Popular Summary of: The release of genetically modified crops into the environment

II. Overview of ecological risk assessment

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This paper is a comprehensive review (25,000 words, reviewing 250 publications) examining some of the multitude of concerns raised about the impact of genetically modified (GM) crops on the environment, their potential for weediness, vertical and horizontal gene flow, ecological impacts, effects on biodiversity and the presence of GM material in other products. Worldwide scientific research to date on each concern is described.

The authors conclude that a crucial component for proper risk assessment is defining the appropriate baseline for comparison and decision making. For GM crops, the best and most appropriately defined reference point is the impact of plants with DNA modifications made by other, more traditional, breeding methods. The latter are an integral and accepted part of agriculture. Many of the positive impacts identified for GM crops are very similar to those of new cultivars derived from traditional breeding.

The Plant Journal is rated among the top 5 international plant science journals. *The Plant Journal* publishes selected original research papers in key areas of modern plant biology with a particular focus on the impact of molecular genetics. It is published fortnightly by Blackwells, in association with the Society for Experimental Biology, by a team of European and North American editors. Over the last 3 years the editors have commissioned papers for a series of science-based analyses of the issues surrounding transgenic crop plants (see **www.blackwellpublishing.com/plantgm/gm.asp**). Their aim is to "undertake a holistic view of the issues involved and to provide an independent and authoritative resource of world-class academic information that will facilitate an informed debate …[realising]… that the GM technology debate is a dynamic work in progress and resources to inform that debate would necessarily have to be up-dated as the discussions evolved." This paper is the second by Dr Tony Connor and colleagues to be published in *The Plant Journal.* The first paper is an overview of current status and regulations.

Introduction

Genetic engineering (GE) is the most recent of a variety of 'new' technologies allowing plant breeders to produce plants with new gene combinations. Other technologies, such as microwaves and immunisations, have been accepted but GE has been the focus of vocal and sometimes violent public concern. Public unease remains strong despite reassurances from scientists, and this may be because GE raises complex philosophical questions about the changing nature of agriculture.

The science of risk and risk assessment

Risk means different things to different people in different situations. It can be thought of as a combination of probability and consequence, i.e. the likelihood of an event multiplied by the impact of the event. Formal risk assessment usually considers three questions: what can go wrong, how likely is it to happen, and what are the consequences if it does happen? It is important to recognise that just because an event may happen, does not mean it will happen.

What risk is acceptable?

Once the chance of a risk occurring has been calculated, political, social, cultural and economic considerations will determine whether people believe it to be acceptable. The GE discussion has shown that risk perceptions differ dramatically, even between experts, depending on individuals, their motives and values. This variation undermines public confidence. In addition the media has a strong bias towards covering stories about risks and hazards rather than benefits because these are more "newsworthy".

Decision makers need to consider to what extent issues such as sustainability, globalisation, ethics and socioeconomics should be part of any GM crop risk assessment.

Concepts for ecological risk assessment

The precautionary principle

Two general concepts have been proposed to guide the ecological risk assessment for GM organisms: the principle of familiarity and, more recently, the precautionary principle. The latter is part of the Cartagena protocol on Biosafety (2000) and is now the basis of regulation in the EU. The concept of familiarity considers whether the GM organism is novel for the ecosystem, but is probably too loosely defined to be very useful for risk assessments. However, there are similar problems with the precautionary principle. This principle was first introduced in the 1992 Rio declaration of the Convention of Biological Diversity as "*where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimise such a threat*". In the recently adopted Cartagena protocol (2000), it reads: "*Lack of scientific certainty due to insufficient scientific information and knowledge regarding the extent of the potential adverse effects of a living modified organism …. shall not prevent … from taking a decision, as appropriate …, in order to avoid or minimise such potential adverse effects*". There is considerable controversy on the meaning, scope and application of this principle, one of the more extreme interpretations being: "*in case of doubt, do not or do nothing*". The main argument against this interpretation is that "doing nothing" is a decision too, with its own premises and consequences.

> For GM crops the precautionary principle should work both ways. The risk of using GM crops should be balanced against the risks of using alternative solutions including the currently used technology.

