The Plant Journal (2003) **33**, 1–18

GM SPECIAL ISSUE

The release of genetically modified crops into the environment

Part I. Overview of current status and regulations

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Summary

In the past 6 years, the global area of commercially grown, genetically modified (GM) crops has increased more than 30-fold to over 52 million hectares. The number of countries involved has more than doubled. Especially in developing countries, the GM crop area is anticipated to increase rapidly in the coming years. Despite this high adoption rate and future promises, there is a multitude of concerns about the impact of GM crops on the environment. Regulatory approaches in Europe and North America are essentially different. In the EU, it is based on the process of making GM crops; in the US, on the characteristics of the GM product. Many other countries are in the process of establishing regulation based on either system or a mixture. Despite these differences, the information required for risk assessment tends to be similar. Each risk assessment considers the possibility, probability and consequence of harm on a case-by-case basis. For GM crops, the impact of non-use should be added to this evaluation. It is important that the regulation of risk should not turn into the risk of regulation. The best and most appropriate baseline for comparison when performing risk assessment on GM crops is the impact of plants developed by traditional breeding. The latter is an integral and accepted part of agriculture.

Keywords: agricultural biotechnology, GM crop regulation, plant breeding, precautionary principle, risk assessment.

'Have no respect for authority of others, for there are always contrary authorities to be found' (Sir Bertrand Russell, 1951).

Introduction

Scientific advances in cell and molecular biology have culminated in the genetic engineering or modification of crops. This latest technology allows the routine development of genetically modified (GM) plants in which DNA from any source can be transferred to specific crops. It offers opportunities to accelerate the efficiency and extent of further crop improvement by the transfer of genes conferring resistance to pests, diseases, herbicides and environmental stress, as well as quality traits such as improved post-harvest storage, flavour, nutritional content and colour. GM crops could also manufacture industrial and pharmaceutical compounds as renewable resources with a production system based on solar energy. Genetic modification of plants has achieved a prominent place in basic and applied plant research. The resulting novel germplasm is anticipated to allow plant breeders to respond much more

quickly to the need for new and improved cultivars, and satisfy the increasing consumer demand for a consistent supply of high-quality grains, fruits and vegetables with reduced blemishes from pests/diseases and reduced pesticide residues. The area worldwide in which GM crops are grown and tested exceeded 50 million ha in 2001 (James, 2001).

Despite the potential benefits of this new technology to improve the reliability and quality of the world food supply, public and scientific concerns have been raised about the environmental and food safety of GM crops. In view of these concerns, the coming years may prove decisive for the commercial and economically viable application of GM crops in agriculture and food production. Without the consent of society at large, GM crops will fail in the marketplace. Safety concerns are being converted into extensive bodies of regulation and legislation. Any assessment and accompanying regulation of the impact of a human activity requires a baseline for comparison. The baseline taken in this review is the impact of corresponding non-GM crops. The effects of GM crops have to be measured against the effects of agriculture in general. With this framework, we will begin by summarising the current status of environmental release of GM crops around the globe. We then provide an overview of the approaches used for regulating their release into the environment. In the accompanying paper (Conner *et al.*, 2003), a detailed description of risk assessments and how they are performed will be presented, followed by a discussion of the perceived risks associated with the release of GM crops.

Table 1 Area of GM crops by country 1999-2001 (data from James, 2001)

	Total area (million ha)		
Country	1999	2000	2001
USA	28.7	30.3	35.7
Argentina	6.7	10.0	11.8
Canada	4.0	3.0	3.2
China	0.3	0.5	1.5
South Africa	0.1	0.2	0.2
Australia	0.1	0.2	0.2
Romania	<0.1	<0.1	<0.1
Mexico	<0.1	<0.1	<0.1
Bulgaria	–	<0.1	<0.1
Spain	<0.1	<0.1	<0.1
Germany	–	<0.1	<0.1
France	<0.1	<0.1	–
Uruguay	–	<0.1	<0.1
Indonesia	–	–	<0.1
Total	39.9	44.2	52.6

Note: in addition to these countries, GM carnations have also been grown in the Netherlands, Japan, Ecuador and Columbia (see text).

Current status of GM crops in the environment around the globe

Worldwide, several organisations are maintaining databases on various aspects of GM crop development and environmental release. Such databases are instrumental for visualising and projecting developments and trends with respect to GM crops, such as areas used for growing, and adoption (or rejection) rates. We will give here an overview of the GM crops grown commercially and outline developments in experimental field releases.

Total area of commercially grown GM crops

The International Service for the Acquisition of Agri-Biotech Applications (ISAAA; http://www.isaaa.org) maintains an up-to-date database on the global areas of commercial major food and fibre GM crops since 1996 and publishes yearly overviews (James, 2001). Prior to 1996, only few commercial releases had taken place. It is widely believed that the first commercial release of a GM crop took place in 1994 in USA. This was the FLAVR SAVR^{TM} tomato (Redenbaugh *et al.*, 1992). However, as early as 1992 some large-scale, essentially 'commercial', plantings of GM tobacco had occurred in China. GM tobacco expressing the coat protein genes of tobacco mosaic virus and cucumber mosaic virus was planted over about 8000 ha in the central Henan province in 1992 (Zhou *et al.*, 1995). Officially, however, China started to commercialise GM crops in 1996 (Chen *et al.*, 2000). In 1996, only 1.7 million ha of GM crops were planted in six countries: USA, China, Canada, Argentina, Australia and Mexico. By the end of 2001, the total area dedicated to GM crops increased to 52.6 million ha and the number of countries growing these crops has more than doubled (Table 1, Figure 1; James, 2001). The cumulative total area of commercially grown food and fibre GM crops since 1996 is over 175 million ha in 16 different countries. This is equivalent to approximately one-tenth of the total area of available fertile land of the world. In addition to the food and fibre crop data maintained by ISAAA, there have been minor commercial plantings of GM carnation as a flower crop in Australia (since 1996), Japan (since 1997), Spain and the Netherlands (1998–2000), Ecuador (since 1998) and Colombia (since 2000).

USA (68%) and Argentina (22%) account for 90% of all commercial GM crops planted to date. The prospective planning of the USDA National Agricultural Statistics Service (NASS) projects a further increase of the planting area in USA in 2002 (NASS, 2002). Together with Canada (6%) and China (3%), these four countries account for 99% of the global GM crop area in 2001 (Table 1). The GM crop area in the developing countries increased from 14% in 1997 to 26% in 2001 (Figure 1; Table 1), which represents a higher

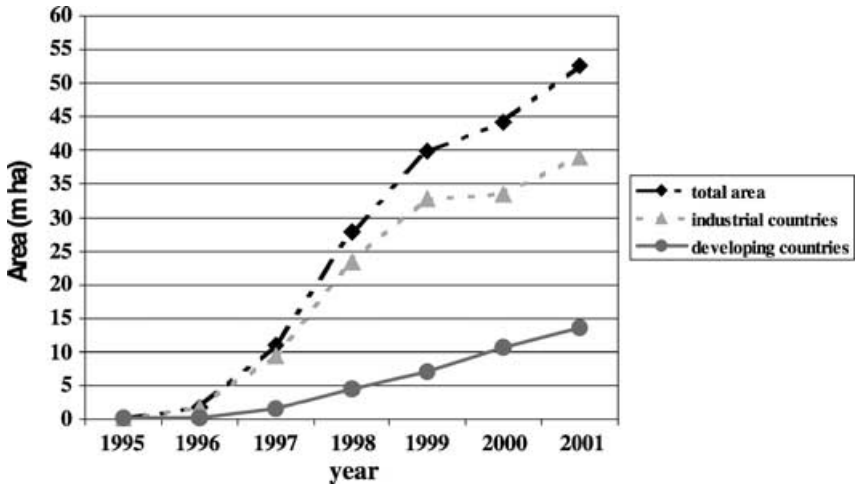

Figure 1. Global area of GM crops 1995–2001 (data from James, 2001).

percentage of growth than in the industrial countries. Over 98% of all GM crops in developing countries are grown in Argentina and China. China has approved 31 applications for commercialisation of GM crops (Huang *et al.*, 2002). In the Latin American continent, Mexico banned GM maize in 1998. Brazil has a moratorium on growing commercial GM crops and is sometimes presented as the country that will supply the world its non-GM soybean (Campolina de Oliveira Soares, 2001). However, especially in regions close to Argentina and Paraguay, GM soybean is already thought to occupy 35% of the Brazilian total soybean growing area, albeit illegally (Schuhmacher, 2002). These figures are not part of the ISAAA overviews. Brazil is expected to approve GM soybean soon (James, 2002). In Asia, India has approved the commercial application of GM cotton in 2002 (James, 2002). In the African continent, South Africa is so far the only country growing commercialised GM crops. Europe and Australasia are not growing substantial areas of GM crops. On a global basis, GM crops are grown by an estimated 5.5 million farmers. Over 5 million (90%) of these are resource-poor farmers, mainly growing GM cotton in China and South Africa (James 2001, 2002).

Crops and traits

A comprehensive database on information and biosafety assessment of GM crops that have received regulatory approval for commercial release is maintained by Agriculture and Biotechnology Strategies Inc. (AGBIOS) (http://www.agbios.com). It includes details of the transgenes used, the science underpinning the transgenic traits, summaries of the environmental and food safety considerations and links to the regulatory approvals. In Canada, where this database originates, the growing of crops with novel traits generated by more traditional plant breeding methods such as mutagenesis and wide hybridisation is regulated along with transgenic plants. Consequently the AGBIOS database includes several entries of crops that are not considered GM elsewhere in the world. Current GM crops approved for commercial release are listed in Table 2 along with their transgenic traits and where approvals have been granted. This list currently includes 16 different crop species and 68 different approval events. The existence of regulatory approvals for commercial release of a GM crop in specific countries does not necessarily mean that there is any intention to grow such a crop in that country. For example, in some countries (e.g. Japan and New Zealand) the importation of grain and fruit for use in the food industry requires, in addition to approvals for use in food, approvals for environmental release when the imported material contains viable propagules. In this context the importation of maize or soybean grain requires environmental approval, whereas the importation of maize or soybean flour does not.

