Biotechnologies in Agriculture and Related Natural Resources to 2015

Anthony Arundel

David Sawaya

The main current uses of biotechnology for agriculture and related natural resources (ANR) are for plant and animal breeding and diagnostics, with a few applications in veterinary medicine. This encompasses the use of both transgenic and non-transgenic biotechnologies. This study provides an overview of the current state of technological development and, through an analysis of quantitative data related to R&D pipelines and the current literature, presents estimates and projections for the types of biotechnologies expected to reach the market for use in ANR to 2015. The trends indicate that several novel agronomic and product quality traits will reach the market for a growing number of crops. Biotechnologies other than genetic modification (GM) will also be used to improve livestock for dairy and meat. Socioeconomic issues, such as market concentration and public acceptance, are also examined to further refine the analysis of issues that will influence biotechnological developments and adoption for ANR. These results point to a future for ANR where biotechnologies play a substantially larger role than today. This will be visible in an increased use of biotechnologies for a wider range of plants and animals, and the active involvement of a growing number of countries in the development of biotechnologies.

Table of Contents

Figures

Tables

Boxes

Abbreviations

ANR	Agriculture and Related Natural Resources
Bt	Bacillus thuringiensis
ETM	Estimated time to market
EPO	European Patent Office
EU	European Union
EUKLEMS	European Union Capital, Labour, Energy, Materials, and Services inputs
FAO	The United Nations Food and Agriculture Organisation
GDP	Gross Domestic Product
GM	Genetic Modification *or* Genetically Modified
GVA	Gross Value Added
HT	Herbicide Tolerant *or* Herbicide Tolerance
ISAAA	International Service for the Acquisition of Agri-Biotech Applications
ISIC	International Standard Industrial Classification
JRC	European Commission's Joint Research Centre
MAS	Marker Assisted Selection
NACE	Classification of Economic Activities in the European Community
NAFTA	North American Free Trade Agreement
NAICS	North American Industry Classification System
nec	Not elsewhere classified
OECD	Organisation for Economic Cooperation and Development
OIE	World Organisation for Animal Health
PCR	Polymerase Chain Reaction
UNU-MERIT	United Nations University – Maastricht Economic and social Research and training centre on Innovation and Technology
USDA	United States' Department of Agriculture
USPTO	United States Patent and Trademark Office

Executive summary

This article covers short-term estimates to 2012-2015 of the use of biotechnology in agriculture and related natural resources (ANR). This includes food and feed crops, animal husbandry, forestry and fishing. The main biotechnologies of relevance to ANR include genetic modification, marker assisted selection, propagation technologies, therapeutics and diagnostics.

Where possible, this article gives qualitative estimates of products that are likely come on the market by 2015, as well as quantitative estimates of the potential or real impacts of biotechnology products. Data are obtained from publicly available sources such as the OECD, Eurostat and the FAO; the UNU-MERIT database of GM field trials, the web-sites of biotechnology firms, European Patent Office (EPO) and United States Patent and Trademark Office (USPTO) patent data, and the published literature. Where available, data are provided for two main types of indicators for each application of biotechnology: current use and trend estimations to 2012-2015.

The contribution of ANR to world gross domestic product (GDP) and employment is difficult to determine, as data on forestry and fishing are not consistently available. In 2006, agriculture alone accounted for approximately 4% of global output of 46.7 trillion and for 40.7% of global employment of 3 billion.

The ANR share of total gross value added and total employment provides an estimate of the maximum possible contribution of biotechnology to economic output and employment in these sectors (for instance if 100% of all agricultural production was dependent, in some way, on biotechnology). Biotechnology applications would then contribute to approximately 2% of gross value-added within the OECD. This assumes no large shifts in the value of ANR products which could occur from improved quality traits for industrial processing or the use of crop species (including plantation trees and grasses) for biofuel production.

Crops

In addition to the literature, three data sources were used to determine the types of crop varieties, based on biotechnology, that could reach the market prior to 2015 and their impact:

- GM field trial data, which are used to identify the focus of research into specific GM traits and predict the types of GM crops that could reach the market by 2015.
- R&D pipeline data on GM varieties derived from the annual reports of the world's largest seed firms.
- Extrapolation from past trend rates in hectares planted to four main GM crop varieties.

Four main trait categories are the focus of current GM plant breeding programmes: herbicide tolerance, pest resistance (including insect, virus, bacteria, fungi and nematode resistance), agronomic traits for improved yield or stress tolerance, and product quality characteristics. These same characteristics are expected to also be the focus of non-GM breeding programmes.

The number of firms active using advanced biotechnology to develop new varieties of plants has been declining over time due to firms leaving the market and to mergers and acquisitions. The degree of increasing concentration is evident from the patent and GM field trial data. Between 1990 and 1994 five firms accounted for 36.7% of biotechnology plant patents granted by the USPTO. The share of the top five firms increased to 80.5% of biotechnology plant patents granted between 2000 and 2004. Between 1995 and 1999, 146 firms applied for at least one GM field trial. Ten years later the number declined by almost half to 76 firms that applied for a field trial between 2005 and 2009.

The public research sector (including universities, research institutes and private non-profit institutions) continues to play an important role in the development of new crop varieties and GM research, both in developed and developing countries. Research institutes in Africa, India and Brazil have used biotechnologies to develop improved crop varieties. The public research sector conducted an estimated 20.7% of all GM field trials in the OECD between 2004 and 2008. The public research sector also accounted for 23.8% of biotechnology plant patent applications at the European Patent Office and for 21.9% of this type of patent at the USPTO between 2001 and 2006.

Due to the absence of regulatory filing requirements (such as those associated with GM crops), there are no consistent data on the share of seed firms that use non-GM biotechnologies such as marker assisted selection (MAS). Data from interviews suggest that almost all seed firms in OECD countries are likely to currently use MAS, GM or other biotechnologies in at least some of their breeding programmes, particularly for large market crops such as maize and soybeans. Almost all varieties of large market crops will probably be developed using MAS or other biotechnologies by 2015 (cotton, maize, potatoes, rapeseed, rice, soybeans, and wheat). The exception is some small market vegetable, berry, and tree fruit crops, where the large cost of identifying markers could limit the use of MAS.

Field trials of GM traits have been conducted for 130 plant species. The 25 species with the highest number of trials account for 94.4% of all field trials of plants. New GM varieties are still most likely to appear in the main GM crops to date of maize, soybeans, cotton and rapeseed. However, GM varieties should appear by 2015 in several plants that do no yet have any commercial GM varieties on the market, including barley, peanuts, peas and sugarcane.

The share of the two main traits that dominate approved products to date, herbicide tolerance and pest resistance, has declined steadily over time. Conversely, investment in GM research programmes for agronomic traits has been increasing, with a ten fold increase in GM trials for agronomic traits since 1990.

A large number of traits appear to have been abandoned, either due to technical failure or lack of commercial markets. In several cases the number of field trials for a specific trait, such as herbicide tolerance in grapes, suggests that the research programme was abandoned even though it was successful or close to success. One possible cause is a concern over public acceptance of products produced from GM crop varieties.