Botanical files

Botanical files (or gene flow indices) are a new idea providing a way of summarising a GM crop's potential to hybridise with its wild relatives in a given environment and the impact this may have. More information is provided in the original paper. Plants are assigned risk potentials for factors such as pollen, seeds or method of fruit dispersal and the distribution frequency of wild relatives. The resulting gene flow indices are only applicable for the region for which they were established.

Assessment of perceived environmental and agricultural risks

Will transgenic crops invade agricultural and natural ecosystems?

THE CONCERN: *GM crop plants may become weeds, adding to farmers' expenses, or they may invade natural habitats, compromise the ecological values of those habitats and threaten attempts to maintain biodiversity.*

There is no consensus on how to define a weed or the attributes that indicate a plant is likely to become a weed. Weeds do, however, tend to have a preference for disturbed habitats and high physical variability, allowing continuous adaptation to changing environments. Alternatively, a plant without these attributes may become a serious weed if it finds itself in an environment for which it is suited that lacks enemies such as herbivores or diseases.

Many "weedy" attributes, such as seed dormancy, physical variability and continuous flowering and seeding, have been bred out of crop plants over thousands of generations. They are not the sorts of traits that scientists have been introducing into crops using GE.

> GM crops are no more likely to become weeds outside farming situations than new crop cultivars have in the past. Domesticated crops would require multiple genetic changes to become successful weeds.

Some forage grasses, legumes and oilseed rape have a shorter history of domestication and are more likely to become weeds. Oilseed rape has been used for many of the investigations into the potential invasiveness of transgenic crops because it provides a worst-case scenario.

Virtually all crop plants have the potential to appear as volunteers (self propagating plants) if seeds are lost or viable vegetative propagules remain in fields. In reality, however, crop plants are rarely seen as weeds. They can sometimes be found in disturbed soils within or alongside farmers' fields, but in such environments they usually survive for only one season.

One way to assess the potential weediness of a GM crop is to calculate its finite rate of increase. This calculation is based on the processes affecting population growth, including fecundity, seed survival, seed germination, and seedling survival to maturity. The calculation can take into account any effects of the newly introduced DNA on any step in the process.

This analysis has been applied to GM oilseed rape with resistance to the herbicide glufosinate. More details can be found in the original paper but the oilseed rape was no more invasive in disturbed or undisturbed habitats than non GM-rape. Similar analyses have been done for other GM crops with the same conclusion.

> Calculations of the potential weediness of GM crops, based on population growth studies, showed that GM crops were no more invasive or persistent than their conventional counterparts in a range of environments.

Will transgenes (DNA introduced by GE) outcross to other species and increase their weediness?

***THE CONCERN:** GM crops may hybridise with related weedy relatives and the transgenes (for herbicide resistance, for example) may be transferred.*

The potential for a crop to hybridise with a weed is highly dependent on sexual compatibility and relatedness. Even if a crop plant and a weed were sufficiently compatible, the survival of any resulting plants would depend on overcoming a number of barriers. Some of these are listed in **Table 1**. Traditional plant breeders use many techniques to encourage plants to hybridise—the process cannot be guaranteed to occur naturally.

One situation where hybridisation is more likely to occur is where a crop species is growing alongside its wild relative. In these situations there has always been the potential for crop genes to transfer to the relative. It is important to consider, therefore, whether GM crops are more prone to transferring genes than their non-GM counterparts. Generally they are not. Two possible exceptions are deliberately introduced changes in flower colour, which may make plants more, or less, attractive to insect pollinators. In addition, deliberately introduced male sterility may increase access by foreign pollen and the chance of hybridisation. In these cases it is the difference produced by the gene that is important, not the fact that the parent was GM.

> For most transgenic traits, GM crops are no more likely to transfer either their transgenes, or any other gene, to other species than crop cultivars have done in the past.

***THE CONCERN:** If transgenes that give resistance to pests and diseases and protection against environmental stress were transferred to weeds this may enhance the fitness of the weeds in particular environments.*

> Cultivars produced by traditional breeding with resistance to pests and diseases and tolerance to environmental stress have not transferred these advantages to weeds in the past and GM crops are not likely to either.