In 1996, the main GM crop grown commercially was virus-resistant tobacco in China, followed by cotton, soybean, maize, oilseed rape, tomato and potato. By trait, virus resistance accounted for 40% of the area (almost entirely due to tobacco in China), followed by insect resistance (37%), herbicide resistance (23%) and quality traits (<1%). The rapid adoption of herbicide-resistant (HR) soybean, notably, in USA resulted in the quick displacement of virus resistance as the dominant GM crop. From 1997 on, GM HR soybean has been the dominant GM crop. China stopped growing GM tobacco in 1997 (Huang *et al.*, 2001). In 2001, the area of GM HR soybean reached 33.3 million ha, which is 63% of the total area of GM crops worldwide (Table 3). GM HR soybean is legally grown in seven countries (USA, Argentina, Canada, Mexico, Romania, Uruguay and South Africa; James, 2001) and supposedly illegally in Brazil (Schuhmacher, 2002). It is estimated that currently 60% of all processed foods in industrialised countries

Table 2 GM crops with approvals for release into the environment for commercial use (information derived from the AGBIOS database, http://www.agbios.com)

Crop species	No. of approvals[1]	Phenotypic trait	Transgene(s)[2]	Countries[3,4]
Carnation (*Dianthus carophyllus*)	1	Longer shelf life (reduced ethylene) Sulfonylurea herbicide resistance	Truncated ACC synthase gene Mutant AHAS gene	Au, EU (Ne)
Carnation (*Dianthus carophyllus*)	2	Modified flower colour Sulfonylurea herbicide resistance	Two anthocyanin biosynthetic genes Mutant AHAS gene	Au, EU (Ne)
Chicory (*Chichorium intybus*)	1	Male sterility Phosphinothricin herbicide resistance	*barnase* expression in tapetum *bar*	EU (Ne), US
Cotton (*Gossypium hirsutum*)	1	Glyphosate herbicide resistance	Mutant EPSPS gene	US, Ja, Ar, Au
Cotton (*Gossypium hirsutum*)	1	Oxynil herbicide resistance	*bxn*	US, Ja
Cotton (*Gossypium hirsutum*)	1	Resistance to lepidopteran insects	*cry*1Ac gene	US, Ja
Cotton (*Gossypium hirsutum*)	1	Resistance to lepidopteran insects Oxynil herbicide resistance	*cry*1Ac gene *bxn*	US, Au, Ch, Ja, Me, SA, Ar
Cotton (*Gossypium hirsutum*)	1	Sulfonylurea herbicide resistance	Mutant AHAS gene	US
Linseed (*Linum usitatissimum*)	1	Sulfonylurea herbicide resistance	Mutant AHAS gene	Ca, US
Maize (*Zea mays*)	2	Glyphosate herbicide resistance	Mutant EPSPS gene	US, Ca, Ar, Ja
Maize (*Zea mays*)	1	Glyphosate herbicide resistance	Mutant EPSPS gene and *gox*	Ca
Maize (*Zea mays*)	2	Male sterility Phosphinothricin herbicide resistance	*barnase* expression in tapetum *bar*	US, Ca
Maize (*Zea mays*)	1	Male sterility Phosphinothricin herbicide resistance	DAM expression in anthers *bar*	US
Maize (*Zea mays*)	2	Phosphinothricin herbicide resistance	*bar* or *pat*	US, Ca, Ja, Ar
Maize (*Zea mays*)	2	Resistance to European corn borer	*cry*1Ab gene	US, Ja, Ca, SA, Ar, EU (Fr)
Maize (*Zea mays*)	2	Resistance to European corn borer Glyphosate herbicide resistance	*cry*1Ab gene Mutant EPSPS gene	Ca, US, Ja
Maize (*Zea mays*)	5	Resistance to European corn borer Phosphinothricin herbicide resistance	*cry*1Ab, *cry*9C or *cry*1Fa2 genes *bar* or *pat*	US, Ar, Ca, Ja, EU (Fr)
Melon (*Cucumis melo*)	1	Delayed ripening (reduced ethylene)	SAM hydrolase gene	US (pending)
Oilseed rape (*Brassica napus*)	2	Glyphosate herbicide resistance	Mutant EPSPS gene and *gox*	Ca, Ja, US
Oilseed rape (*Brassica napus*)	1	High laurate and myristic acid seed content	Thioesterase gene	US, Ca
Oilseed rape (*Brassica napus*)	1	Oxynil herbicide resistance	*bxn*	Ca, Ja
Oilseed rape (*Brassica napus*)	3	Phosphinothricin herbicide resistance	*pat*	Ca, US, Ja
Oilseed rape (*Brassica napus*)	5	Male sterility/fertility restoration system Phosphinothricin herbicide resistance	*barnase* and *barstar* expression in tapetum, both coupled with *bar*	Ca, Ja, EU (Fr), EU (UK), US
Oilseed turnip (*Brassica rapa*)	1	Glyphosate herbicide resistance	Mutant EPSPS gene and *gox*	Ca
Papaya (*Carica papaya*)	1	Resistance to papaya ringspot virus	Viral coat protein gene	US
Potato (*Solanum tuberosum*)	2	Resistance to Colorado potato beetle	*cry3*A gene	US, Ca
Potato (*Solanum tuberosum*)	1	Resistance to Colorado potato beetle Resistance to potato leafroll virus	*cry3*A gene putative viral helicase and replicase genes	US, Ca
Potato (*Solanum tuberosum*)	1	Resistance to Colorado potato beetle Resistance to potato virus Y	*cry3*A gene Viral coat protein gene	US, Ca
Rice (*Oryza sativa*)	1	Phosphinothricin herbicide resistance	*bar*	US
Soybean (*Glycine max*)	1	Glyphosate herbicide resistance	Mutant EPSPS gene	US, Ca, Ar, Ja, Ur, Br[5], Me, SA
Soybean (*Glycine max*)	1	High oleic acid seed content	A fatty acid desaturase gene	US, Ja, Ca
Soybean (*Glycine max*)	4	Phosphinothricin herbicide resistance	*pat* or *bar*	US, Ca

Squash (*Curcubita pepo*)	1	Resistance to watermelon mosaic virus 2 Resistance to zucchini yellow mosaic virus	Viral coat protein gene Viral coat protein gene	US
Squash (*Curcubita pepo*)	1	Resistance to cucumber mosaic virus Resistance to watermelon mosaic virus 2 Resistance to zucchini yellow mosaic virus	Viral coat protein gene Viral coat protein gene Viral coat protein gene	US
Sugarbeet (*Beta vulgaris*)	1	Glyphosate herbicide resistance	Mutant EPSPS gene	US
Sugarbeet (*Beta vulgaris*)	1	Phosphinothricin herbicide resistance	*pat*	US
Tobacco (*Nicotiana tabacum*)	1	Oxynil herbicide resistance	*bxn*	EU (Fr)
Tomato (*Lycopersicon esculentum*)	2	Delayed fruit softening by suppressing polygalacturonase activity	Truncated or full-length PG gene (sense or antisense)	US, Me, Ja
Tomato (*Lycopersicon esculentum*)	1	Increased shelf life (reduced ethylene)	Truncated ACC synthase gene	US
Tomato (*Lycopersicon esculentum*)	1	Delayed ripening (reduced ethylene)	SAM hydrolase	US
Tomato (*Lycopersicon esculentum*)	1	Resistance to lepidopteran insects	*cry*1Ac gene	US

[1]Each approval may involve the release of the transgenic trait in more than one cultivar; there may be more than one approval in a country; all the cultivars may not be approved in all countries listed.

[2]Abbreviations: ACC, aminocyclopropane cyclase; AHAS, acetohydroacid synthase; *bar*, a phosphinothricin acetyltransferase gene; *barnase*, a ribonuclease gene; *barstar,* a ribonuclease inhibitor gene; *bxn,* nitrilase gene; DAM, DNA adenine methylase; EPSPS, 5-enolpyruvylshikimate-3-phosphate synthase; *gox*, glyphosate oxidase gene; *pat*, a phosphinothricin acetyltransferase gene; PG, polygalacturonase; SAM, S-adenosylmethionine.

[3]Country abbreviations: Ar, Argentina; Au, Australia; Br, Brazil; Ca, Canada; Ch, China; EU, European Union; Ja, Japan; Me, Mexico; SA, South Africa; US, United States of America, Ur, Uruguay. For European Union entries the first country of notification is mentioned in brackets: Fr, France; Ne, the Netherlands; UK, United Kingdom. Countries are listed in chronological order of approvals.

[4]The consent for environmental release for commercial planting does not necessarily mean consent to place the product in the market, or for use as human food or animal feed. Additional countries may have approved these products for use as human food or animal feed.

[5]Decision reversed by courts, reinstatement pending.

Table 3 Dominant GM crops in 2001 (data from James, 2001)

Crop	Trait	Area (m ha)	% total GM crop area
Soybean	Herbicide resistance	33.3	63
Maize	Total all traits	9.8	18
	Insect resistance (Bt)	5.9	11
	Herbicide resistance	2.1	4
	Stacked Bt/herbicide resistance	1.8	3
Cotton	Total all traits	6.8	14
	Herbicide resistance	2.5	5
	Insect resistance (Bt)	1.9	4
	Stacked Bt/herbicide resistance	2.4	5
Oilseed rape	Herbicide resistance	2.7	5

contain GM soybean-derived ingredients (Nelson *et al.*, 2001). In USA, a further increase in planting area is projected for soybean (68 to 74%) in 2002 (NASS, 2002).

GM maize occupied 9.8 million ha in 2001 (18%). This is predominantly insect-resistant maize grown in six countries (USA, Canada, Argentina, South Africa, Spain and Germany). Other major GM crops are GM cotton (6.8 million ha, 14%) and oilseed rape (2.7 million ha, 5%). In USA, the area is projected to rise for both maize (26 to 32%) and cotton (69 to 71%) in 2002 (NASS, 2002). India, the third largest cotton growing country in the world, has approved the commercial application of insect-resistant GM cotton in 2002 (James, 2002), and is expected to grow over 0.15 million ha of GM cotton soon. This will be about 2% of the total cotton area in India. All other GM crops (Table 3) account for less than 0.1 million ha.

