

Genetically Modified Crops and Other Organisms: Implications for Agricultural Sustainability and Biodiversity

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We are at the dawn of a revolution in how we grow food and many other products on this planet, a revolution that is pushing society into rethinking what we want out of agriculture. Biotechnology and other advances in plant and animal breeding and crop technology are already offering an unprecedented range of choices for how we use agricultural land, and how we produce fish and forests. Visions of the future for agricultural land vary between weedless and pestless “green concrete” and visions of a new organic agriculture producing high-quality, high-yield crops yet protecting and nurturing biodiversity. Given the rapid pace of new developments in agricultural biotechnology and the culture of the research world, consumers, farmers, policymakers and regulators throughout the world are struggling to come to terms with these choices. Some consumers, especially those in Europe, are perplexed, anxious, and desperate for information about the potential effects of biotechnology on their food and their environment. The media have sensed that this issue is not going to go away from public consciousness in the foreseeable future, and are actively promoting widespread debate on how we should best use the profound discoveries emanating from the new genetics. This is perhaps the most important debate of the new millennium, because its outcomes will have global implications for food and raw material production for the rest of our history.

I will explore some of the implications of using the present outputs from the agricultural bio-

technology industry, draw attention to the science which seems to be missing from the debate, and to look toward the future, when we may well turn to biotechnology to build a more sustainable agriculture. The views are mostly those of the UK statutory conservation bodies and inevitably Eurocentric, but I will try to pose some fundamental questions about the implications of agricultural biotechnology for developing countries.

Statutory conservation advisors in the UK are *not* opposed to genetic modification as a technique for changing the characteristics of plants and animals. It is simply another, but very powerful, tool for plant and animal breeding. On the contrary, we see real promise in genetic modification for eventually producing more sustainable and environmentally friendly crops and farming. Biotechnology *could* give us a future where perennial crops have in-built resistance to pests and diseases, fix their own nitrogen, and give higher yields. We may eventually be able to produce entirely new plants, designed specifically to produce food, medicines, industrial chemicals and fuel. But let us not be blinded by such dreams; like all new technology, genetic modification is risky. European society is deeply concerned about the direction that research and development (R&D) in this technology appears to be going, and the statutory conservation agencies are trying hard to stimulate a debate, not on *whether* genetic modification should be used, but on *how* and *where* it might best be used.

In Europe, where our landscape and wildlife are inextricably mixed with, and dependent upon,

farming, we already have serious environmental problems with “conventional” chemical-dependent agriculture. We have surface and groundwater pollution, soil degradation and erosion, and alarming declines in biodiversity. These are the costs of increasing yields, aimed at driving down costs of food to consumers and attempts to compete on world markets. We are still overproducing some commodities and the damage to our environment continues. These agricultural processes were enabled by the introduction of new plant varieties and more effective chemical regimes, including new generations of pesticides. In whatever way we measure the impacts of intensive agriculture, we must conclude that in its present form it is probably not sustainable. By this I mean that, although *levels of production* may be sustainable for perhaps decades, the *social, environmental, and economic consequences* of these processes may not be sustainable for that period of time.

Biotechnology may offer a way out of this dependence on unsustainable agriculture by eventually producing crop plants that enable agriculture to sustain yields but minimize environmental impacts. But the perception in Europe is that some of the present generation of genetically modified (GM) crops, especially those developed for the US agricultural situation, which are herbicide-tolerant and insect-resistant, may present yet further risks to biodiversity in our present intensive agricultural system. I will explore some of the reasons why these GM systems are being proposed and I will argue that the advent of genetic modification has thrown into sharp focus the need for reappraisal of agricultural strategy in Europe. We need clear thinking, scientific information, and realistic views to minimize the risks and maximize the benefits, which I see not just in terms of yet more production and profit.

Before exploring the potential benefits of genetic modification in agriculture, I would like to look more closely at some of the perceived risks associated with growing the present generation of GM crops in Europe. I believe that some of these have been understated by both the industry and by some regulatory authorities both in Europe and overseas. I believe there has been a *laissez faire* attitude toward the potential environmental effects of GI crops. This attitude toward such a powerful technology is potentially dam-

aging not only to the industry but also to politicians, policymakers, and regulators. It is they who are faced with the task of convincing the public that GM crops will bring real benefits to the public and the environment, at minimal risk. It would not be unfair to suggest that up to now the European public are far from impressed by the arguments in favor of GM crops put forward by the biotechnology companies.

