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The status and prospects for genetically modified crops in Europe

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Abstract

Despite the rapid expansion in the global area planted with genetically modified (GM) crops, there has been resistance to this technology in Europe: this article considers why. Molecular technologies used to produce GM crops are reviewed and crops currently and soon to become available listed. It is argued that the prospects for GM crops depend on: (1) consumer acceptance — which depends on the perception of the benefits GM crops offer and on confidence in the legislative framework and regulatory procedures designed to identify and quantify any potential disadvantages; (2) further technological advances — which might reduce any adverse consequences of and enhance the benefits from GM crops; (3) patent law — which underpins incentives for private investment and largely determines the development of market structure; and (4) the relative profitability of GM crops vis à vis conventionally bred varieties — which will be a key determinant of the area planted. Importantly, regulations which increase consumer confidence may also raise the costs of planting GM crops and therefore will act to reduce the area planted. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Genetically modified crops; Biotechnology; Intellectual property rights; Profitability

Introduction

The first-ever outdoor test of genetically modified (GM) crops took place in 1987. By 1996, 23 crops had received approval for commercial production in the US, 12 in Canada and 7 in Japan (Fraley, 1996). In 1996 more than 2 million ha of genetically improved crops (including maize, soybeans, cotton and potatoes) were planted

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in North America. This increased to 8.1 million in 1997 and 20.5 million in 1998 (Gene Exchange, 1998, p. 13). The global area planted with GM crops in 1997 and 1998 (excluding China) is put at 11 million and 27.8 million ha respectively, in countries including America, Canada, Argentina and Australia (Gene Exchange, 1998, pp. 7, 13). The rapid expansion in area is again illustrated by the increased acreage planted with Liberty Link oil seed rape[1] from 16,000 ha in 1995 to 150,000 ha the following year, with around 500,000 ha planned in 1997 (Agrow, 1996, p. 7) and this expansion is expected to continue. A global market value for GM crops of over US$2 billion is expected by the year 2000 (Zechndorf, 1998) rising to an estimated US$5840 million by the year 2005 (Agrow, 1996, p. 7). However, there has been substantial resistance to GM crops in Europe, where the perceived risks of releasing GM plants for commercial production are seen to out-weight their potential benefits (Table 1).

The prospects for commercial production of GM crops will depend in the first instance on consumers and environmentalists' acceptance of the benefits of individual genetic modifications. More ready acceptance is likely if the potential disadvantages that may accompany commercial planting are satisfactorily addressed. At the very least this requires consumers and environmentalists to have absolute confidence in the legislative framework which identifies and regulates against identified disadvantages. Even this, however, will not necessarily lead to consumer demand, and additional layers of regulations are likely to increase the costs of developing GM crops and therefore to reduce their competitiveness vis à vis traditionally bred crops.

This article outlines the current status of GM crops in Europe and the key influences on their prospects. The following section introduces the molecular biotechniques which are used to genetically modify plants, and lists those GM crops which are currently available globally or which are in their final stages of commercialisation. The third section reviews European legislation and its application, while some key reasons for resistance to GM crops in Europe are presented in the fourth section. The fifth section discusses some technological developments which may reduce the concerns of consumers and environmentalists and the sixth section reviews the role patent law has on the development of GM products and market structure. The seventh section examines how these factors might affect the on-farm economics of planting GM crops, while the final section summarises the prospects for GM crops in Europe.

Biotechnological developments and potential

Plant breeding has contributed to the increase in agricultural productivity. To take one example from the many available (Franks, 1999), Duvick (1986) estimated the yield gain due to plant breeding at about 1% per year for maize, wheat and soybean in the USA. Plant breeding based on molecular techniques applied to traditional

[1] Liberty link oilseed rape is genetically modified for protection against glufosinate, the active ingredient in Liberty, a broad spectrum herbicide produced by AgrEvo.

Table 1
Some potential advantages and disadvantages of GM crops

Advantages	Disadvantages
Improving existing crops	
Increase in quality of commercial varieties. Bring new varieties to the market more quickly. Extend the geographical range of current crops, e.g. soils currently too saline or acidic, and into arid regions.	Consumer perceptions of risk to health, in particular resistance to antibiotics and the development of allergies. Possibility that out-crossing may produce populations of herbicide and pesticide resistant weeds and pests. Volunteer crop plants becoming an economically costly weed problem. Implications of growers' contracts, restricting farmers' rights, e.g. to retain seed and growing contracts.
Developing new crops	
Develop plant crops for new markets, e.g. replacing petroleum based products. Develop a pharmaceutical industry based on plants.	
Environmental concerns	
Plants for bioremediation, i.e. the absorption of heavy metals from soils to clear up pollution. Placing genetically based resistance in the crop will reduce the negative impacts of sprayed and otherwise applied pesticides.	Risks to the gene pool of populations of wild relatives of commercial crops. Removal of target species may create fundamental changes to ecosystem networks. Either direct or indirect detrimental impact on non-target species.
Marketing	
Increase the shelf-life of foods will reduce wastage.	May act to reduce food freshness.
Legal	
	Uncertainty surrounding liability for any economic damage to neighbouring crops.