***THE CONCERN:** Transgenes giving herbicide resistance may increase the fitness of weeds in an environment where the herbicide continues to be used.*

TABLE 1. Factors determining the likelihood of gene introgression from crop plants to related species.

	PRE-ZYGOTIC BARRIERS TO HYBRIDISATION		ESTABLISHMENT OF HYBRID PLANTS
1.	Spatial isolation of parent populations	12.	Seed dormancy
2.	Synchrony in flowering	13.	Direction of cross (maternal effects influencing seedling vigour)
3.	Direction of the cross (the parent from which the pollen and ovules originate)	14.	Growth vigour of hybrid plant
4.	Specific parental genotypes	15.	Habitat conditions (natural, ruderal, cultivated)
5.	Method of pollen dissemination and presence of pollen vectors	16.	Competition from other plants
6.	Pollen competition from maternal population	17.	Influence of pests, diseases, predators
7.	Environmental conditions		
	POST-ZYGOTIC BARRIERS TO HYBRIDISATION		**PROPAGATION OF HYBRID PLANTS**
8.	Mitotic compatibility of the two parental genomes	18.	Ability to propagate vegetatively
9.	Ability of endosperm to support hybrid embryo development	19.	Persistence, dissemination and invasiveness of vegetative propagules
10.	Direction of cross (maternal effects on seed/fruit development)	20.	Pollen and ovule fertility (meiotic stability and chromosome pairing)
11.	Number and viability of hybrid seeds	21.	Ability to produce sexual progeny (selfed and backcrossed)
		22.	Ability to survive over subsequent generations
		23.	Seed number, viability and dormancy
		24.	Habitat conditions, plant competition, pests, diseases and predators

While this is a potential concern, it must again be remembered that herbicide-resistant plants have been developed by traditional plant breeding and arise by entirely natural means. The development of weedy populations with herbicide resistance is not a new situation for agriculture and the industry is generally well aware of the problems that this can impose on weed management practices.

> The development of herbicide resistance in weed species should be resolved from the perspective of good agricultural management regardless of whether herbicide-resistant crops are GM or traditionally bred.

Will GM crops contribute to horizontal gene transfer?

Horizontal gene transfer (HGT) is defined as the transfer of genetic material from one species to another species that is not usually sexually compatible (vertical gene transfer is gene transfer within the species). The extent to which HGT occurs is unclear but it may be a significant source of genomic variation in bacteria and possibly a route for evolution in eukaryotes.

THE CONCERN: *HGT will result in the transfer of transgenes from plants to other species and cause harm. Possible recipients include micro-organisms in soil or in the digestive tract of humans and livestock.*

The initial debate on HGT focused on the presence of antibiotic marker genes in GM plants. It was suggested that their presence could contribute to problems with antibiotic resistance in strains of human pathogenic bacteria. This concern has been considerably reduced because antibiotic resistance markers can now be removed from GM plants before release or alternative markers used.

Concern has now shifted to whether HGT could affect an animal's intestinal microflora when GM crops are consumed, whether transgenes could enter intestinal cells and change their phenotype, or whether transgenes could enter soil microflora and create novel pathogens, or have other detrimental influences.

For plant DNA to be transferred by HGT a whole set of conditions must occur.

1. **AVAILABLE.** DNA from the plant must be free from the cells, of sufficient length and persist long enough for uptake. DNA in dying plant cells is generally rapidly degraded but it can survive in some soils, aquatic environments or the digestive tract of mice long enough to be available for uptake.
2. **UPTAKE.** A bacterial recipient must be in a suitable state for DNA uptake (competent) and a mechanism for uptake needs to be in place. How often this occurs in bacteria in natural surroundings is unknown but competence can be induced in the laboratory.
3. **ESTABLISHMENT.** The recipient cell needs to incorporate, maintain and use the incoming DNA. Integration will depend on sequence homology and a gene will only be useful if it can be read by the recipient's cell machinery.