In 2001, GM herbicide resistance was widely deployed in soybean, oilseed rape, maize, and cotton, and accounted for 77% of the total area of GM crops (Table 3). Whereas the total area of HR crops continues to increase (from 28.1 million ha in 1999 to 40.6 million ha in 2001), the global area of crops solely with insect resistance has decreased from 8.9 million ha in 1999 to 7.8 million ha in 2001. This is due to gene stacking. The area with crops containing genes for both herbicide and insect resistance raised from 2.9 million ha in 1999 to 4.2 million ha in 2001.

Another way to portray the global status of GM crops is to analyse the adoption rates of the four major GM crops, soybean, cotton, canola and maize (Figure 2). In 2001, 46% of the area planted to soybean was GM (up from 36% in 2000) and 20% of the area planted to cotton was GM (up from 16% in 2000). The global areas of oilseed rape and maize planted to GM crops remained unchanged from 2000 to 2001, and accounted for 11 and 7% of the total areas, respectively (James, 2001). The global adoption rate of GM crops is among the highest for any new technology in agriculture.

Environmental releases of GM crops in field trials

Prior to actual commercialisation, GM crops are usually tested in experimental field trials. Several databases give an overview on approvals issued for environmental release. The Biosafety Information Network and Advisory Service (BINAS) of the United Nations Industrial Development Organisation (UNIDO) maintains a database of field trials around the world (http://binas.unido.org/binas/trials.php3). This database is partly linked with the Biotrack database (http://www.olis.oecd.org/biotrack.nsf) of the Organisation for Economic Co-operation and Development (OECD), which contains approvals/permits issued for experimental field releases of GM organisms in its 30 member countries. In USA, the Information Systems for Biotechnology (ISB) has databases (http://www.isb.vt.edu/cfdocs/fieldtests1.cfm) for field testing and petitions. The European Commission

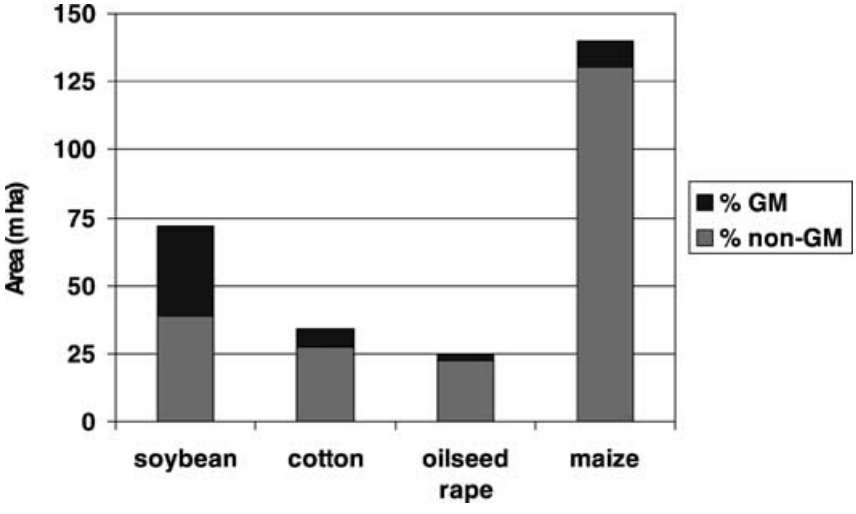

Figure 2. Global adoption rates for principal GM crops in 2001 (data from James, 2001).

maintains an overview of the notifications of environmental release of GMO's in the European Union (http://biotech.jrc.it/dbcountries.asp).

The OECD database currently records over 10 300 permits, 98.4% of which concern GM plants. The first experimental field tests took place in 1986. The total number of approvals in the OECD member states has been rapidly rising to reach a peak of 2312 permits issued in 1998. The numbers of approvals in databases do not reflect the actual number of field releases performed due to different legal procedures for approval in different countries. Some countries require separate applications for every specific modification in a specific plant, for each location and year. In contrast, other countries will issue a single approval/permit for applications involving groups of crops, and/or for GM plants with a range of different genes over multiple sites and years. This discrepancy makes it difficult to separate changes in field experimentation on GM crops from changes in response to pressure from political, public and market forces. Although the number of approvals for release only approximates the actual number of field releases, there has been a clear decline in the number of approvals since 1998. Such a decline is especially apparent from the numbers of notification in the EU countries. In Switzerland, a referendum rejected the ban on the use of GM plants in 1998, but all subsequent applications for field trials have not been approved. This decline in GM field experiments reflects a combination of the above discrepancy in recording number of permits, a reduced activity in GM research and the GM material used in previous years being approved (deregulated) for commercial use.

In contrast to the decline in field trials in EU countries, the number of approvals is again on the rise in USA. In many non-OECD countries of Asia, Africa, South America and Eastern Europe, the number of field trials is also increasing. In Indonesia, multilocation field tests are being conducted on insect-resistant maize, cotton and potato, as well as on HR maize, cotton and soybean. Other GM crops being developed are maize, peanut, cacao, soybean, potato, sweet potato, sugarcane and rice. Thailand has conducted pre-commercialisation field trials for insect-resistant cotton and virus-resistant papaya. In addition, GM crops being developed include delayed ripening papaya, as well as virus-resistant beans, chilli, tomato, pepper and rice. In India, Bt cotton has been evaluated in over 100 field trials in different planting regions and permission for commercial growing in 2002 has just been granted (James, 2002). Large-scale, multisite field trials on mustard have recently been approved. Several other GM crops are in an advanced stage of research, especially concerning Bt-mediated insect resistance in rice, cotton, tobacco, potato, eggplant, cauliflower, cabbage and pigeonpea. China may well have the largest plant biotechnology capacity outside of the USA (Huang *et al.*, 2002). Field releases comprise numerous GM crops such as rice, tobacco, potato, maize, soybean, orange, tomato, eucalyptus, sweet pepper, oilseed rape and poplar. Field trials have taken place since 1990 and from 1997 to 1999, 132 trials were approved (Chen *et al.*, 2000). The total number of approvals has recently reached 251 (Huang *et al.*, 2002). In the extensive field trials, more than 90% of the area targets yield-related traits such as insect and disease resistance. In the Philippines, multilocation field tests on insect-resistant maize are currently being conducted. GM crops are being developed in all relevant major local crops. The same is the case in Malaysia, Vietnam and other countries in the region. In South America, GM crops are being cultivated in Chile, but only for seed multiplication purposes for export. This involved 115 different crops in 2000–2001. Approvals for experimental field trials on other traits and/or crops continue to be made in several Latin American and Caribbean countries. The total number of field trials in this part of the world in the period 1987–98 is estimated to be almost 600 (Artunduaga-Salas, 2000). Cuba is performing tests on GM potato, sweet potato, papaya and sugar cane (La Rosa, 2000). In Central and Eastern Europe, such as Bulgaria, Lithuania, Moldova, Romania, Russia and Ukraine, several GM crops are being evaluated or are in the process of registration. These involve GM cultivars from multinational companies. Field trials in Ukraine were postponed in 1999 due to pressure from Western Europe (Blume, 2000). In South Africa, the first application for field trials dates back to 1989 (Kandawa-Schulz, 2000). The number of field tests on GM organisms increased from 12 in 1995 to 45 in 1999. These have included soybean, maize, cotton, and a range of fruits, vegetables and trees, with further commercial releases anticipated in the near future. In Egypt, field trials have been conducted on insect-resistant potato and virus-resistant cucurbits. GM crop research is focussing on improved productivity in a variety of crops. Kenya has performed field tests on virus-resistant sweet potato and field tests are anticipated on GM maize and cotton. Zimbabwe has carried out trials for tobacco in 1994, but these were stopped for legal reasons. It is currently conducting field trials for insect-resistant cotton (Kandawa-Schulz, 2000).

Trends and developments

The high adoption rate of GM crops in agriculture is thought to reflect grower satisfaction and benefits for the whole production chain. It is predicted that in the six principal countries that are currently growing GM crops, the area will continue to grow in 2002 (James, 2001) and beyond. The number of farmers planting GM crops is expected to soon reach 6 million or more (James, 2002). For USA, the area prediction for 2002 is already confirmed by the prospective

GM crop planting statistics (NASS, 2002). A novel approach into the fate of GM crops in the future are detailed economic calculations of the actual market impact and profitability for the individual farmer of growing given GM crops (Nelson, 2001). These are most reliable when based on several years of experience with GM crops and are so far only available for USA situation. Such assessments may influence farmer's future decisions. In case of HR soybean, the average farm saved on herbicide costs, but unless the technology reduced management cost sufficiently to cover the seed premium, such soybean would not be profitable on 71% of the farms (Bullock and Nitsi, 2001). In case of insect-resistant cotton, adoption has generally resulted in economic surpluses (Falck-Zepeda *et al.*, 2001). For insect-resistant maize, a study concludes that in the period 1996–2001, farmers have, on average, faced overall net losses in 3 years and net profits in three other, depending on insect infestation levels (Benbrook, 2001). The general conclusion seems fairly obvious for a plant biologist: farmers who generally face high insect infestations have more to gain from insect-resistant GM crop technology than farmers who face low infestation levels (Bullock and Nitsi, 2001). Such studies show that GM crops are becoming a normal part of everyday agriculture, subject to standard market considerations and forces.

In addition to developments in USA, the interest in the use of GM crops across the developing world is significantly increasing. Research efforts and progress in many developing nations suggests that the adoption of novel GM crops will substantially increase over the coming decade. In 2002, the combined population of countries with significant GM crops approved for consumption will be up to 3 billion, almost half the world's population (James, 2002). The situation in, notably, the EU shows basically the opposite of the above trends. Research attention in the EU is shifting away from GM crops. Large-scale commercial growing of GM crops is not expected in the foreseeable future and field trials may further reduce in volume. The decline is often taken as evidence for the objections of society against GM crops, and is thought to reflect a response to pressure from political, public and market forces in these parts of the world (PABE, 2001). Notably, countries that depend on the EU for future joining or export may have to reconsider growing of GM crops based on market considerations. This by itself is topic of debate. For example, these developments are used by an influential environmentalist group to claim that the (its) opposition against GM crops results in significantly reduced market share (Greenpeace International, 2001) and predict that this will also eventually reduce the area of GM crops in USA (Greenpeace International, 2002). GM wheat is currently controversial in parts of USA. The actual future of GM crops is therefore likely to depend primarily on social, political and legislative developments.

