needs to be answered is what do we want agriculture to deliver? What kind of biodiversity do we want? Only then will it be possible to devise farming systems that deliver our expectations.

Summary of presentations

1) Setting the Scene: The British Countryside 2003, courtesy of modern agriculture

Conventional agriculture and the environment

Modern agriculture has had significant negative impacts on biodiversity in the UK. Three quarters of the British landscape is agricultural land. Big changes over the last century in the way that it is managed have resulted in a decline in plant, invertebrate and bird numbers. The species that have been hardest hit are specialists, which thrive in very particular habitats. Some have become extinct in the wild. These include plants like the corn cockle, once common in arable fields, now found only in wildflower mixtures.

Andrew Watkinson from the University of East Anglia described how modern agriculture has already produced a landscape in which many fields have very few invertebrates and very few weeds, providing little food for other types of wildlife, especially birds. In the course of the 20th century there was a 95% decline in the number of weed seeds in the environment. From 1900 – 1930 there was a range of plants, many of them annuals, which were fairly widespread. By the 1960's some had become very rare, like *Agrostemma githgago*, the corn cockle, which used to be widespread, but has since declined to extinction. All those seen in the countryside now have come from wild flower seed mixes. Other plants that have dwindled in number or disappeared include the cornflower, corn cleavers, and the red hemp nettle and pheasant eye. All are wildflowers associated with arable farming.

There has been a shift in the type of weeds in the fields, with the dwindling of many that are good food sources for birds. A comparison of surveys in 1978 and 1990 reveals that mixed weed and broad-leaved weed communities declined, with an increase in arable fields with grass weeds, like wild oats and black grass. Increasing intensity of field management has led to more fields with just a few scattered weeds and an increase in the number of completely weed-free fields. Insect surveys have not been carried out on the same scale as bird surveys, but those that have been done, by the Game Conservancy Council for example, show many invertebrate populations are in also decline.

How has this happened? No one factor is to blame, rather it is the result of an increase in intensification and specialisation of farming, with a move from mixed farming to a predominance of arable farming in the east and grassland in the west. Two major influences on biodiversity have been the switch from planting spring cereals to planting autumn cereals, meaning an earlier harvest; and the move from cutting grass for hay to the production of silage for animal fodder, meaning more mowing, more reseeding, more fertilising and more tillage. Other factors include the increased quantities of pesticides and herbicides being used on farms and the disappearance of large stretches of hedgerow.

There are signs that since the 1990s the decline in some types of wild life has been slowing, possibly due to incentive schemes to protect the environment. However, as we approach the debate over the potential impact of GM crops on the environment, it needs to be set against this background of a landscape where modern agriculture has already produced a serious decline in biodiversity. Will GM ameliorate or exacerbate the situation? The suspicion is that it could do either; depending on how individual farmers choose to use the technology and manage their farms. In the words of one speaker “if a farmer wants to manage the environment well, he will do so whatever system of farming he uses.”

Ever more silent springs?

A particularly hard hit group of species is farmland birds. Numbers have fallen dramatically in the last 25- 30 years and a broad spectrum of species has been affected including tree sparrow, yellow hammer, barn owl, linnet, lapwing and skylark. The three hardest hit species, the tree sparrow, the corn bunting and the grey partridge, have suffered more than an 80% decline in three decades. Some birds have increased in number, for example woodpigeon, jackdaw and stock dove but these tend to be generalists rather than farmland specialists.

Juliet Vickery of the British Trust for Ornithology showed how modern agriculture has resulted in this drop in bird numbers. It is due to loss of semi natural habitat, changes in and specialisation in cropping patterns and the increasing use of agrochemicals. In particular, the loss of crop rotations and changes in arable farming and grass have led to a reduction in breeding habitats and sources of winter food. Many birds require different habitats at different stages in their lifecycle, so diversity is critical. For example, the lapwing nests preferentially on spring cereal, but takes its chicks to feed on invertebrates in nearby grassland.

The switch from spring to winter cereals has also taken its toll. A large proportion of skylarks need to produce two broods of young each year in order to maintain the population. They are ground nesting birds and need cover for their nests, but need open ground for access to the nest and for foraging. As a result of winter rather than spring cereals being planted, crops become taller and denser earlier in the season and are too tall and too dense for skylarks to attempt a second brood. Consequently many only manage to rear one brood each year and skylark numbers are declining.

When considering the potential impact that GM crops might have on biodiversity, it has to be borne in mind how dramatically bird numbers have already fallen. Studies of weeds within arable crops, a source of food for seed-eating finches and buntings, show that many fields are completely weed-free, whilst relatively few are weed-rich and contain enough weeds to be a source of food for bird and invertebrates. This is important for seed-eating finches and buntings, which are falling in numbers due to lack of winter food sources. Equally, the increased use of pesticides means there are fewer insects for birds to feed on in both winter and summer.