breeding strategies, where genetic material is mixed through natural crossing, can reduce the time taken to develop new crop varieties from 12–15 to 6–7 years (Farmers Weekly, 1997), thereby cutting varietal development costs and advancing the contribution of plant breeding to crop production. But the unique contribution of new molecular techniques is to allow plant breeders to utilise DNA from species that are not sexually compatible with agricultural crop species,[2] thereby increasing

[2] Traditional breeding programs recognise desirable traits by examining the phenotype of plants that are likely to be sexually compatible with high yielding, commercial varieties. Once crossed, the new plants are exposed to the pathogen to identify and select resistant plants. Plants identified as offering a high level of resistance are then backcrossed with the commercial variety so that the introduced trait is isolated within the characteristics of the commercial variety. However, backcrosses and screenings are expensive, time consuming and inefficient; generally few resistant plants are identified and often the

the gene pool available to plant breeders to include distantly and unrelated plants, animals, bacterial and viral DNA.[3]

These new biotechnologies, which are often branded together as genetic engineering,[4] are comprised of "a set of enabling techniques for bringing about specific man-made changes in deoxyribonucleic acid (DNA), or genetic material, in plants, animals and microbial systems, leading to useful products and technologies" (Agenda 21, Chapter 16, paragraph 16.1; Johnson, 1993). Huttner et al. (1995) view them as "a set of tools that exploit the molecular systems of the living world" (p. 26). Together they can be used to identify useful genes, isolate those genes, switch the expression of the traits controlled by the gene on or turn them off, and transform genotypes by introducing (or removing) a single isolated gene or a series of genes from different organisms into (or from) a host plant.

These advances in genetic molecular technology often use genetic markers. Genetic markers are genes that are closely linked to the target gene, so detecting the presence of the marker gene in a transformed cell indicates, with high probability, the successful transfer of the target gene (Law, 1995). This eliminates the need to grow the transformed seed to test its phenotype, thus speeding up the replication process. Marker genes are also used to develop genome maps, which show the location of genes on chromosomes (Tanksley and McCouch, 1997). Genetic maps are under preparation for maize, tomatoes, cotton, rice, tobacco, millet, barley, oil seed rape and sunflower, as well as other crops. For example, over 1100 genes have been assigned positions on the 42 chromosomes of the wheat plant (Law, 1995).

These advances are allowing breeding strategies to move from searching for the physical expression of advantageous traits (the phenotypes), which is a good strategy when the trait of interest is controlled by one gene — this is often the case with disease resistance for example — to searching for genes when the trait of interest is governed by gene complexes, e.g. yield, photoperiodism and vernalisation (Tanksley and McCouch, 1997). Most of the GM crops developed up to now have influenced characteristics that are controlled by single genes (see Table 2). Quantitative characteristics, for example, yield, photoperiodism and photosynthesis efficiency, are controlled by many genes and the ability to manipulate these characteristics would represent a major step forward in plant breeding technology.

The advances made by molecular science allowed Raybould and Gray (1993) to

introduced gene has deleterious side effects, e.g. genes that convey resistance to disease may have yield penalties (Law, 1995). The fertility problem has meant that breeders have been largely confined to using genes from biologically close varieties and species (i.e. the primary gene pool).

[3] For example, Monsanto's trademarked Roundup-Ready soybean is a genetically engineered variety of soybean which contains gene sequences from cauliflower mosaic virus, a petunia and a bacterium (*Agrobacterium sp*.). One of the bacterial genes codes for resistance to glyphosate, the trademarked herbicide Roundup which is manufactured by Monsanto. The other genes are intended to control the expression of the glyphosate gene. As a result the herbicide Roundup can be used to kill weeds in soybean crops without injuring the soybean plants.

[4] Genetic engineering is used to refer to a range of terminology including, gene engineering, recombinant technologies, recombinant DNA technologies, molecular techniques/technologies, gene manipulation/transfer and transgenesis.

Table 2
AgrEvo's and Monsanto's GM product launch schedule for the USA[a]

	AgrEvo		Monsanto	
Existing products include:	Liberty link oil seed rape and maize		NewLeaf insect resistant potatoes, Bt Cotton, and Roundup Ready (RR) oil seed rape, soybean, cotton, and maize. Yield guard maize, and oil seed rape with improved oil	
Genetic modification	Crop	Date	Crop	Date
Herbicide resistant	Soybean	1998	RR Maize	1998/99
	Oilseed rape	1998	RR Sugar beet	2000
	Sugar beet	1999	RR Oilseed rape	2000
	Cotton	2000		
	Rice	2001		
Insect resistance	Maize	1998	Bollgard cotton	1998
	Vegetables	1999	Tomatoes	1998/89
			Weevil resistant cotton	2000+
Hybrids	Oil seed rape	1997		
	Mustard	1999		
	Oilseed rape	2000		
Seed link	Maize	1998		
	Vegetables	1998		
Insect plus virus protected	–		New leaf potato	1998/99
Virus protected	–		Tomatoes	1998/99
Enhanced oils	–		Oil seed rape	1998/99
Improved oils	–		Oil seed rape	1998/99
High sugar	–		Tomatoes	2000
High solids	–		Potatoes	2000
Improved oils	–		Soybean	2000+
High sugar strawberries	–		Strawberries	2000+