Several studies have looked for HGT from transgenic plants to bacteria but none, so far, have found it. Some studies have found gene transfer to plant-associated fungi but there is no evidence for stable integration and subsequent inheritance.

> It appears HGT can occur but at exceptionally low frequencies.

Another route for HGT could be via a plant virus that carried a section of DNA from one host to another. For RNA viruses (viruses that consist of RNA and not DNA) it would seem highly unlikely that DNA would become integrated in the genome of a related plant. For DNA viruses, there is some evidence for transfer of genetic material from virus to plants. (See original paper for more details.)

It is important to remember that a transgene constitutes only a fraction of a GM plant's total DNA and has a correspondingly low chance of being transferred. For example, if *Arabidopsis thaliana*, the plant with the smallest known DNA content, contained three transgenes, each 3000 base pairs long, only seven parts in 100 million of the total genome would contain the transgenes.

If HGT to microbes or cells is possible, the next relevant question becomes “so what”? The answer to this will depend on the nature of both the gene and the recipient. Detailed risk assessments have been done for the gene *nptII* that gives resistance to the antibiotic kanamycin. Kanamycin resistance is naturally widespread in the microbial soil and intestinal flora. This, combined with the very low occurrence of HGT, suggests that the likelihood of a bacterium receiving the gene from another (bacterial) source is much greater than the likelihood of a bacterium receiving the gene from a transgenic plant. Similar arguments hold for the antibiotic hygromycin. Both antibiotics are unsuitable for use in humans.

> Overall, the likelihood and impact of HGT suggests the possibility deserves less attention in the regulatory process than other concerns. HGT from GM plants to other organisms should be considered a calculable risk and genes with obvious potential impacts, such as resistance to a useful antibiotic, should be avoided.

Will GM crops have unanticipated ecological impacts in the future?

The view that GM crops are 'unnatural' has contributed to a perception that widespread use of such plants will lead to secondary or indirect ecological effects with undesirable consequences. This is a relatively new area of research, and what to measure and how to measure it are still being debated. More work is needed to clarify the relevance of measurements in terms of the environment, and it must be remembered that not every observable secondary ecological effect will be negative.

GM crops containing insect-resistant Bt (*Bacillus thuringiensis)* toxin have been comprehensively studied. Possible environmental effects include a direct effect on non-target insects due to exposure to GM plant material and any indirect effect on non-target insects via so-called multi-trophic food chains.

Any non-target insects that are vulnerable to Bt toxin will be affected if they eat any part of the GM crop. There was considerable media coverage when Monarch butterfly caterpillars that had fed on Bt maize pollen in a laboratory experiment died. Follow-up experiments showed the caterpillars rarely encountered or ate enough pollen in the wild to receive a toxic dose.

Another species that may be affected directly by Bt crops is the honey bee (*Apis mellifera*). At high doses Bt is toxic to bees but pollen from GM plants is unlikely to reach the doses required. Research with most of the widely grown commercial crops has found no effect on colony performance.

> Any secondary ecological impacts of a GM crop must be balanced against the impacts of the farming practices and crops it will replace.

THE CONCERN: *There may be impacts from GM crops further along the food chain.*

The Bt protein is relatively unstable so it will not remain or build-up in the food chain. Given that conventional agricultural practice is to kill the target species with broad-spectrum chemicals, the use of Bt in GM crops will have less effect because only the insects eating the crop are killed.

> Generally, no differences in insect predator numbers or undesirable effects have been found between GM-Bt cotton and non-GM cotton or other GM crops compared to traditional crops.

Commonly, predators and parasites reared on insects feeding on GM plants do not grow to the same weight as those reared on insects feeding on non-GM plants. This is probably because there are less insects available on Bt-defended plants or because Bt-exposed insects are nutritional poor for the predator/parasite.

One study, with lacewing, found the larvae died when they were fed prey raised on Bt maize. The researchers suggested Bt, which is normally not toxic to lacewings, had become toxic during processing by the lacewings' prey. It seems much more likely the prey used (*Spodoptera littoralis*) was not a good food for lacewing. Not all interactions will result in negative impacts. Bt maize, for example, has reduced levels of insect damaged tissue, therefore it is less infestated by fungi that produce the mycotoxins that are toxic to humans and domestic animals.