The estimates from the GM field trial data are corroborated with data on GM varieties derived from the annual reports of four of the world's largest seed firms. The four firms report research programmes for 112 new crop-trait combinations, with maize accounting for 43% of the total, followed by soybeans (33%), rapeseed (13%), and cotton (9%). Pest resistance accounts for 25 research programmes (22%) and herbicide tolerance for 24 research programmes (21%). However, the main GM firms are moving into both second generation product quality traits (34 research programmes or 30% of the total) and agronomic traits (24 research programmes or 21% of the total). There are also six research programmes under pest resistance into the more technically difficult traits for resistance to nematodes and fungi.

The number of hectares planted to GM and the GM share of hectares planted is forecast to increase for all four main GM crops to 2015. The fastest uptake of GM technology has been for soybeans, with GM varieties accounting for 65.8% of global cultivation in 2008. Based on past trends, the GM share is estimated to increase to 88.2% of all hectares planted to soybeans in 2015. GM cotton also sees a substantial increase in its global share from nearly 47.1% in 2008 to 72.7% in 2015. Maize could increase from approximately 23% to just over 30% by 2015 and GM rapeseed is forecast to increase from 18.5% to 21.3% of hectares planted. These projections, based on past trends, could be substantially increased by the adoption of GM crops in countries growing a large share of world hectares (*e.g.* China and India adopting GM maize) and by the introduction of significant improvements in GM varieties that result in faster uptake by farmers.

Potential trends – 100% biotech crops

The maximum contribution of biotechnology to the food, feed and industrial feedstock sector would be reached when 100% of crops are based on varieties developed through biotechnology. This is unlikely to occur for any crop because there will continue to be markets for organic or traditional varieties, but GM or MAS varieties of soybeans and maize could be responsible for the vast majority of total plantings by 2012.

There are very few GM varieties on the market for many high value-added crops including vegetables, nuts, fruits, olives and wine grapes. The rate at which varieties based on biotechnology are adopted in this group will depend on consumer acceptance issues and the cost of GM, MAS and other biotechnologies used in plant breeding.

Animal husbandry

Livestock accounts for approximately 40% to 50% of the value of agricultural production in OECD countries, with the main outputs being dairy products, eggs, meat, and fibre (wool, hair, etc). Biotechnology has three main applications for livestock: breeding, propagation, and health applications.

The largest current commercial application of the use of biotechnology in animal breeding is the application of MAS to conventional breeding programmes for pigs, cattle, dairy cows, and sheep. This will continue up to 2015. The most probable application of advanced propagation techniques to reach the market is the cloning of GM animals to produce pharmaceuticals, followed by cloned breeding stock. The first commercial use of the latter technology for meat production could occur in non-OECD countries, where public opposition to meat derived from cloned animals could be less important than in OECD countries.

Generally, the costs of bio-pharmaceuticals combined with limited applications (they are too expensive for chronic disease in animals) are likely to restrict their use in livestock to either products such as growth or meat quality enhancers (bST and porcine somatotropin) or for economically expensive infective diseases for which other treatments are not available. Over the short term, the most important application of biotechnology to animal health is likely to be for diagnostics for genetic conditions and for recombinant vaccines. Genetic diagnostics for diseases hold great promise, but the technology is not as advanced as other biotechnology applications.

Other applications: fishing, forestry and insects

Up to 2015, the largest potential for biotechnology in fishery applications are for wild stock management, for diagnostics and therapeutics for aquaculture, and the use of MAS and related non-GM biotechnologies for breeding fish, mollusc and crustacean varieties for aquaculture.

Biotechnology applications in forestry include the use of MAS and GM in breeding programmes and somatic embryogenesis for micropropagation of conifer species. Improved growth rate varieties of GM trees could be ready for commercialisation by 2012, and reduced lignin varieties for paper making (or bioethanol) by 2015. MAS could be widely used in breeding programmes, particularly in countries such as Canada and New Zealand with major forestry industries.

Honey bees are the most economically valuable insect species with potential applications of biotechnology. The most probable developments include *(1)* insecticide and pest resistant varieties of honey bees, developed using MAS or possibly GM technology (more likely to appear towards the end of the time period 2012 to 2015), and *(2)* more extensive diagnostic tests for pathogens that attack honey bee hives. The latter should appear continuously over time.

Developing countries

The potential applications of biotechnology to living natural resources in developing countries is enormous, both because developing countries contain more than 70% of the world's agricultural and forest land and because agriculture is relatively more important to their economies, in terms of share of GDP and employment, than in the developed world. Developing countries have been early adopters of agricultural biotechnologies, accounting for slightly less than half of all GM plantings in 2008. Although this initial wave of agricultural biotechnology uptake in the developing world was mainly driven by technologies developed in OECD countries, developing countries are moving towards developing technologies on their own. Agricultural biotechnology R&D budgets in some large developing countries are beginning to approach those of OECD countries and activities such as field trials of GM crops are widespread. To 2015, developing countries will become much more heavily involved in biotech commercialisation, especially for new varieties of indigenous crop species and to adapt other crops to local conditions.

Public attitudes

The application of GM technology to plant and animal breeding has been affected by public opposition. This is by no means limited to Europe. Concern over a lack of markets in many OECD countries, including the United States, could be reducing private sector investment in developing GM varieties of fish, honey bees, and food animals. In crops, the main application of GM technology has been for animal feed crops and for crops that are used in food processing, with few GM crops on the market that are directly eaten by consumers. If public opposition continues, firms could continue to limit investment in GM to feed and industrial feedstock crops such as trees or bioenergy feedstock plants such as grasses. Non transgenic biotechnologies such as MAS and cisgenesis have not raised public concerns to date, which could encourage wider use of these technologies.

Conclusions

The trends explored in this article indicate that R&D is likely to continue to result in commercially valuable products that will be adopted in an increasingly large number of regions. New crop varieties with improved agronomic traits are expected to reach the market by 2015. These new varieties will not only deliver yield gains, but could reduce the environmental impacts of intensive agriculture. Furthermore they will help agriculture deal with changing environmental conditions due to climate change by improving tolerance to drought, heat or cold, and salinity.

Demand for food, feed and fibre is expected to increase substantially in the future due to population and income increases across the globe. To meet increased demand, a diverse range of solutions are going to need to work in concert. Biotechnological solutions will play a major role, but will not provide a silver bullet. They will need to be combined with other strategies to modernise agricultural methods and increase agricultural productivity (*e.g.* through farmer education, improved water management and conservation, and precision farming).