It may be possible to manage GM crops in such a way that some weeds and the insects associated with them are left for birds. But it is equally possible that GM may produce even more weed-free, invertebrate free fields. If GM crops are introduced to the farms that already have reduced weed numbers in the fields, it will have little impact on bird populations. But if the few remaining farms with a weed-rich fields husband GM crops, they may become weed-free and pest free, thus decreasing the reservoirs of food and cause bird numbers to drop even further.

How does organic farming fit in?

Liz Stockdale from Rothamsted Research presented a joint paper with Elm Farm Research Centre which summarised work that has been done to investigate the science of organic farming and its impact on crops, soil, microorganisms, and environment.

Organic farming systems aim to work with natural systems and the environment to deliver increased productivity whilst considering the health of the soil, animals, plants and the environment as well as human health. Organic farming in Europe is now a legally defined system of farming. This legislation helps to protect the increasing number of consumers who buy organic food by ensuring that the way organic food is produced is carefully defined and monitored. The detailed standards that underpin organic farming combine philosophical principles and scientific elements with practical agriculture. At present organic farming standards do not allow for the use of any genetically modified organisms (GMOs).

In the UK, mixed organic farms with crops and livestock are most common, although specialist organic horticultural and livestock units do also occur. Organic farm management is focused on the whole farm system and its interactions with the climate, environment, social and economic conditions, rather than considering the farm as comprised of individual enterprises. The agricultural practices employed are based on the belief that they are the most environmentally beneficial.

Crop rotation is crucial. This involves not only crop diversity on a piece of land over time, but also seeking diversity in space through the intercropping of species and varieties. It is regarded as important to maintain soil organic matter levels and foster biological activity by regular return of organic materials to the soil and by careful use of mechanical interventions, cultivations, mechanical weeding etc. Nitrogen self-sufficiency is achieved through the use of biological nitrogen fixating crops like clover, vetch and grain legumes. Weed, disease and pest control are carried out using a variety of partial solutions; crop rotation, encouraging natural predators, organic manuring, choosing resistant varieties and minimal biological and chemical intervention.

In 1998, MAFF, the Ministry for Agriculture, Fisheries and Food, said that "well-practised organic farming is one of the more environmentally-friendly systems of food production". They came to this conclusion for several reasons. Organic standards require the sympathetic management of infrastructure for wildlife; organic farming has a higher proportion of grassland and more variety in crop structure, including the use of spring cereals and under sowing; organic farming prohibits or restricts the use of synthetic fertilisers, pesticides and veterinary medicines. In addition, unimproved grassland is protected, and there are generally lower livestock densities on organic farms.

Like all farming systems, organic farming interacts with and has an impact on the environment. The organic standards seek as far as they are able to enforce best environmental practices, however, environmental impact largely depends on farm-by-farm practice. The data collected to date show that, on average, organic farming can deliver positive benefits to the environment in comparison with conventional agriculture, and play a role in mitigating the disaster for biodiversity.

2) What we know about GM

Genes – the great escape?

Alan Gray from Centre for Ecology and Hydrology discussed evidence on the escape of genes from crop plants into relatives in wild populations. Genes do flow, that is move within and between populations of flowering plants. This is what happens during pollination. Of the 13 most important crops in the world, by area, 12 can produce hybrid crosses with wild relatives: wheat, rice, maize, soybean, barley, cotton, sorghum, millets, beans, rapeseed, sunflower and sugarcane. In the USA, where GM is a significant aspect of modern agriculture, some crop plants have compatible wild relatives with which they could hybridise. At present not a lot is known about gene flow, the movement of genes within and between plant species. This is for several reasons. Firstly, many genes are shared because of common ancestry. The relationship between crops and wild species is a complex one and there may be occasions when there is convergent evolution. Secondly, there is also large-scale movement of seed in modern agriculture, which confuses the picture of how far genes can flow in the wild. However, gene flow studies are being done and modern molecular techniques offer new tools for studying current rates of gene flow. Consequently, it is now clear that gene flow varies greatly from species to species and from place to place.

Most crops are grown outside the range of their wild ancestors and it is possible to predict the likelihood of gene flow from a crop on a national or local basis. Research has shown that the areas where gene flow is most likely are on the periphery of agricultural land, in field margins, For example research has been done into the hybridisation of Bargeman's cabbage, *Brassica rapa,* with oilseed rape, *B. napus* and between sugar beet and weed beets. It is clear that under certain specific conditions, extensive gene flow can occur within the crop and in agricultural environments. However, it seems to be more restricted between the crop and relatives growing in semi-natural habitats such as riverbanks and sea walls.

It has now been possible to produce estimates of the distances by which crops need to be separated in order to prevent gene flow. Furthermore, it is not pollination which is likely to produce the greatest amount of gene flow, but transportation of seeds over large distances by lorries and so on. When assessing the risk, it is always assumed that some gene flow will occur, so the important question to ask is what will be the consequences?

Superweed invaders?