Risks to Natural Biodiversity

There are many genetic transformations in crops, such as altered starch, oil, and fat content, which will probably have little or no adverse impact on biodiversity. Most of the present generation of GM crops carry transformations for the insertion of genes for herbicide tolerance and insect resistance into existing crop varieties. My comments will therefore focus on the genetically modified herbicide tolerant (GMHT) and genetically modified insect resistant (GMIR) crops which are closest to commercial use in Europe, but are being used commercially now over some 40 million hectares worldwide.

Gene Flow and Transfer of Traits to Other Species

Recent research confirms that genes introduced into some genetically improved crops will spread into related native species (Chevre and others 1997). Gene transfer is almost inevitable from crops that have interfertile relatives in adjacent natural ecosystems, but not from crops such as the maize and cereals grown in Europe, whose closest relatives are on the other side of the oceans. Should we worry about this? After all, genes have been moving for many years from “conventionally” bred crops to wild relatives; for example, in the UK hybrids occasionally occur between oilseed rape (*Brassica napus*) and native species like wild turnip (*B. rapa*) (Raybould and Gray 1993; Department of Environment, Transport and the Regions 1999). The difference of course is that genes inserted into GM crops are often derived from other phyla, giving traits that have not been present in wild plant populations, and if introduced accidentally, may change the fitness and population dynamics of hybrids between native plants and crops, eventually backcrossing into the native species and becoming

established. So the issue is not so much the *rate* of gene flow (on which there has been copious research), rather the *impact* that this might have on agriculture and biodiversity (on which there has been almost no research). Conventional plant breeding, using mutagenesis and embryo rescue techniques, also produces lots of completely new genes in crops, about which we know very little. Interestingly, these are often the very crops being used by organic farmers and being sold as “natural foods”!

Most geneticists would argue that most “foreign” genes introduced into crop/native hybrids would in fact *decrease* their fitness in the wild, leading to rapid selection of these genes out of the population. This is particularly true of genes designed to prevent germination of saved seed, like the so-called terminator gene - if this were to “escape” it would commit instant suicide and certainly not spread into the natural world as has been suggested by some anti-GM campaigners.

There is no difference to the farmer between buying seed with terminator technology and buying hybrid seed, because neither can be saved and grown next year. There is a serious issue about whether farmers in the developing countries should become locked into a cycle of dependence on patented seed, but the genetics of this technology is not a direct environmental threat (see Pinstrip-Andersen and Cohen, This volume).

Transfer of certain genes, such as resistance to insects, fungi and viruses could *increase* fitness (ability to reproduce) of any resulting hybrids, possibly forming aggressive weeds or plants that swamp wild populations. Weeds having tolerance to a range of herbicides could also emerge; these would be difficult to control in agriculture, or in natural ecosystems like grasslands. Farmers may eventually need mixtures of herbicides to control them, causing yet more damage to biodiversity. There is already evidence from North America that this “multiple tolerance” and resistance to herbicides is beginning to emerge (see Cook, This volume).

If nontarget plants acquired insect resistance from GM crops, they could damage food chains dependent on insects feeding on previously nontoxic wild plants. Not only would there be a direct effect, for many insects are entirely dependent on single plant species, but acquisition of resistance in wild plants may change their popula-

tion dynamics, increasing the risks of them invading agricultural land and natural ecosystems. These ecological genetics principles also apply to virus and fungus resistances. This is an even more serious issue for developing countries where control of invasive plants is a major problem for subsistence farmers and may have implications for biotopes of global importance.

The science we urgently need to be able to assess these risks is simply not being done. At the moment we do not know what effect escaped genes might have on natural and farmland ecosystems. This lack of science is disturbing, given the commercial pressure and rapid timetable for the introduction of GM crops into our landscapes. Science will never tell us *everything* about what might happen, but no science will tell us *nothing*.

Genetic transfer to native ecosystems not only carries ecological risk, but also undermines fundamental reasons for conserving plants and their dependent ecosystems *in situ*. Our understanding of ecological genetics depends on research on gene pools of species making up native ecosystems, and the genetic code of each wild species holds information which may eventually benefit us. So-called “genetic pollution” of native gene pools raises some legitimate questions about the loss of basic scientific resources. As scientists, we are keenly interested in the genetics of native populations, so to add genes from other phyla unwittingly and randomly to gene pools is not necessarily a good idea.