Introduction

As a technology for propagating and changing the characteristics of living organisms, biotechnology has many current and potential applications in agriculture and related natural resources (ANR), covering the use of plants, animals and insects to produce food, feed and fibre for human use or consumption. ANR can be divided into three main applications fields for biotechnology: *(1)* food, animal feed, and industrial feedstock crops, *(2)* animal husbandry and related activities such as fishing, aquaculture and bee-keeping, and *(3)* forestry. The first group mostly consists of annual and biannual plant species, but it also includes perennials such as grapes, berries, and orchard trees. Biofuels form a fourth application field that can use crop plants, animals (fats for biodiesel) and forestry products as energy sources. The future of biofuels is not evaluated here as they are covered extensively in *The Bioeconomy to 2030: Designing a Policy Agenda* (OECD, 2009).

The main purpose of this article is to identify the types of biotechnology products in ANR that are already on the market, both within the OECD and in developing countries, and to estimate the types of new products that could reach the market by 2015. This introduction looks at the economic and environmental factors influencing the future of ANR (these factors have a strong influence on the use of biotechnology), describes the data sources used in this article, and provides an overview of the potential economic contribution of biotechnology in ANR. The remaining chapters look at specific application fields, with a final chapter on the use of biotechnology in developing countries.

The future of agriculture and related natural resources

Increased demand, higher incomes, and environmental developments are predicted to increase the average price of food, feed and other resource-based commodities up to 2017 compared to the decade before 2008. This will reduce, but not entirely eliminate, the long-term decline in the real price of agricultural and related commodities. This is even the case after the sharp fall in prices in early 2008 (OECD-FAO, 2008).

Demand for food and feed will increase as a result of the world population growing to approximately 8.3 billion in 2030 (UN, 2006),[1] with 97% of the population growth expected to occur in developing countries. An increase in average incomes will have a major effect on increasing demand, with global gross domestic product (GDP) expected to rise 57% from an average of USD 5 488 per capita in 2005 to USD 8 608 per capita in 2030. The GDP share of countries outside the OECD will increase from 21% of global GDP in 2005 to 30% in 2030 (OECD, 2008a). Increased incomes in developing countries will spur demand for meat, fish and dairy products, which require large inputs of animal feed. A third factor which could spur demand for natural resources is a growing market for biofuels.

There are two main methods for increasing the supply of agricultural products to meet future demand. One is to increase the amount of land under cultivation, which increased by 10.4% between 1961 and 2005.[2] This may not be sufficient to overcome supply constraints, as the FAO estimates that the amount of new farmland for food production will grow more slowly in the future (FAO, 2002). The second solution is to increase yields through the adoption of improved crop varieties worldwide and intensive agricultural techniques in developing countries. The latter will require investment in education, infrastructure, and technology.

The ability to increase supply could run up against environmental constraints from water scarcity and climate change. The same factors that are contributing to increased demand for agricultural products, such as the rapid increase in global demand for meat and dairy products, will increase water use in the future. Agriculture is the largest consumer of water globally, accounting for about 70% of all water withdrawals (OECD, 2008b). Meat production is especially water intensive.[3] Another growing concern is how to manage an expected long-term decline in inexpensive sources of phosphorous, a key plant nutrient (Vaccari, 2009).

Current trends towards greater water scarcity, combined with a possible increase in the frequency of droughts from climate change, could result in a massive increase in the number of people living in areas under water stress (see Table 1). By 2030 the total population living in areas of high and medium water stress is expected to increase by 38% and 72%, respectively. Conversely, the share of the global population living in areas with low or no water stress is expected to increase by only 4%. Water pollution could also increase, with an estimated 5 billion people (1.1 billion more than today) in 2030 without connection to a sewage system (OECD, 2008b). An increase in the use of fertilisers to improve yields could also have a negative impact on water quality.

Table 1. **Population living in areas under water stress[1,2] (in millions)**

Water stress level	2005	% of world population	2030	% of world population	Total population change (2005-30)
Severe	2 837	44%	3 901	47%	38%
Medium	794	12%	1 368	17%	72%
Low	835	13%	866	11%	4%
None	2 028	31%	2 101	26%	4%
Total	6 494	100%	8 236	100%	27%

Source: OECD, 2008b.

Notes: 1. The 2030 estimates are based on extrapolation of historical and current trends into the future and assume that no new policies are enacted.
2. The columns may not sum to 100% due to rounding.

Global warming will also play a role. Temperature increases in the range projected for 2030 will affect ecosystems and human activities. For example, both the Stern Report and the IPCC estimate that warming of approximately 1°C could decrease water availability and increase drought in low-latitude areas, as well as increase the risk of wildfires. It could also decrease crop yields in low-latitude areas, although this might be partly compensated by increases in yields at higher latitudes. That beneficial effect would not, however, continue at higher warming levels, with expected crop yields declining in all areas with a 3° C temperature increase (Stern, 2006; IPCC, 2007).

Agricultural systems in developing countries are likely to acutely experience all of these supply and demand effects. By 2017, they should surpass the OECD area in production of the most traded food commodities. They will also account for an increasing share of global food imports and exports (OECD-FAO, 2008). These countries have also been at the forefront of the adoption of genetically modified (GM) crops. If adoption rates continue at past trends, GM crop plantings (as measured in hectares planted) in developing countries will surpass that of the developed world in 2012 (Sawaya and Arundel, 2009).

Sustained high demand and prices for food and water will provide a strong incentive for investment in technologies that can increase agricultural productivity while reducing the environmental impacts of intensive agriculture. Agricultural biotechnologies, especially those that increase yield and tolerance to salinity and drought in commercially valuable plant varieties, are a possible solution in many parts of the world. Of note, biotechnology is not the only solution to future supply constraints. Other methods include education, water harvesting and improved irrigation practices, precision farming, integrated pest management, and improved storage to reduce after harvest losses from pests.

Estimating the use of biotechnology in ANR

The term "biotechnology" covers a wide range of technologies. In this article we limit biotechnology to modern, technologically advanced biotechnologies for use in breeding programmes to develop new varieties of living organisms, propagation, and for managing the health of commercially valuable plant and animal stocks (see Box 1).

Box 1. **Main advanced biotechnologies used in agriculture and related natural resources**

Breeding: New varieties of food and feed crops, fibre crops (trees and grasses), animals for meat, dairy and fibre, and fishes and molluscs for aquaculture are continually developed by firms and public sector research institutions. Breeding programmes can increase yields, pest and herbicide resistance, resistance to environmental stresses such as cold, heat, and drought; and improve product characteristics. The application of biotechnology to breeding can reduce the time required to develop a new variety and make it easier to introduce valuable novel traits. The goals of breeding programmes are determined by economic and environmental factors. Biotechnologies for breeding can be divided into two groups, based on the current regulatory structure for new varieties:

Non-transgenic breeding methods: This includes the use of marker assisted selection and related genomic technologies such as genotyping, polymerase chain reactions (PCR), and high throughput sequencing to speed up conventional breeding. It does not use interspecies gene transfer, as with GM. Marker assisted selection (MAS) uses molecular or physical markers to identify desired genetic traits for subsequent breeding. Other non-transgenic biotechnologies are used to increase genetic variety or access desired traits, such as molecular mutagenesis, gene shuffling, cisgenesis (Jacobsen and Schouten, 2007), and intragenetic vectors (Conner *et al.*, 2007).