One of the fears about the introduction of GM crops is that they will become invasive, or that GM elements will transfer into wild plants, which will then become an invasive nuisance. Mick Crawley from Imperial College, University of London examined the evidence that exists that such super weeds might be a threat. The evidence is that some plants do "escape" but they do not create invasive sub-populations. Most populations of escapees are short lived, although seed may persist for longer in the environment.

Some people fear that GM plants might behave as alien invaders, in much the same way as some of the ornamental plants that have escaped from gardens into the wild. Problem plants that have become invasive include Rhododendron *(Rhododendron ponticum),* Butterfly bush *(Buddleja davidii)* and Japanese knotweed *(Fallopia japonica)*. However, of the thousands of exotic species available in garden centres, less than 0.1% become invasive. Moreover, those aliens that do become invasive have several things in common: they are perennial plants, often woody and thicket forming and they are garden ornamentals with genotypes unfamiliar to the UK, allowing them to flourish due to the lack of native competition. In contrast, most GM crops are herbaceous annuals that are not thicket forming. They are arable crops and are genetically similar to existing crops. For these reasons, the “Alien Species Model” is not considered to work well when considering the potential risk of GM crops. Therefore it is better to look at how crop plants behave outside arable fields as a model of how GM crop plants might behave.

One example is oilseed rape (*Brassica napus)* on motorway verges. Questions that can be asked about the invasiveness of this plant include: are oilseed rape populations increasing? Do they form self-replacing populations? Are they invasive of natural habitats? Where do the seeds come from? How long can seeds survive in the soil seed bank?

A ten year study analysed oil seed rape plants on the M25 motorway around the outskirts of London on the way to and from an oilseed rape processing plant where a lot of seed is spilled from lorries in transit to the processing plant and the seed bank is long-lived, persisting over 10 years. The study found that most oil seed rape plant populations are short-lived and survive less than four years. Soil disturbance is necessary for recruitment from seed and populations subsequently decline because of increasing competition from grasses. Additionally, oilseed rape is not invasive of adjacent natural habitats.

What is needed now is not more theory or more models, but good comparative, long-term field trials. Current evidence suggests that for the current set of crop plants like rape, maize and sugar beet, and for existing GM constructs like herbicide tolerance and insect resistance, there is no evidence to suggest that GM will convert crop plants into species that are invasive of natural habitats. The process of GM does not inherently increase invasiveness and non-GM plants pose significantly greater, known threats of invasion.

The Canadian experience of genes in the wild

In Canada, GM herbicide resistant oil seed rape (*B. napus*) has been grown quite widely by farmers since its introduction in 1996. Three types of GM herbicide resistant rape plant were grown in 2001, glyphosate, imidazolinone and glufosinate resistant strains, which represented 55%, 15% and 15% of the 4.5 million hectares of oil seed rape grown in Canada.

Linda Hall from the University of Alberta, Canada explained that farmers choose to grow the GM strains to improve weed control, increase yield and productivity and to reduce the amount of tillage that the crops require. Predictions prior to the large-scale cultivation of these crops, together with studies of what has happened in the field, provide a unique case study of gene flow via pollen movement in field conditions. 90% of oilseed rape grown in Canada is *B. napus* and has a 21.8% likelihood of outcrossing. Outcrossing diminishes with distance and is less than 1% at locations 100 metres from the pollen source. It has been shown that there is very low frequency of gene flow via pollen over 2 km in field scale.

All oilseed rape sets large amounts of seed, which may produce plants that are in effect escapees, known as volunteers, or weeds. Volunteer oil seed rape is the 18th most abundant cropping weed in western Canada and these volunteers extend the potential for gene flow through time. The genes they carry confer resistance to the herbicides glyphosate, glufosinate and imidazolinone. All of these plants can be controlled with another class of herbicide, auxinic herbicides.

Experiments were carried out to determine how genes for herbicide resistance flow into and within wild populations to produce plants with multiple resistances. In one study, 924 volunteer plants were collected and screened with all three herbicides and two plants were identified resistant to glyphosate, glufosinate and imidazolinone herbicides. They were then backcrossed to assess the frequency of resistance genes, and determine how the multiple resistance had developed in those plants. The results showed that resistance to the three herbicides had been acquired over several generations, which is common in these kinds of growing conditions.

Based on the Canadian experience of GM herbicide resistant crops, the occurrence and consequences of gene flow must be evaluated on a case-by-case basis. All cases will differ by scale, environmental and agronomic conditions, the presence of weedy or crop relatives, and available methods of control. Each example must be evaluated relative to other environmental consequences.

How do you assess the risk of GM crops to the environment?

All new technologies carry risks, so it is important to assess the risk and compare it with the benefits. This will determine whether a technology will be adopted, or rejected on the outcome of this balance. Guy Poppy from the University of Southampton presented an example of tiered risk assessment being used to determine the effects of GM, with particular focus on the effects of insect resistant GM plants on non-target species of insect.

