## *Chapter 5*

# How critical is modern agricultural biotechnology in increasing productivity sustainably?

*This chapter provides a succinct synthesis of the potential impacts of agricultural biotechnology on resource productivity and efficiency in OECD countries in comparison with conventional agricultural practices and identifies some of the associated main policy issues. Although this chapter touches on the full range of agricultural biotechnology tools and applications, the main focus is on disease-, insect- and pesticide-resistant and drought-tolerant crops.*

## Key messages

- Modern biotechnology can be potentially applied in several applications in agriculture, but some elements have proved highly controversial in some countries. Commercialisation of biotech crops has been limited to a few crops, mainly feed, and a small number of traits.
- Modern biotechnology can: i) speed up conventional breeding programmes and provide farmers with disease-free planting materials; ii) it can create crops that are resistant to pests and diseases, replacing toxic chemicals; iii) it can provide diagnostic tools and vaccines to help in controlling devastating animal diseases; and iv) value-enhanced or output-oriented products with traits derived from modern biotechnology can address additional and more complex challenges, such as drought tolerance and nitrogen-use efficiency. Empirical evidence shows that, on average, positive economic effects are being generated by first-generation biotech crops, depending on the trait considered, while the effects on biodiversity are ambiguous and context specific.
- Concerns about potential risks to the environment, consumer perceptions and institutional conditions continue to have a critical influence on the adoption of modern agricultural biotechnology and its consequent impacts.

## What is biotechnology and how is it used in agriculture?

### *Innovating through science and technology*

This chapter provides a succinct synthesis of the potential impacts of agricultural biotechnology on resource productivity and efficiency in OECD countries in comparison with conventional agricultural practices, and identifies some of the associated main policy issues. It is not intended to provide an exhaustive review of the full range of agricultural biotechnology tools and applications. Genetic engineering, particularly in the crop sector, is the area in which biotechnology has the most direct effect on agriculture in many countries, and has given rise to pressing public concerns and policy issues. Although this chapter touches on the full range of agricultural biotechnology tools and applications, the main focus is on disease-, insect- and pesticide-resistant, and drought-tolerant crops.[1]

Biotechnology comprises a number of related technologies with a wide range of current and potential applications in many sectors and is of significant interest to policy makers. Biotechnology is being used to address problems in all areas of agricultural production and processing and has the potential to contribute to meeting the challenges of green growth. Biotechnology contributes to the development of new varieties of plants and animals, new diagnostic tools, breeding, and veterinary therapeutics and vaccines. Biotechnology can overcome production constraints that are more difficult or intractable under conventional breeding schemes. It can speed up conventional breeding programmes and provide farmers with disease-free planting materials. It can create crops that resist pests and diseases, thus replacing toxic chemicals that harm the environment and human health, and it can provide diagnostic tools and vaccines that help control devastating animal diseases.

Renewed interest in biotechnology has arisen in parallel with the emergence of the notion of the bio-economy – the economic sectors that are based on bioscience and biotechnology innovation (OECD, 2009). For example, the use of renewable resources, which is expected to increase substantially over time, can require specific properties of the plant that can be developed using genetically engineering technologies.

Most of the bio-economy strategies or visions adopted by OECD countries include references to biotechnology. The United States' National Bioeconomy Blueprint, published in 2012 and which recognises the bio-economy as a political priority because of its potential for economic growth and social benefits – considers that biotechnology, including agricultural biotechnology can make an important contribution to the bio-economy through the development of innovative products and processes, the creation of jobs and growth – the "greening" – of the agricultural sector (www.whitehouse.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf).

The OECD study into the bio-economy in 2030 suggests rapid adoption of biotechnology for better diagnostics and improved varieties of farmed plants and animals. But achieving the full promise of the bio-economy by 2030 requires a policy framework that can address technological, economic and institutional challenges (OECD, 2009).

Modern agricultural biotechnology includes a range of tools that scientists employ to understand and modify the genetic make-up of organisms for use in the production or processing of agricultural products: genetically engineered crops, such as insect- and herbicide-resistant plants or transgenic animals, such as pigs that can digest cellulose, or transgenic fish, such as faster-growing salmon. Modern biotechnology in general refers to the combination of life-science with engineering that includes recombinant DNA technology (Tramper and Zhu, 2011). The applications not only include crops and farm animals, but also food products such as cheeses, bakery products, wine, beer, a wide range of pharmaceutical products and other areas of the bio-economy.

The OECD's definition of biotechnology is deliberately broad, covering all modern biotechnology, as well as many traditional or borderline activities. Its defines biotechnology as follows: the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services (Box 5.1).[2,3]

### Box 5.1. OECD definition of biotechnology

***Defining biotechnology***

*The single definition*

The provisional single definition of biotechnology is deliberately broad. It covers all modern biotechnology but also many traditional or borderline activities. For this reason, the single definition should always be accompanied by the list-based definition which operationalizes the definition for measurement purposes. The single definition is:

*The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.*

**The list-based definition**

The following list of biotechnology techniques functions as an interpretative guideline to the single definition. The list is indicative rather than exhaustive and is expected to change over time as data collection and biotechnology activities evolve.

***DNA/RNA***: Genomics, pharmacogenomics, gene probes, genetic engineering, DNA/RNA sequencing/synthesis/amplification, gene expression profiling, and use of antisense technology.

***Proteins and other molecules***: Sequencing/synthesis/engineering of proteins and peptides (including large molecule hormones); improved delivery methods for large molecule drugs; proteomics, protein isolation and purification, signaling, identification of cell receptors.

***Cell and tissue culture and engineering***: Cell/tissue culture, tissue engineering (including tissue scaffolds and biomedical engineering), cell fusion, haploid induction, embryogenesis, vaccine/immune stimulants, embryo manipulation.

***Process biotechnology techniques***: Fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and phytoremediation.

***Gene and RNA vectors***: Gene therapy, viral vectors.

***Bioinformatics***: Construction of databases on genomes, protein sequences; modelling complex biological processes, including systems biology.

***Nanobiotechnology***: Applies the tools and processes of nano/microfabrication to build devices for studying biosystems and applications in drug delivery, diagnostics etc.

*Source*: www.oecd.org/sti/biotech/statisticaldefinitionofbiotechnology.htm.

Interpreted in this broad sense, the definition of biotechnology covers many of the tools and techniques that are commonplace in agriculture and food production, such as fermentation and brewing.[4] For example, conventional plant breeding has been the method used to develop new varieties of crops for hundreds of years. The most controversial of the improved biotechnologies are transgenic crops also called genetically engineered or genetically modified organisms, commonly known as GMOs.[5] Genetic engineering is a tool for "precision breeding," enabling the insertion of genes with desirable traits even from different species. The genetic diversity of agricultural crops is a crucial factor in the ability of agriculture to adapt to climate change, to maintain increase the resistance of crops to pests and diseases and to meet changing consumer preferences. There is concern that current crop breeding does not utilise sufficient genetic diversity (van Heerwaarden et al., 2013).

It should be emphasised, however, that modern agricultural biotechnology is more than genetic engineering. The most significant breakthroughs in agricultural biotechnology, for example, are coming from research into the structure of genomes and the genetic mechanisms behind economically important traits. The rapidly progressing discipline of genomics, revolutionising understanding of the ways in which genes, cells, organisms and ecosystems function, is opening new horizons for marker-assisted breeding and genetic resource management: it provides information on the identity, location, impact and function of genes affecting such traits – knowledge that may increasingly drive the application of biotechnology in all agricultural sectors (Boxes 5.2 and 5.3).

**Box 5.2. Genomics: The new revolution**

Genomics, the study of all the genetic material in an organism, is leading to tremendous advances in biotechnology. Genomics is both generating new tools and techniques and producing huge amounts of biological data for scientists to analyse. As a result of genomics, genes for desirable traits can be rapidly identified and used to create new biotechnology products.

It should be stressed that genomics does not necessarily involve genetic modification or synthetic biology. Rather, genomics technologies can be applied to animal and plant breeding to greatly improve the efficiency of selection of traits. In the case of trees, this is especially important given the long timescales needed for growth and trait expression. Genomics can address several challenges facing sustainable agriculture. For example, the combination of drought/heat tolerant traits with the ability of a plant to make its own fertilisers addresses several vitally important challenges, including water security, food security, resource depletion and climate change.

**Box 5.3. Bio-fortification: Creating *Golden Rice***

Bio-fortification – the creation of plants that make or accumulate micronutrients – aims to increase the nutritional quality of staple crops through breeding and is used for the production of functional foods. The breeding can either be through conventional or traditional ways or through genetic engineering methods. Crops produced through bio-fortification tend to be rich in nutrients such as iron, zinc, and Vitamin A. Bio-fortification differs from ordinary fortification because it focuses on making plant foods more nutritious as the plants are growing, rather than having nutrients added to the foods when they are being processed. *Golden Rice* is a good example of a bio-fortified crop. In this specific case, bio-fortification was obtained by genetic modification of the rice plant to produce and accumulate pro-vitamin A in the grain, a trait not found in nature. Initially developed in Switzerland and Germany in the late 1990s, *Golden Rice* has now spread to other places – although its critics point out that dealing with Vitamin A deficiencies may not best be achieved through the engineering of a rice cultivar (Scoones, 2002).

*Source*: Hall and Dorai (2010), "What have been the farm-level economic impacts of the global cultivation of GM crops? Systematic review", www.environmentalevidence.org/wp-content/uploads/2014/07/CEE11-002.pdf.

## Genetic engineering in agriculture is in its infancy

Genetically engineered commodities have been classified into one of three generations. Input-oriented traits, such as pest resistance and herbicide tolerance to improve yields and/or reduce costs of production, represent the first generation. The second-generation focuses on value-enhanced or output-oriented traits, such as nutritional features and processing characteristics (e.g. extra vitamins that might make the food more attractive to consumers; nutrient-enhanced seeds for feed). Third-generation crops include traits that produce pharmaceuticals, improve the processing of bio-based fuels, or produce products beyond food and fibre (Fernandez-Cornejo, et al., 2014). Today, commercially available transgenic crops are only of the first-generation type, although all three generations are in various stages of research and development.