Genetic modification (GM): The insertion of a gene or genes from one species into another species that cannot interbreed under normal conditions (transgenes). This technology also uses many of the biotechnologies identified above under "non-transgenic breeding methods".

Propagation: Advanced reproduction methods include plant tissue culture,[4] cloning, apomixis and somatic embryogenesis

Health (diagnostics and therapeutics): Biotechnology based diagnostics are used in the surveillance and identification of plant and animal diseases. Therapeutic drugs are primarily used in animal husbandry. The application of diagnostics and therapeutics to ANR is closely related to similar technologies developed for human health applications. A therapeutic class limited to ANR is biopesticides, which use insects or microorganisms to attack plant pests.

Several data sources are used to identify current uses of biotechnology and to estimate trends in the three main application areas, as summarized in Table 2. The reliability of the forecasts varies by application field, due to data availability. The most robust forecasts are for new varieties of species developed through GM technology, followed by new varieties using MAS and related biotechnologies. Due to regulatory requirements, quantitative data on field trials of new GM plant varieties are available for 27 of the 30 OECD countries, plus non-OECD countries that are members of the European Union.[5] The field trial data were obtained from public sources in Australia, Japan, Mexico, New Zealand, the United States and the European Union. The data include information on the date of the field trial, the country where it was conducted, the organisation applying for the trial, the type of trait, and the plant species. The longest data series is for the European Union and the United States, beginning in 1987. For all countries, data are available up to December 31, 2008.

Table 2. **Data availability for biotechnology by application**

	Data sources by type of biotechnology		
Application field	New varieties	Propagation	Diagnostics & therapeutics
1. Food, feed, and industrial feed stock crops (incl. pharmaceuticals)	UNU-MERIT GM field trial database Annual reports of seed firms for GM pipeline Annual reports of seed firms for MAS activity FAO, ISAAA and other sources for crop hectares and prices FAO BioDec database	Literature	Literature
2. Animal farming - dairy, meat and wool - aquaculture and marine - beneficial insects (honey bees)	Literature, interviews FAO BioDec database	Literature	Literature
3. Forestry	UNU-MERIT GM field trial database FAO BioDec database	Literature	Literature

The second best data coverage is for the use of MAS, with almost all breeding firms developing the ability to use this and related technologies. However, regulatory requirements for new varieties based on MAS and other non-GM biotechnologies such as gene shuffling are much less strict than for GM, and therefore data are much less comprehensive.

The number of plant patent applications at the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO) are used to evaluate the level of concentration in plant biotechnology and the contribution of the public research sector to new inventions in plant biotechnology. The patent data for the EPO cover patent applications between 1980 and 2006 inclusive. The USPTO data cover applications from 2001 to 2007 and patent grants from 1980 to 2006.

The analyses of the patent data are limited to patents assigned to at least one of IPC classes A01H1 to A01H4, C12N15/82, C12N15/83, or C12N15/84. The results exclude patent applications or grants for new plant varieties only (IPC classes A01H5 – A01H17). It is important to exclude patents that are only assigned to the latter IPC classes because many firms choose to protect plant varieties in the United States through a patent rather than through plant breeder's rights. Many of these varieties could have been developed without the use of modern biotechnology.[6] Annex B provides full details on the IPC classes used in this article.

This paper assumes that the types of plant breeding research programmes underway using GM technology are indicative of the types of research programmes that are underway using non-transgenic breeding technologies. This is a reasonable assumption because similar economic goals are likely to drive all plant breeding programmes. In both cases, firms focus their development on economically valuable traits for crops with large markets. The main difference between GM and non-transgenic biotechnologies from the perspective of the firm is that the latter is not influenced by regulatory barriers and, to date, political opposition to their use.

While this article's goal is to provide quantitative estimates for all technology areas, only qualitative information is available for the use of biotechnology to develop new varieties of animals. Where available, data are provided for two main types of indicators for new varieties of plants and animals: current use and trend estimations to 2012-2015. Examples for GM crops are as follows:

1. **Current use:** Data on current use are obtained from publicly available sources, such as the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) for GM crops and estimates of the total hectares planted to specific types of target GM crops worldwide and by major region (OECD, EU, North America, and South America) from FAO data.
2. **Forecasts to 2015**: Forecasts are based on projections from past adoption rates for biotechnology and from data on ongoing research projects. For example, ISAAA data on the number of hectares planted to GM crops per year over the past decade are used to estimate GM crop hectares up to 2015. GM field trials (a measure of investment in specific research projects) and data from the annual reports of seed firms are used to estimate the types of new GM varieties that should reach the market between 2008 and 2015.

Maximum potential impact of biotechnology in ANR

An important issue for both Government policy and firms is the maximum potential of biotechnology applications to output in the ANR sectors. This potential can guide both public policy and public and private investment in biotechnologies of relevance to this sector. The upper limit would be reached if biotechnology contributed to 100% of economic output. As an example, the upper limit for maize production would occur if maize varieties, developed using biotechnology, accounted for all hectares planted to maize. Of note, the maximum potential impact is not expected to be reached in the foreseeable future, due to many factors that are likely to maintain markets for other technologies.

The maximum potential for the ANR sectors can be estimated from national account data for the sector "Agriculture, hunting, forestry and fishing".[7] Agriculture includes growing all crops, all forms of animal husbandry, and related services such as seed production and propagation. Hunting (largely trapping) is a very minor part of ANR in all OECD countries and can largely be ignored. Forestry includes logging and related services such as tree planting, plantation management, and propagation of tree varieties. The most important activity that is not included under "Agriculture, hunting, forestry and fishing" is animal veterinary products (pharmaceuticals and diagnostics), which is assigned to the manufacturing sector under pharmaceuticals.

The full contribution of ANR to world GDP and employment is difficult to determine, as data on forestry and fishing are not consistently available. In 2006, agriculture alone accounted for approximately 4% of global output of USD 46.7 trillion and for 40.7% of global employment of 3 billion.

Table 3 gives basic statistics on the economic importance of the ANR sectors for the EU-25, most non EU members of the OECD, plus a few comparable results for Brazil, Russia, India and China. The contribution of ANR to total national gross value added (GVA)[8] equals 1.77% of total GVA in the EU-25 in 2004 and 1.73% of total gross value added in the United States, with agriculture accounting for most of the value-added from ANR: 86% in the EU-25 and 95% in the United States. Unfortunately, separate value-added data for agriculture (Column *(3)*) are not available for the other OECD countries.

These results suggest that the maximum potential contribution of the use of biotechnology in the ANR sectors ranges from 1.25% of GDP in Japan to 9% of GDP in New Zealand, with an OECD average of approximately 2%. Elsewhere, we provide a "probable" estimate of the contribution of biotechnology in the ANR sectors within the OECD in 2030, based on potential applications in forestry, agriculture and fishing. The average contribution across all OECD countries in 2030 is estimated at 1% of OECD GDP in 2030.