There is clearly a need to set up effective monitoring systems to detect gene transfer and research to assess ecological impacts. Research in this area would be in the interests of both the industry and the environment. It would be far better for biotechnology companies to produce the next generation of GM crop plants with in-built mechanisms, such as pollen incompatibility, to prevent gene flow. Perhaps the ecologically simplest way to ensure genetic isolation is to make sure that wherever possible plants used for genetic modification are unrelated to native species and edible crops whose center of origin is within the intended market territory. Biotechnology companies should start thinking now about which plants are chosen as platforms for biomedical and industrial product transformations. If biotechnology is ever to become a standard technique for plant breeding, I predict that genetic isolation of

crops from the rest of the living environment will become normal practice, as will the removal of certain genes such as antibiotic resistance.

Genetic Modification of Native Species

At least two research programs in Europe and the United States have recently inserted novel genes into *native* species. One is concerned with inserting herbicide tolerance and genes for increased yield into native grasses, aimed at establishing monocultural high-output forage crops. The other is aimed at inserting genes for insecticide immunity into predatory mites, so when a field is treated with insecticide the mites survive and set about mopping up any surviving pests.

These developments greatly increase the risks of gene transfer and may run unacceptably high risks, because such genetically improved native organisms are completely cross-fertile with native species. From a farmland management perspective, the long-term prospect of having most pasture planted with herbicide-resistant grasses, and then sprayed to eliminate all other plants, could have devastating effects on remnant populations of wild plants, invertebrates, and birds that live in these agricultural grasslands. There is also a real danger that such new varieties of native plants would be fitter than natives and colonize natural ecosystems with unpredictable results.

This scenario is especially important in Europe, where we farm a much greater proportion of land than in the United States, and have less wilderness. The UK and other European governments are committed to several international agreements to conserve wildlife, and we know we cannot do so solely by trying to protect isolated sites. This means that we need to farm in a way that allows biodiversity to thrive within farmland, alongside or within crops, unlike in the United States where intensively farmed areas are often quite separate from large protected wildernesses. Why then are commercial companies and research institutions introducing agricultural biotechnology without assessing properly and holistically the potential risks and benefits to biodiversity? Perhaps regulatory systems throughout the globe need to give some clear signals to the industry about where the boundaries

between the possible and the unacceptable might lie. In other words, like in medical R&D, we may need an ethical framework to help science and industry to develop R & D strategies for different agro-ecosystems.

Genetically Improved Crops and Agricultural Intensification

The prospect of gene transfer causes concern for crops that have wild relatives in the same ecosystem, and occupies reams of headline comment in the press. Perhaps of greater importance is the fact that management of some genetically improved crops would be very different from conventional intensive agriculture or organic farming.

In the United States, genetically modified herbicide tolerant (GMHT) crops are grown under a regime of broad-spectrum herbicides applied during the growing season. Farmers report almost total weed elimination from GMHT crops, which include cotton, soybean, maize, beet, and oilseed rape. They also report substantial reduction in herbicide use (see Pinstrup-Andersen and Cohen, This volume). Recent research in the United Kingdom confirms that weed control in GM beets and other GMHT crops is likely to become much more efficient (Read and Bush 1998). These results are hardly surprising since this is the main purpose behind the technology.

This GMHT system will soon be available, at least experimentally, for virtually all mainstream agricultural crops, including vegetables. Broad-spectrum herbicides used on commercial scale GMHT crops during the growing season may be far more damaging to farmland ecosystems than the selective herbicides they might replace. Using these herbicides in the growing season may also increase the impact of spray drift onto marginal habitats such as ancient hedgerows (field margins common in Europe) and watercourses. It is not only the *volume* of herbicides that is the issue but their *efficiency* and *impact* on wildlife.

When insect resistance and herbicide tolerance are combined in the same crop variety, there may be few insects capable of feeding on the crops and few invertebrates and birds would be able to exploit the weed-free fields. In Europe we already have massive declines in farmland birds, with

several previously common species now close to extinction.

The problem with assessing the environmental impact of these changes in management is that the regulatory system and the public has very little scientific data on which to assess the real risks, and potential benefits, from adopting GMHT crop systems. Formal risk assessments submitted by the biotechnology companies as part of the regulatory process deal with this issue inadequately. In the United Kingdom, the Department of Environment, Transport and the Regions and the Ministry of Agriculture, Food and Fisheries have realized this, changed the regulatory system, and commendably have started some field-scale experiments to try to answer some of these important questions.