In the case of plants, agricultural biotechnology encompasses a range of modern plant breeding techniques. The best known technique is genetic modification, although the term also covers such techniques as Marker Assisted Breeding, which increases the effectiveness of conventional breeding without involving the transformation of isolated genetic material into the genomes of plants. The main goals of biotechnology include: i) agronomic traits to improve yields and provide resistance to stress, such as heat, cold, drought or salinity; ii) herbicide tolerance, to allow plants to resist the effects of specific herbicides; iii) pest resistance to improve the ability of the plant to resist harmful insects, viruses, bacteria, fungi or nematodes; and iv) product quality characteristics, such as modified colour, or flavour, modified starch or oil composition to improve nutritional value or processing characteristics, and the production of medical and industrial compounds.

For livestock, biotechnology has three main applications: breeding, propagation and health. Diagnostics can be used to identify serious inherited diseases, so as to remove afflicted animals from the breeding population. The largest commercial application of biotechnology in animal breeding is the use of Marker Assisted Selection (MAS) to improve the accuracy and speed of conventional breeding programmes, by employing biological markers to identify certain traits. MAS is widely used in both OECD and non-OECD countries.

However, whether the traits selected through biotechnology are in support of a green growth agenda depends very much on the goals of crop improvement efforts. While breeding approaches to develop drought-tolerant, pest-resistant varieties could have a benign effect on green growth, the same techniques could be used to address traits, such as responsiveness to chemical fertilisers, which are not intrinsically sustainable.

### *Adoption of first generation biotech crops has been rapid, but narrowly based*

The use of biotech (transgenic) crops has increased steadily since the first commercial plantings in North America in 1996. Over the 1996-2014 period, the global area planted with biotech crops increased by more than 100-fold – from 1.7 million hectares in 1996 to 181.5 million hectares. This represents just over 12% of the world's arable land, and is largely constituted of soybeans, maize, cotton and oilseed rape (canola) (James, 2015).

A significant development in 2014 was the over fivefold increase in the adoption of the first biotech drought-tolerant maize (which uses less water per hectare) planted in the United States in 2013 (from 50 000 ha in 2013 to 275 000 ha in 2014).

Although 28 countries worldwide are growing biotech crops, adoption has been uneven across countries and commercialisation has involved only a few crops and traits. Five countries (United States, Brazil, Argentina, Canada and India) accounted for almost 90% of the global area planted in biotech crops in 2014, and two crops (soybeans and maize) and two traits (insect resistance and herbicide tolerance) accounted for more than 70% of the global area planted in biotech crops (Figure A5.1, Table A5.1).

Worldwide, for nearly half of the biotech crop area herbicide tolerance is the dominant trait introduced, followed by insect resistance. Stacked traits is an important and growing feature of biotech crops (28% of the global 181 million hectares), with 13 countries having planted biotech crops with two or more traits in 2014. Herbicide tolerance soybean is the most dominant transgenic crop grown commercially (48% of the global area devoted to biotech crop total, mainly in Brazil, the United States and Argentina), followed by Bt maize (33% – mainly in the United States) and Bt cotton (14% – mainly in India, the China, the United States and Pakistan) and herbicide tolerance canola (mainly in Canada and the United States (James, 2015).

### Box 5.4. Biotech crops in the United States

*Biotech seed suppliers and technology providers*

The number of field releases for the testing of biotech varieties approved by USDA's Animal and Plant Health Inspection Service (APHIS), which is an important indicator of R&D activities in agricultural biotechnology, grew from 4 in 1985 to 1 194 in 2002 and averaged around 800 per year thereafter. Also, releases of biotech varieties with agronomic properties (like drought resistance) jumped from 1 043 in 2005 to 5 190 in 2013. As of September 2013, about 7 800 releases were approved for biotech maize, more than 2 200 for biotech soybeans, more than 1 100 for biotech cotton and about 900 for biotech potatoes. Releases were approved for biotech varieties with HT (6 772 releases), IR (4 809), product quality such as flavour or nutrition (4 896), agronomic properties like drought resistance (5 190) and virus/fungal resistance (2 616). The institutions with the most authorised field releases include Monsanto (6 782), Pioneer/DuPont (1 405), Syngenta (565) and USDA's Agricultural Research Service (370). As of September 2013, APHIS had received 145 petitions for deregulation (allowing biotech seeds to be sold) and had approved 96 petitions: 30 for maize; 15 for cotton; 11 for tomatoes; 12 for soybeans; 8 for rapeseed/canola; 5 for potatoes; 3 for sugar beets; 2 each for papaya, rice, and squash; and 1 each for alfalfa, plum, rose, tobacco, flax, and chicory.

*Farmers*

Three crops (maize, cotton and soybeans) make up the bulk of the area planted to biotech crops. In 2013, about 169 million acres of these biotech crops were planted, or about half of total land used to grow crops. In 2013, the area of HT crops planted accounted for 93% of soybean acreages, 85% of maize acreage and 82% of cotton acreage. Farmers planted insect-resistant (Bt) cotton to control pests on 75% of cotton acreage and Bt maize was planted on 76% of maize acreage in 2013.

The adoption of Bt crops increases yields by mitigating yield losses from insects. However, empirical evidence regarding the effect of HT crops on yields is mixed. Generally, stacked seeds (seeds with more than one biotech trait) tend to have higher yields than conventional seeds, or seeds with only one biotech trait. Biotech maize with stacked traits grew from 1% of maize acres in 2000 to 71% in 2013. Stacked seed varieties also accounted for 67% of cotton acres in 2013.

Planting Bt cotton and Bt maize seed is associated with higher net returns when pest pressure is high. The extent to which HT adoption affects net returns is mixed and depends primarily on the extent to which weed control costs are reduced and seed costs are increased. HT soybean adoption is associated with an increase in total household income because HT soybeans require less management and enable farmers to generate income via off-farm activities or by expanding their operations.

Insecticide use has decreased with the adoption of insect-resistant crops. Farmers generally use less insecticide when they plant Bt maize and Bt cotton. Maize insecticide use by both genetically engineered seed adopters and non-adopters has decreased – only 9% of all US maize farmers used insecticides in 2010. Insecticide use on maize farms declined from 0.21 pound per planted acre in 1995 to 0.02 pound in 2010. The establishment of minimum refuge requirements (planting sufficient acres of the non-Bt crop near the Bt crop) has helped delay the evolution of Bt resistance. However, there are some indications that insect resistance is developing to some Bt traits in certain areas.

The adoption of HT crops has enabled farmers to substitute glyphosate for more toxic and persistent herbicides. However, an overreliance on glyphosate and a reduction in the diversity of weed management practices adopted by crop producers have contributed to the evolution of glyphosate resistance in 14 weed species and biotypes in the United States. Although the herbicide glyphosate is more environmentally benign than the herbicides that it replaces, weed resistance may lead to higher management costs, reduced yields and profits, and increased use of less environmentally benign herbicides. Best management practices (BMPs) to control weeds may help delay the evolution of resistance and sustain the efficacy of HT crops. BMPs include applying multiple herbicides with different modes of action, rotating crops, planting weed-free seed, scouting fields routinely, cleaning equipment to reduce the transmission of weeds to other fields, and maintaining field borders.

The price of biotech soybean and maize seeds grew by about 50% in real terms (adjusted for inflation) between 2001 and 2010. The price of genetically engineered cotton seed grew even faster. The yield advantage of Bt maize and Bt cotton over conventional seed has become larger in recent years as new Bt traits have been incorporated and stacked traits have become available. Planting Bt cotton and Bt corn continues to be more profitable, as measured by net returns, than planting conventional seeds.

*Source*: Fernandez-Cornejo, J., S. Wechsler, M. Livingston and L. Mitchell (2014), *Genetically Engineered Crops in the United States*, USDA, Economic Research Service Economic Research Report Number 162, www.ers.usda.gov/media/1282246/err162.pdf

Data on adoption patterns show: i) adoption rates and speed of herbicide tolerant plants which are higher than for insect resistant plants; ii) herbicide tolerant soybean worldwide being the crop with the highest adoption rate; iii) herbicide tolerant sugar beet in the United States being the crop with the highest speed of adoption; and iv) biotech maize being the crop where adoption substantially increased with a combination of traits.

The differences in adoption pattern can be explained by the differences in the cultivation problems addressed. For example, the dominance of herbicide-resistant transgenic varieties is linked to the use of the large area where it can be applied. Glyphosate and other broadband herbicides control almost all plants, and can be applied under different agro-climatic conditions and the technology is easy to apply. Moreover, their use can encourage the use of no-till, by removing the need for mechanic weeding (e.g. soybeans and canola).

Public policies also play a key in explaining the narrow geographical development of biotech crop use. Although several OECD countries have granted regulatory approvals to biotech crops for use as food, feed or environmental release since 1996, biotech crops are planted in only nine OECD countries – United States, Canada, Mexico, Australia, Spain, Portugal, Czech Republic, Slovakia and Chile for seeds (Table A5.1). In terms of food or feed approval, the OECD country with the highest number of approved events for biotech crops is Japan, followed by the United States, Canada and Mexico (James, 2015).[67] The information presented in Table A5.1 clearly shows that currently the United States (with 70.1 million hectares and with an average of around 90% adoption across all crops) and Canada are the two OECD countries where biotech crops are of main importance.

In the European Union, only one biotech crops is currently authorised for cultivation – insect-resistant Bt maize (MON810).[8] Commercial planting of this crop is grown on relatively small areas. The Bt maize (MON810) aims to protect the crop against a harmful pest – the European corn borer. In 2014, Bt maize – which aims to protect the crop against a harmful pest (the European corn borer) was cultivated in five EU member states (Spain, Portugal, Czech Republic, Slovakia and Romania), with a total area planted of 143 016 hectares (of which 131 538 hectares planted in Spain). It represents 1.6% of the 9.6 million hectares of maize cultivated in the European Union (or 30% of maize cultivated in Spain). New GM traits, genes and crops that have been tested in field trials, but are not authorised for commercial planting, include crop varieties which provide different nutritional or industrial qualities (such as easier conversion to biofuel), or increased tolerance to environmental stresses such as freezing, drought or salinity.