[a] (source: Agrow, 1996; papers supplied by Monsanto).

state that the foundations for the routine transformation of all UK crops were in place. Law (1995) stated that "transformation is now possible for almost all of the plants cultivated by man" (p. 6) and the capacity to genetically engineer living species is growing exponentially (UNEP, 1996, p. 691).

However, no GM crops are currently licensed for both commercial production and consumption in Europe. The following section examines the European regulations which cover the commercial licensing of GM crops and their implementation.

Status of GM crops in Europe

The regulatory framework of EU member states is tied to one another because a company applying for a commercial licence to grow a GM crop can choose which European country it prefers to handle the application. That country then sends its recommendation to other EU countries for comment and, if there are no objections, a licence is granted. Licences can be granted for importation, consumption and/or commercial release. However, if only one country objects the Commission puts the matter before a regulatory committee comprised of member states' national experts. If that is carried, approval is granted across the whole of Europe, but if there is no majority the Commission takes the decision to the Council of Ministers. If the Council fails to act within 3 months, the Commission puts its recommendation into effect. However, the crop then still needs to pass a final hurdle: to be cultivated in Europe it has to be entered into national trials and then be accepted to go on a National Seed Register and from there onto the Community Varieties Register (Franks, 1998a,b; Emmott, 1998).

All applications for licences must be accompanied by risk assessments. These must include information on the parental plants, the genetic modification, the GM plant, the site of release, the release itself, the post-release monitoring and waste treatment plans and the potential environmental impact of the release of the GM crops, inter alia (DoE, undated). Member states' experts decide whether the submitted risk assessments cover the necessary criteria, but also whether they accept the assessments presented. They have the authority to attach conditions on the commercial release of the GM crop by, for example, placing restrictions on the management of the crop.

The Bt-maize experience

These European procedures have been challenged by some member states. The Austrian and Luxembourg governments refused to accept GM crops in any form, despite clear instructions from Brussels to abide by European regulations. These governments have imposed unilateral bans on Novartis's Bt-maize and the French government has recently also imposed a temporary ban on this product. The French government initially refused to licence Novartis's Bt-maize, citing concerns of the dissemination of transgenic genes into the environment (Science, 1997). However, in November 1997 the French government did grant a licence for its commercial production (Agra Europe, 1998a, p. EP/8) and in February 1998 Bt-maize was entered onto its national seed register. At that time it was thought that 15,000 ha would be planted, however, only about 1000 ha were actually sown for the 1998 harvest, principally because of uncertainty over labelling regulations (Agra Europe, 1998b, p. M/11). Shortly afterwards, in October 1998, a temporary ban was imposed on this crop following a challenge on the inclusion of the maize on the national seed register (Agra Europe, 1998c, p. EP/7). This temporary ban has now been followed by a 2-year moratorium on planting all GM rape seed in France: a moratorium that is to be challenged by the European Commission as a contravention of EU legislation.

The UK experience

As at 30 September 1997, 267 licenses have been granted for trials involving GM crops in the UK (The Genetically Modified Organisms Public Register; DoE, 1997) though, at the time of writing, only one GM crop has been licensed for commercial release in the UK (Novartis's Bt-maize), and this crop cannot be grown commercially as it has not been placed on the UK or the European Seed Register. Other GM crops have received UK licences for human consumption but not cultivation (AgrEvo's oil seed rape), and for cultivation but not human consumption (Bejo Zaden's BV red hearted chicory) (Franks, 1998a).

In 1997, a Ministry of Agriculture, Fisheries and Food (MAFF) discussion paper stated "Genetically modified herbicide tolerant crops are likely to become commercially available in the UK in 1998" (MAFF, 1997, p. 3). This assessment proved to be incorrect. In October 1998 a 3-year agreement was reached between biotechnology firms, DETR and MAFF, that no insect resistant GM crop will be introduced commercially for 3 years and no herbicide resistant GM crop for 1 year — in effect a voluntary moratorium on the commercial introduction of GM crops. Of particular concern is the effect of this new technology on the wider environment. The UK government is intent on making sure that the scope of EU Directives (90/220 covering the release of GM crops into the environment) is sufficiently broad to cover two particular concerns. First, the indirect ecological effects of GM crops (i.e. effects on non-target species) as well as their direct effects. Second, the UK government is keen to introduce long-term monitoring arrangements designed to pick up any possible unexpected effects of GM release (Agra Europe, 23 October 1998, p. EP/9). To this end, the UK Minister of Agriculture has set up a committee to examine the evidence of the impact of GM crops on the wider ecosystem.