THE CONCERN: *GM plants expressing antimicrobial proteins or Bt toxins could affect soil microbial communities.*

Bt toxins in soil are estimated to have a half-life of 10 to 30 days. The rate of degradation is highly dependent on soil type; clay particles can bind and inactivate Bt irreversibly. Bt is not taken up and accumulated by other plants and research has shown that microbes near the roots of GM plants are unchanged. Exceptions include GM peroxidase-producing alfalfa and GM tobacco modified for decreased lignin. (More details are in the original report.)

Studies to date have not really answered the key questions about antimicrobial effects and this remains a challenge for the future. Some researchers are looking at soil-dwelling nematodes as indicator organisms for changes in soil micro-organism communities. Results to date have been mixed.

Caution is needed in interpreting the results of studies looking at differences in microbial ecology because the process of producing GM plants can introduce minor changes in metabolism unrelated to the DNA introduced. Similar metabolic changes can also happen in traditionally bred cultivars. Plant breeders are developing new cultivars that deliberately and beneficially change the balance of microbial and invertebrate species within soil ecosystems.

> It is too early to conclude whether GM crops can have a negative impact on agricultural and natural ecosystems by means of secondary ecological effects. Few examples of secondary effects have been found to date that are negative enough to result in problems at an ecosystem level.

Will GM crops lead to superpests and superdiseases?

THE CONCERN: *The widespread cultivation of GM crops with pest or disease resistance will impose intense selection pressure on pest populations to adapt to the resistance mechanism.*

The history of traditional plant breeding has shown that pest and pathogen populations can quickly adapt to crop cultivars with new resistance genes. It would, however, be unwise for plant breeders to stop breeding for resistance simply because the target pest or disease might overcome that resistance.

Agricultural management strategies, including refuges or areas of non-GM crops within the main crop, have already been developed to minimise the establishment of populations with resistance. Refuges are intended to maintain a group of susceptible insects within the pest population and the strategy could, theoretically, delay the development of resistance for decades. In addition pests should be exposed to a range of mortality mechanisms as part of an integrated pest management plan.

It has been suggested that the use of isogenic (genetically identical) lines or strains of the same crop plant differing only in the presence/absence of various genes for specific pests or pathogens could delay the development of insect resistance. This approach assumes insects will not be able to adapt to several resistance strategies at the same time. It is only the advent of GE technology that has made it possible to easily produce isogenic crop lines. Mixtures of GM lines could also be reconstructed each year prior to seed sowing. GE will also allow multiple resistance genes to be added to one line.

> Pests and diseases are equally as likely to adapt to resistance in crops irrespective of whether the resistance was introduced through traditional or GE techniques. GE offers some unique possible solutions for the future, but farmers should continue to use recognised integrated pest management strategies to minimise the development of resistance.

Will GM crops affect biodiversity?

THE CONCERN: *Introducing GM crops into the environment will affect and/or destroy biodiversity. A more useful question is whether GM crops pose threats to biodiversity that are any different from conventional crops.*

The Convention on Biological Diversity defined biodiversity as "*the variability among living organisms from all sources including,* inter alia, *terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*". Other organisations have developed their own definitions. It has been estimated that there are 5-15 million species on earth. The number of micro-organisms is poorly understood. There may be 10^9 different genes present in all living organisms on earth and when all the alternative alleles for all genes are considered across all species, the numbers become mind-boggling. An extreme conclusion is that each living organism is essentially a unique individual.

Several scenarios predict "irreversible" and "catastrophic" harm to biodiversity as a result of the use of GM crops. Equally, several scenarios predict the opposite.

THE CONCERN: *GM crops could threaten the centres of crop diversity or dominate at the local level to the detriment of native species.*

There is ongoing discussion about the possible presence of transgenes in Mexican maize landraces. Any gene from commercial maize varieties, whether transgenic or not, may cross into landraces. The issue comes down to whether transgenes are more likely to increase gene flow or weediness.