Legislation and regulation of the release of GM crops around the globe

North America and Europe have paved the way for the development and environmental release of GM crops. They have also defined the general framework for a regulatory system. The 1989 framework of the National Research Council (NRC) in USA was an early attempt to regulate the application of GM technology in the field and still offers a good overview of concerns and regulatory issues (NRC, 1989). The 1993 OECD guidelines for industrial applications of GM organisms (OECD, 1993a,b) resulted in an extended framework for evaluating the environmental impact of GM organisms and safety assessments for application of GM in food and feed. More recently, the Cartagena protocol on Biosafety helps to provide a more general framework for implementation in individual countries (SCBD, 2000). BINAS offers a database of regulatory issues (http://binas.unido.org/binas/regs.php3), providing information on competent authorities, relevant laws, regulations and/or rules for individual countries. Other points of entry for regulatory affairs are the biosafety webpages of the International Centre for Genetic Engineering and Biotechnology (ICGEB) (http://www.icgeb.trieste.it/biosafety) and the AGBIOS databases (http://www.agbios.com).

Many countries are now faced with the challenge to put in place regulatory systems to ensure safe and effective evaluation of the impact of GM crops. Several organisations are instrumental in helping countries to generate the capacity to establish such systems. Among these are the International Service for National Agricultural Research (ISNAR) of the Consultative Group on International Agricultural Research (CGIAR, e.g. Cohen, 1999; McLean *et al.*, 2002; Persley *et al.*, 1993), the ICGEB and the United Nations Environment Program (UNEP; http://www.unep.ch/biosafety). UNEP issued International Technical Guidelines for Safety in Biotechnology in 1995 (UNEP, 1995). A UNEP-Global Environment Facility (GEF) project on the development of National Biosafety Frameworks is designed to assist countries to develop their National Biosafety Frameworks so that they can comply with the Cartagena protocol on Biosafety. Currently 77 countries are enrolled. Here, we will present an overview of the main characteristics of the prevailing regulatory systems in various parts of the world, beginning with the four countries growing the major areas of GM crops in the world (Table 1). The information presented here is largely based on public availability of information in the English language, among which is a valuable broad overview and analysis of the regulatory framework in five countries (MacKenzie, 2000). Systems and details for regulating GM crops are complex, often confusing and constantly evolving. In view of the potential changes in this field, the information presented might be quickly superseded. The broad and geographical overview of

regulations aims to facilitate finding relevant information sources and updates, as well as making comparisons. The ISNAR initiative to prepare up-to-date country reports with overviews of the regulatory policies and procedures of individual countries, such as now available for Egypt (Madkour *et al.*, 2000) and Argentina (Burachik and Traynor, 2002), is worth following for the future.

USA

In 1986 the Co-ordinated Framework for Regulation (CFR) of Biotechnology specified the Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA), the Environmental Protection Agency (EPA) and the Food and Drug Agency (FDA) as the primary governmental agencies for regulating biotechnology in USA. The 1986 'Co-ordinated Framework for the Regulation of Biotechnology' is still in use today (MacKenzie, 2000). A useful oversight of the regulatory process for transgenic crops in USA is maintained by Byrne *et al.* (2002). Regulatory assessments had to be science, risk and case based. A crucial decision in this CFR was that no new and specific biotechnology regulation system was necessary. The at-that-time-current laws, the Federal Plant Pest Act, the Federal Plant Quarantine Act and the Federal Insecticide, Fungicide and Rodenticide Act, provided adequate statutory authority for biotechnology regulation (MacKenzie, 2000). This decision implies that in USA the regulation focuses primarily on the characteristics of the product, rather than the way in which the product is produced. This product-based assessment is a major difference with the philosophy of regulation in, for example, the EU, which is process based. This process–product difference of philosophy has sparked considerable controversy over recent years.

The Biotechnology, Biologics and Environmental Protection (BBEP) unit of USDA-APHIS focuses on the environmental impact of GM plants under (revised) regulation 7 CFR Part 340. The current procedure for field testing is relatively simple. A notification process can be used for most crops and many genes for field testing of GM plants. This is a simplified process, as compared to a permit, and takes only 30 days before the field trial can commence. An acknowledgement from USDA-APHIS is required prior to planting. When a formal permit is required, APHIS must come to a Finding of No Significant Impact (FONSI) (MacKenzie, 2000). For the release of GM plants with anti-pest proteins, such as insect-resistant plants, the EPA has joint responsibility for the regulatory oversight along with the USDA. In current EPA terminology, such plants contain 'plant-incorporated protectants'(PIPs), formerly known as 'plant-pesticides' (Deegan, 2001). For field tests of PIP-containing GM plants greater than 4 ha (10 US acres) in size, an Experimental Use Permit (EUP) from EPA is required.

Currently, BBEP reviews about 1000 applications for field testing and deregulation each year (NAS, 2002). Such a review takes on average 10 months for applications not involving the notification process. EPA's review typically requires 18 months (CAST, 2000). The FDA is responsible for determining human food and animal feed safety and wholesomeness of all plant products, including those produced via genetic modification. The FDA follows a decision-tree safety assessment approach essentially based on the concept of 'substantial equivalence' (FDA, 1992). This concept in relation to the regulation of GM food and feed is reviewed in considerable detail elsewhere (Kuiper *et al.*, 2001). Global developments prompted the FDA in January 2001 to sharpen its assessments, but the 1992 regulations are still used. The time frame for approval ranges from 6 to 12 months after data submission.

The USDA-APHIS/EPA regulation of the environmental release is based on the concept of 'familiarity' (OECD, 1993a). This concept can be considered the ecological counterpart of the concept of 'substantial equivalence', although in some publications these two concepts are also considered separately for environmental release. Familiarity considers whether the GM plant is comparable to its traditionally bred counterpart in environmental safety. Such comparison may assess the relevant issues in a GM crop without direct experience. Familiarity considers the biology of the plant species, the trait introduced, and the agricultural practices and environment used for crop production. In comparison with a suitable counterpart, often the parental non-GM crop, the aim is to establish if the GM change presents any new or greater risks relative to that counterpart. This allows a relative level of safety to be established for the GM crop. A related concept is that of the 'antecedent organism'. If an organism has already been evaluated (i.e. is familiar), future assessments of that organism can be less stringent. The precise meaning of 'familiarity' and the subsequent consequences for regulation have been discussed extensively without national (or worldwide) consensus. The main points of discussion are to define 'comparable' and to decide when something is 'sufficiently comparable'.

Applications for environmental release are evaluated on a case-by-case basis and concern weediness, gene transfer, effects on wildlife, altered disease susceptibility and several related aspects of the GM crop (CAST, 2000, 2001). In 1994, EPA proposed to regulate anti-pest GM plants as if they were pesticides, then in 1999 questioned whether GM seeds should be subject to pest control regulations. A National Academy of Sciences report (NAS, 2000) recommended the formal adoption of the EPA's 1994 proposed regulations and to further strengthen its oversight in various ways. These developments could be interpreted as a move in the direction of a process based rather than a product-based regulation in USA. Most of

the EPA regulations were issued in 2001, but some issues such as the way in which plants with viral coat proteins should be regulated, are still being debated (Deegan, 2001). A recent National Academy of Sciences evaluation of current US regulation (NAS, 2002) suggested tighter monitoring of the environmental release of all crops, including those resulting from 'traditional breeding' (Gewin, 2002).

Argentina

Argentina was among the earliest countries to establish a system for regulatory oversight of GM crops. Since 1991, its system has evolved and expanded to meet the changing context of scientific and international developments. The Agricultural Directorate of the Secretariat of Agriculture, Livestock, Fisheries and Food has several agencies involved in regulating the use of GM crops and their products. Major agencies are the National Advisory Commission on Agricultural Biosafety (CONABIA), the National Institute of Seeds (INASE) and the National Agrifood Health and Quality Service (SENASA), while the National Directorate of Agrifood Markets (DNMA) is also involved in the commercialisation of GM crops. Recently, a National Advisory Commission on Policies for Agricultural Biotechnology was created to define guidelines concerning broader policy issues (Burachik and Traynor, 2002). CONABIA is a multidisciplinary advisory group that is responsible for the regulation of products of agricultural biotechnology. It evaluates the scientific and technical issues of environmental release of GM crops and makes recommendations to the Secretary of Agriculture who makes the final decisions. The guidelines developed by CONABIA are legally based on Resolution 289/97, modifying Resolution 837/93 (Huarte, 2000). The guidelines are basically similar to those in North America and are based on the characteristics and risks of the products and not on the process (Mackenzie, 2000). They involve a combination of pre-existing and newly written laws and regulations. After at least one release into the environment has been approved and the safety of the GM crop has been demonstrated, the applicant can apply for a 'flexibilisation' permit which allows future releases by simply providing notification of the location, area, sowing date and intended harvest date. Burachik and Traynor (2002) give a useful overview of the organisation, current status and future trends of the biosafety regulatory framework in Argentina.