Advocates of GM crops have argued they will enhance wildlife by giving farmers more choice over when to apply herbicides. Furthermore, they have suggested that the current risk assessment procedures be replaced by environmental impact assessments, which would take into account any benefits as well as any disadvantages of planting GM crops.

Therefore, at present, although some GM crops can be imported into Europe none can be planted commercially. Although there is a clear legislative pathway along which applications for licences for trial and release can be made and granted, the risk assessments required to surmount these hurdles have been challenged. That they have failed to record consumer and environmentalists' legitimate concerns is reflected in the moratorium currently in place in four European countries. Given that consumer confidence is the foundation upon which this technology will flourish or founder, these tacit acknowledgements must be seen as hindering the prospects for GM crops in Europe.

European resistance to GM crops

Despite the global growth in commercial planting there has been substantial resistance to GM crops in Europe, where the application of biotechnology to agriculture has lagged behind its use in medicine (Nature, 1997a; Farmers Weekly, 1998b).[5] According to a survey reported in Nature (1997a), only 35% of UK consumers thought that GM crops would reduce world hunger: the main concern of 74% of consumers was the need for proper labelling. The survey also provided some evidence that moral doubts act as a veto irrespective of people's views on the use of this technology and its risks.

Consumers and environmental safeguards

Regulations to control the safety of genetic modifications, in all its forms, date back as far as 1978 in the UK (The Agronomist, 1998, p. 20). The legislation governing the licensing of genetically modified organisms includes the Environmental Protection Act 1990, and the Genetically Modified Organisms (Deliberate Release) Regulations 1990 and 1995 (which implement an EU Directive 90/220 covering the release and marketing of GM crops). These require that consent is granted by the Secretary of State for the Environment. The Minister is advised how to deal with applications by the Advisory Committee on Releases into the Environment (ACRE), which can advise on any conditions which it is felt should be attached to its approval. Three other independent bodies advise the Ministry of Agriculture, Fisheries and Food: the Advisory Committee on Novel Foods and Processes (ACNFP), the Food Advisory Committee (FAC) and the Advisory Committee on Pesticides (ACP).

Consumer concerns

Consumer organisations have expressed concerns over several aspects of GM crops. In particular: (1) antibiotic resistant marker genes may be transferred to bacteria in the stomach of animals and confer resistance properties, thus eliminating the effectiveness of the antibiotic (Science, 1997, p. 1063; ACRE, 1997, p. 8); (2) allergenicity from the expression of certain transgene products derived from known allergens (ACRE, 1997, p. 5; Franck-Oberaspach and Keller, 1997); and (3) lack of consumer choice due to inadequate labelling.

As discussed above, marker genes are used to speed up the selection and multiplication processes, but are not required for the growth of GM plants in the field. Recent developments in biotechnology have allowed marker genes to be selectively removed once they have completed their useful work. Although ACRE considers the risk of marker genes to human health and the environment to be "low" (ACRE, 1997, p. 8) it goes on to say "it is good practice to excise unnecessary genes", and that doing so might facilitate considerations of applications for the marketing of the GM product (p. 8). Barber (1997) states that although the risk associated with marker genes "is considered very small, the use of [marker] genes should be avoided for future geneti-

[5] Developments in medical products, such as human insulin, clot-dissolving tissue plasminogen activator, new vaccines for hepatitis and genetic diagnosis tools for muscular dystrophy, have created a global market worth £15,000 million (Gershon and Hodges, 1997; Zilberman et al., 1997).

cally modified products" (p. 1). Given the sensitivity of this issue to consumers, it would be expected that all antibiotic resistance marker genes are removed from the GM crop prior to applications for licences in the future, or that genes with properties other than antibiotic resistance should be used as markers.

Food labelling

There have been three focuses in the debate on food labelling: (1) whether GM foods should be labelled and, if so, (2) which products should be labelled and (3) what form of words should be used. This issue has attracted the attention of leading USA politicians and the World Trade Organisation, as it has far reaching economic consequences. Stringent labelling requirements could increase costs at every stage of the production and marketing process, making GM crops more expensive to grow and process and therefore increasing the price of GM food to consumers, resulting in a reduction in the area planted.

The Deliberate Release Directive (90/220) covered the rules for packaging and labelling. In January 1997, after 4 years of discussion between the European Parliament and the European Commission, this directive was replaced by the Novel Food Regulation (258/97). This regulation states four circumstances under which food and food ingredients containing or consisting of genetically modified organisms and foods and food ingredients produced from, but not containing, genetically modified organisms should be labelled (Table 3).