### Box 5.5. EU legislative framework covering GMOs

Authorisation for the import, cultivation and processing of GMOs in the EU requires, *a priori*, authorisation at the EU level, based on a scientific risk safety assessment on health and the environment conducted by the European Food Safety Authority (EFSA). The risk assessment for GMO plants that are used for non-food or non-feed purposes include, *inter alia*, assessments of persistence, invasiveness and selective advantage or disadvantage. While cultivation of GMOs is recognised to be an issue with strong national or local dimensions, EU legislation offered limited possibilities to member states to adopt GMO cultivation on their territory. Member states could only restrict or ban the cultivation of GMOs by adopting safeguard clauses where new serious risks to human health, animal health and the environment have been identified, following cultivation of the GMO. In 2009, 13 member states requested the European Commission to grant more flexibility in this area.

In March 2015, an amendment was adopted which aims at giving EU member states enhanced flexibility by broadening the criteria for refusing to permission to cultivate GMO on their territory. In particular, during the authorisation procedure of a GMO, EU member states may demand that the geographical scope of the authorisation be adjusted to exclude all or part of their territory. In addition, the amendment permits that EU member states to “opt-out” of the EU authorisation (i.e. be able to restrict or prohibit cultivation of GMOs that have been authorised at the EU-level on “compelling grounds” related to, *inter alia*, environmental policy objectives, town and country planning, land use, socio-economic impacts, agricultural policy objectives and public policy). However, the amendment does not allow Member states to ban a GMO on the grounds of risk to health or the environment: this will remain the domain of EU’s food safety body, EFSA and of the safeguard clauses.

*Source*: http://ec.europa.eu/food/plant/gmo/legislation/future_rules_en.htm

In the European Union, there are considerable differences in the attitudes of member states towards the use of biotech crops, including a wide range of views on the impacts of these crops on biodiversity (EC, 2011). A number of EU countries have chosen to adopt the precautionary principle, with nine of them implementing national ban on GM crop cultivation (Austria, France, Germany, Greece, Hungary, Italy, Poland, Luxembourg and Bulgaria). Anyone who wants to release a GM organism or market a GM product has to get formal authorisation before doing so. Applications for approval to market a product (including crop seeds for cultivation, food or feed) are assessed and decided upon at EU level, while applications to release a GM organism for R&D purposes are considered at national level (Box 5.5).

## Profitability expectations are mainly based on yields and relative costs

### *Positive but varied farm-level economic impacts*

Like any farm management practice, biotechnology will have economic impacts on farmers' wellbeing. Productivity gains encompass higher returns on all factors of production or lower input requirements per unit of production. This could lead to higher crop yields (due to the presence of fewer insects or pests), lower pesticide and fertiliser applications, less demanding production techniques, higher product quality, better storage and easier processing. These gains should be assessed in comparison with conventionally produced crops, produced under the same production system. Ultimately, higher productivity may result in lower producer and consumer prices.

Enhanced economic return will be one of the primary incentives for farmers to grow a biotech crops. The potential income-related impacts for farmers include changes in the use of inputs; associated costs; output (quantity and quality); and gross income. The overall economic impacts of biotechnology will depend on a wide range of factors including (among others) the impact of the technology on farming practices and yields, consumers' willingness to buy biotech products and regulatory requirements and associated costs. In the longer term, other factors, such as industry concentration on the production and marketing of biotechnology crop technology, may also influence the level and distribution of economic benefits.

Farmers who adopt the new technology, especially those who adopt early, may reap benefits in terms of lower production costs and/or higher output.[9] Other farmers could be placed at a competitive disadvantage depending on how consumer preferences and regulatory regimes evolve. If the attitude of consumers is generally accepting of biotech crops and if regulatory requirements are not too onerous, adopting farmers would gain and non-adopting farmers would lose (this is usually the case with biotech cotton). If consumer opinion is negative, however, non-adopting farmers could turn this into a competitive advantage and command a price premium for non-biotech products.[10] Another consideration to be taken into account is that biotechnology is mainly controlled by a few large companies, which can raise issues of competition.

Biotech-adopter farmers could also directly influence the economic benefits of non-biotech adopter farmers. For example, non-adopters of herbicide tolerant crops might also benefit from an induced effect on cost savings. On the other hand, if there is inadvertent gene flow from biotech adopter to non-biotech adopter fields then such eventuality may create problems for non-biotech adopter farmers willing to sell their products in specific markets (e.g. organic certified markets).

Thus, the net economic impact of biotech on farms can be a complex and dynamic concept that is not easily measured. Although, in the first instance, biotech will only be widely adopted if it provides economic benefits for farmers, a number of economic and institutional factors affect the farm-level profitability of biotech crops in addition to their purely agronomic characteristics.[11]

Overall, the farm-level profitability of biotech crops is likely to be influenced by key variables such as differences in yield, reductions in insecticide or weed management costs, differences in seed prices, and differences in the price received by the farmer between the biotech crop and its conventional counterpart. Moreover, a combination of underlying factors, such as local socio-economic and cultural factors, are also important drivers.

There is a voluminous and ever increasing body of literature concerning the potential economic effects of biotech crops, which has found positive economic impacts, although the impacts vary between and within countries, across years and between different crop or trait combinations (Annex 5.A). It appears that the more heterogeneous the growing environment, pest pressures, farmer practices and social context, the more variable are any benefits likely to be. Thus, the extent of economic benefit associated with different crop-trait combinations is likely to vary widely.

For example, a study by Klumper and Qaim (2014), which performed a meta-analysis approach – on 147 published biotech crop studies conducted during 1995-2014 worldwide – found that, on average, biotech technology has reduced chemical pesticide use by 37%; increased crop yields by 22%; and increased farmer profits by 68%. One of the key findings of the Hall et al. (2013) study, who performed a *systematic literature review* approach[12], is that planting GM crops as opposed to a non-GM equivalent, resulted in a positive farm-level economic impact.

The methodological difficulties in measuring the impacts of biotech crops should not be underestimated and a degree of caution should be exercised in analysing and utilising the results. For example, several studies only compare farm-level and short-term profitability and results are very sensitive to changes in the price of seeds, agro-chemical inputs and commodity prices. In addition, in several profitability studies, prices for biotech crops and conventional crops are assumed to be the same. Other conceptual limitations, particularly in early studies, include the use of gross rather than net margins (i.e. they do not take into account land and labour costs) and very small data samples, and a bias associated with the self-selection of farmers growing biotech crops (Smale, 2012).

### *Increased seed costs but lower chemical costs*

Generally, studies have found that certain categories of costs are lower following adoption of biotech crops (notably chemical costs), while others are consistently higher (specifically, seed costs). Cost categories that are particularly high for biotech crops when compared to non-biotech crops include seed costs and technology fees (value of biotech technology) (the latter are an entirely additional cost not incurred with conventional crops), while chemical costs are generally lower.

Changes in farm costs have been shown to vary through time, but the results are inconclusive as to why. It appears that the greatest benefits have been recorded by the earliest studies (profits were highest and cost increases were lowest) and that the benefits from cultivating biotech crops have declined since then.

### *Improved yields for insect tolerant and cost savings for herbicide tolerant biotech crops*

Overall, available empirical evidence suggests that farmers who have adopted biotech crops obtained higher yields in many cases because of more cost-effective weed control and reduced losses from insect pests, although there is significant variation by crop, trait, location and year. While yield effects of herbicide-tolerant crops are generally minor as farm level benefits are mainly on the cost side, the yield gains of Bt crops can be significant. The largest yield increases have been observed in Bt cotton, followed by Bt maize. The yield effects in herbicide-tolerant crops are, on average, moderate, as they mainly facilitate simplified crop management, particularly weed control and encourage no till.

Unsurprisingly, the yield gains reported for soybeans are smaller than those for cotton and maize, as biotech soybean varieties are mainly herbicide-resistant and the yield effect there is small. As noted earlier, the primary impact of biotech herbicide-resistant technology has been mainly to provide cost savings and easier weed control rather than improving yields. The studies also show a wide range of yield effects, which can be explained by differences in environmental (e.g. different pest pressures, seasonal variations), economic and surrounding policy conditions between countries. The introduction of an insect-resistant variety results in a larger yield gain in countries where farmers do not use insecticides to control plant pests (e.g. many developing countries) compared with countries where crop protection is commonly practiced (Bennett et al., 2013).

### *Positive impacts of employment and labour productivity are mainly evident in non-OECD countries*

Insect-resistant and herbicide-tolerant crops can reduce on-farm labour demand as they reduce the number of pesticide applications, increase flexibility and simplify crop management. According to Marra and Piggott (2006), farmers in the United States highly value the simplified weed control offered by herbicide-tolerant crops. The non-pecuniary benefits have been estimated to be about USD 10 to USD 25 per hectare. In countries with a high use of insecticides for pest control, insect-resistant crops not only reduce labour demand, but also provide labour benefits via reduced health costs.

While the effects of labour productivity will be more pronounced in non-OECD countries, such as the China and India, major employment effects are expected in the up- and down-stream sectors of OECD countries. As modern biotechnology is a key technology for the emerging bio-economy, additional employment opportunities can be expected in the bio-economy sector (OECD, 2009).

## Potential to maximise environmental benefits and to reduce risks are enhanced through sustainable pest management

### *Adoption of herbicide-tolerant crops could help improve soil and water quality*

Biotechnology can support green growth by improving the environmental performance of primary production and industrial processing and by helping repair degraded soil and water. Examples include: i) the use of bioremediation – using micro-organisms to reduce, eliminate, contain or transform into benign products the contaminants present in soil, sediments, water or air; ii) improved crop varieties that require less tillage (reducing soil erosion and compaction) or fewer pesticides and fertilisers (reducing water pollution); and iii) industrial biotechnology applications to reduce greenhouse gas emissions from chemical production (e.g. biotechnological processes to produce chemicals and plastics) (OECD, 2009).

There may also be other types of beneficial environmental impacts associated with biotech crops. Biotech crops change farming practices and contribute to savings in energy and air emissions or reductions in soil erosion relative to conventional crop equivalents, due to less frequent operations in the field. Herbicide-tolerant crops may lead to environmental benefits by letting farmers use herbicides that do need not to be incorporated with the soil, thereby encouraging a shift to no-till and conservation tillage practices, and reducing associated GHG emissions.[13]

In contrast to crops requiring conventional chemical applications, herbicide-tolerant crops may reduce wind and water sediment damages by allowing for reductions in ploughing. These techniques also facilitate the use of winter cover crops, thereby limiting nutrient leaching (e.g. nitrates). Certain biotech crops in the pipeline could also increase removal of toxic heavy metals from the soil, either by incorporating them in the cells or transforming them into less toxic substances. The scientific evidence concerning these environmental impacts of biotech crops is still emerging.