Of note, the maximum and probable contribution of biotechnology in the future is not directly equivalent to economic impacts, which depend on the additional value-added from using biotechnology compared to alternative technologies. The concept of a "contribution" assumes that alternative technologies are no longer economically competitive, even though the difference in productivity could be relatively minor.

In absolute terms, the GVA of ANR sectors has declined in the European Union but increased in the United States between 1996 and 2004. However, the ANR share of total value added has declined on average by 2.47% per year in the EU-25 and by 1.05% per year in the United States. The only OECD countries with an increase in the ANR share of total value added are Australia and New Zealand. The share of total employment in ANR has declined in all countries. This trend is likely to continue into the future: even if biotechnology contributes to 100% of ANR sectors, the share of these sectors in the total value added and employment of OECD countries could continue to decline, unless there is rapid growth in new applications such as biofuels or the production of valuable chemicals in plants.

In 2007, the European Commission's Joint Research Centre (JRC) estimated the current contribution of modern biotechnology to the European life resources sectors (essentially equivalent to ANR) as between 0.01% to 0.02% of GVA (Reiss *et al.,* 2007). The higher estimate is equivalent to approximately USD 2.5 billion, or 1% of European Union ANR output. Only 19% of the contribution of biotechnology to European ANR sectors was from breeding and propagation biotechnologies, due to the low use of GM in Europe and uncertainty over the use of MAS. The estimated biotechnology contribution is largely due to activities that are not included in national accounts in ANR sectors, such as veterinary products, diagnostics, and feed additives (81% of the total contribution). Given the evidence of the use of MAS in seed development (see the section on "Food, feed, and industrial feedstock crops"), this is likely to be a substantial underestimate of biotechnology's current contribution to European ANR output.

Table 3. **Basic economic statistics for the Agriculture and related Natural Resource (ANR) sectors: 2004 or latest available year**

	USD	ANR share of total gross value added (%)	Agriculture share of total gross value added (%)	Average annual change in ANR share of total gross value added (%)	Total employment (000)	ANR share (%) of total employment	Average annual change in ANR share of total employment (%)
EU-25	12 000	1.77	1.55	-1.82	202 760	5.86	-2.47
US	10 980	1.83	1.73	0.52	149 512	2.42	-1.05
Australia	645	3.82	-	1.39	9 207	4.76	-1.14
Canada	1 089	2.21	-	-5.75	15 314	2.65	-5.04
Iceland	14	9.34	-	-2.65	0.159	6.88	-4.04
Japan	4 911	1.25	-	-4.81	66 222	5.96	-2.01
Korea	897	3.78	-	-6.23	21 557	8.82	-3.12
Mexico	742	3.79	-	-6.10	-	-	-
New Zealand	99	9.19	-	5.29	1 443	0.65	-0.69
Norway	262	1.46	-	-7.62	2 310	3.60	-4.02
Switzerland	387	1.36	-	-4.55	-	-	-
Brazil	943		8.0		96 340	20.0	
China	2 500		11.9		798 000	45.0	
India	796		19.9		509 300	60.0	
Russia	733		5.3		73 880	10.8	

Sources: EUKLEMS for EU-25 and the United States, OECD STAN database for other OECD countries. Data on agriculture alone are only available from EUKLEMS. CIA World Factbook (2007) for GDP for other OECD member states and for all data for Brazil, China, India and Russia.

Notes: 1. Value-added data are for 2004 for the EU-25 and the US, 2003 for Japan, Korea, Mexico and Norway, 2002 for Iceland and Switzerland, and 2001 for Australia, Canada, and New Zealand.

2. Total gross value-added data for Australia, Canada, Japan, Korea, Mexico, New Zealand, Norway, and Switzerland are GDP estimates for 2006. All data for Brazil, Russia, India and China are estimates for 2006. ANR employment is limited to agriculture.

3. Employment data are for 2004 for the EU-25 and the US, 2003 for Canada, Iceland, Japan, Korea, New Zealand and Norway, 2001 for Australia.

Food, feed and industrial feedstock crops

Biotechnology has two main applications for food, feed and industrial feedstock crops. The first is transgene GM, where a gene from one species is inserted into another species. The second application is the use of breeding technologies derived from biotechnology research and applied to conventional breeding, without the transfer of genes between incompatible species. These include biotechnologies such as MAS, cisgenesis, and gene shuffling combined with directed evolution. Other uses of biotechnology, such as biopesticides or diagnostics for the detection of plant diseases and pests, are so far of secondary importance to food, feed and industrial feedstock crops.

The International Seed Federation (2008) estimated that the 2008 global seed market was approximately USD 36.5 billion, of which 64% (USD 20.5 billion) is in OECD countries.[9] A large number of firms are involved in developing new seed varieties, including firms ranging in size from less than 50 employees to over ten thousand employees, but there is a lack of data on the number using biotechnologies in plant breeding.[10] Between 2004 and 2008 inclusive, 300 firms applied to patent a process for plant breeding or a biotechnology plant patent at either the EPO or the USPTO. This provides a minimum estimate of the number of firms over these five years that could have used biotechnology in plant breeding within the OECD.[11]

The adoption of biotechnology in the agricultural sector varies by crop variety. For example, only four crops, soybean, maize, cotton and rapeseed (canola), account for the vast majority of all hectares planted with GM varieties. Therefore, estimates of the current adoption of biotechnology and of future trends are best calculated on a crop by crop basis.

The economic and environmental effects of new crop varieties are due to the characteristics of the trait that is included in the plant variety. Both GM and non-GM research programmes focus on one or more of the following traits:

- *Herbicide tolerance (HT)* allows plants to resist the effects of specific herbicides. HT has been developed using both GM technology and other breeding techniques.
- *Pest resistance* improves the ability of the plant to resist harmful insects, viruses, bacteria, fungi and nematodes. The most common form of GM pest resistance uses a gene from bacteria (Bacillus thuringiensis, or *Bt*) to emit an organic toxin that kills some insect species.
- *Agronomic traits* improve yields and provide resistance to stresses that can reduce yields, such as heat, cold, drought and salinity.
- *Product quality characteristics* include modified flavour or colour, modified starch or oil composition that improves nutritional value or processing characteristics, and the production of valuable medical and industrial compounds.

In addition, GM research often involves *Technical traits,* such as molecular markers. Research into technical traits improves the efficiency of breeding programmes, but has little or no commercial value for growers.

Increasing concentration

A healthy, competitive sector is often characterised by a large number of firms that are capable of using scientific and technological knowledge to develop new and improved products and processes. However, many sectors, such as the automobile industry, have gone through a "shake-out" period in which capabilities are increasingly concentrated in fewer and fewer firms (Klepper, 1996). This can improve the rate of innovation by allowing the remaining firms to benefit from economies of scale and thereby increase their investment in innovation. Conversely, increasing concentration can reduce the number of firms that can experiment with a technology, leading to a decline in the rate of innovation. In the ANR sectors, increasing concentration would be of concern if it reduced the use of advanced biotechnology to develop improved varieties of a large number of crops, particularly small market crops. Concentration can be measured by both the number of firms active in a technology and the concentration of activities in a few firms. For plant biotechnology, concentration can be measured using plant patents and GM field trials.