Evaluating risk involves not just identifying a hazard, but also potential exposure to that hazard and thus a more quantitative understanding of the risk. In the case of insect resistant GM plants, this means considering insect exposure to the GM plants, the toxicity, and the way in which the insecticidal protein made by the GM plant works. He described tiered studies conducted at Southampton University.

There are three different sets of experiments, which enable identification of all the direct and all the indirect risks. In the first tier, a “worst case scenario” is produced in the laboratory in which insects have no choice but to eat the GM plant. In the second tier, a semi-field environment is produced in an extended laboratory experiment, where there is a degree of choice for insects. The third tier is provided by field trials.

Tiered trials provide an early identification of hazards and some quantification of risk. They also enable detailed information about target organisms, comparison of insect resistant GM crops with the use of insecticides and information useful for planning post release trials and monitoring. There is still a need for large-scale trials over a longer time frame, and comprehensive evaluations of the flora and fauna. Although a tiered risk assessment can provide much information about the biosafety of GM plants, they can’t address all the questions. For example, tiered trials cannot account for the behaviours of individual farmers in how they use the technology, nor can it provide predictive models, although combining modelling with tiered studies using empirical data may allow predictions to be made. When communicating risk to the public, it is imperative to note that all agricultural practices pose risks to the environment. Only when cost/benefit analyses are made can we begin to decide which technologies are acceptable and appropriate. In order to do this, it is important that we know what GM is to be compared with and what risks are acceptable in relation to benefits.

What about the soil?

Things that aren’t immediately obvious in the environment are the vast number of microorganisms that live in the soil. What will the impact be of GM crops on these? Soil microorganisms play a vital role in natural cycles such as the carbon cycle and the nitrogen cycle. They are a source of plant nutrition, nutrient cycling, pesticide and pollutant decomposition and the source of soil fertility. There are around 10^8 bacterial cells in every gram of arable soil, belonging to around 10^4 different species, and around 1km of fungal hyphae in that same gram of soil.

Penny Hirsch from Rothamsted Research provided an overview of the complexities of soil wildlife and the part it plays in nutrient cycles. In doing so she pointed out that the impact of GM plants on soil organisms must be considered in relation to the other gross effects of conventional agriculture on the soil. Plant roots, the types of crops grown, chemical inputs and mechanical disturbance due to ploughing all have an impact on the soil microorganisms.

Studies of the effects of GM oil seed rape and GM potatoes on soil microorganisms show that variations between cultivars have a bigger effect than GM plants in soil bacteria. However, there may be differences in the way that GM plant material may decay within the soil. Overall, the complexity and diversity found within soil may be a barrier to gene flow.

Herbicides and herbicide tolerant crops

One of the main challenges in the agricultural industry has been to develop herbicides that kill weeds without affecting crops. This is a particular problem in broad-leaved crops, which may have very closely related weeds. One approach to overcoming the problem is to produce crops which are resistant to herbicides, in particular those herbicides that are effective against a broad spectrum of weeds. In North America, there has been considerable interest amongst farmers in the use of such GM herbicide resistant crops. The main benefit reported by farmers is the simplification of weed control, rather than reduced cost of weed control, although reduced tillage does result in financial savings and environmental benefits through the use of less fuel.

Jeremy Sweet from NIAB in Cambridge presented evidence about the ways in which herbicide resistant GM crops may be used to benefit wildlife and promote greater biodiversity in the agricultural environment. One method involves postponing any herbicide treatment until weeds are visible in the fields, rather than applying herbicides as a preventative treatment. Herbicides such as glufosinate and glyphosate do not have soil residual effects like many other conventional herbicides. Using them on established weeds will not prevent future germination of weeds in the fields. In addition, the reduced need for tillage of arable land using GM herbicide resistant crops will not only save fuel, but will result in less mechanical disturbance of the soil, so conserving soil moisture and soil biodiversity, including weed seed banks.

Experiments using GM herbicide resistant strains are ongoing and some results have not yet been published. Studies carried out to date include product efficacy, gene flow studies, effects on target and non-target species, and on field margins where herbicides may drift.

Experiments on herbicide resistant GM crops have been comparing them and their management with other herbicide resistant conventional crops. Early indications show that the introduction of GM crops may pose new problems, notably in the production of herbicide resistant volunteers that will then require additional control. The introduction of GM crops which require the use of broader spectrum herbicides like glyphosate and gluphosinate may also have a negative impact on arable ecosystems by reducing biodiversity further. However, these problems are not inevitable and are dependent on the way in which a farmer uses GM technology and herbicides.

Can GM deliver sustainable agriculture?

Chris Lamb from the John Innes Centre described plant science as being in a golden era. Looking 20 years ahead, scientists will be able to produce new strains of crop plants which will lead farmers down a path towards sustainable agriculture, benefiting from increased crop yields whilst using fewer artificial fertilisers, herbicides and pesticides. This will be important in a world where food production will need to double over the next 50 years, whilst minimising inputs to agriculture. Higher yields will be achieved through a better understanding of the genetics of pest and pathogen resistance, how to maximise nutrient use efficiency, resilience to stress, increased fertility and a better understanding of how to design plants for agricultural needs.