Due to higher yields, biotechnology crops might reduce pressure on land resources and diminish the need for clearing the land or for land preservation, thereby reducing pressure on natural habitats from agricultural land-use. Drought-tolerant biotech crops have become available (thereby saving water). Salinity-resistance of the soil could contribute towards the continuation of agriculture in regions affected by this phenomenon, which is primarily linked to irrigation.

The development of biotech crops that can be grown in adverse conditions (high salt, drought susceptible conditions, etc.) and utilise water and nutrients more efficiently, reduces the dependency on non-sustainable intensive high input agriculture. This is particularly important where such adverse conditions exist and where water is in short supply.

Several studies have attempted to assess the environmental impacts of first-generation biotech crops, but the complexity of ecological systems presents considerable challenges for experiments to rigorously assess the benefits and risks of these technologies. In aggregate, the conclusion from the literature is that there is no validated evidence to associate these crops with higher risks to the environment compared with conventional varieties of the same crop (EC, 2010). Studies also highlight that the nature and magnitude of impacts can vary spatially, temporally and according to the trait and cultivar modified (FAO, 2003; Wolfenbarger and Phifer, 2000).

### *Reduction in chemical use will benefit the environment*

As noted earlier, energy use is lower under biotech cropping systems compared to the conventional crop equivalents. Reduction in pesticide use associated with the production of biotech crops have been considered to have potential benefits for human health and the environment.[14] In comparison with conventional agricultural practices, cultivation of biotech crops could lead to a reduction in the use of environmentally harmful chemicals to control weeds and pests because certain pesticides are no longer used, the frequency of treatments is reduced, or the area treated is reduced. Studies have also found that, as a result of the rapid adoption of herbicide-tolerant crops, there has been a marked shift away from the more toxic herbicides towards less toxic forms (Brookes and Barfoot, 2013). Moreover, insect-resistant varieties may lead to reduced pest pressure, and this could have positive regional spin-off beneficial effects to non-adopters.

The scientific consensus appears to be that the use of transgenic insect-resistant Bt crops is reducing the volume and frequency of insecticide use on maize, cotton and soybean (see Annex 5A. These results have been especially significant for cotton in Australia, China, Mexico, South Africa and the United States.

The environmental benefits include less contamination of water supplies and less damage to non-target insects. Reduced pesticide use suggests that Bt crops could be beneficial to in-crop biodiversity in comparison with conventional crops that receive regular, broad-spectrum pesticide applications. However, as noted earlier, in some regions where biotech herbicide-tolerant crops have been widely grown, farmers have overly relied on the use of single herbicide, such as glyphosate to manage weeds and this has contributed to the development of weed resistance (Box 5.4).

While, *a priori*, a considerable reduction in the overall quantity of pesticides used could be expected, one survey conducted in the United States finds that an initial reduction in the quantity of herbicide used on a farm in the first three years following the introduction of herbicide-tolerant crops of biotech soybeans, maize and cotton, followed by a subsequent increase (Benbrook, 2012). This resulted from an increase in resistant weed species and a reduction in the price of competing herbicides. However, the amount of insecticide used decreased over the nine-year period of the survey. Changes in pesticide use depend on a number of factors, including rates of use on existing conventional crops, price relativity of pesticide products, value of the crop, climatic conditions in individual years, relative toxicity of pesticide products and build-up of resistant weed species.

### *Fertiliser use efficiency uncertain*

The contribution of first-generation biotechnology crops to improvements in nitrogen-use efficiency (NUE) is indirect via yield-improving traits (pest and/or herbicide resistance) (e.g. reduced damage to the root system of biotechnology-maize resistant to maize rootworm can lead to greater nitrogen uptake). In contrast, the adoption of herbicide-tolerant soybean crops increases the use of glyphosate, which is toxic to the nitrogen-fixing symbiont *Bradyrhizobium japonicum* – important for supplying soybeans with nitrogen. Further, concerns exist about the impacts of biotechnology crops on soil microbes and hence nutrient cycling, but empirical evidence is lacking.

The net effect of biotechnology crops on NUE is still uncertain and needs further investigation. Rosegrant et al. (2014) found that NUE in new crop varieties have strong yield impacts and reduces negative environmental impacts from fertilisation. Studies investigating the effects of biotech crops consider biotechnology to be neutral in terms of fertiliser use (see, for example, Qaim and Traxler, 2005).

### *Impacts on biodiversity can vary spatially, temporally and according to the trait and cultivar modified*

Innovations are not inherently more sustainable or biodiversity-friendly than conventional practices. The changes associated with biotech crop production practices can have positive or negative effects on biodiversity, and the overall impact can vary according to the precise management practices, environment and landscape context, and may only be noticeable after a number of years (Box 5.6).

As is the case of conventional farming systems, the main impacts of current biotech crops on biodiversity are mostly related to the changes in management practices involved, particularly changes in herbicide or insecticide use, reduced till and zero-till practices, and altered crop-rotation practices. The scale and direction of these impacts depends very much on how farmers manage biotech crops, the regulatory restrictions imposed on biotech crop management, and on how the biotech crop system is compared with conventional crop management practices.

Changes in insecticide use on biotech insect-resistant crops can be associated with benefits for biodiversity if insecticide or fungicide use decreases in frequency and toxicity, particularly if biotech crops are used with Integrated Pest Management (IPM). Changes in management of biotech herbicide-tolerant crops can influence biodiversity through: i) the change in herbicide application and timing; ii) the change in the type(s) of herbicide applied; and iii) associated changes in farming practices, including reduced or no-tillage and alterations in crop rotations or monoculture.

Scientists acknowledge that there is insufficient evidence to predict what the long-term impacts of transgenic herbicide-tolerant crops will be on weed populations and associated in-crop biodiversity. Biotech herbicide-tolerant crops change the types of herbicides used (usually glyphosate combined with a pre-emergence herbicide). The altered herbicide use associated with herbicide-tolerant biotech crops may reduce weed populations, resulting in reduced populations of weed-associated wildlife, such as seed-eating birds. But changes in herbicide use could also be beneficial for biodiversity if the frequency and toxicity of herbicide use are decreased and if weed populations continue to provide habitat and food resources for wildlife.

Biotech herbicide-tolerant crops enable greater flexibility of herbicide use and this can be implemented in a way that either increases in-field biodiversity or that significantly decreases it, depending on the timing and frequency of herbicide applications. Some evidence shows that growing biotech herbicide-tolerant crops in the United States has not resulted in decreasing the quantity of herbicide used on crops, but has produced a large-scale adoption of herbicides with a lower environmental toxicity rating than the previously used treatments, because glyphosate is a relatively quick-acting, readily degradable herbicide.[15] There is concern, however, that greater use of herbicides – even less toxic ones – will further erode habitats for farmland birds and other species.

As mentioned earlier, biotech herbicide-tolerant crops facilitate the greater uptake of reduced tillage or zero-till farming systems, which are beneficial to biodiversity. However, a lack of weed resistance management could result in the proliferation of herbicide-resistance weeds.[16]

Biotech herbicide-tolerant crops systems have led to a greater use of monocultures and the corresponding reduction in crop rotations, with adverse impacts on farmland biodiversity. This has given rise to concerns that the expansion of biotech herbicide-tolerant crops has contributed to a reduction in biodiversity, particularly in Latin America. However, while the expansion of agriculture may have reduced biodiversity, to link this expansion with biotechnology is questionable, as the agricultural expansion may have happened with or without the technology and increased productivity through biotech crops may have reduced the amount of land needed for the same amount of product. For instance, the expansion of soybean production has largely been driven by the increase in demand for protein feeds (Backus et al., 2009). Soybean traders, together with other stakeholders, have organised a

Soybean Moratorium, which has been in place since 2006, under which is undertaken not to "purchase soy from lands that have been deforested in the Amazon biome from this date." (Cargill, 2014)

**Box 5.6. Possible impacts of biotech crops on biodiversity: What does the scientific evidence show?**

*Risks or benefits with a measureable impact on a biodiversity assessment endpoint*

- Impacts of changed management of biotech herbicide-tolerant crops
- Biotech Bt crops have few direct impacts on natural biological control
- Biotech Bt maize affects soil processes compared to conventional maize, but to no greater degree than between crop types, tillage and pesticide use systems
- Biotech Bt crops may have some effect on non-target Lepidoptera, but have not been found to have significant effects on bees or other non-target organisms

*Risks or benefits that are likely to occur, but have not been associated with a clear negative effect on a biodiversity assessment endpoint*

- Impacts of changed management of biotech insect-resistant Bt crops
- Risk management specifications for biotech insect-resistant crops are mandatory, but not for herbicide-tolerant crops
- Gene flow occurs, but it is often difficult to clarify or achieve consensus on the actual harm to biodiversity
- Secondary pest problems occur on biotech Bt crops, but the biodiversity consequences are not clear

*GM cropping is associated with indirect land-use change, but the biodiversity implications are disputed*

*Risks to biodiversity extrapolated from small-scale test results*

- There is evidence from small-scale tests of non-target impacts of protease inhibitor genes

*Risks demonstrated in experiments but very difficult to prove in the field*

- Horizontal gene transfer has been demonstrated in experiments but is very difficult to detect in the field

*Source*: Underwood, E. (2013), "The kinds of possible impacts of GM crops on biodiversity and current evidence on impacts", Annex to Chapter 6(b) in Underwood, et al. (2013), *Technology options for feeding 10 billion people. Climate change and agriculture; biodiversity and agriculture*..

### *Other environmental and economic concerns*

Despite the rapid adoption of biotech crops by farmers in many countries, controversies about this technology continue. Concerns about economic and environmental impacts of biotech crop are one reason for widespread public suspicion.