Firms with head offices in the United States dominate plant patents for genetic modification or for plant breeding processes (patents for plant varieties only are excluded from these analyses). Out of 3 049 plant patent applications by firms at the EPO between 1980 and 2007 (for which full data are available for the application year and the name of the applicant), American firms accounted for 41.0%, European firms for 40.9%, and other countries for 18.1%. However, American dominance in 3 786 USPTO patent grants to firms between 1980 and 2006 is much higher, with American firms accounting for 75.1% of the grants, European firms for 15.2%, and other countries for 9.7%.

The number of firms applying or receiving a plant patent has been increasing over time, with the number of applicant firms at the EPO increasing from 36 firms between 1980 and 1984 to 252 firms between 2000 and 2004 (the results for 2005 to 2006 are not comparable because they cover a much shorter time period). Similarly, the number of firms granted a plant patent in the United States increased from 57 between 1980 and 1984 to 235 between 1995 and 1995, as shown in Table 4. The sudden decline in patent grants at the USPTO after 1999 is due to changes in the criteria for plant patents, including stricter disclosure rules, which delayed approvals (Blank, 2009; Lawrence, 2004). The decline in patent grants in the last time period of 2000 to 2004 is not reflected in the number of patent applications between 2003 and 2007, with 274 firms making 2 962 patent applications.

In contrast to the growing number of firms making at least one patent application at the EPO or USPTO, or receiving a patent grant at the USPTO, plant patent ownership has become increasingly concentrated, particularly for USPTO patents. The top five patent applicant firms in Europe applied for 22.6% of all plant patents between 1985 and 1989, but for 31.4% of plant patents between 2000 and 2004. In the United States, concentration has grown to a much higher level. Between 1980 and 1984 the top five firms received 31.6% of all plant patent grants, increasing to 49.6% in 1995 to 1999. The level of concentration is even higher for the more recent data for USPTO patent applications. Between 2003 and 2007, the top firm accounted for 63.2% of all plant patent applications and the top ten firms for 71.7%.[12] Of note these results underestimate the concentration of patenting because patenting by subsidiaries are not reassigned to the parent firm.

Table 4. **Percent of plant patents by leading firms: 1980-2007**

			Share of all patents		
	Number of firms	Number of patents	Top firm	Top 5 firms	Top 10 firms
EPO Patent applications					
1980-1984	36	63	9.5%	31.7%	54.0%
1985-1989	100	248	5.6%	22.6%	40.7%
1990-1994	134	442	6.7%	28.3%	44.4%
1995-1999	219	939	10.5%	32.3%	45.9%
2000-2004	252	1 008	9.4%	31.4%	44.1%
2005-2006	105	349	12.1%	42.4%	55.3%
USPTO patent grants					
1980-1984	57	135	8.8%	31.6%	47.8%
1985-1989	107	474	9.7%	35.7%	50.4%
1990-1994	137	875	13.0%	36.7%	54.4%
1995-1999	235	1 705	24.2%	49.6%	61.1%
2000-2004	56	597	55.6%	80.5%	87.1%
USPTO Patent applications					
2003-2007	274	2 962	28.4%	63.2%	71.7%

Source: Authors, based on EPO patent applications, USPTO patent grants (1980-2004) and USPTO patent applications (2003-2007). Excludes the public research and private non-profit sectors and individual patentees.

Notes: 1. Limited to patents assigned to either plant process IPC codes or plant genetic modification IPC codes and to patents for which full information is available on the application year and the applicant name.
2. The top firm in USPTO patent applications between 2003 and 2007 is DuPont Pioneer Hi-Bred, followed by Monsanto, Syngenta, BASF and Ceres. The latter is involved in energy crops.
3. EPO data for 2005-2006 include 31 patents applications after 2006.
4. See Annex B for a description of eligible IPC codes.

Increasing concentration is also apparent in the GM field trial record. Peak activity in the number of firms active in GM field trials occurred between 1995 and 1999, with slightly over 6 000 field trials of plant varieties conducted by 146 firms. In an equivalent five year period between 2004 and 2008, the number of GM field trials had decreased 17% to slightly over 5 000, but the number of firms active in field trials had declined by 50% to 76 firms. Monsanto, the leading firm in both time periods, increased its share of all field trials from 31.7% between 1995 and 1999 to 47.2% between 2004 and 2008.[13] Table 5 shows that the share of all GM field trials by the top five firms increased from 60.8% between 1995 and 1999 to 79.4% between 2004 and 2008. In the second time period, 97.4% of all field trial applications were conducted by the leading 25 firms.

Over the same two time periods, the ability to use GM technology has been increasingly concentrated in American firms, whose share of all GM field trials increased from 64.2% of the total between 1995 and 1999 to 81.5% of the total between 2004 and 2008. The share of field trials performed by European firms declined from 32.8% to 16.2% over the two time periods. Firms based in other countries accounted for 3.0% of all trials in the first time period and 2.3% in the second period.[14]

Table 5. **Percent of GM plant field trial applications by leading firms**

	1995-1999 6 091 field trials	2004-2008 5 029 field trials
Top firm[2]	31.7%	47.2%
Top 5 firms[3]	60.8%	79.4%
Top 10 firms	72.1%	90.3%
Top 20 firms	82.3%	95.7%
Top 25 firms	84.9%	97.4%

Source: Authors, based on UNU-MERIT (2009).

Notes: 1. As measured by number of field trials conducted.

2. The top firm in both periods was Monsanto.
3. The top five firms between 1995 and 1999 were Monsanto, Hoechst, Pioneer, Dekalb and DuPont. Between 2004-2008 the top five firms were Monsanto, Targeted Growth, DuPont Pioneer Hi-Bred, Syngenta, and Bayer CropScience.
4. See Annex A for a description of the UNU-Merit field trial database.

The above results show that the number of firms applying for a plant patent has increased over time, although patent ownership is increasingly concentrated in fewer firms, particularly for USPTO patents. Research in plant biotechnology continues to be diversified, either because firms believe that they can license new technology to one of the major plant breeding firms or because the plant patent is a by product of other research (many of the firms that apply for or receive a plant patent are not active in plant breeding, although this share has been decreasing over time).

In contrast to the patent record, the number of firms active in GM field trials has declined sharply, possibly because of increasing costs for seed development from the application of biotechnologies such as GM, MAS, and gene shuffling, and high regulatory costs for GM varieties (OECD, 2009). Both factors could have reduced the financial viability of many small and medium sized firms. In addition, there has been a substantial increase in the share of GM field trials conducted by the leading firms.