However, these regulations were widely seen as unsatisfactory. There is difficulty with the definition of "existing equivalent foodstuff" and the Commission has not produced guidelines or detailed labelling rules to accompany the Regulation. The European Commission has reissued guidelines for labelling two specific products — Monsanto soya and Novartis maize (Regulation 1139/98). These guidelines propose that these two GM crops are labelled as "may" contain GM crops if manufacturers cannot rule out the possibility of the presence of GM material, but only ingredients where "protein or DNA resulting from genetic modification is present" need to be labelled. Furthermore, a de minimis threshold is proposed, which means if the protein

Table 3
Food labelling issues

Labelling requirements must ensure the consumer is informed of:	
1	Any characteristic or food property such as composition, nutritional value or nutritional effects and intended use of food.
2	The presence in the novel food or food ingredient of material which is not present in an existing equivalent foodstuff, and which may have implications for the health of certain sections of the populations.
3	The presence in the novel food or food ingredient of material which is not present in an existing equivalent foodstuff and which may give rise to ethical concerns.
4	The presence of an organism genetically modified by techniques of genetic modification.

or DNA is there but only in small amounts (3% is being talked about) it will not need to be labelled (Emmott, 1998, p. 5). However, under pressure, the Commission has recently agreed to label all food as either containing or not containing GM crops, though the de minimis debate continues.

Whether the regulation will have consumer confidence is unclear. What seems a straightforward requirement to label food made with GM crops has resulted in an apparently endless series of discussions and resulted in legislation that is difficult to interpret. Labelling is needed if the key issue of consumer choice, based on quality assurance and traceability schemes, is to be upheld. UK consumers, in particular, have become sensitised to food labelling following the BSE (bovine spongiform encephalopathy) crisis (Loader and Henson, 1998): few consumers can be sympathetic to the problems placed in the way of clear, unambiguous labels. Indeed, consumers may demand that labels do more than reflect the immediate composition of food, for example, so they are able to buy animal products which themselves have not been fed with GM crops.[6]

Environmental concerns

Many of the concerns expressed by environmentalists arise because GM crops are able to reproduce and evolve in the environment and because it would be extremely difficulty, if not impossible, to recapture them should they threaten important ecosystems (ACRE, 1997, No. 7). Four areas give particular concern;

- the escape of transgenes into the environment (OECD, 1993; Raybould and Gray, 1993; Ellstrand, 1992; Ellstrand and Hoffman, 1990), leading to a risk of resistance developing in target populations (McGaughey and Gelernter, 1998; Powles et al., 1997), threatening genetic diversity and compromising registered organic standards;
- the risk of the GM plant itself becoming a weed;
- concerns over the wider ecosystem because of direct and indirect effects on non-target species (ACRE, 1997, p. 8; Mantegazzini, 1986; Diamond, 1997); and
- the lack of any mandatory post-release monitoring of the environmental effects of GM crops (NFU, 1995).

An OECD (1993) report highlights some of these concerns when it stated that “for many crop species it would be impossible to grow a GM variety in practical agriculture without some form of inter-pollination taking place with plants from adjacent fields of the same crop” (p. 27). It continues “in practical agriculture it is inevitable that a crop plant cannot be isolated from nearby native weed species. It follows that, under normal field conditions, ‘containing’ introduced genetic traits so that they

[6] Consumers may be aware of Europe’s ban of the use of the growth hormone recombinant BST, used to increases milk production, however it permits the import of foodstuffs manufactured from milk produced using rBST (Swinbank, 1996). Consumers may require labelling that prevents their unknowingly consuming food produced using GM crops.

remain exclusively in the varieties of crop plants into which they were originally introduced is an unrealistic objective" (p. 27).

Many of the concerns expressed by environmentalists revolve around the genetic complexity and the uncertainty of the outcome of releasing GM crops into the environment. These factors led to environmentalists arguing that the precautionary approach, which presumes that an environmental hazard is possible rather than that proof of the hazard should always be required, should guide the granting of commercial licences (Hill, 1994). Such a change in the regulatory framework would most likely lead to further delays in the licensing of GM crops; but these may be acceptable if they re-capture public confidence. The agreement to withhold commercial introduction of GM crops reached between biotechnology firms and the UK government in October 1998 (a de facto moratorium) indicates a real concern with the lack of existing post-release monitoring of the environmental effects of GM crops.

Responses to consumer/environmental issues

Advances in biotechnology have allowed ACRE to be able to request that unnecessary gene sequences, which are nevertheless transferred to the host plant in the transformation process, are removed (ACRE, 1997, p. 3).[7] Recent refinements in transformation techniques have allowed smaller segments of chromosomes containing the desired gene to be isolated and inserted, thereby reducing the likelihood of transferring adverse genes. It is also likely that additional environmental assessments, including post-release monitoring, will be introduced when the revisions to the European Directive 90/220 are completed (Agra Europe, 1998a, p. EP/8). Statements made by ACRE show the awareness that a strong argument for GM crops is the precision with which DNA is altered leading to the true perception of biotechnology being a clean technology.