#### Economic concerns

While the production of biotech crops may give rise to certain direct economic return in the form of increased yield, improved quality due to control of pests or reduced input costs, concern has been expressed that any such economic return will be more than offset by a reduction in market value of the produce of biotech crops. In addition, concern has been expressed that the cultivation biotech crops in a region may lead to a reduction in the value and competitiveness of conventional and organic crop produce from that region. The ability of non-biotech crop growers from a biotech crop-growing region to market their produce may also be diminished due to a reduction in the number of market outlets available. In addition, there may be possible implications for the following crops in the rotation. The economic loss is potentially greater for higher value crops such as organic produce and the loss may extend to following crops over a period of time. Such issues relating to economic loss necessitate the requirement to determine liability, assess the level of loss incurred and establish possible measures to redress such loss.

The possibility that biotech farms could contaminate non-GM farms via unintentional, inadvertent gene flow constitutes a challenge for the coexistence of biotech farming and non-GM agriculture, including in particular organic certified agricultural systems. Organic farmers are not allowed to use seed or plants with any transgenic content. For example, the EU Regulation for organic farming (EC No. 2092/91) forbids the use of living modified organisms (LMOs).

Organic farmers are not allowed to use seed or plants with any transgenic content. In July 2003, the European Commission published guidelines for the development of strategies and best practices to ensure the co-existence of LMO crops with conventional and organic farming, with the intention of helping EU member states to develop workable measures for co-existence in conformity with EU legislation. The guidelines set out the general principles and the technical and procedural aspects to be taken into account: approaches to co-existence should be developed in a transparent way, based on scientific evidence and in co-operation with all concerned; and measures should be specific to different types of crop and regional and local aspects should be fully taken into account.

The way contracts for the use of biotech crops were drafted – with concerns that contracts were too binding for farmers – also raised much controversy. Biotechnology has led to increased concentration on the seeds sector and farmers are becoming increasingly dependent on a limited number of suppliers. In addition, farmers who adopt biotechnology are confronted with several constraints: biotech seeds are often sold with contracts which generally preclude seed-saving by farmers; biotech firms have developed technologies that render biotech crops sterile in order to protect the research-value of biotech seeds and to limit gene flow into the environment; and biotech companies often charge a "technological fee", which has to be taken into consideration with property and patenting rights. The technological fee and the restriction on seed-saving imply increased seed costs, and oblige farmers to comply with the requirements of the biotechnology firms.

Another issue is that the "first generation" of genetically engineered products has focussed on agronomic traits which have not been perceived as delivering significant benefits to consumers compared to conventional varieties. But the modification of agronomic traits is only the beginning of the contribution of genetic engineering in modifying the food chain. The envisioned benefits of output trait biotech crops could bring substantial benefits to consumers in both developed and developing countries. The choice of which innovations will go forward is likely to be determined in part by the private sector's expected profitability estimates and the legal framework, which permits countries to appropriate the return to their research. Intellectual Property Rights or patent rights allow the patent holder to exclude all others from making, using, offering for sale, selling or importing the claimed invention for a limited time period (20 years).

### Environmental concerns

Environmental concerns centre around the possible effects – direct or indirect – of biotech crops on non-target organisms and on the transfer of biotechnology traits to populations of wild plants (FAO, 2003). The potential transfer of herbicide-resistant and insect-resistant traits to weedy species and the persistence of feral crop plants carrying these traits raise issues about possible impacts on the environment. Other concerns relate to whether biotech crops will give rise to the development of resistance in pests and diseases, which would then prove difficult to control, using conventional methods. The question has also been raised as to whether biotech plants will be poisonous to non-target species including herbivores, pollinators, soil-inhabiting organisms and biological predators. Finally, it is important to bear in mind that modern plant breeding has the potential to produce biologically novel crops and cropping systems without the use of transgenesis.

## Moving forward: Policy priorities to boost the beneficial impacts of modern agricultural biotechnology

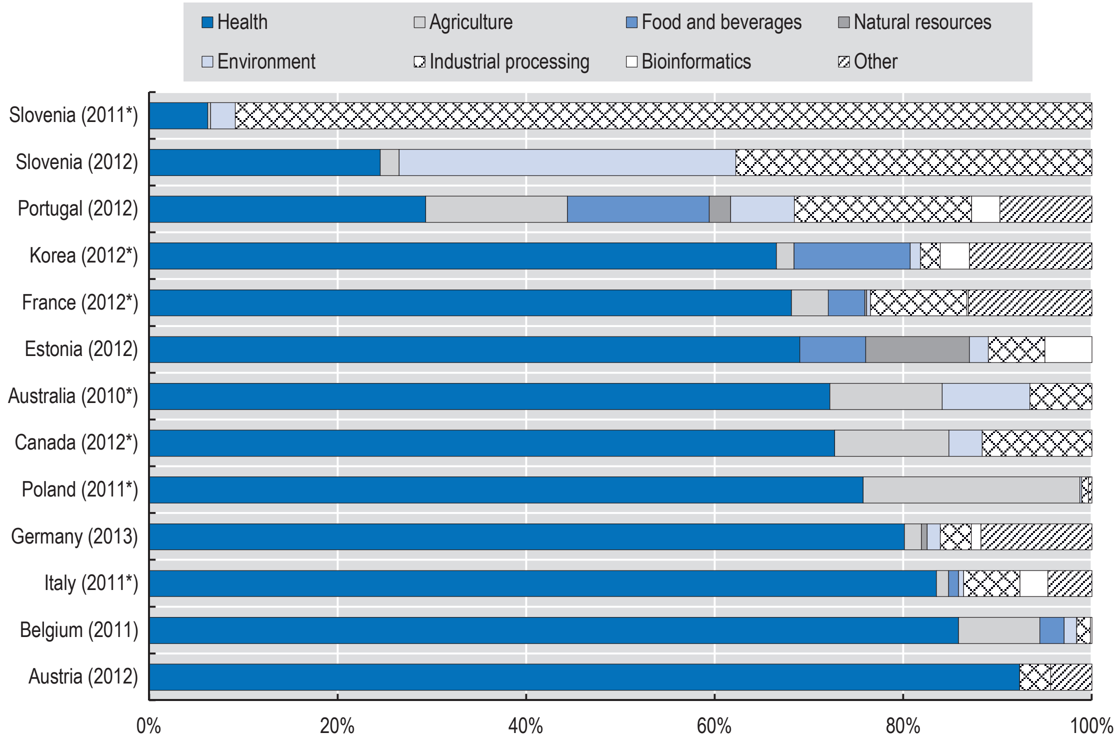
### *Public R&D investment an important factor in enhancing availability and accessibility of new biotechnologies*

If modern agricultural biotechnology is to be perceived and used as one of the solutions for fostering green growth in agriculture, policy will have to play a significant role, in investing in research, establishing the regulatory frameworks necessary to ensure that biotech applications meet acceptable bio-safety and environmental standards and in increasing public awareness of the potential benefits (as well as risks) (OECD, 2009).

Despite growing awareness of the importance of innovation for increasing agricultural productivity sustainably, and even though government funding for R&D is permitted under international trade agreements, public spending on agricultural R&D accounts for only a small share of total support to agriculture – around 2% in the OECD area.

OECD data on business enterprise expenditures on R&D (BERD) for biotechnology provide a direct measure of research effort. According to OECD data, the United States devotes almost 10% of total US BERD to biotechnology and accounts for about 66% of total biotechnology BERD expenditures in the 28 countries for which data are available. On average, biotechnology accounted for 5.9% of total BERD in the countries with data available in 2011. However, the share of BERD on biotechnology for agriculture is rather small for all these countries (Figure 5.1).

**Figure 5.1. Percentage of biotechnology R&D by application, latest available year**



*Notes.* Results are limited to dedicated biotechnology firms, except for biotechnology R&D firms for Australia, Estonia, Italy and Slovenia, and biotechnology firms for Korea. Australia: reported results are for agricultural biotechnology; environmental biotechnology; industrial biotechnology and medical biotechnology. Canada: reported results are for agricultural biotechnology; environmental biotechnology; industrial biotechnology and medical biotechnology. France: data, which are provisional, reflect firms' activity related to research, rather than their principal activity. Italy: results are by primary application. Korea: "Agriculture" includes "Natural resources". Poland: results are by primary application. "Industrial processing" includes "Food and beverages". Slovenia: "Industrial biotechnology" instead of "Industrial processing".

*Source*: OECD, *Key Biotechnology Indicators*, http://oe.cd/kbi, October 2014.

Public-sector investment on R&D has contributed to the basic science underpinning agricultural biotechnology. But in contrast to the green revolution – which was driven by the public sector – most applied research in agricultural biotechnology and almost all commercial development are performed by the private sector. Biotechnologies are controlled mainly by a small group of multinational companies and the cost of obtaining material transfer agreements and licenses could slow public R&D. Establishing and maintaining national agricultural research capacity is therefore a critical determinant factor of the availability and accessibility of new biotechnologies which are suitable to the particular agro-ecological environment.

Modern agricultural biotechnology is cross-sectoral and interdisciplinary. Genetic engineering in crops, for example, cannot proceed without knowledge derived from genomics and is of little practical use in the absence of an effective plant-breeding programme. Agricultural biotechnology should therefore be part of a wider agricultural knowledge and innovation strategy that brings about interactions between multiple stakeholders.

### *Assuring safety at reasonable cost indispensable for the development of modern agricultural biotechnology over time*

All OECD member countries, as well as many non-members, have a system for performing environmental assessments of genetically engineered plants used in the production of foods and feeds. In the majority of countries, these systems have been in place for a number of years. National approaches to biosafety have been enhanced by successful multilateral activities aimed at developing a common approach to both the principles and practice of risk/safety assessment. Much of this common understanding was developed through work at the OECD, where biosafety projects, addressing, *inter alia*, transgenic crops, have been in place since approximately.

The main objectives of the OECD work on biosafety, which dates back to 1986, are to: promote harmonisation in the sharing of information and risk assessment practices; assist countries in ensuring a high standard of safety; aid in the mutual understanding of the regulatory systems among countries; and avoid non-tariff barriers to trade. There are two aspects to the OECD’s work on biosafety. First, the OECD’s Working Group on the Harmonisation of Regulatory Oversight in Biotechnology primarily addresses the environmental risk/safety assessment of transgenic organisms. Second, the Task Force for the Safety of Novel Foods and Feeds specialises mainly in the safety assessment of foods and feed derived from transgenic organisms.