The results for both plant patents and GM field trials point to a large decline in the number of firms that can use biotechnology to develop new plant varieties. The question then is if this increase in concentration is having, or likely to have, a negative effect on innovation in the plant breeding sector? The decline in the number of firms active in GM field trials, which are close to the commercialisation phase, is potentially more worrisome than the increase in concentration of plant patents. The results given in this article suggest that the growing level of concentration could be a problem because most GM research has been focused on a limited number of large market crops – though GM research has expanded into other crops. Currently, small and medium sized firms continue to be active in non-GM plant breeding, although their numbers have been depleted through acquisitions by the major seed firms. The apparent inability of many of the remaining small and medium sized seed firms to use biotechnology could reduce the rate of innovation by these firms. This is of concern because these firms are often active in small market and regional crop varieties where the major seed firms are less active.

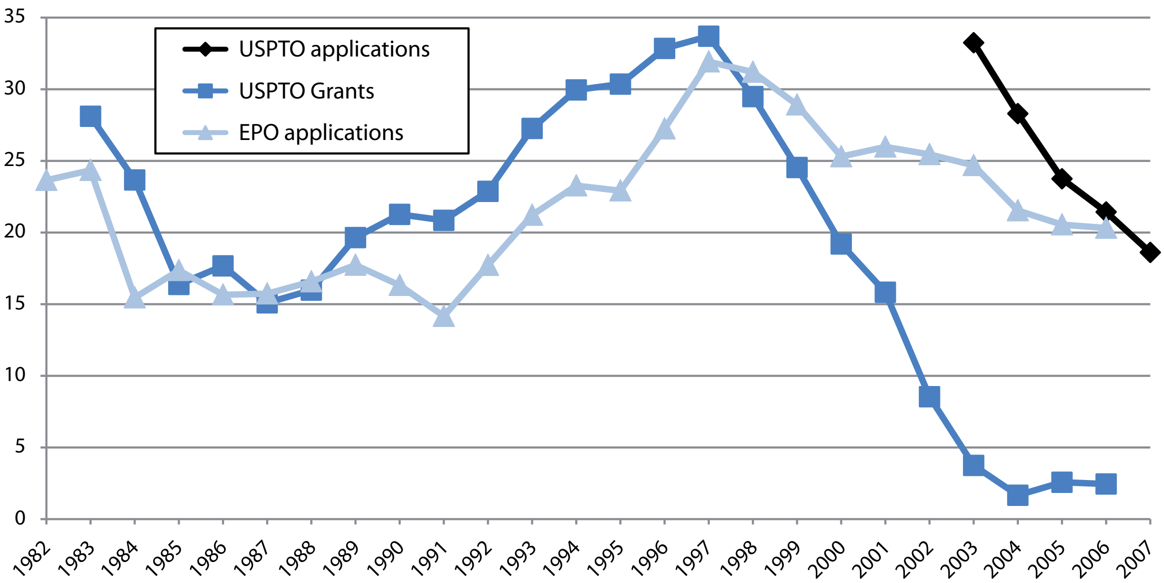
Role of the public sector

The public research sector (defined here to include universities, government research institutes and private non-profit research institutes) continues to play an important role in the development of new crop varieties, both in developed and developing countries, where research institutes in Africa, India and Brazil have used biotechnologies to develop improved crop varieties. A major success is NERICA rice, developed by the Africa Rice Center (WARDA) using molecular biology and plant cell culture.

Between 1980 and 2006, the public sector applied for 23.8% of plant patents at the EPO, received 21.9% of plant patent grants from the USPTO, and made 24.9% of plant patent applications at the USPTO between 2001 and 2007.[15] This is considerably higher than the public sector contribution to all types of patents, estimated by Graff *et al.* (2003) at only 2.7% of USPTO patent grants between 1981 and 2000.

However, the role of the public sector peaked in the late 1990s and early 2000s, as shown in Figure 1, particularly for USPTO patent grants and applications. It is not known if this is due to a fall in public sector investment in plant breeding or to a conscious decision not to patent inventions made in the public sector. In either case, the private sector share of plant patents has increased substantially, particularly for USPTO patents.

Figure 1. **Share of plant patent grants or applications made by the public sector**



Source: Authors, based on EPO and USPTO data.

Notes: 1. The results are three year moving averages.

2. Plant patents are limited to IPC classes for genetic modification in plants and for processes for plant breeding. Plant patents for varieties only are excluded. Trials conducted jointly by the private and public sectors (12.0% of public sector plant patent grants from the USPTO) are assigned to the public sector.

The public research sector within the OECD also plays an important role in GM field trials, with 19.2% of all plant field trials within the OECD between 1987 and 2008 conducted by public research institutions. Unlike the patent record, the public sector share has increased slightly to 20.7% of all plant field trials between 2004 and 2008.

Table 6 gives the number of field trials performed by public sector institutions and private sector firms and the percentage distribution of all trials by trait category. Compared to private firms, the public sector conducts a higher share of trials for second generation agronomic and product quality traits and for technical traits that form the foundation for advances in GM technology. As an example, technical traits account for 25.2% of all trials by the public sector compared to 11.2% of all trials by private firms. The most frequent purpose of technical trials in the public sector is to identify markers. An analysis of agricultural patents between 1982 and 2000 also found that the public sector focused on agronomic traits such as stress resistance (Graff *et al*., 2003).

The public sector is also more active in small market crops, with most of private sector investment in the commercially more attractive large market crops (maize, rapeseed, soybean, cotton, rice, wheat and potatoes). Between 1987 and 2008, the public sector conducted 39.9% of its GM field trials on small market crops, over twice the 17.6% share of private sector trials for small market crops. These shares are roughly stable over time.

Table 6. **Distribution of GM trials for specific plant traits by the public and private sectors (1987-2008)**[1]

	Public sector		Private sector	
	Number	Percent	Number	Percent
Herbicide tolerance	575	11.0	8 152	35.7
Pest resistance	1 407	26.9	6 338	27.8
Product quality	900	17.2	3 362	14.7
Technical	1 320	25.2	2 553	11.2
Agronomic	845	16.2	2 348	10.3
Other	181	3.5	62	0.3
TOTAL	5 228	100.0	22 815	100.0

Source: Authors, based on UNU-MERIT (2009).

Notes: 1. The public sector includes 122 plant GM field trials by private non-profit institutes. The total number of trials by trait (28 043) is greater than the number of GM plant field trials (21 464) due to trials that test more than one type of trait.

2. See Annex A for a description of the UNU-Merit field trial database.

Current status of biotechnology

An estimate of the current use of biotechnologies by seed firms can be constructed from publicly available data on the use of GM and an estimate of the prevalence of MAS capabilities among seed firms. This information provides an estimate of the share of seed firms that have the technical capabilities to use biotechnology in their breeding programmes. This section also examines the types of GM varieties that have reached the market and the extent of their use.