The development of new crops with improved tolerance to abiotic factors (such as drought, salinity, frost) and the potential advent of 'pharmed' crops producing vaccines and GM biomass systems, may also change crop management, perhaps increasing demand for arable land in the long term, and putting further pressure on natural biodiversity on marginal land.

Agricultural Intensification and Declining Wildlife

If we want to make predictions about how intensification enabled by GM crops could affect biodiversity, we can turn to evidence of declines in farmland plants, insects, and birds resulting from agricultural intensification in Europe over the past 30 years. Factors responsible include abandoning traditional crop rotations, increased pesticide efficiency and drift, use of artificial fertilizer, drainage, and intensification of soil cultivation (McLaughlin and Mineau 1995). There is overwhelming evidence demonstrating that the use of more effective pesticides (including herbicides) over the past 20 years has been a major factor causing serious declines in farmland birds, arable wild plants, and insects. Pesticides not only have direct toxic effects on wildlife but they also enable modern crop management changes to take place. Winter-sown crops, for example, rely heavily on effective fungicides. Thirty years ago winter sowing was unknown in the United Kingdom and winter stubbles were widespread, providing an essential food source for wintering

flocks of birds. There are many examples of declines in farmland wildlife in the UK and these are typical of intensively managed farmland throughout Europe.

It is important to remember that although these declines in biodiversity have been severe in many intensively managed areas, there are still viable populations of many farmland-dependent species throughout Europe. Some of these, however, are only just surviving the impact of intensive agriculture.

Twenty-five of the 200 species of British "arable plants" are now "Nationally Scarce" and a further 24 are "of conservation concern" and included in the 1983 IUCN Red Data Book (RDB) (McLaughlin and Mineau 1995; Wilson 1994). Not only have many arable plants become threatened but there has also been a marked shift towards a less diverse, grass-dominated flora (Kleijn and Snoeiijing 1997). More effective herbicides are responsible; similar trends have been observed elsewhere in Europe (Eggers 1984; Andreasen, Stryhn, and Streibig 1996; Wilson 1992, 1994). Changes in herbicide practice have also been a major factor in reducing the distribution of insects such as the common blue butterfly (Aspinall 1988), the larvae of which feed on broad-leaved weeds.

Over half of British farmland birds are now in serious decline and 13 are red-listed (Siriwardena and others 1998). The 78 percent drop in grey partridge (*Perdix perdix*) numbers observed in the United Kingdom between 1972 and 1996, has been directly attributed to increased herbicide and pesticide efficiency. Skylark (*Alauda arvensis*) populations have declined by 75 percent over this period mainly due to increased pesticide efficiency (Campbell et al. 1997). Recent research implicates agricultural intensification in the decline of other songbirds (Ewald and Aebischer 1999).

Besides the aesthetic and scientific reasons for conserving biodiversity within and around agricultural crops, there is another important utilitarian reason for wanting to do so. This is the need to maintain the food chain links between native species and crop systems. This link is vital if we are to preserve the function of biodiversity to deliver early warning of dangers in crops or the chemicals used to manage them. Without these links, we are unlikely to be able to detect any dangers arising from the new agriculture by

monitoring wildlife; the first organism in the food chain will increasingly be *Homo sapiens*. This “natural early warning system” has served agriculture and the public very well over the past 50 years. It detected the toxicity of DDT and aldrin-based organochlorine pesticides (Sheail 1985) and showed up the potentially lethal effects of PCBs before toxic levels built up in humans. This is not just an issue for the industrial countries. It is a natural alarm system which is probably the most cost-effective way of monitoring environmental safety in developing countries. We abandon this biological system at our peril.

Regulatory Arrangements in the U.K.

Until research makes the ecological consequences of using new genetically modified crops clearer, the UK government, acting on advice from regulatory committees and statutory conservation agencies (English Nature 1997), have negotiated a delay in commercial releases of GIHT and GIIR crops for at least the next 3 years, to enable sufficient time for ecological research such as the present field scale trials to take place. In the UK alone, at least 27 studies have started. Information from such research can then be used by regulators to make more informed and publicly defensible decisions about whether GM crops should be commercialized, and under what conditions and in what environments. The delay also allows time to develop better regulations controlling where and how these crops may be grown. In the United Kingdom there is currently no mechanism for on-farm regulation of GM crops, but we believe that for some GM crops this should be put in place. Delaying commercial release could also allow development of better genetically improved crops with, for example, in-built safeguards against gene transfer. The crops coming to commercialization today are the first generation of new biotechnology products. We are therefore engaged in science aimed at determining whether these products are appropriate for release into the English landscape.