> In general the spread of modern agriculture based on genetically narrow populations of uniform hybrids is likely to pose a greater threat to the genetic diversity in maize than the presence of transgenes.

THE CONCERN: *Where GM crops are adapted to unusual environmental conditions, such as salt or drought, indigenous plant communities may be overrun by new crops.*

This potential problem is not restricted to GM cultivars. In reality the ability to get greater productivity from marginal land may take the pressure off remaining natural ecosystems.

THE CONCERN: *GM crops could influence the number and type of micro-organisms in the rhizosphere or soil.*

The most important issue here is whether any effect on species that rely on agricultural practices for survival should be considered a disruption of a "natural" equilibrium. Variation by itself will be huge and outcomes, which will not necessarily be negative, are difficult to anticipate. Post-approval monitoring should be encouraged.

> The best baseline for comparing the impacts of GM crops on micro-oganisms is the impact of conventional crops grown under existing farming practices.

> The biodiveristy associated with agricultural crops, called agrobiodiversity, has reduced over time as world production has concentrated on a handful of food crops. GM agriculture may contribute to this trend. Conversely, GM crops could contribute to increased agrobiodiversity. The use of GM soybean, canola, cotton and maize has reduced pesticide use by approx 22.3 million kg of formulated product. This is likely to have had a positive impact on agrobiodiversity.

It is impossible to assess or predict the long-term effects of GM or conventionally bred crops on agrobiodiversity as these, if any, may take 10 to 100 generations of a species to become obvious. The effects may be positive, negative or neutral.

> The very complexity of ecosystems that makes them difficult to predict and understand also buffers these ecosystems from the relatively minor impact of GM crops.

> Compared to ongoing native land conversion and habitat fragmentation, the possible threats posed by GM crops seem minor and largely hypothetical. There is little disagreement that the development of human civilisation and human activities such as agriculture and industry are a major cause of the loss of biodiversity at large. GM crops are no more, or less, likely to affect biodiversity than any other change in agriculture.

Will GM crops affect the purity of other crops?

THE CONCERN: *Conventional non-GM crops will, inevitably, receive transgenes from GM crops, resulting in situations that are either undesired or unlawful.*

This has already happened. GM Starlink maize containing the *cry*9C gene was found in non-GM maize grains in the US. The organic farming industry is particularly concerned about genetic mixing through pollen dispersal and mixing of seed. Liability may become a major issue.

> Genetic modification *per se* does not change the frequency with which genetic mixing occurs. Modern molecular biological techniques, however, have enabled us to detect mixing at very low levels. The level of mixing has not changed, just our ability to detect it.

Maintenance of seed quality is important for modern agriculture. Seed quality is controlled by the Association of Official Seed Certification Agencies or the OECD Seed Certification System. The accidental presence of impure seed within the seed supply of a cultivar is known as adventitious seed and strict management guidelines are imposed by all seed quality assurance schemes.

Farmers growing crops for seed use agricultural methods such as isolation distances and rotation cycles, involving a minimum number of years between crops of the same species, to achieve standard levels of 98 to 99% purity. The seed industry acknowledges that obtaining 100% genetic purity is not feasible or economical to attain. The levels specified represent a compromise between the stringency imposed on seed production and the market need for affordable seed, especially for crops grown over large areas.

While existing quality systems measure purity based on the appearance of plants it is now possible to estimate cultivar purity on the basis of genotype. This increased accuracy is likely to reveal higher frequencies of unanticipated material occurring in commercial seed than previously recognised.

> Existing cultivars that are widely used and traded, and thought to be homogenous, pure and stable, may actually contain considerable variability at the gene level. This will present new challenges for commercial seed production and will require a thorough reassessment of existing quality assurance paradigms for both GM and non-GM cultivars.

Any improvement in seed production technology to minimise the incidence of foreign DNA entering seed is likely to be matched by the enhanced sensitivity of the diagnostic tests. Since gene flow cannot be realistically prevented, a threshold level must be established to enable the seed industry to provide quality seed at an affordable price. The threshold level should be based on a realistic understanding of what is achievable and it must be within the sensitivity and error rate of routine analytical procedures (currently set at 0.1% in the case of PCR-based assays).