Plant science will also deliver new types of crops, leading to a more diversified agricultural system. Lamb envisages an interesting interface between the pharmaceutical and food industries for enhanced nutrition as well as medicines in plants. Plant research will develop novel industrial materials like starches, oil and plastics, as well as speciality chemicals, tailored to minimise the need for downstream, energy expensive, environmentally damaging industrial processing. Crops will be cheap, clean and smart bio factories. “Green Polymer” companies could be the 21st century equivalent of ICI in the 20th century. They could help revitalise agriculture by drawing on crop breeding to create new crops more appropriate for green bio factory functions than food delivery.

All of this relies on crop breeding, which is a two-stage process. First you identify the potentially useful genetic variation. Second, you assemble desirable gene combinations in commercial lines. This can be done through conventional plant breeding, with its “cross it and see” approach producing many candidate seedlings and mixing between 50 000 and 100 000 genes, many of which you don’t want in your new generation. Even in conventional plant breeding, new genetics has had an impact. It enables improved identification of genes for key traits as well as scanning for useful genetic variation. It also enables the more rapid transfer of knowledge between species (e.g. among different cereals) and the use of better tools for “molecular-tracking” in complex breeding programmes.

However, using GM technology will enhance plant breeding even further. The technology allows a cut and paste approach, enabling more precise tailoring of genes, the introduction of novel genes, the movement of genes from closely related species, the introduction more rapidly of desirable traits (like drought tolerance or salt tolerance) into different varieties and the avoidance of undesirable linked characteristics. It should also be possible to avoid the disruption of desirable traits. In short, GM should speed up plant breeding and offer opportunities simply not available through conventional plant breeding, as well as allowing the adaptation of existing crops for new non-food purposes and the domestication of new industrial crops.

The first generation of GM products focussed primarily on herbicide tolerance or Bt genes for insect resistance, where a single gene, often from a non-plant source, has a simple valuable effect. As the technology matures, much GM-assisted breeding will be used to facilitate the introduction of genes from wild varieties of the same crop species, wild relatives or closely related species, e.g. rice to barley or wheat, or to reintroduce a tailored version of a gene back into the same species, with scientists exploiting the aggregate predictive knowledge of gene and protein function to engineer small changes to produce desired outcomes.
There are examples of how GM can be used to produce results that could not have been achieved by other methods. One example is the production of exactly the desired traits in the

development of dwarf rice varieties, which also retain the special flavour and fragrance of basmati rice. Although dwarf varieties of rice had been bred before by conventional methods, the desired basmati flavour had been lost. Once the precise gene had been identified that produces dwarf wheat plants, it could be transferred to basmati rice plants to produce dwarf, flavoursome varieties. These are now being grown in field trials in India.

A second example of the value of GM is in crop protection against disease without the use of chemicals, where the challenge is to genetically induce pest resistance. An example is resistance against the ring-spot virus which was devastating papaya crops in Hawaii. Using sequences of genes from the virus, researchers were able to stimulate a natural defence mechanism against plant viruses, producing ring-spot resistant lines of papaya. No chemical protection is needed on the plants. Similar reductions in the need for agrochemicals have been seen in new "Bt" strains of cotton grown in Australia, China and India. This not only means that consumption of fossil fuels is reduced but less chemicals are being used on crops, with benefits to the health of farm workers, a serious concern in some parts of the world.

Finally, it is possible for GM technology to offer totally new industrial products such as starch produced in plants that can be used as an industrial polymer. Some of the requisite technologies already exist, but potential products have been shelved in some cases due to concerns in industry about the cumbersome regulatory process.

Debate, comment, questions and answers

This section contains key questions raised by the audience during the discussion that took place at the end of the day involving panellists and participants. The views expressed are those of the participants, and do not necessarily reflect the views of the Royal Society or those of individual panellists.

GM and Biodiversity

We know it is possible to manage for biodiversity under conventional systems, and by and large farmers don't, so under what conditions will GM crops be managed for biodiversity when crops aren't now?

Firstly a decision needs to be made about what the UK wants to achieve. What level of biodiversity do we want and how are we going to co-ordinate that across the landscape of Britain? Once there is a reasonable plan and a strategy, there needs to be financial measures in place to encourage farmers to manage the land to achieve that. Only when we know what it is that we want, can we decide which technologies are appropriate.

We need to use publicly funded science to help us define what we mean by sustainable systems, and then design the systems to produce it. It is clear that many believe that agriculture should not, and possibly cannot, continue as it is.