Concerns regarding cross pollination have led researchers to attempt to introgress DNA into chloroplast DNA rather than the cell's nuclear DNA. For most plants the genetic trait will then be inherited maternally and not by pollination, thus preventing gene escape through pollen and reducing hybridisation problems (Daniell et al., 1998). However, this research is still in its infancy and has been questioned. Stewart and Prakash (1998) and Cummins (1998) offer examples where chloroplast DNA is not always maternally inherited; the former suggest that crosses with weedy relatives could still lead to transgenic weeds. Another approach is to ensure male sterility which would make out-crossing impossible. Alternatively, high value crops could be grown indoors.

ACRE has the authority to attach growing conditions to commercial licences. For example, in regions where rare and potentially valuable genetic resources may be at risk from commercial release, they could prohibit the planting of GM crops. Agron-

[7] Monsanto's fodder beet, sugar beet and oil seed rape do not contain antibiotic-resistant marker gene (Farmers Weekly, 1998a, p. 70).

omic constraints can also be imposed to counter any potential problems. These may involve farmers:

- planting barrier crops;
- maintaining reproductive isolation distances between crops and valuable and vulnerable wild gene pools;
- planting GM and traditionally bred crops close to one another;
- segregating GM and traditional crops during planting, harvest, storage and processing (depending on regulations governing labelling);
- co-ordinating husbandry practices with neighbouring farmers;
- planting plants (which may be genetically modified) which attract insects that prey on the pest;
- planting plants that attract non-target species to increase the probability of adequate populations of these species surviving.

The organic movement is fiercely opposed to genetic modification technology. It is particularly worried about the organic status of crops should cross pollination from GM crops on neighbouring farms result in transgenic material entering crops otherwise grown to the organic standard. This problem is far from being resolved.

Most of the constraints suggested above are likely to increase the costs associated with planting GM crops. However, potential benefits such as reducing pesticide use may give GM crops an advantage if future legislation was to limit the use of pesticides, either directly, by imposing pesticide free areas, (e.g. close to sensitive water sources), or indirectly (e.g. by taxing pesticide applications). Should labelling regulations require total separation of GM and traditional crops the cost at each stage of harvesting, storage, transport and processing may result in more expensive GM food, resulting in a smaller area of GM crops being planted. It might also lead to food production systems becoming dedicated to growing, transporting and processing (and even selling) either GM or traditional crops.

Intellectual property rights and company structure

Legislation plays a key role in the prospects for the development of new molecular processes and GM products, and on the uptake and diffusion of commercially available GM varieties. It also plays a role in shaping patent law, which is a major determinant of public and private investment into research and marketing because of its key role in determining the ability to recover an economic return on investments.

Intellectual property rights and pricing policy

Intellectual property rights (IPR) give the inventor exclusive rights to use an invention for a specified period of time. In 1980, US patent law permitted GM crops to be patented. By 1994, 80% of all GM patents awarded for the development of finished plant varieties of agricultural crops had been awarded to private companies or individuals (Fuglie et al., 1997). This contrasts with the experience in Europe. In 1995, opponents of patents on genetic material exploited a loophole in the 1973 European Patent Convention to argue that transgenic plants can be considered a plant variety and, therefore, were not patentable. The European Biotechnology Patent Directive (1997) seeks to change this interpretation and in doing so to assist in clearing the backlog of around 1200 patent applications for plants, and 500–600 on animals that have built up (Nature, 1997b).[8]

The draft European directive "explicitly allows patenting of life, including human genes, provided that a truly inventive step and industrial use can be proved,[9] and provided that the procedures involved are within defined ethical limits"[10] (Nature, 1997b, p. 314). A discovery of a gene in its natural state is thus not patentable as some element of science is required (p. 309). However, once the function of a gene is determined that gene can be patented; there is no requirement for commercial applicability.

Legislation governing patents is of the utmost importance in the development of GM crops. This is because knowledge and technological innovation are examples of goods which are: (1) non-rival (as they can be used many times and are not limited to a particular place, person or time), and (2) non-excludable (a good is non-excludable if one person cannot charge another for its use — either because of the good's technological characteristics or because of legal restraints and penalties). For a private firm to develop a new product it must have confidence in its ability to recover research and development costs: for this to be possible a non-rival and non-excludable good must be made rival and excludable, and it is this that patent law can achieve (Lesser, 1997; Langford, 1997; Fulton, 1998).

The degree of rivalry and excludability of an economic good has implications for the structure of the commercial market. Romer (1990) argues that when a non-rival goods is an input into a firm's production function, the production function changes from a constant to an increasing returns-to-scale function (i.e. unit production costs decrease as output increases). This is because technology can be used repeatedly in the many development activities the firm undertakes. A production function that exhibits increasing returns-to-scale implies: (1) that the firm cannot survive as a price taker but needs to gain market power, and (2) to remain competitive the firm must expand to acquire that market power (Fulton, 1998).

Whilst patents can change a non-excludable good into an excludable good, so can farmers' contracts. These are contracts struck between GM seed producers/biotechnology companies and farmers which gives the GM producer sole

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[8] It was given approval in July 1997 by the European Parliament.