Canada

In 1990, the Canadian federal government published its regulatory framework for biotechnology to harmonise the benefits of biotechnology-derived products with the need for protection of the environment and human health and safety. Canada uses a product-based approach for evaluation, placing emphasis on the novel traits or attributes introduced into a plant. All plants or products with new characteristics not previously used in agriculture and food production in Canada are monitored, irrespective of whether GM or more traditional plant breeding methods were used for development. Since 1994, Canada has approved a total of 43 novel food products, many of which are GM crop based (MacKenzie, 2000). The concept of familiarity is also the guiding principle in the Canadian system. Regulatory agencies responsible for products derived from plant biotechnology in Canada are the Canadian Food Inspection Agency (CFIA), Health Canada and Environment Canada. Food, feed and seed are regulated by CFIA, whereas Health Canada and Environment Canada establish criteria and monitor the inspections. Health Canada regulates drugs, vaccines, diagnostics and medical devices. Environment Canada, under the Canadian Environmental Protection Act, regulates other biotechnology products. The Plant Biosafety Office (PBO) of the CFIA monitors all (confined) field trials of novel crop varieties to ensure that the trials comply with the guidelines for the environmental release (Regulatory Directive 2000–07; amended February 2002). Unconfined release aimed at marketing (Regulatory Directive 94–08) requires a molecular characterisation, the requirements of which have been harmonised between Canada and the USA in 1998 (for contents, see CFIA, 1998). In addition to these regulatory requirements, a novel GM crop must be registered through the variety registration of the CFIA the same way as all other new crop cultivars grown in Canada. For transparency, all decision documents describing any assessment and its results are available for the public on the PBO webpages (PBO, 2002).

China

China has implemented a very pragmatic approach to GM crop regulations. Regulations are basically product based and explicit attention is given to the economic interest of a given application. The State Science and Technology Commission, jointly with the Ministry of Public Health, the Ministry of Agriculture, and the Chinese Academy of Sciences, drafted a 'Regulation on Biosafety Control of Genetic Engineering' that established the legal framework for the release of GM crops. Following wide discussion, the final document was issued and implemented by the State Science and Technology Commission in late 1993 (Ding, 1995). Between 1996 and 2000, the Chinese Office of Genetic Engineering Safety Administration approved 251 of 353 GMO applications (Huang *et al.*, 2002). China is also in the process of labelling imported GM crops (soybean and oilseed rape) and locally produced GM tomato and cotton.

European Union

In the EU, the GM crop regulatory system is composed of several regulations, directives and amendments thereof, that are assembled in a time-consuming and highly complex interplay between the European Commission (EC), the European Parliament (EP), the relevant Council of Ministers and the individual Member States. In the EU's legal framework, a 'regulation' is a law that all Member States should eventually adopt in their local laws by passing through their individual parliaments. A 'directive' is a minimal set of demands that should be interpreted and implemented in the national legislation of the Member States. As a result, a 'directive' can have different implementations in different Member States. This obviously adds to the complexity of understanding GM crop regulation in the EU. The Belgian Biosafety Server (http://biosafety.ihe.be) compiles a regularly updated access to all European legislation and regulations.

In 1990, the EU implemented two directives. Directive 90/219/EEC, with amendment 98/81/EC added in 1998, involved the contained use of GM (micro)organisms. Directive 90/220/EEC involved the deliberate release of GM organisms, including plants, into the environment. In February 2001, the EP adopted Directive 2001/18/EC, which defines new GM crop rules to come into force in October 2002. It presents a substantially revised version of the previous directives. Central in these regulations is that GM is considered something new and special for which existing legislation is not sufficient. The EU regulatory system is therefore process based rather than product based: the way something is made determines the regulatory framework. This is thought to contribute to better acceptance of genetic modification, notably in the food sector. However, it seems more likely that it may have resulted in a heightened awareness and concern in Europe compared to the North American continent. The major philosophical shift in Directive 2001/18/EC compared to its predecessors is the explicit adoption of the precautionary principle as a guide, rather than or in addition to the concepts of familiarity and substantial equivalence. This was motivated by, among other considerations, the Cartagena protocol on Biosafety. The precautionary principle is a difficult concept that originates from the discussions about maintaining biodiversity. This principle requires the evaluation of indirect or delayed effects and changes in agricultural practices. Marketing consents will be time-limited and conditional upon post-marketing surveillance (the precautionary principle is discussed in more detail in the accompanying paper (Conner *et al.*, 2003)). The EC realises that the precautionary principle may be difficult to apply. Therefore, it is stated that reliance on the precautionary principle is no excuse for detracting from the general principles of risk management such as proportionality, non-discrimination, consistency, examination of the benefits and costs of action or lack of action and examination of scientific developments (CEC, 2000). How this will be put in practice remains to be seen.

Directive 2001/18/EC, as its predecessor 90/220/EEC, distinguishes two categories for environmental release. Releases for research and development are made under Part B of the Directive, which is generally used for conducting experimental field trials on GM crops. These releases are filed and granted at the national level by the individual Member State concerned. The time frame required for approval differs between Member States and runs from about 3 months to essentially indefinite periods. Releases for placing a GM product on the market require consent under Part C of the Directive. Such consents are given at the EC level and may take from 2 years to indefinite periods for approval, but once issued, apply across all Member States.

In contrast to its predecessor, Directive 2001/18/EC includes provisions for the labelling and traceability of GM food, feed, seeds and pharmaceuticals. Unfortunately, such process-based labelling seems much more prone to fraud. Other provisions include a time-limited consent and phasing out of genes encoding resistance to antibiotics in use for medical or veterinary treatment by 2005 for commercial releases and 2009 for research purposes. A public registry of all approved products will allow consumers to trace GM products. Although the basic philosophy of the regulation is quite different, the data requirements for assessing safety of GM plants and plant products are similar in USA and the EU. The information required in the EU tends to be more extensive, mainly with respect to molecular characterisation, monitoring and traceability. Traceability is defined as a possibility to prove the origin of GM organisms or their products at any stage and at any time during their progression along all steps of the market chain. However, validated standardised test methods do not yet exist. Overall, it is currently impossible to give a reasonable estimation of a time frame for approval in the EU. The slow, and possibly indefinite, Part C procedure, in addition to the Novel Foods and cultivar registration procedures, make commercial release of any GM crop in the EU a lengthy, and therefore possibly unappealing, endeavour.

Since June 1999, a *de facto* moratorium on commercial licensing of new GM products has been in place in the EU. Six EU Member States (Austria, Denmark, France, Greece, Italy and Luxembourg) decided that they would not accept any new GM approvals at least until a revision of Directive 90/220/EEC was in place. Such legislation is under development. In July 2001, the EC presented proposals for legislation on traceability and labelling of GM organisms and products derived from GM organisms (CEC, 2001a) and for GM food and feed (CEC, 2001b). In addition, regulations dealing with the transboundary transport of GM material across the EU are being established in accordance with the

international obligations in the Cartagena protocol on Biosafety.

Australasia

The regulatory methodology in Australia has largely developed alongside the technology as the need arose. A Genetic Manipulation Advisory Committee (GMAC) was initially established as a non-statutory body to oversee the development and use of novel genetic manipulation techniques. From June 2001, Australia's new gene technology regulatory regime is governed by the Gene Technology Act (GTA) which regulates all dealings (e.g. research, manufacture, production and importation) with organisms that have been modified by gene technology (MacKenzie, 2000). A key aspect is that the GTA provides one central, enforceable scheme for regulating GM organisms through the Office of the Gene Technology Regulator (OGTR, 2002). The Regulator assesses applications for release of GM organisms and prepares a risk assessment and risk management plan. This activity is supported by three key committees (MacKenzie, 2000), the Gene Technology Technical Advisory Committee (GTTAC), the Gene Technology Ethics Committee (GTEC) and the Gene Technology Community Consultative Group (GTCCG) to provide scientific, ethical and policy advice.

New Zealand has taken a very conservative approach to adopting GM technology. Field trials on GM crops were initially approved by the 'Interim Assessment Group' administered by the Ministry for the Environment. In 1998, this was superseded by the new Environmental Risk Management Authority (ERMA), which currently regulates the development, field testing and release of GM organisms under the Hazardous Substances and New Organisms Act. The assessment process is one of the most rigorous in the world. New regulations continue to be put in place to limit the commercial development of GM crops. In July 2000, a moratorium on further applications to field test GM organisms was imposed pending a Royal Commission on Genetic Modification on the risks and opportunities for GM in New Zealand. Although this Royal Commission basically endorsed the continuation of GM technology (Eichelbaum *et al.*, 2001), the New Zealand government is currently developing further legislation for additional controls on the release and use of GM crops.

Japan

In 1987, Japan formulated and issued its guidelines for application of organisms derived from recombinant DNA technology in agriculture, forestry, fisheries, the food industry and other related industries (MacKenzie, 2000). These guidelines were based on the OECD guidelines and revised in 1992 and 1995. In 1995, The Society for Techno-Innovation Agriculture, Forestry and Fisheries (STAFF) established an 'Information Desk for the Application of rDNA Organisms', which is the main source of information presented here (STAFF, 2002).

The Japanese system is largely product based and the concepts of familiarity and substantial equivalence form the basis of the Japanese guidelines. Two guidelines have been established for experimentation (one for experiments in university research facilities and one for all other research facilities) and six guidelines apply to industry applications. Three of the six industry guidelines refer to the safety assessment of the application of GM crop plants. These fall under the jurisdiction of the Ministry of Agriculture, Forestry and Fisheries (MAFF) or the Ministry of Health, Labour and Welfare (MHLW). Cultivation of GM crops, and the importation of GM plant material that can propagate in the natural environment, is regulated under the guideline for rDNA organisms, which is overseen by MAFF. In order to utilise a GM crop, it must be confirmed that the plant will not have a new impact on the agriculture and ecology of Japan (MacKenzie, 2000). Two separate stages of applications are distinguished: application in a simulated model environment, and application in an open system. Before applying to either system, the applicant must obtain the approval of MAFF confirming that the safety assessments satisfy the requirements. In April 2001, new legislation was introduced that set a zero tolerance for imports containing GM products unapproved by Japan (RNS, 2002). At the same time, a threshold of 5% for approved GM crops was introduced for food products to be labelled as GM.

Other countries

Various Asian countries are in the process of establishing their legislative framework for environmental and commercial release of GM crops. India has established a Genetic Engineering Approval Committee (GEAC) to oversee GM crop applications. In the Philippines, the National Committee on Biosafety mandates the guidelines and approvals. The approval permit stipulates that the performance of the GM crop and its effect on the environment as well as human and animal health are assessed. Recently, the Philippines government released guidelines to take effect from 1 July 2003 that will regulate the importation and commercialisation of GM crops. Malaysia is in the process of drafting their Biosafety law and is developing their field testing regulations. Currently, 26 Asian and Pacific countries participate in the UNEP-GEF project (UNEP, 2002).