The main outputs related to environmental risk/safety assessment include the series of ‘biosafety consensus documents’ which compile information regarded as relevant by countries to risk and safety assessment (e.g. the use of the crop or trait in agricultural practice; its taxonomy; characteristics of its reproductive system; knowledge of its wild relatives including those with which it can hybridise; its centre of origin and diversity; and its weediness).

A separate but complementary series of documents has also been published, which address the safety assessment of novel foods and feeds, especially those derived from transgenic varieties. Once again, they are intended for use in regulatory safety assessment.

It is important to note another significant multilateral effort, the Cartagena Protocol on Biosafety, which is a key international instrument dealing with “living modified organisms” (LMOs) in transboundary movements. The objective of this Protocol is to contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of LMOs resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity. The Protocol has established an advance informed agreement (AIA) procedure to ensure that countries are provided with the information necessary to make informed decisions before agreeing to the import of such organisms into their territory. The Protocol has also established a Biosafety Clearing-House (BCH) to facilitate the exchange of information on, *inter alia,* LMOs used for Foods Feeds or Processing. The BCH also assists countries in the implementation of the Protocol.

### Box 5.7. The Gene Technology Act in Australia

The development and use of GMOs in Australia is regulated through an integrated legislative framework which includes the Gene Technology Regulator and a number of other regulatory authorities, with complementary responsibilities and expertise. This arrangement both enhances co-ordinated decision-making and avoids duplication.

The Gene Technology Act 2000 and the Gene Technology Regulator 2001, which administers the Act, in conjunction with corresponding State and Territory legislation, underpin the framework. Implementation of the framework is overseen by the Gene Technology Ministerial Council, which comprises representation from all Australian jurisdictions. Its object is to protect human health and safety, and to protect the environment, by identifying risks posed by, or resulting from, gene technology, and by managing those risks.

Transparency is built into the regulatory system through requirements in the gene technology legislation for the Regulator to: maintain a publicly accessible record of GMO and GM product dealings; provide quarterly and annual reports to the Australian parliament; and conduct extensive consultation with the public and a wide range of experts, agencies and authorities on applications for dealings involving the intentional release of GMOs into the environment.

The inter-governmental Gene Technology Agreement 2001 (GTA) sets out the understanding between Commonwealth, State and Territory Governments regarding the establishment of a nationally consistent regulatory system for gene technology. The GTA requires an independent review of the Act every five years. The first review was completed in 2006. The 2006 review found that the Act and the national regulatory scheme had worked well over the previous five years (2000-05), and that no major changes were required. The review panel recommended a number of changes intended to improve the operation of the Act. In particular, the 2006 review recommended that the Act be reviewed in five years (2011) to ensure that it continues to accommodate emerging trends. The 2011 review was limited to issues within the scope of the object of the Act (i.e. health and safety of people and the environment). The review also considered the findings from the 2006 review.

*Source*. Office of the Gene Technology Regulator, www.ogtr.gov.au/internet/ogtr/publishing.nsf/Content/home-1; Australian Government, Department of Health, www.health.gov.au/internet/main/publishing.nsf/Content/gene-techact-review

### *Governments need to listen to public concerns and inform them of the risks*

Confidence in the decisions that governments make on behalf of the public is a precondition for public acceptance and adoption of agricultural biotechnology products. A well-defined biosafety regulatory system is a prerequisite for realising the benefits that modern agricultural biotechnology can provide to foster green growth, as weak regulatory systems could fuel public distrust and trigger opposition to modern agricultural biotechnology.

In addition to assessments based on scientific evidence, public perception of risk is also important in ensuring acceptance. There are distinct national and regional differences to acceptability of modern agricultural biotechnology. Continuing concerns about possible food safety and environmental risks have slowed or even stalled commercialisation in many countries. Public attitudes to biotechnology, including consumers' perceptions on the "naturalness" of biotech foods will play an important role in determining how widely genetic engineering techniques will be adopted in food and agriculture (Van Haperen, 2012; Van den Heuvel et al., 2008).

As noted earlier, genetically engineered technologies have been mainly applied to four crops: soybean, cotton, maize and oilseed rape. Genetically engineered sugar beet, alfalfa and potato are additional crops gaining in importance. Innovations are also expected for wheat, barley, rice and many other species (Stein and Rodriguez-Cerezo, 2009). The main application of biotechnology for crops has been for animal feed crops and for crops used in food processing; neither of which produce agricultural products for direct human consumption.

New value-enhanced traits (second generation) are likely to be developed among field crops. However, to succeed these products should not only be able to deliver improved quality, but also good agronomic performance. In contrast with the first generation genetically engineered crops where farmers expected a direct benefit on their use of pesticides and herbicides (in order to minimise their input costs), the adoption rate of the new generation may proceed more slowly. In addition, some of the value enhanced genetically engineered crops might be limited to niche markets (EC, 2001).

One of the stumbling blocks to the commercialisation of biotech crops has been the reluctance of the downstream sector such as millers, brewers, soft drink companies, and fast food chains to use GMOs (Gruère and Sengupta, 2009; Venus et al., 2012). This has recently changed in the United States and Canada for potato (e.g. Johnson, 2014), sugar beet (Dillen et al., 2012), and wheat (e.g. Arnason, 2013). Overall, this adoption difficulty can be traced back to consumer concern about food products derived from biotech crops.

Overall, products based on biotech crops have been successful in those parts of the world where the technology is accepted. Restrictive regulatory systems have arisen, also as a result of negative public perceptions that have little to do with scientific evidence and objective risk assessments (Miller, 2007). Greater consumer acceptance of this technology is a necessary precursor to regulatory reform.

Consumer acceptance of foods with biotech ingredients varies with product characteristics, geography, and the information that the public is exposed to. Most studies in OECD countries find that consumers are willing to pay a premium for foods that do not contain biotech ingredients: willingness-to-pay for non-biotech foods is highest in the European Union, where some retailers have policies limiting the use of biotech ingredients. Non-biotech foods are available in the United States, but there is evidence that such foods represent a small share of retail food markets.

Social factors play a key role in the debate of biotech crops. Some farmers may reject biotech crops for ethical, cultural and other reasons (although available empirical studies about adoption or rejection do not indicate that ethical reasons are an important factor among farmers). One important factor that has been identified for the European Union is the view of neighbours, friends, and local communities. Some farmers who were considering cultivating biotech crops observed their families being threatened (Venus et al., 2012), while others reported social pressure from organic farmers (Binimelis, 2008).

### *Notes*

1. For more information on OECD's work on biotechnology, see the OECD biotechnology at: www.oecd.org/sti/biotech/.
2. For this reason, the OECD recommends that it should always be accompanied by a list-based definition based on seven categories that serves as an interpretative guideline. The categories are: DNA/RNA, Proteins and other molecules, Cell and tissue culture and engineering, Process biotechnology techniques, Gene and RNA vectors, Bioinformatics and Nanobiotechnology. In addition, respondents are usually given write-in option for new biotechnologies that do not fit any of the categories. A firm that reports activity in one or more of the categories is defined as a biotechnology firm.
3. The Convention on Biological Diversity (CBD) defines biotechnology as: “any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" (Secretariat of the Convention on Biological Diversity, 1992). This definition includes medical and industrial applications as well as many of the tools and techniques that are commonplace in agriculture and food production. The Cartagena Protocol on Biosafety defines “modern biotechnology” more narrowly as the application of: (a) In vitro nucleic acid techniques, including recombinant deoxyribonucleic acid (DNA) and direct injection of nucleic acid into cells or organelles, or (b) Fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers and that are not techniques used in traditional breeding and selection (Secretariat of the Convention on Biological Diversity, 2000).

4. For example, micro-organisms have been used for decades as living factories for the production of life-saving antibiotics including penicillin, from the fungus *Penicillium*, and streptomycin from the bacterium *Streptomyces*. Modern detergents rely on enzymes produced via biotechnology, hard cheese production largely relies on rennet produced by biotech yeast and human insulin for diabetics is now produced using biotechnology.

5. Different countries have different preferences for terms which describe products of modern biotechnology. This document uses the term "transgenic crops" or "transgenic organisms". For the purposes of this text, the term transgenic organisms is equivalent to the terms "genetically modified organisms" (GMOs), "genetically engineered organisms " or "living modified organisms (LMOs)". For convenience, applications of these terms for crops are referred to as biotech crops.

6. Data on GE events are also available in the OECD Biotrack Product Database, regularly updated on a voluntary basis by national authorities, see www2.oecd.org/biotech/.

7. Among the biotech crop events, the herbicide-tolerant soybean event GTS-40-3-2 has the most number of approvals, followed by the herbicide-tolerant maize event NK603, insect resistance maise MON810 and insect resistant maize Bt11 (James, 2015).

8. The Amflora potato, which was authorised in 2010 for cultivation and industrial processing, is no longer cultivated since 2011.

9. Early adopters of any agricultural technology tend to benefit more than later adopters because they achieve a cost advantage over other farmers, earning a premium for their innovation. As more farmers adopt the technology, the cost reduction eventually translates into a price decline for the product that means, while consumers continue to benefit, the gains to farmers decline.

10. This is the case of certain animal products labelled as free from GM in Europe, and a large number of GM free products from the United States. However, multiple countries produce GM and non-GM so there is an economic benefit trade-off. Some large farms in North America do both, depending on price expectations.

11. Smallholder farmers, for example, may be entrepreneurial in spirit but they often lack the security to take risks and in order to create and maintain a favourable environment for entrepreneurship a range of barriers outside the control of the farmer must be addressed, such as poor or absent infrastructure, unsupportive laws and regulations, lack of investment capital, social barriers, lack of training facilities for farmers, support services and extension staff and constrained access to markets (poor communications, marketing facilities, lack of reliable and timely market information) (Kahan, 2012).

12. A systematic review (also systematic literature review or structured literature review) is a literature review focused on a research question that tries to identify, appraise, select and synthesize all high quality research evidence relevant to that question. It is an approach which synthesises and critically appraises the evidence.

13. The two most common herbicides are Roundup Ready, with the effective chemical glyphosate and BASTA, with the effective chemical glufosinate (Wolfenbarger and Phifer, 2000).