There is one particular application of GM crops where additional care may be required. These are the applications collectively known as “molecular farming” in which GM crops produce pharmaceuticals, vaccines, biodegradable plastics or speciality (bio)chemicals. Stringent levels of containment will be required to keep these products out of the food chain. Either specific areas of the world should be dedicated for specific productions, or additional molecular mechanisms used to prevent gene flow should be put in place. Several possible molecular mechanisms are being developed including genetic use restriction technologies (GURTs or terminator technology). Such technologies are currently not acceptable to some sections of the public but they could be useful in preventing truly undesired gene flow.

What is the proper baseline for appropriate ecological experimentation?

When conducting experiments to assess the ecological risk of GM crops, it is critical to use appropriate controls. Ideally the GM crop should differ from the control only in having the transgene. This is not always possible. (See the original paper for more details. The paper also contains discussion on the opportunities presented by GE technology to investigate the effects of particular genes.)

> There has been a much greater emphasis on gaining knowledge on the impacts of GM plants in recent years. It is ironic that the way field tests on GM plants are regulated with stringent containment controls and without multi-generation observations, mean that regulatory authorities, the very bodies with most to gain from the information, lose a considerable knowledge gathering opportunity.

Concluding remarks

There is an increasing body of evidence from industrial and developing countries that current GM crops, in conjunction with conventional agricultural practices, can contribute to a cost-effective, sustainable, productive and sufficiently safe form of agriculture.

Over the last five years the promises of current GM crops have met the expectations of farmers in both industrialised and developing countries and gained an appreciable market share. Can we afford to ignore such benefits? The risk of not using GM crops, particularly in relation to developing countries, where the technology may have most to offer, should be considered more explicitly. A ban on GM crops could limit the options of farmers and be imprudent rather than precautionary.

Governments, supported by the global scientific and development community, must ensure continued safe and effective testing and implement harmonised regulatory programmes that inspire public confidence.

Nowadays it is almost impossible to enter any GM crop discussion without preconceptions. Polarisation works well in the media. Media coverage, and a diminished public trust in regulatory authorities, may explain why GM crops have met rancorous public resistance in Europe. Social change and technical innovation is looked upon with a sense of disquiet, and the expected benefits are given less credence than the feared risks. It is very difficult to change such attitudes. Focusing on the prime goal of producing the GM crop and making a clear distinction between goals that could also have been accomplished with plant breeding and goals that could not, may depolarise discussions.

Many of the crop traits being modified by transgenes are the same as those that have been targeted for many years by plant breeding. The impacts identified for GM crops are, therefore, very similar to the impacts of traditional breeding and have been an integral part of agriculture for many years. Consequently, the risks of growing most GM crops on the environment or ecosystems will be similar to the effects of growing, processing and consuming similar new cultivars from traditional breeding. In view of the problems faced by modern agriculture, it will be largely counterproductive to re-evaluate the potential environmental effects of traditionally bred crops.

The challenge is to identify as efficiently and as early as possible, examples where the potential environmental and ecological impacts of GM crops are less preferable than the practices GM crops are designed to replace. Whenever and wherever unresolved questions arise concerning undesired impacts of GM crops, science-based evaluations should be used on a case-by-case approach to answer them to the best of our ability. The risk assessments conducted to date have used the best available information and should continue to do so.

It is often stated that regulation should be based on the soundest science possible, while acknowledging the limits to certainty. Science may be an ideology, but in our judgement it is the best approach for addressing complex issues in a debate. Science can help to define the kind of evidence that would be sufficient and/or would satisfy sceptics. The increased knowledge underpinning GM crops provides a greater confidence in the assurances that science can give when evaluating and monitoring the impacts of GM crops relative to traditional breeding. The resulting regulation is not a static activity but needs continuous revisiting based on that increased knowledge and experience.

A major problem arises when the general public demands that “no risk” can be demonstrated, since more than training in plant sciences or life sciences is necessary to resolve the issues. In this, plant scientists have a special responsibility.