European countries on the way to becoming members of the EU are expected to fully implement the EU regulatory system. Hungary and Slovenia are the closest to having this legislation in place. Other countries of Central and Eastern Europe, including many republics of the former Soviet

Union, are in the process of developing appropriate rules and legislation. Romania, Bulgaria, Estonia and the Russian Federation have laws, whereas several other countries (Belarus, Moldova) are preparing legislation (BioSafety meeting, 1999). The MATRA programme of the Dutch Ministry of Foreign Affairs aims to support the establishment of national biosafety frameworks in conformity with the EU regulatory system and other international obligations such as the Cartagena protocol on Biosafety (MATRA, 2002). In Ukraine, a biosafety committee has been installed and legislation is being considered. In 1999, Ukraine turned to Canada to help establish its regulatory system. The philosophical differences between the legislation in the EU and North America is complicating matters considerably (Blume, 2000). Currently, 13 Central and Eastern European Countries participate in the UNEP-GEF project (UNEP, 2002). Norway has implemented the EU regulations in the framework of the European Free Trade Area (EFTA)-EU agreement in its 1993 Gene Technology Act. Switzerland has a Federal Co-ordination Centre for Biotechnology in place to oversee dedicated legislation.

In South America, legislation with a wide scope of GM organisms exists in Brazil, Cuba, Mexico and Peru, whereas other countries limit the scope to GM plants, or have no legislation in place yet (Artunduaga-Salas, 2000). Bolivia's regulations were confirmed by law in 1994. Regulations for commercialisation are specific, except for Columbia and Uruguay. The Instituto Interamericano de Cooperación para la Agricultura (IICA) has provided guidance on the development and harmonisation of regulations (e.g. Jaffé, 1994), with the CGIAR Research Centres providing assistance. Currently, 16 Latin American and Caribbean countries participate in the UNEP-GEF project (UNEP, 2002).

In Africa, several African governments are facilitating the applications of agricultural biotechnology to help increase productivity. The need for increased productivity is probably nowhere greater than in Africa (Mushita, 2001), which is currently experiencing the highest population growth rate and the highest levels of malnutrition of any region in the world. Various GM crop research activities towards this aim are reaching the field testing stage. In South Africa, the South Africa Committee for Genetic Modification (SAGENE) has based its environmental release considerations on guidelines developed in the UK, with a GMO act dating from 1997. Decisions regarding GM organisms consider more than safety issues. In this manner, the decision-making process has acquired public credibility and support. In Egypt, existing legislation not tailored to GM crops was used to permit a few field trials, with the expectation that commercialisation will proceed and appropriate legislation will be put in place. An overview of the current developments in biosafety legislative system in Egypt is given by Madkour *et al*. (2000). Kenya implemented regulations and guidelines in 1997, overseen by the National Biosafety Committee. Zimbabwe has also developed national guidelines, with its 2000 regulations being legally binding. The policy framework to regulate and monitor the import, manufacture, use and release of GM organisms is currently being developed in several other African countries such as Uganda, Namibia, Nigeria and Cameroon, often with assistance from the United Nations Environment Programme (UNEP). Namibia has based its guidelines on the South African model. Many other African countries, however, currently lack the financial support to develop appropriate guidelines, policies and/or legislation (Kandawa-Schulz, 2000). Currently, 22 African countries participate in the UNEP-GEF project (UNEP, 2002).

Regulatory information for environmental release

Despite all differences in philosophy and implementation of regulations in various countries, the questions asked and the science underpinning the regulations are generally alike. Regulatory bodies throughout the world require the documentation of similar information when considering applications for the release of GM crops. This involves providing responses to a profile of questions, set out under the regulations issued. As an example of the typical information required for assessing the environmental release of GM plants, the prescribed questions from regulations in the UK are presented in Table 4. Documentation of responses to such questions results in a detailed description of the GM plant, how it has been modified and information on the intended conditions of the proposed release.

A key component of applications for environmental release is a detailed environmental risk assessment, which considers potential harm to human health, other organisms and the environment. It also identifies possible ways that any risks can be minimised or avoided. The scientific base for such assessments will be addressed in the accompanying paper (Conner *et al*., 2003). It is not unusual for a regulatory body to seek further information from an applicant, or request that additional points are clarified. Such applications are usually publicly notified with an opportunity for public comment and participation in the approval process. A panel of experts usually reviews the full proposals, with the regulatory body making the final decision. This involves placing particular emphasis on the risk assessment and any procedures for risk management. The science behind the main issues under consideration during the risk assessment is discussed in the accompanying paper (Conner *et al*., 2003). The depth and extent of the information required varies between the regulatory bodies in different countries, as can the relative perception of risk versus benefit. Furthermore, the regulatory bodies in some countries are more risk adverse and impose substantially greater containment controls for risk management than others.

Table 4 Typical information required for assessment of environmental release of GM plants; the 41 prescribed questions from Schedule 1 of the 1995 Regulations for the Deliberate Release of GM Higher Plants of the UK

General information

1. The name and address of the applicant
2. The title of the project

Information relating to the parental organism

3. The full name of the plant: family, genus, species, subspecies, cultivar
4. Information on the reproduction of the plant: mode, generation time and sexual compatibility with other cultivated or wild plant species
5. Information on the survivability of the plant: survival structures, dormancy etc
6. Information concerning dissemination of plant: means, extent and factors affecting dissemination
7. The geographic distribution of the plant
8. If the plant species is not normally grown in Member States, describe the natural habitat
9. Information on any significant interactions of the plant with organisms other than plants in the ecosystem where it is usually grown, including toxicity to humans, animals and other organisms

Information relating to the genetic modification

10. A description of methods used for genetic modification
11. The nature and source of the vector used
12. The size, function and donor organism(s) of each DNA sequence intended for insertion

Information relating to the genetically modified plant

13. A description of the trait(s) and characteristics of the GM plant which have been modified
14. Information on sequences inserted or deleted: size/structure, copy number of insert, information on any vector sequences or foreign DNA remaining in the GM plant. The size/function of any deleted regions. Cellular location of insertion (eg. chromosomal, mitochondria, chloroplast etc.)
15. Information on the expression of the insert: expression and parts of the plant where expressed
16. How does the GM plant differ from the recipient plant in mode/rate of reproduction, dissemination, survivability
17. The genetic stability of the insert
18. The potential for transfer of genetic material from the GM plants to other organisms
19. Information on any toxic/harmful effects on human health and the environment arising from the genetic modification
20. The mechanism of interaction between the GM plants and target organisms
21. Any potential significant interactions with non-target organisms
22. A description of detection and identification techniques for the genetically modified plants
23. Information about previous releases of the GM plants

Information relating to the site of release

24. The location and size of the release site or sites
25. A description of the release site ecosystem, including climate, flora and fauna
26. Details of any sexually compatible wild relatives or cultivated plants present at the release sites
27. The proximity of the release sites to officially recognised biotopes or protected areas

Information relating to the release

28. The purpose of the release
29. The foreseen dates and duration of the release
30. The method by which the GM plants will be released
31. The method for preparing and managing the release site, prior to, during, and after the release
32. The approximate number of GM plants (or plants per m^2) to be released

Information on the control, monitoring, post-release plans and waste treatment plans

33. A description of any precautions to minimise or prevent pollen or seed dispersal from the GM plant
34. A description of the methods for post-release treatment of the site or sites
35. A description of post-release treatment methods for the GM plant material including wastes
36. A description of monitoring plans and techniques
37. A description of any emergency plans

Information on potential environmental impact of the release of the genetically modified plants

38. The likelihood of any GM plant becoming more persistent or invasive than recipient plants
39. Any selective advantage or disadvantage conferred to other sexually compatible plant species, which may result from genetic transfer from the genetically modified plant
40. Potential environmental impact of the interaction between the GM plant and target organisms
41. Any possible environmental impact resulting from potential interactions with non-target organisms

A similar set of information is usually required for applications involving the release for research and development, as well as for subsequent commercialisation, although the extent of documentation required will vary depending on the intended purpose. As GM plants pass from containment greenhouse conditions, through small-scale contained field tests to experimental agronomic trials, the knowledge base about the GM plant, the stability of expression and phenotypic performance of the transgene, and the potential impacts of the GM plant is increasing. This information is valuable for risk assessment considerations when applying for larger farm-scale trials and eventual commercial release.

Trends and pitfalls in the regulation and legislation of GM crops: concluding remarks

The ongoing globalisation of agricultural production and the projected increased role of GM crops in that production puts pressure on the global harmonisation of regulation and legislation of GM crops. Greater harmony over key terms in legislation is clearly important. Harmonisation will not only concern the safety of growing and consuming GM crops, but will also include various issues raised by various organisations and interest groups. For example, by the World Trade Organisation (WTO) with regards to trade, economy and distinguishable production chains, or by numerous non-governmental organisations (NGO's) addressing the developed–developing country division of the world, and by numerous consumer organisations for freedom of choice. There is already some legal tension between the WTO and GM crop regulation with respect to trade policy and market access (Josling and Nelson, 2001). Another legal direction for GM crop regulations is going to be the issue of liability in various forms (tort based, contract based, as well as regulation based; Moeller, 2001), sparked in part by the Starlink corn case (Dorey, 2000). The liability issue will be of particular interest for regulations aimed at maintaining GM crop-free production chains. Regulations for any process-based labelling of GM crop-derived food and feed may be compromised in the near future and it is unclear how potential incidences of fraud are going to be prevented. Other issues concerning regulations will be mainly ethical or philosophical in nature. A major issue is whether the regulations in societies with a food surplus can, or will, deny societies with a food deficit the access to GM technology that may help to alleviate the problem, even if only partially.