Will the result of GM be cleaner crops and further loss of biodiversity? There is growing evidence that there are ways to mitigate against that kind of environmental result, but there is more that we need to know about how to manage GM crops in a more environmentally friendly manner. The real challenge lies in where the incentives are. How can we provide incentives within agriculture to encourage farmers to farm in a particular way? There may be opportunities with the review of the CAP (Common Agricultural Policy). It should be possible to introduce new incentives to farmers that increase biodiversity under a countryside stewardship scheme or similar.

If we are serious about doing something positive for the environment, “we don’t want anything that is as good as conventional crops for the environment, we want something which is better.” The current approach of trying to get every farmer to do a little bit, whether it be field margins, and boundaries, managing ditch edges may be the way forward. However, this is just one possible strategy.

At present 10% of agricultural land in the UK is in set aside. Will GMOs enable us to maintain this ‘luxury’ of wildlife conservation on agricultural land? Is it better to have weedy crops, or separated strips of food for birds?

You can have strips of crops and semi natural habitat. The question is whether we want to separate them on a larger scale. At the moment there are wild field margins and small areas of woodland across the landscape, which are bird habitats. We don’t know enough about how birds disperse or move to know the scale at which these resources need to be available to maintain or increase bird populations. Do we want isolated nature reserves in a sea of agricultural desert? Reversal of the decline in wild birds across the country should be done in such a way as to allow everyone across the country to see most of these birds at their back door. We have not explored other possible uses for set aside land such as flood defence, climate change etc.

The gap between maximising yield and sustainable agriculture

Publicly funded crop development has been more or less stopped in Europe and the USA. The Plant Breeding Institute in Cambridge brought together researchers using molecular tools, plant geneticists and plant breeders, field geneticists. That was split apart, and the plant breeding part was commercialised and the other research moved to the John Innes Centre. Perhaps it is time to look at doing something like this again. Commercial breeding is directed mostly towards increasing yield whereas public sector science is more directed towards sustainability and new crops and new industries. There is a gap between the two that needs to be bridged in order to develop the future of modern agriculture.

Environmental concerns associated with GM

Gene flow and the escape of transgenes from crops into wild population and surrounding crops

When attempting to measure the risk from gene flow, it is very difficult to measure when there are very low levels of distribution. Hence when looking at some of the graphs showing risk of pollen spread against distance, there is a very long “tail” which does not disappear. This probably represents very rare events in extreme conditions, which can skew risk assessments. Mathematical modelling shows that if you have two frequency distributions super-imposed, one with relatively short-range pollen dispersal by the normal windborne mechanisms, but the other a long-range distribution that includes one or more extreme event (e.g. turbulent weather conditions), this can make a big difference to the risk assessment. The long-range distribution means that to reduce percentage contamination to 0.1% requires a much greater separation distance between GM and non-GM crops than is required to achieve a 1% contamination.

Genes flow, but what about the effects of these genes on plant fitness?

This is relevant to the risk gene flow poses. Only a small number of genes have been put into wild plants to see how they affect fitness. For example, if you put the Bt gene into sunflowers, you get an increase into fitness. If you put a virus-resistance transgene into a wild squash, you don't have any effect on fitness. More research is needed into this area.

Health concerns associated with GM

What about where you have crop plants used to produce non-food products like drugs, as is the case in the USA. What if the genes get out through cross-pollination and contaminate regular crops, resulting in the scenario that food supplies are contaminated? How far is it safe to go?

This issue was debated the Royal Society on the previous evening, when measures to prevent and restrict gene flow were discussed. The transcript of this meeting can be found on the Royal Society website at www.royalsoc.ac.uk/gmplants. At this meeting, the comment was made that at face value it does seem foolish to put non-edible products into food crops using transgenes. Companies are being encouraged to use non-food crops for non-food products, and to use the non-reproductive parts of the plants to produce these products, like leaves or tubers, so that there is less chance that the transgenes will get into the food chain.

A representative of the Food Technologists' Association said that food scientists support GM on the condition that the technology is responsibly developed and attention is given to food safety, environmental and ethical issues. As scientists we should not be for or against anything, except the methodology of science. There are great potential benefits, especially for the developing world, in time to come. So there is a responsibility to do the work, examine the evidence and solve the problems.

Questions of food safety

A participant asked a question about farm livestock fed on GM feed like maize. The participant was concerned about the possibility of transgenes getting into the bacteria in cows stomachs and upset them. Research into this has only been done on mice and rats. In response a member of the audience said that research has been carried out at Reading University on ruminants fed GM foodstuffs and there is no trace of transgenic DNA in the meat or the excrement of those animals.

Farming system concerns associated with GM

Herbicide resistant crops

In the USA, the use of herbicide resistant plants initially resulted in herbicide use going down. Subsequently, it was claimed that the weed populations have changed and the farmers in response have introduced new practices. As a result, pesticide use has risen again. How can a system be formulated or managed so that it promotes encouragement of wildlife and the environment? What sort of incentive can be provided to get the flexibility we wish?