[9] Inventions which satisfy the three criteria, (a) they are novel, (b) they are the result of an inventive step, and (c) they have a commercial use, have been granted patents which allow retention of all commercial rights over the product for 20 years. However, discoveries are not patentable, and a debate has existed as to the nature of DNA, is it an invention and therefore patentable, or is it a discovery and therefore not.

[10] "The approved parliamentary draft excluded patents on procedures for human reproductive cloning and germline therapy, and methods using human embryos" (Nature, 1997b, p. 314).

rights over planting seeds saved from GM crops (see Franks, 1998b, for more details of these contracts).

As patents influence market structure and competition between competing companies they affect pricing strategies. Farmer contracts also influence pricing strategies, by preventing the ownership of the germplasm passing to farmers, firms can recover development costs over a longer time period allowing smaller annual fees rather than a larger one-off payment. This clearly makes GM crops more economically viable, particularly as farmer contracts may also specify that farmers use pesticides formulated by sister or parent companies.

Company structure and private investments

The increasing returns-to-scale implies that businesses need to expand by merger or take-over — which in turn creates a non-competitive, oligopalistic market structure — and that they have to integrate vertically, for example by acquiring control over seed distributors. This is a logical outcome arising from the need to prevent large seed companies using their market power to bid down the costs of the GM crop seed; the ability to do this increases the risk of not recovering research costs and therefore may prevent the development of profitable products.

These theoretical predictions of horizontal mergers and vertical integration have taken place as the market in GM crops has matured. For example, Monsanto has integrated vertically by buying into seed development and distribution companies; cotton (through Delta, and Pine Land, Calgene — which owns a cotton seed company), soybean (Agrow soybean), oil seed rape (Calgene), tomatoes (Gargiulo and Calgene), potato (Nature Mark), maize (licensing agreements with DeKalb Genetics Corp., Golden Harvest Seeds and Sandoz) and other fruit and vegetables (Empresas La Moderna) (Gene Exchange, 1997, p. 11). Monsanto also agreed to pay US$1.02 billion to buy Holden's Foundation Seeds, which supplies genetic material to more than 35% of the corn acres planted in the USA (NFU, 1997). Other companies have grown by merger. For example, Sandoz merged with Ciba-Geigy in December 1996 to form Novartis and AgrEvo was formed by the merger of Hoechst and Schering. It is estimated that ten companies now control about 90% of the world's crop protection market (Farming News, 1998, p. 36).

Another incentive for company merger is the potential impact of genetic transformation on the demand for crop protection chemicals. For example, patent laws and farmer contracts have allowed Monsanto exclusive rights to GM plants modified to resist Roundup which, therefore, safeguards its valuable Roundup market (estimated at US$1.5 billion in 1996) when its Roundup patent expires in the year 2000.

Pricing of GM seeds

Zilberman et al. (1997) set out the theoretical value of the genetic component of an improvement in plant varieties. The price charged for GM seed should reflect the expected difference in net margin of planting a GM variety and a traditionally bred variety. This will reflect the difference in prices, yield and any savings realised in farm inputs, such as farm chemicals, energy, equipment and labour (Langford, 1997). But market structure will determine the proportion of any increase in profitability that is retained by the farmers or captured by the GM seed distribution company.

Companies developing and marketing GM crops in America have recovered their research and investment costs by:

- increasing GM seed prices;
- levying a technology/licence fee;
- contracting farmers to use its own formulation of agrochemicals; or
- a combination of these approaches.

The companies that are likely to place GM crops on the UK market in the first wave of licenses (AgrEvo, Novartis and Monsanto) have been unable to provide any indication of the likely strategy they will favour in the UK. Perhaps a rough rule of thumb that may be used would lead to the potential financial benefit being divided between farmers and manufacturer; for example, 40% to the manufacturer and 60% to the farmer.

The economics of planting GM crops

The appeal of commercial planting of GM crops by European farmers will primarily depend on their profitability vis à vis traditional varieties. A cost–benefit analysis is needed to compare reduced costs (arising from more timely and simplified spraying regimes, reduced mechanical damage from pesticide application, better levels of crop protection) and changes in output value (through improved quality and/or yields) with higher costs (increased GM seed prices and licence/technology fee, compliance with growing practices and farmer contracts). Importantly, the impact on net margin will depend primarily on the effectiveness of the genetic modification under European conditions, and whether and to what degree restrictions are placed on growing, labelling and handling GM crops.

Costs of growing GM crops are best examined as indirect (fixed and overhead) and direct (variable) costs. Direct costs are those referred to above, and may include higher GM seed costs, licence/technology fees and other costs associated with the terms and conditions of farmer contracts. Indirect costs include changes to the farming system needed to prevent or reduce risks associated with:

- GM plants appearing in following crops as volunteers;
- resistance to the genetic modification arising in target pests and weeds (caused by changes in agricultural practices that may alter the selection pressure on genetic variability);
- the transgenes moving from the GM crop to weed species resulting in superweeds (Kling, 1996).