For the appropriate regulation of biosafety, the key issue to resolve has been, and will remain, 'when is safe sufficiently safe?' This requires appropriate science for determining what is meant by 'safe' and judgement for deciding the meaning of 'sufficiently'. The current era of genomics, proteomics, etc. is delivering technologies that will allow the measurement of gene expression at the RNA and protein levels, as well as molecules of each specific metabolite in a plant. Future regulation aimed at 'absolute safety' may eventually demand such measurements as a routine requirement based on the premise that everything that can be measured should be measured, irrespective of its potential (ir)relevance. The baseline for 'safe' should be comparison and the judgement of 'sufficiently' should take the comparative risk into account. The judgements made during a comparative assessment should represent the concerns of the public. However, caution should be observed when items in regulatory procedures are put in place solely for the purpose of enhancing public confidence. The role of regulators must be to recognise when impacts of GM crops might become unacceptable and to require changes to existing or GM farming practices to obtain the balance that society demands. But, what a given society wants and how much it might be willing to pay for additional assurances is unknown.

In this context, the impact of regulation is going to be a crucial issue that must not be forgotten. It is important to emphasise that the regulation of risk is currently turning into a risk of regulation. The regulatory process itself may already cause one of the greatest risks (Brown, 2001). The level of scrutiny imposed is unprecedented for the products of plant breeding. As regulations become impractical, compliance with them becomes less controllable and they are likely to become considerably more costly than anticipated. The plant breeding industry, in general, does not have the resources for GM crop material to be assessed in the same detail as a pharmaceutical. The cost of meeting regulatory requirements is currently a significant negative impact on the release of GM crops compared to the release of cultivars from traditional breeding. Excessive regulatory reviews will frustrate and curtail research and application to such an extent that only a few large multinational companies can afford to make progress. In this manner, over-regulation will help to promote a situation that is a concern of many: corporate control of agriculture (Dawkins, 2002). This trend is already clearly apparent and may result in the creation of a single (or a few) companies dominating world food production and increasing world dependence (Dawkins, 2002; Josling and Nelson, 2001).

A potentially even larger danger of the trend toward zero-risk in current regulation is that a similar risk scrutiny will be imposed on the activity of traditional, non-GM plant breeding. The results of a recent National Academy of Sciences study (NAS, 2002) already suggests that conventional crops may pose undesired environmental risks and should be monitored (Gewin, 2002). This would basically be the end of plant breeding as we know it, and dramatically affect the future of plant science. Such ends do not seem to justify the means. Plants, crops and innovation in crops and crop growing will remain essential for global well being in the future.

Acknowledgements

We thank numerous colleagues and peers for information, interpretations and discussions on several issues surrounding legislation and regulation of plant genetic engineering. We also thank Tracy Williams, Jeanne Jacobs, Keith Redenbaugh and Tom Nickson for comments and corrections, as well as the editorial staff of *The Plant Journal* for their patience while preparing the manuscript. JPN was supported by Program subsidy 347 of the Dutch Ministry of Agriculture, Nature Management and Fisheries and AJC was supported by contract C02X0203 from the New Zealand Foundation for Research, Science and Technology.

References

Artunduaga-Salas, R. (2000) Biosafety regulations on transgenic plants in Latin America and the Caribbean. The Andean countries as a model. In *Proceedings of the Sixth International Symposium on the Biosafety of Genetically Modified Organisms* (Fairbairn, C., Scoles, G. and McHughen, A., eds). Saskatoon, Canada: University Extension Press, pp. 21–25 (http://www.ag.usask.ca/isbr/Symposium/Proceedings/Section2.html#21).

Benbrook, C.M. (2001) *When Does It Pay to Plant Bt Corn? Farm-Level Economic Impacts of Bt Corn, 1996–2001.* Minneapolis, USA: Institute for Agriculture and Trade Policy (IATP), p. 4 (http://www.gefoodalert.org/library/admin/uploadedfiles/WhenDoes_It_Pay_to_Plant_Bt_Corn_Farm-Level_Ec.pdf).

Biosafety Meeting (1999) *Proceedings of the fifth Central and Eastern European Conference for Regional and International Co-operation on Safety in Biotechnology*, December 12–14, Sofia, Bulgaria (http://www.vanolstweb.nl/cee/attachments/Sofia%201999%20summary%20report.doc).

Blume, Y.B. (2000) Key issues for Ukrainian acceptance of genetically modified plants and a comparison with other Central and Eastern European Countries. In *Proceedings of the Sixth International Symposium on the Biosafety of Genetically Modified Organisms* (Fairbairn, C., Scoles, G. and McHughen, A., eds). Saskatoon, Canada: University Extension Press, pp. 15–20 (http://www.ag.usask.ca/isbr/Symposium/Proceedings/Section2.html#15).

Brown, J.K.M. (2001) Is too much risk assessment risky? *Trends Biotechnol.* **19**, 124–125.

Bullock, D. and Nitsi, E.I. (2001) GMO adoption and private cost savings: GR soybeans and Bt corn. In *Genetically Modified Organisms in Agriculture. Economics and Politics* (Nelson, G.C., ed.). San Diego, CA: Academic Press, pp. 47–58.

Burachik, M. and Traynor, P.L. (2002) *Analysis of a National Biosafety System: Regulatory Policies and Procedures in Argentina.* ISNAR Country Report 63. The Hague, the Netherlands: International Service for National Agricultural Research, p. 58 (ftp://ftp.cgiar.org/isnar/Publicat/cr63.pdf).

Byrne, P., Ward, S., Harrington, J. and Fuller, L. (2002) *Transgenic Crops: an Introduction and Resource Guide.* The regulatory process for transgenic crops in the US. Website Colorado State University, Colorado (http://www.colostate.edu/programs/lifesciences/TransgenicCrops/evaluation.html).

Campolina de Oliveira Soares, A. (2001) Campaign overview: for a GMO-free Brazil. In *Proceedings of the Flipside of Genetic Engineering; Genetic Engineering – Opinions from the South, 29 October 2001.* The Hague, the Netherlands: various organisations (http://www.gentechdebat.nl/news/shownews.asp?itemid=99).

CAST (Council for Agricultural Science and Technology) (2000) *Ecological Impact Assessment.* Science Source for Food, Agricultural, and Environmental Issues. Ames, IA, USA: CAST (http://www.cast-science.org/biotechnology/20001011.htm).

CAST (Council for Agricultural Science and Technology) (2001) *Evaluation of the US Regulatory Process for Crops Developed Through Biotechnology.* Issue Paper 19. Ames, IA, USA: CAST (http://www.cast-science.org/pubs/cropregulation.pdf).

CEC (Commission of the European Communities) (2000) *Communication from the Commission on the Precautionary Principle.* Brussels, Belgium: CEC, p. 29 (http://europa.eu.int/comm/dgs/health_consumer/library/pub/pub07_en.pdf).

CEC (Commission of the European Communities) (2001a) *Proposal for a Regulation of the European Parliament and of the Council concerning the traceability and labelling of genetically modified organisms and traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC.* Brussels, Belgium: CEC (COM 2001, 182 final; 2001/0180 (COD)), p. 27 (http://europa.eu.int/comm/food/fs/gmo/biotech09_en.pdf).

CEC (Commission of the European Communities) (2001b) *Proposal for a Regulation of the European Parliament and of the Council on genetically modified food and feed.* Brussels, Belgium: CEC (COM 2001, 425 final; 2001/0173 (COD)), p. 64 (http://europa. eu.int/comm/food/fs/gmo/biotech08_en.pdf).

CFIA (Canadian Food Inspection Agency) (1998) *Canada–US Bilateral on Agricultural Biotechnology.* Appendix I: Molecular genetic characterisation data (http://www.inspection.gc.ca/english/plaveg/pbo/usda/usda03e.shtml).

Chen, Z., Gu, H., Li, Y., Tian, J. and Qu, L.-J. (2000) Prospects for and safety issues with transgenic food. In *Proceedings of the Sixth International Symposium on the Biosafety of Genetically Modified Organisms* (Fairbairn, C., Scoles, G. and McHughen, A., eds). Saskatoon, Canada: University Extension Press, pp. 4–5 (http://www.ag.usask.ca/isbr/Symposium/Proceedings/Section2.html#4).

Cohen, J.I. (ed.) (1999) *Managing Agricultural Biotechnology. Addressing Research Programme Needs and Policy Implications.* Oxford, UK/The Hague, the Netherlands: CABI Publishing.

Conner, A.J., Glare, T.R. and Nap, J.P. (2003) The release of genetically modified crops into the environment. II. Overview of ecological risk assessment. *Plant J.* **33**, 19–46.

Dawkins, K. (2002) *Gene Wars: the Politics of Biotechnology*, 2nd edn. New York, USA: Seven Stories Press.

Deegan, D. (2001) Plant-incorporated protectant rules affirmed by administration: comments invited on supplemental notice and report. US EPA-CEMR, p. 2 (http://www.epa.gov/scipoly/pressrelease.pdf).

Ding, Y. (1995) Biosafety in China. In *Proceedings of the third International Symposium on the Biosafety Results of Field Tests of Genetically Modified Plants and Micro-organisms* (Jones, D.D., ed.). Oakland, CA: University of California, pp. 69–71.

Dorey, E. (2000) Taco dispute underscores need for standardized tests. *Nature Biotechnol.* **18**, 1136–1137.

Eichelbaum, T., Allan, J., Fleming, J. and Randerson, R. (2001) *Report of the Royal Commission on Genetic Modification.* Wellington, New Zealand: Royal Commission on Genetic Modification (http://www.gmcommission.govt.nz/RCGM/index.html).

Falck-Zepeda, J.B., Traxler, G. and Nelson, R.G. (2001) Cotton GMO adoption and private profitability. In *Genetically Modified Organisms in Agriculture. Economics and Politics.* (Nelson, G.C., ed.). San Diego, CA, USA: Academic Press, pp. 47–58.

FDA (Food and Drug Agency) (1992) Statement of policy: foods derived from new plant varieties: notice. *Federal Register*, **57**, 22984–23005 (http://www.cfsan.fda.gov/~lrd/bio1992.html).

Gewin, V. (2002) Academy proposes tighter crop monitoring. *Nature*, **415**, 948.

Greenpeace International (2001) The Lost Markets of Genetic Engineering. Digest 'Genetically Engineered Food', p. 5 (http://www.greenpeace.org/~geneng/reports/food/lostmarkets2.htm).