How can you sell GM herbicide resistant crops to farmers by claiming that it will remove more weeds from the crop than any other product, and then say it will also be good for wildlife? There are studies that show that there are ways of managing herbicide tolerant crops, which could produce some benefits for wildlife. But would they produce benefits for wildlife over and above conventional farming practise?

It really comes down to how individual farmers manage their crops. A recent Brooms Barn Study showed that using transgenic crops enable farmers to leave more weeds in their fields for longer. However, the longer weeds are left in fields, the more yield will be lost. So what do you do as a farmer? You can wait and leave food for birds, but at the risk of losing yield. Or you can put herbicide on early in the season, increasing costs and decreasing biodiversity. The studies show that there are ways of managing herbicide tolerant crops that require lower herbicide use, decreasing the negative effects on biodiversity and reducing costs for farmers, without a significant loss of yield. However, these benefits are dependent on farmers acting in a particular way that will require them to change from their traditional agricultural methods.

If you want to sell this technology, to start with a herbicide resistant food plant is not a very clever move!

If we are really worried about this technology being accepted, it seems we are trying to fight on too many fronts. We are trying to convince people that the food is safe, and that we are benefiting biodiversity as well. The technology of genetic modification is being debated in terms of the politics and economics of farming, as well as scientific risks and uncertainties. One way to focus people on this technology seriously may be to bring forward one very obviously beneficial type of GM crop, for example glasshouse-grown plants producing pharmaceuticals. This would then enable the public to get used to the technology, appreciate the benefits and then move out into the fields.

Delivering the promise of GM

Is GM really going to deliver all these new products, and why haven't we seen more yet after all the hype?

There is a long lead-time in the translation of fundamental scientific advance to practical application. There are things in the refrigerator waiting to go, for example there are many nutraceuticals (substances that are foods or part of a food which provide medicinal or health benefits) such as plants with altered oil contents, which are healthier, but the appropriate regulatory framework does not exist in the UK to allow us to progress further.

Impact of GM in the developing world

Can GM deliver crops that are salinity and drought resistant?

There isn't much publicly funded plant breeding in the Northern hemisphere, but given the right structures and funding, much can be done. An example would be the Rockefeller Foundation's funding of research into rice. Since 1982, rice has gone from being poorly understood to the model crop for detailed research. A charitable trust saw the potential for

GM rice in the developing world and put money into it, based on both scientific and economic potential. An interesting example is what is happening in China. Papers presented at the last Bio-safety Conference in China in September 2002 reviewed the economic reasons why China needs to embrace certain types of technology. They have thought through the economic and social benefits of things like looking for salt tolerant strains of rice. Approximately 30% of Chinese paddy fields cannot now grow rice because of salt build up and strains of GM rice may be developed that are resistant to high levels of salinity.

Will GM crops end up in the control of a few producers as a result of patenting?

The majority of seed that farmers plant will be developed through commercial companies. These will range from small and independent to the large multinationals. This raises issues about Intellectual Property as the patenting gives you the limited monopoly to build a new drug or test a new drug or plant. This can help to recoup a lot of the costs of development. However, a patent is also a licence to sue in a civil tort. You don’t have to do that and you don’t have to patent in poor countries if you don’t wish to. There are some tensions developing, but with tolerance and goodwill, advances could be made available free to developing countries.

Has anyone done an assessment of the potential impact on the introduction of GM to the livelihoods worldwide of small producers who cannot afford to buy fresh seed each year?

The cost benefit analysis carried by the Prime Minster’s Strategy Unit in the UK has four strands to it:

- Environmental cost benefit
- Industry cost benefit
- Consumer cost benefit
- Cost benefit to people in developing countries

A talk being given at a simultaneous meeting being held at the Royal Society of Arts suggests that UK evaluations of gene flow and the possible contamination of indigenous species are impossible to apply in India, where seed is collected on farms of a hectare or two by bullock cart. Perhaps there is a problem that in the UK GM agriculture is being thought about in terms that apply locally, not the conditions that exist elsewhere.

One example of this is the rejection of food aid from the US by Zambia on the grounds that it was genetically modified. This was based on scientific advice given to the Zambian government and resulted in rejection of the grain from the USA, in spite of the fact that 2.7 million people are starving.

We do not look at science in developed countries in the same way as developing country scientists in terms of the traits that are relevant to poor countries. This is true not only in agriculture, but in medicine. When you look at what is invested into understanding tropical diseases, it is not very much compared to research into the diseases of the developed world. New alliances need to be forged so that advances from the new technology are taken up by developing countries to solve their problems.

Security of food supply

In October 2000 there were 6 billion humans on the planet, and the projection is that world population will be somewhere between 9 and 10 billion by the middle of this century. In addition to this, diets are changing in some parts of the world – in China for example people want to eat more poultry, so the need for primary production will double. This growth will need to happen through technology and management. Prime agricultural land is reducing, as cities are built and highways made and so on. This is all going on against a background of global climate change, and with water as the limiting resource in the latter part of the century. We should not assume global food security is assured. We should look very hard, as a society, before throwing away a potentially very accurate breeding tool.