Biotechnology and Biodiversity

In Britain, over 70 percent of our land is farmed, and much of our wildlife depends on this farmland. Farmland is important to biodiversity

throughout Europe and if we cannot stop degradation of biodiversity on this land, we risk failing to deliver the requirements of international treaties such as the Convention on Biological Diversity (CBD) and EU Directives such as the Birds Directive and the Habitats and Species Directive. Conventional intensive agriculture is already threatening our farmland wildlife and several EU Governments are now trying to introduce agri-environment measures to reverse these declines.

The irony is that biotechnology may hold the key to *less* damaging forms of agriculture, yet it appears that it is currently being used by some parts of the industry in some countries to produce the opposite effect. We are challenging the industry to change direction in R&D, toward producing crops that contribute to more sustainable forms of agriculture, demonstrating real and tangible benefits for the environment. I believe this needs to be done wherever the products of biotechnology are intended to be used, whether in industrial or developing countries.

Environmental damage resulting from the unwise use of biotechnology in agriculture would be a serious issue in developing countries where biodiversity and environmental factors such as unpolluted ground and surface water are fundamental resources used by large numbers of people. Intact and rich ecosystems are important not only for their intrinsic values but also as sources of revenue, whether from sustainable harvesting or from tourism.

Future Strategy

Europe needs to decide the right path for its future agricultural strategy. We need a much clearer and more confident view of what we require from our agriculture, particularly in terms of food production levels, biodiversity, and sustainability. In the United Kingdom we have recently adopted farmland bird populations as a key measure of agricultural sustainability. In other words, we will test the effects of our agricultural policies and practices in terms of whether they increase or decrease farmland bird numbers. It is quite possible that farming systems involving GM herbicide-tolerant and perhaps some insect-resistant crops will fail that test, but we need more research before we can be certain. Other countries may well have different indicators.

We also urgently need to send clear signals to the biotechnology industry about what *we* as the customers want them to produce. Some challenges for the immediate future might include:

- Securing fungal resistance in adult plants by “switching on” resistance genes that are active in the seed, but not currently in adult plants. This seems to be an elegant and safe use of biotechnology which could lead to significant reductions in fungicide use.
- Achieving insect resistance by altering physical characteristics of plants, perhaps by increasing hairiness or thickening the plant cuticle. This could reduce insecticide use, without using in-plant toxins.
- Altering the growing characteristics of crops (for example, shortening the growing season or changing the timing of harvests), offers the prospect of allowing more fallow land and less autumn planting. The recent discovery of dwarfing genes by the John Innes Institute in the U.K. could be a significant step towards the production of higher yielding and more reliable spring-sown cereals.
- Developing crops (including trees) that can tolerate high levels of natural herbivory yet remain viable.
- Preventing outcrossing by engineering pollen incompatibility and other mechanisms into crops. This could significantly reduce the risk of spread of GM traits into native species.

Many of these new traits could be simply transferred from one crop variety into another or be accomplished by switching on or off genes already present in the plant. Such transformations are likely to be more acceptable to the public than moving genes between phyla. The consequences of short-circuiting genetic distance between species, which has been maintained over long periods of time and geographic isolation, are simply not well enough understood to be able to assess the risks.

The real challenge is developing traits like these, which could eventually form part of organic farming systems of value for society as a whole.

Conclusion

Biotechnology and the new science of genomics, which is giving us new insights into how genes

function, offer a whole new range of options for how we could use land, because for the first time in our history we really can design crops to suit the land and the purpose rather than having to adapt land and purpose to suit the crop. New sustainable agricultural systems will need support from packages of possible incentives, subsidies, and regulatory measures to make them profitable and attractive to growers.

Perhaps we also need new institutions, and more multidisciplinary teams dedicated to the search for more sustainable farming systems, to think through and explore how we might design new agricultural systems such as mixing different crops in the same fields or having nitrogen-fixing perennial crops in sustainable permacultures. We need to break free from the paradigms of the past, where advances in agricultural yield have always meant retreats in sustainability. This is also important for developing countries where biotechnology may be able to offer new solutions to old problems of crop pests and disease in otherwise ideal crops, rather than trying to export conventional, chemically-based agriculture with its damaging effects on biodiversity and the wider environment and on human health. These are serious scientific and strategic challenges for agricultural biotechnology, for regulators, policymakers and for politicians; they are urgent issues for all of us, for the pace of discovery will not slacken.

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