Greenpeace International (2002) GE crops – increasingly isolated as awareness and rejection grow. Background information 'international genetically engineering campaign', p. 6 (http://www.greenpeace.org/~geneng/highlights/gmo/usda_mar28.pdf).

Huang, J., Rozelle, S., Pray, C. and Wang, Q. (2002) Plant biotechnology in China. *Science*, **295**, 674–677.

Huang, J., Wang, Q., Zhang, Y.D., Zepeda, J.F. (2001) *Agricultural Biotechnology Indicators: China.* Working Paper, Centre for Chinese Agricultural Policy, Chinese Academy of Sciences. Supplementary material (Supplement D) to Huang ***et al.*** (2002) (http://www.sciencemag.org/cgi/data/295/5555/674/DC1/4).

Huarte, M. (2000) Argentina. In *Developing Country Profiles. Proceedings of the International Workshop on Transgenic Potatoes for the Benefit of Resource-Poor Farmers in Developing Countries, Manchester, UK, 5–9 June, 2000* (Lizárraga, L. and Hollister, A., eds). Lima, Peru: International Potato Center (CIP), pp. 9–13 (http://www.bangor.ac.uk/psp/pot_nov00/country/argentina.htm).

Jaffé, W.R. (ed.) (1994) *Armonizacion de la bioseguridad en el Cono Sur: supervisión de Plantas Transgénicas.* Marzo, Costa Rica: IICA.

James, C. (2001) *Global Review of Commercialised Transgenic Crops: 2001.* ISAAA Briefs no. 24: Preview. Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications (http://www.isaaa.org/publications/briefs/Brief_24.htm).

James, C. (2002) World-wide deployment of GM crops: aims and results – state of the art. In *Discourse on Genetically Modified Plants*. Bad Neuenahr, Germany: Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft, April 19 (http://www.gruenegentechnik.de/Doku_Fachtagung/james_engl.pdf).

Josling, T. and Nelson, G.C. (2001) Looking into the future. In *Genetically Modified Organisms in Agriculture. Economics and Politics.* (Nelson, G.C., ed.). San Diego, CA: Academic Press, pp. 143–148.

Kandawa-Schulz, M. (2000) Biosafety regulations, releases and research activities in selected African countries. In *Proceedings of the Sixth International Symposium on the Biosafety of Genetically Modified Organisms* (Fairbairn, C., Scoles, G. and McHughen, A., eds). Saskatoon, Canada: University Extension Press, pp. 6–14 (http://www.ag.usask.ca/isbr/Symposium/Proceedings/Section2.html#6).

Kuiper, H.A., Kleter, G.A., Noteborn, H.P.J.M. and Kok, E.J. (2001) Assessment of the food safety issues related to genetically modified foods. *Plant J.* **27**, 503–528.

La Rosa, J. (2000) Cuba. In *Developing Country Profiles. Proceedings of the International Workshop on Transgenic Potatoes for the Benefit of Resource-Poor Farmers in Developing Countries, Manchester, UK, 5–9 June, 2000* (Lizárraga, L. and Hollister, A., eds). Lima, Peru: International Potato Center (CIP), pp. 26–28 (http://www.bangor.ac.uk/psp/pot_nov00/country/cuba.htm).

MacKenzie, D. (2000) *International Comparison of Regulatory Frameworks for Food Products of Biotechnology*. Ottawa, Canada: Canadian Biotechnology Advisory Committee, p. 62 (http://www.cbac-cccb.ca/documents/en/InternatComparisons_MacKenzie.pdf).

Madkour, M.A., El Nawawy, A.S. and Traynor, P.L. (2000) *Analysis of a national biosafety system: regulatory policies and procedures in Egypt.* ISNAR Country Report 62. The Hague, the Netherlands: International Service for National Agricultural Research, p. 41 (ftp://ftp.cgiar.org/isnar/Publicat/cr62.pdf).

MATRA (2002) Implementation of national biosafety frameworks in pre-accession countries of Central and Eastern Europe (http://www.biosafety-cee.org).

McLean, M.A., Frederick, R.J., Traynor, P.L., Cohen, J.I. and Komen, J. (2002) *A Conceptual Framework for Implementing Biosafety: Linking Policy, Capacity, and Regulation.* Briefing Paper 47. the Hague, the Netherlands: International Service for National Agricultural Research, p.11 (ftp://ftp.cgiar.org/isnar/publicat/bp-47.pdf).

Moeller, D.R. (2001) *GMO Liability Threats for Farmers. Legal Issues Surrounding the Planting of Genetically Modified Crops*. Mineapolis, USA: Institute for Agriculture and Trade Policy (IATP), p. 8 (http://www.gefoodalert.org/library/admin/uploadedfiles/GMO_Liability_Threats_for_Farmers_PDF_Ver.pdf).

Mushita, A.T. (2001) An African view on genetic engineering. In *Proceedings the Flipside of Genetic Engineering; Genetic Engineering – Opinions from the South*. The Hague: various organisations, October 29 (http://www.gentechdebat.nl/news/shownews.asp?itemid=96&returl=/conferentie/Default.asp?).

NAS (National Academy of Sciences) (2000) *Genetically Modified Pest-Protected Plants: Science and Regulation*. Washington, DC: National Academy Press (http://www.nap.edu/books/0309069300/html/).

NAS (National Academy of Sciences) (2002) *Environmental Effects of Transgenic Plants: the Scope and Adequacy of Regulation*. Washington, DC: National Academy Press (http://books.nap.edu/books/0309082633/html/index.html).

NASS (National Agricultural Statistics Service) (2002) *Prospective Plantings*. March 2002 (http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bbp/pspl0302.pdf).

Nelson, G.C. (ed.) (2001) *Genetically Modified Organisms in Agriculture. Economics and Politics.* San Diego, CA: Academic Press.

Nelson, G.C., Babinard, J. and Josling, T. (2001) The domestic and regional regulatory environment. In *Genetically Modified Organisms in Agriculture. Economics and Politics.* (Nelson, G.C., ed.). San Diego, CA: Academic Press, pp. 97–116.

NRC (National Research Council) (1989) *Field Testing Genetically Modified Organisms: Framework for Decisions*. Washington, DC: National Academy Press (http://books.nap.edu/books/0309040760/html/index.html).

OECD (Organisation for Economic Co-operation and Development) (1993a) *Safety Considerations for Biotechnology: Scale-Up of Crop Plants*. Paris, France: OECD (http://www.oecd.org/pdf/M00022000/M00022009.pdf).

OECD (Organisation for Economic Co-operation and Development) (1993b) *Safety Considerations of Foods Derived by Modern Biotechnology: Concepts and Principles*. Paris, France: OECD (http://www.oecd.org/pdf/M00007000/M00007573.pdf).

OGTR (Office of the Gene Technology Regulator) (2002) Publications and forms (http://www.health.gov.au/ogtr/publications/index.htm).

PABE (2001) *Public Perceptions of Agricultural Biotechnologies in Europe.* Final report of the PABE research project, Lancaster, UK: Lancaster University, p. 113 (http://www.lancs.ac.uk/depts/ieppp/pabe/docs/pabe_finalreport.pdf).

PBO (Plant Biosafety Office) (2002) *Decision Documents. Determination of Environmental and Livestock Feed Safety* (http://www.inspection.gc.ca/english/plaveg/pbo/dde.shtml).

Persley, G.J., Giddings, L.V. and Juma, C. (1993) *Biosafety: the Safe Application of Biotechnology in Agriculture and the Environment.* Research Report no. 5. The Hague, the Netherlands:

International Service for National Agricultural Research p. 46 (ftp://ftp.cgiar.org/isnar/Publicat/PDF/RR-05.pdf).

Redenbaugh, K., Hiatt, M., Martineau, B., Kramer, M., Sheehy, R., Sanders, R., Houck, C. and Emlay, D. (1992) *Safety Assessment of Genetically Engineered Fruits and Vegetables; a Case Study of the FLAVR SAVR™ Tomato*. Boca Raton, FL: CRC Press.

RNS (Reuter News service) (2002) FACTBOX – Japan's new rules for biotech crop imports (http://www.planetark.org/dailynewsstory.cfm?newsid=10300).

Russell, B. (1951) A liberal decalogue. In *New York Times Magazine*, 16 December 1951, p. 42 (as reprinted in the Autobiography of Bertrand Russell, 3: 1944–69, pp. 71–72).

SCBD (Secretariat of the Convention on Biological Diversity) (2000) *Cartagena Protocol on Biosafety to the Convention on Biological Diversity: Text and Annexes*. Montreal: Secretariat of the Convention on Biological Diversity (http://www.biodiv.org/doc/legal/cartagena-protocol-en.pdf).

Schuhmacher, K.D. (2002) The importance of genetically modified products in the trade of agricultural goods and foodstuffs. In *Dokumentation Diskurs Grüne Gentechnik*. Berlin, Germany: Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft (in German) (http://www.gruenegentechnik.de/Doku_Anh290102/Schuhmacher_vortr.pdf).

STAFF (Society for Techno-Innovation Agriculture, Forestry and Fisheries) (2002) System and procedures for the application of recombinant DNA crop plants in agriculture, forestry, fisheries and the food industry. In *Introduction to Japanese Government Guidelines Regarding Recombinant DNA Crop Plants*. Tokyo: STAFF (http://www.s.affrc.go.jp/docs/sentan/eintro/intro.htm).

UNEP (United Nations Environment Programme) (1995) *UNEP International Technical Guidelines for Safety in Biotechnology* (http://www.unep.org/unep/program/natres/biodiv/irb/unepgds.htm).

UNEP (United Nations Environment Programme) (2002) *UNEP-GEF Project on development of national biosafety frameworks* (http://www.unep.ch/biosafety/).

Zhou, R.H., Zhang, Z.C., Wu, Q., Fang, R.X., Mang, K.Q., Tian, Y.C. and Wang, G.L. (1995) Large-scale performance of transgenic tobacco plants resistant to both tobacco mosaic virus and cucumber mosaic virus. In *Proceedings of the third International Symposium on the Biosafety Results of Field Tests of Genetically Modified Plants and Micro-Organisms* (Jones, D.D., ed.). Oakland, CA: University of California, pp. 49–55.