Agronomic practices which could be imposed to counter these potential problems include:

- managing new crop rotations;
- planting barrier crops;
- maintaining reproductive isolation gaps between crops and valuable and vulnerable wild gene pools;
- inter-farmer co-operation in husbandry practices.

Examples of imposed agronomic practices include:

- The restrictive management practices used on the American Bollgard Cotton crop requires 4% of the crop to be planted with non-genetically resistant cotton.
- To counteract resistant heliothis moths in GM cotton the Australian National Registration Authority requires that each hectare of GM cotton grown is matched with a similar area of susceptible cotton or 5% of completely unsprayed cotton crop (Wilson, 1996).

Currently a consortium of representatives of the agricultural and food industries are working towards producing guidelines for the growing and handling of GM produce, but no guidelines are yet available to indicate what restrictive management practices may be needed for any genetically modified crop under UK conditions. The UK's National Farmers Union (NFU) has commented that "isolation may be necessary" (NFU, 1995, p. 7) but it warns that farmers find these measures "unpopular, difficult to implement" and that this "will reduce the flexibility of land use" (NFU, 1995, p. 8).

If food containing GM crops needs to be labelled then additional costs may include segregation of GM and traditionally bred crops at every stage of the planting, growing, harvesting and marketing operations.

Any restrictions attached to the growing of GM crops are also likely to increase the costs of their cultivation. If regional restrictions are placed on growing GM crops, such as zoning or regional bans, then farmers inside these zones may ask to be compensated for profits forgone, as they will not directly benefit from safeguarding the valuable genetic resource. Such payments could be appended to existing agri-environmental schemes by, for example, amending management blueprints in Site of Special Scientific Interest management agreements, developing new tiers in the Environmentally Sensitive Areas Scheme, by reviving relatively unused agri-environmental schemes (such as biosphere zones), or using new land zoning policies, for example based on biodiversity zones (Philips, 1996).[11]

What the comparative net margin is, between GM crops and conventionally bred varieties, under UK conditions is unclear. There is practically no data on the expected yields of GM crops, of the variable costs of GM crop seed or licence/technology

[11] Biosphere and biodiversity zones consist of concentric circles of land, in which progressively tighter constraints are imposed as one passes towards the core or central zone.

fees or of possible fixed and overhead costs (Franks, 1998c). While the increase in the area planted in America suggests that GM crops have been priced to give farmers a financial incentive to adopt GM technology, the financial and agronomic conditions present in America may not be completely transferable to European agricultural systems, which tend to be more complex and less homogenous. Therefore, it is likely that the costs incurred by UK farmers in moving to these crops will be larger than those incurred by American farmers, particularly if additional labelling requirements require the segregation of crops throughout the production chain.

Conclusion

This article has reviewed the status and prospects for GM crops in Europe. Despite potential environmental and economic advantages, GM crops have been resisted in many European countries. Consumer surveys suggest a lack of confidence in the assessment of potential risks to the environment and to consumers. The argument that elements of environmental risk, in particular post-release monitoring, have not been adequately assessed has received support by recent government action, including in the UK where a voluntary agreement is in place restricting the commercial introduction of GM crops.

Consumer perceptions of a mismatch between scientific and lay assessment of risk (sensitised after the BSE food scare), together with moral issues, are prominently responsible for public resistance to GM food. Curiously, this reluctance has not appeared to extend to pharmaceutical use of GM crops: perhaps because the benefits of improved health are more clearly understood. Miflin (1996) stated that the new biotechnologies are very powerful and “have challenged many people’s beliefs and conceptions” (p. 29): this novelty may be another element behind the resistance expressed by European consumers.

If consumers refuse to buy GM products, none will be grown or imported. This outcome would exclude society from potential benefits, including lower pesticide use, improved food quality and land reclamation. It is difficult for consumers to understand the resistance to clear and unambiguous labels being attached to food made from a GM crop. It is important though that consumers’ concerns should not be allowed to restrict the substitution of molecular techniques for conventional techniques in varietal development programmes where cross-breeding would have occurred naturally (because of sexual compatibility).

Given a quantifiable consumer demand, the area planted with GM crops will depend on their financial costs and benefits. Costs will be affected by (1) regulations placed on developing, growing and processing crops, and selling food made from GM crops and (2) the market structure of the firms which develop, multiply and market GM crops. These costs will be influenced by labelling, an issue of considerable economic importance, and one which has implications for future rounds of world trade negotiations.

One avenue of advancing the debate on GM crops in Europe is to further reduce risks and improve the benefits associated with GM crops. This has already been happening, for example, perceived risks are being reduced by more accurate manipulation of genomes — producing a cleaner technology. Benefits could be improved by developing the knowledge and technology to manipulate characteristics such as photoperiod and vernalisation; characteristics controlled by more than one gene. Should cleaner technology result in benefits that are more clearly demonstratable then objections to the disadvantages associated with current GM crops would very likely decline. Society may consider the economic costs of rejecting a technology that has the potential to alter the global pattern of food production too high.

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