14. See for example, Royal Society, 1998; Ervin, et al., 2000; Fernandez-Cornejo and McBride, 2002; Wolfenbarger and Phifer, 2000; Kleter and Kuiper, 2005.

15. However, there is also recent evidence that suggests that glyphosate may actually have a higher environmental toxicity than previously considered and that its environmental risk rating should be revised (FoEE, 2013; Helander et al., 2012).

16. Risk management specifications are mandatory for biotech insect-resistant crops, but not for herbicide-tolerant crops. As a result, rigorous resistance management measures and monitoring have been required for insect-resistant biotech crops (particularly Bt maize and Bt cotton) since the

first approvals. In contrast, the evolution of herbicide-resistant weeds is now posing problems for biotech herbicide-resistant crops in the United States, Argentina, Paraguay and Brazil. The consequences for biodiversity derive from the increased use of herbicides to control resistant weeds that are more toxic and/or more persistent in the environment than glyphosate, such as 2,4-D or dicamba, and/or increases in glyphosate applications (Brookes and Barfoot, 2013).

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## Annex 5.A

## Types of transgenic traits in commercial cultivation

Currently, there are three main types of traits used in commercial cultivation: herbicide tolerance; insect resistance; and virus resistance. Insect resistant transgenic crops are used as a way of controlling specific pests. Insect resistant crops have been developed by integrating genes derived from various strains of a bacterium Bacillus thuringiensis (Bt), which produces toxins that kill certain insect pests, for example, the European maize borer and the South-western maize borer. Insect resistance genes have been introduced in maize and cotton.

For herbicide-tolerant traits, the insertion of a herbicide tolerance (HT) gene into a plant enables farmers to spray wide-spectrum herbicides on their fields to control weeds without harming the crop. Herbicide-tolerant crops include soybean, maize, rapeseed, cotton, sugar beets and alfalfa. Virus resistance genes have been introduced in tobacco, potatoes, papaya and squash. Transgenic crops, which involve two or more traits (e.g. stacked events), have also been developed. The most common stacked events at present are combinations of HT and insect resistance (e.g. Bt).

In addition to this relatively small number of biotech crops which have been commercialised so far, it is important to note that there is an impressive range of crops and traits in R&D, many of which have already been in field trials. Many of these are likely to be commercialised in the near future. It takes around a decade for a new transgenic crop variety to be developed from the field trial stage to commercialization.[1] New genetically modified traits include improved plant nutrient use, altered crop metabolism for industrial products, abiotic stress tolerance including, freezing-tolerance and salinity-tolerance, disease resistance traits; nitrogen use efficiency, and bioremediation capacity. In particular, crops in the pipeline include soybeans with improved animal nutritional qualities through increase protein and amino acid content; crops with modified oils, fats and starches to improve processing and digestibility, such as high stearate canola, and low phytate or low phytic acid maize. The OECD's Product Database (www2.oecd.org/biotech/ ) contains information on most transgenic crops which have been approved for commercial use (planting, and/or food and feed use) in OECD countries.

### *Empirical evidence of the effects of biotech crops*

#### *Economic effects*

A study by Klumper and Qaim (2014) performed a meta-analysis approach – on 147 published biotech crop studies conducted during 1995-2014 worldwide – in order to evaluate the impacts of biotech crops (soybean, maize or cotton) on yields, pesticide use, and farmer profits. The study found that, on average, GM technology has reduced chemical pesticide use by 37%; increased crop yields by 22%; and increased farmer profits by 68%. Impacts vary, especially by modified crop trait and geographic region. Yield gains and pesticide reductions are larger for insect resistant crops than for herbicide-tolerant crops. Yield and farmer profit gains are higher in developing countries than in developed countries.

Hall et al. (2013) performed *a systematic literature review approach* to review and analyse the available literature published between 2006-10 on the costs and profits of genetically modified (GM) crops in agriculture in comparison with conventional agriculture. One of the key findings from the

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[1] Actual commercialisation depends on the time for and outcome of the biosafety regulatory approval.

review is that, in every case, planting GM crops as opposed to a non-GM equivalent, resulted in a farm-level economic impact. This was particularly notable for certain economic variables, namely gross profit and seed costs, but less significant for other economic variables such as price and energy costs. In some cases the economic impact was positive for farmers and in other cases it was negative. Generally, the change in gross profit, revenue and net profit was positive, while the change in seed costs, labour costs and total variable costs was negative. As price was generally not differentiated, the profit and revenue increases are probably largely due to increased yield (decreased losses). Economic impact was shown to vary by crop/trait combination, indicating that treating "GM crops" as one homogenous technology is an unhelpful approach, and that the impact of each crop/trait combination should be examined individually. Economic impact was also shown to vary by development status of the country, suggesting that the baseline state of agricultural production at the time of commercialisation is a key factor influencing economic impact. The change in farm level profit was least positive in the most developed countries, where net profits were 66% higher for GM crops, while seed costs were 97% and total variable costs 23% higher for GM crops.

Qaim (2009) found that on average (when reviewing 19 studies) the gross margin gains were higher for Bt cotton than Bt maize, suggesting that farm-level economic impacts from cultivating GM cotton were likely to be more positive for farmers than cultivating GM maize. Important productivity gains are also reported by Brookes and Barfoot (2013), while Barrows, Sexton and Zilberman (2015) estimate the land use savings of GM cotton, maize and soybean at about 13 million hectares over the period 2000-10.

Carpenter (2010), when reviewing 49 previous studies, found evidence of a negative economic impact, resulting from cultivation of GM cotton in a range of countries, including Australia, China, Colombia, India and South Africa. Similarly, Wang et al. (2008) found that those farmers who had planted Bt cotton in certain Chinese villages made less money than the farmers who planted conventional cotton.

The collective study of INRA/CNRS experts (Beckert, et al. 2011), reaches a more cautious conclusion, pointing out that although yields of GMO herbicide resistant crops could be increased in the early years of adoption, they could be decreased after five years. This is partly due to the emergence of resistance as farmers are obliged to use more toxic herbicides and pay higher prices for seeds than for conventional seeds. For Bt crops, the yield does not increase. The Union of Concerned Scientists (2009) study concludes that the overall impact of genetically engineered crops on yields is modest, with no yield increase for herbicide-tolerant soybeans (the most widely planted biotech crop).

Review studies of farm-level impacts have noted considerable variation in both the nature and scale of impact. For example, the scale of increase in gross margins from cultivating Bt and Ht crops has been found to vary enormously between countries, from USD 12 per ha in the United States (for maize) to USD 470 per ha in China (for cotton) (Qaim, 2009). Further inter-country variability has been demonstrated for GM cotton, with a 12% increase in profits recorded in Mexico, and a 340% increase in profit recorded in China (Pehu and Ragasa, 2007). Large variability from year to year and region to region has also been noted by some studies. The more heterogeneous the growing environment, pest pressures, farmer practices and social context, the more variable are any benefits likely to be.

The National Center for Food and Agricultural Policy, which estimated the impacts of nine transgenic crops in the EU, found that, collectively, these nine transgenic crops have the potential to increase yields by 8.5 million tonnes per year, increase grower net income by USD 1.6 billion per year and reduce pesticide use by 0.014 million tonnes per year. Transgenic tomatoes would offer the greatest yield and grower income increase, while herbicide-tolerant maize would result in the largest reduction in pesticide use. The largest increase in yields is estimated for transgenic sugarbeet, whereas for glyphosate tolerant maize, wheat and rice yields would remain unchanged (Gianessi, Sankula and Reigner, 2003).

Traxler (2004) found that yields of glyphosate-tolerant soybeans are not significantly different from yields of conventional soybeans in either the United States or Argentina. A study by USDA

(1999a) reports that while glyphosate-tolerant soybeans appear to have low yields, in some US Midwest regions, farmers planting Bt maize produced yields that were 26% higher than conventional, non-modified crops. Brookes et al. (2003) found that the effect of Bt insect-resistant maize yield in Spain varies depending, inter alia, on location, climatic factors, timing of planting and on whether insecticides are used, with a country average yield benefit of 6.3%. In Australia, the yield advantage offered by GM rapeseed over non-GM varieties is estimated to be 12.7% (Foster, 2003), while in Canada it is estimated at 10% (Serecon et al., 2001).

In the United States, it was estimated that through the use of biotechnology-enabled control of maize rootworm, 10 million acres of farmland produced USD 231 million in additional annual revenue from crop yield gains, reduced insecticide use by 5.5 million pounds annually, and eliminated 5.5 million gallons of water annually from the farming process (NCRC, 2010). The report also notes that yield gains from herbicide tolerant and insect resistance maize were higher in places where pest pressure is high and the pest/weed control methods prior to adoption had a relatively low efficiency. *Environmental effects*

Knox et al. (2012) carried out *a systematic literature approach* to analyse the available literature published between 2006-10 on the environmental impacts of commercial biotech crops. The database analysis undertaken indicated that adoption of biotech crops caused a significant increase in the ratio of environmental change with biotech crops as compared to conventional farming. However, due to the limitations and diversity of the environmental indicators extracted from the articles, it cannot be ascertained whether this shift represents a beneficial or detrimental environmental change.

Brookes and Barfoot (2013), applying the Environmental Impact Quotient (EIQ) indicator – which includes the impact of pesticides on the environment, farm workers and consumers – to biotech crops, found that biotech traits have contributed to a significant reduction in the environmental impacts associated with insecticide and herbicide use on the areas devoted to biotech crops: the use of pesticides on the biotech crop area was reduced, on average, by 8.9% and the EIQ by 18.3% over the 1996-2011 period. In absolute terms, the largest decline in pesticide use was associated with biotech herbicide-tolerant maize, followed by biotech-insect resistant cotton, while the largest environmental impact has been associated with the adoption of biotech insect resistant maize, followed by biotech insect resistant cotton and biotech herbicide-tolerant canola. Overall, the environmental impacts associated with herbicide use were larger than the decline in their absolute volumes, suggesting a switch to more environmentally benign herbicides from those generally used on conventional crops. Applying the EIQ to herbicide-tolerant soybean varieties indicates an overall positive environmental impact compared with non-herbicide tolerant soybean varieties. The study also estimated that biotech crops have led to reduction in GHG emissions of 14.6 million tonnes of carbon dioxide over the 1996-2011 period, arising from reduced tractor fuel use and additional soil carbon sequestration.