GM and organic farmers

Some of the organisations associated with organic farming have made anti-GM thinking into an essential part of organic farming. Many organic farmers are very worried that they could lose their licences as organic farmers if pollen happened to drift in from adjoining GM crops.

The key issue in terms of contamination and organic licences is that the law, as it currently is written in Europe, says that GM modification is not allowed within organic systems. Organic licences would be endangered if there were potential contamination from GM crops.

There have been reports of problems in Canada, with rogue GM oil seed rape plants allegedly becoming a widespread problem. If this is the case, is it reasonable to have a standard with zero tolerance for contamination by pollen from adjoining fields when it is well known that pollen, GM or otherwise, travels? If Canada has decided to allow GM crops, is it reasonable to expect organic farmers to be able to produce 100% GM free crops?

What we need is an integrated approach to the management of all crops, from GM through to organic.

Risk Assessment

Much of the debate is about the relative impacts of different agricultural systems on the environment, but as yet, there is no system to assess relative sustainability, or to regulate it. Over the last 20 years, the responsibility of where and how novel cropping systems are introduced in the UK has been handed to the market, not to public science. Is this really the best way to find better farming systems? Is risk assessment based on relative costs and benefits a better system?

How should possible costs, discovered ‘down the line’, be included in the risk assessment? Should we be planning for unknowns? Do we need a policy for clean up if it all goes wrong to be developed alongside the technology?

It is always assumed that to do something is more risky than not to do something, yet the current agricultural system poses a lot of risks. How about asking what the risk is for NOT allowing GM crops and getting the benefits from that?

Ask yourself another question: is it more precautionary to move forward cautiously or to stay where you are, with the hazards or risks you are currently accepting?

Regulation of GM in the UK

Agriculture in the UK is one of the most highly regulated industries in the world. For example, details of proposed field trials of GM crops in the UK are freely available on the Internet. Independent scientists review the experiments, details of the locations of the sites are published, making the locations known to anyone who wishes to destroy the sites in protest. One could even view the UK risk assessment procedure as being so strong that it has suppressed the number of field trial applications, which are down from 40 a year to 5 per year in 2002, compared to 1000 a year in the USA.

It was commented that surely it is better for research to be done in countries where there is regulation, like the UK, than for it to disappear off somewhere else, where regulation is not as strong?

Comment and criticism on the day's proceedings and the wider public GM debate

A few of the attendees were very critical of the day's proceedings although some of these made it clear that they had only been present for the final discussion. They were also critical of the Government's GM debate. One attendee expressed the opinion that the debate on GM in the UK was purposely excluding all the critical voices and evidence of hazards were being "dismissed and buried." The participant cited the BMA's reservations over the long-term health impact of GM food as evidence of hazards, and the fact that toxicity and allergenicity of GM foods had not been addressed at the day's meeting. It was pointed out that these were discussed at the previous day's meeting at the Royal Society.

There was a complaint from one participant about what he saw as an attempt to "police the boundary between scientific and non-scientific comments." A member of the audience complained that several comments from the floor were criticised for being non- scientific, yet speakers used political metaphors such as pest control as "an arms race between pest resistance and new countermeasures, or weapons on the other hand." This use of this metaphor, he said, represented the objectives of modern agriculture as promoting industrialised, intensive monoculture and framed the task of science as the need to find new weapons so that the crops can win the arms race.

A speaker from the floor expressed the opinion that the meeting would have been more balanced if it had ended with the organic farming presentations. His opinion was that the meeting seemed like a sales talk for GM, and he alleged that the meeting was part of the strategy of the government to push the GM agenda forward.

In reply to criticisms made of the Royal Society, a Fellow and former Vice-President said that the day's meeting was based on scientific evidence and fact and he felt that the meeting had been well designed. "To say that Royal Society is losing trust of the community it serves is wrong. It would be better if people listened dispassionately to the evidence and the science and used it to address the questions."

The President of the Royal Society refuted any suggestion that the Cabinet Office had instructed the Society to put the meeting together as one of its contributions to the wider public debate on GM (as had been alleged by one participant). The aim was for all voices were to be heard at the meeting, and the President commented that this had been achieved.

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Royal Society policy statements on related issues

- Genetically modified plants for food use and human health – an update (February 2002)
- The use of genetically modified animals (May 2001)
- Transgenic plants in world agriculture (July 2000)
- Review of data on possible toxicity of GM plants (June 1999)
- GMOs and the environment – Royal Society response to the inquiry by the House of Commons Environmental Audit Committee (April 1999)
- Scientific advice on GM foods – Royal Society response to the inquiry by the House of Commons Science and Technology Committee (April 1999)

Copies of these reports are available from the Royal Society by calling 020 7451 2585 or can be downloaded from the Royal Society website www.royalsoc.ac.uk/policy