Kleter et al. (2007) calculated that for pesticide applications on conventional versus biotech rapeseeds in the United States, applications of pesticide active ingredients, total ecological impact per hectare, ecological impact, and farmer impact were 30, 42, 39, and 54% lower, respectively.

Gusta et al. (2011) and Smyth et al. (2011a, 2011b) show that the adoption of herbicide-torelant canola has changed weed control practices in Canada, where shifts from soil-incorporated- to foliar-applied post-emergent herbicides have taken place. As a result, the environmental impact of canola production – based on a modified EIQ – dropped by 59% between 1995 and 2006.

Studies published so far on the effects of transgenic plants on agricultural biodiversity indicate that there is a lack of consensus of the consequences of gene flow and conclude that more data and new models are needed to analyse the possible long-term unexpected effects of transgenes (Ervin and Welsh, 2005).

The US National Research Council has concluded that GM crops in the United States have brought environmental benefits but “excessive reliance on a single technology combined with a lack of diverse farming practices could undermine the economic and environmental gains” (NRC, 2010).

Wolfenbarger et al. (2008) conducted a meta-analysis on the effects of Bt crops on functional guilds of non-target arthropods. They could not find uniform negative or positive effects when comparing Bt crops with their non-GM counterparts, treated without any additional insecticides. Some species-specific effects have been identified, but when the non-GM counterpart has been controlled with insecticides, Bt crops exhibited a higher abundance of non-target arthropods. The effect of Bt-maize pollen on non-target Lepidopetera in Europe has been estimated to be extremely low.

Perry et al. (2010) calculated mortality rates in the worst-case scenario of less than one individual per 1 572 (one per 5 000 at the median) for butterflies and less than one individual per 392 (one per 4 366 at the median) for moths. Comparing this with alternative cultivation practices, they conclude that no negative environmental impacts of Cry1Ab expressing Bt corn have so far been reported. Álvarez-Alfageme et al. (2011) point out previous results showing the toxic effect of Cry1Ab and Cry3Bb on ladybirds feeding on maize; these were not replicable.

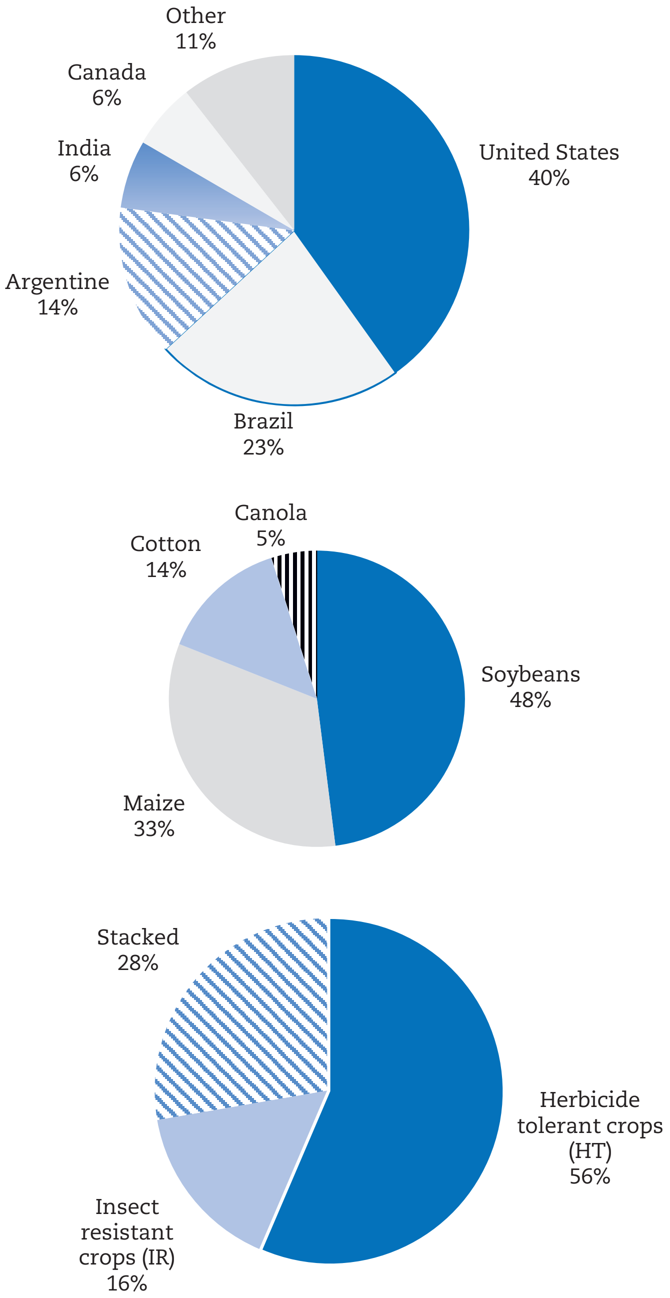
The Farm-Scale Evaluation study initiated by the government of the United Kingdom compared biodiversity in fields of glyphosate-tolerant sugarbeet, maize and rapeseed with that in comparable plots of equivalent non-transgenic varieties in adjoining fields (DEFRA, 2003). The findings showed that there were differences in the abundance of wildlife between genetically modified herbicide-tolerant crop fields and conventional crop fields. However, the study stressed that the differences found arose not because the crops had been genetically modified, but because the GM herbicide-tolerant crops gave farmers new options for weed control. The differences on which herbicides were used and how they were applied.

The Royal Society has published the results of extensive farm-scale evaluations of the impacts of transgenic herbicide-tolerant maize, spring oilseed rape (canola) and sugarbeet on biodiversity in the United Kingdom. These studies found that the main effect of these crops compared with conventional cropping practices was on weed vegetation, with consequent effects on the herbivores, pollinators and other populations that feed on it. These groups were negatively affected in the case of transgenic herbicide-tolerant sugarbeet, positively affected in the case of maize and showed no effects on spring oilseed rape. The studies concluded that commercialisation of these crops would have a range of impacts on farmland biodiversity, depending on the relative efficacy of transgenic and conventional herbicide regimes and the degree of buffering provided by surrounding fields.

In the United Kingdom, a large-farm scale evaluation of four biotech herbicide-tolerant cropping systems concluded that GMO herbicide-tolerant rapeseed and sugar beet (but not biotech herbicide-tolerant maize) reduced the abundance of weeds and associated wildlife compared to the conventional management at that time (Brooks et al., 2003; Brooks et al., 2005; Firbank et al., 2006; Haughton et al., 2003; Hawes et al., 2003; Heard et al., 2003). The negative effect on weeds was considered sufficiently important to conclude that, on balance, the biotech herbicide-tolerant crops would reduce biodiversity (UK ACRE, 2004a; 2004b; 2005). In contrast, research in the United States, Canada and South America has come to the opposite conclusion (i.e. that biotech herbicide-tolerant crops have increased weed diversity) (Gulden et al., 2009; Gulden et al., 2010; Puricelli and Tuesca, 2005; Scursoni et al., 2006; Young et al., 2013). The authors conclude that this is because glyphosate has allowed more broad-leaved weeds to survive and causes greater species richness and evenness than the conventional weed control used in comparable US farming systems.

There is also evidence to suggest that changes in pesticide use rates have been variable (van den Bergh and Holley, 2001). For example, USDA studies found that, in the aggregate, as more farmers adopted transgenic crops, insecticidal treatments have been reduced on maize, whereas the use of glyphosate, such as Roundup ®, on maize and soybeans has increased (USDA, 1999a and 1999b). However, the use of more toxic chemicals has decreased. The situation varies by production method and by region.

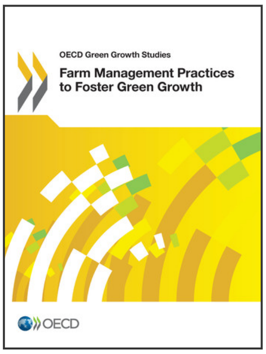
**Figure A5.1. Global area of biotech crops, by country, crop and trait, 2014** (%)



*Source*: James (2015), *Global status of commercialized biotech/GM crops: 2014*, ISAA Brief 49-2015.

**Table 5A.1. Global area of biotech crops in 2014, by country**

| Rank | Country | Area (million hectares) | Biotech crops |
|---|---|---|---|
| 1 | United States | 73.1 | Maize, soybean, cotton, canola, sugarbeet, alfalfa, papaya, squash |
| 2 | Brazil | 42.2 | Soybean, maize, cotton |
| 3 | Argentina | 24.3 | Soybean, maize, cotton |
| 4 | India | 11.6 | Cotton |
| 5 | Canada | 11.6 | Canola, maize, soybean, sugar beet |
| 6 | China | 3.9 | Cotton, papaya, poplar, tomato, sweet pepper |
| 7 | Paraguay | 3.9 | Soybean, maize, cotton |
| 8 | Pakistan | 2.9 | Cotton |
| 9 | South Africa | 2.7 | Maize, soybean, cotton |
| 10 | Uruguay | 1.6 | Soybean, maize |
| 11 | Bolivia | 1 | Soybean |
| 12 | Philippines | 0.8 | Maize |
| 13 | Australia | 0.5 | Cotton, canola |
| 14 | Burkina Faso | 0.5 | Cotton |
| 15 | Myanmar | 0.3 | Cotton |
| 16 | Mexico | 0.2 | Cotton, soybean |
| 17 | Spain | 0.1 | Maize |
| 18 | Colombia | 0.1 | Cotton, maize |
| 19 | Sudan | 0.1 | Cotton |
| 20 | Honduras | <0.05 | Maize |
| 21 | Chile | <0.05 | Maize, soybean, canola |
| 22 | Portugal | <0.05 | Maize |
| 23 | Cuba | <0.05 | Maize |
| 24 | Czech Republic | <0.05 | Maize |
| 25 | Romania | <0.05 | Maize |
| 26 | Slovak Republic | <0.05 | Maize |
| 27 | Costa Rica | <0.05 | Cotton, soybean |
| 28 | Bangladesh | <0.05 | Brinjal/Eggplant |
|  | **Total** | **181.5** |  |



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