Non GM biotechnologies

While the number of firms active in GM technology can be readily identified from publicly available GM field trial data, there are no consistent data on the share of seed firms that use other biotechnologies such as MAS, molecular mutagenesis, or cisgenesis. The available data are largely limited to the use of MAS, which can speed up breeding programmes. The technological capabilities that are required to use MAS are also necessary for all other types of biotechnology for plant breeding. A series of interviews with five French and German firms active in breeding maize varieties found that all five firms used MAS. The larger firms appeared to use MAS in every maize breeding programme, with

100% of all turnover due to MAS maize varieties, but the one smaller firm estimated that only 33% of its turnover was from MAS maize (Menrad *et al.,* 2006).[16]

Data from the European Seed Association for 2006 were analysed to explore the use of biotechnology by 41 member firms active in plant breeding. The combined turnover of these firms in 2006 was approximately 50% of the USD 7.9 billion European seed market. Of the 41 member firms, 25 (61%) had conducted GM field trials, including many medium-sized firms with less than 500 employees.[17] The websites for the remaining 16 firms were checked to see if they used other biotechnologies and to evaluate the relationship between firm size, market specialities, and the use of biotechnology. Five of the 16 firms reported using MAS in their breeding programmes or had close research links with other firms or institutes that used MAS. Seven of the remaining nine firms were small firms with less than 100 employees that were primarily involved in breeding vegetable varieties. One large firm with 600 employees and active in forage crops did not contain any references to MAS on its website. Another firm has its head office in Japan and provides very little information on its English language website on breeding programmes. The smallest firm that was identified as a MAS user had 160 employees.

The results on the use of MAS and increasing concentration in the sector suggest that, with the exception of small seed firms active in breeding vegetable varieties, almost all seed firms are likely to currently use MAS, GM or other biotechnologies in at least some of their breeding programmes for new crop varieties.

A possible barrier to the adoption of MAS that was identified in the interview study cited above is the cost of identifying markers. It could be difficult to recoup these costs in small market crops such as vegetables, which could also explain the number of small breeding firms that are still active in this market segment. The cost of MAS could also limit its use in other crops over the short term. However, the benefits of using MAS, due to faster development times for improved traits, suggest that almost all varieties of some large market crops in developed countries, such as maize and soybeans, are probably already developed using MAS or GM. Almost all varieties of other large market crops will probably be developed using MAS or other biotechnologies by 2015 (alfalfa, cotton, potatoes, rapeseed, sugar beet, tomatoes, and grains such as rice, wheat, barley, rye and oats).

GM crops

GM technology has a major advantage over all other types of plant breeding technologies. Once a gene or set of genes for a desirable trait has been identified, the gene can be inserted into different plant species. For example, *Bt* genes that provide resistance to lepidopteran insects have been inserted into both cotton and maize.

GM approvals and adoption

Table 7 and Figure 2 provides details on the types of GM crops and traits that have been approved for commercial use in the United States or for which commercial use is pending approval. 74% of all approved or pending traits are for first generation traits such as herbicide tolerance, insect/virus resistance, or a combination of the two.

Second generation traits include agronomic and product quality traits. These account for 19% of the total, of which over half are for different tomato varieties with altered ripening characteristics. Agronomic traits include yield enhancement and tolerance to adverse growing conditions such as cold, drought or heat. These types of traits could be particularly valuable in the future to manage the effects of climate change and to meet growing demand. Of note, no traits for yield improvement or tolerance have been approved to date, although the pest resistance traits can increase yields by reducing crop predation. Two agronomic traits are pending: one is for freeze tolerant Eucalyptus and the other is for drought tolerant maize.

The remaining 7% of approved or pending GM traits are for male sterility. Sterility is a valuable trait that prevents crossing between GM varieties and non GM crop varieties or wild relatives, but it has no direct economic benefit to farmers.

Table 7. **USDA approved and pending GM crop varieties as of August 8, 2009**

				Traits[1]							
Plant	Number of varieties	Status[2]	Year of first approval[1]	HT	HT-IR	IR	VR	PQ	AG	MS	PQ trait
Alfalfa	1	P		1							
Beet	2	A	1998	2							
Beet, sugar	1	A	2008	1							
Chicory	1	A	1997							1	
Cotton	12	A	1994	6	1	5					
Cotton	2	P	-		1	1					
C.bentgrass	1	P	-	1							
Eucalyptus	1	P	-						1		
Flax	1	A	1998	1							
Maize	22	A	1994	6		10		1		2	High lysine
Maize	6	P	-	2	4	1		1	1	1	Starch processing[3]
Papaya	1	A	1996				1				
Papaya	1	P	-				1				
Plum	1	A	2004				1				
Potato	5	A	1994			5	3				
Rapeseed	7	A	1994	6				1		2	Improved oil profile
Rose	1	P	-					1			
Rice	2	A	1999	2							
Soybean	7	A	1993	6				1		1	Improved oil profile
Soybean[4]	5	P	-	1		1		1			High oleic acid
Squash	2	A	1992				2				
Tobacco	1	A	2001					1			Low nicotine
Tomato	11	A	1992			1		10			Fruit ripening altered
Total[5]	*94*			*35*	*6*	*24*	*8*	*17*	*2*	*7*	

Source: Authors, based on USDA (2009a).

Notes: 1. HT = herbicide tolerance, HT-IR = combined herbicide tolerance and insect resistance, VR = virus resistance, PQ = product quality trait, AG = agronomic trait, MS = male sterility. Status: A = approved, P = pending.

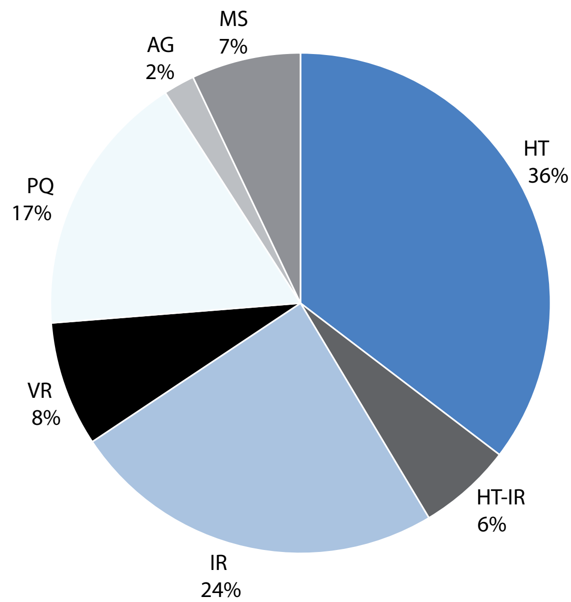
2. Gives the data of the first approval of a GM variety of each plant species. Many varieties will have received the approval status after this date. The date for "pending" refers to the earliest date for varieties still in the pending application status.

3. Variety includes thermostable alpha-amylase which accelerates the conversion of starch to sugar and should decrease the cost of ethanol production. See "Klevorn, TB, Syngenta's Product Pipeline", *www.bio.org/foodag/action/20040623/klevorn.pdf* (last accessed 7 January, 2008).

4. The traits of two pending soybean varieties were not disclosed.

5. Columns do not sum do to stacked traits.

Figure 2. **USDA approved and pending GM traits, by type, as of August 8, 2009**

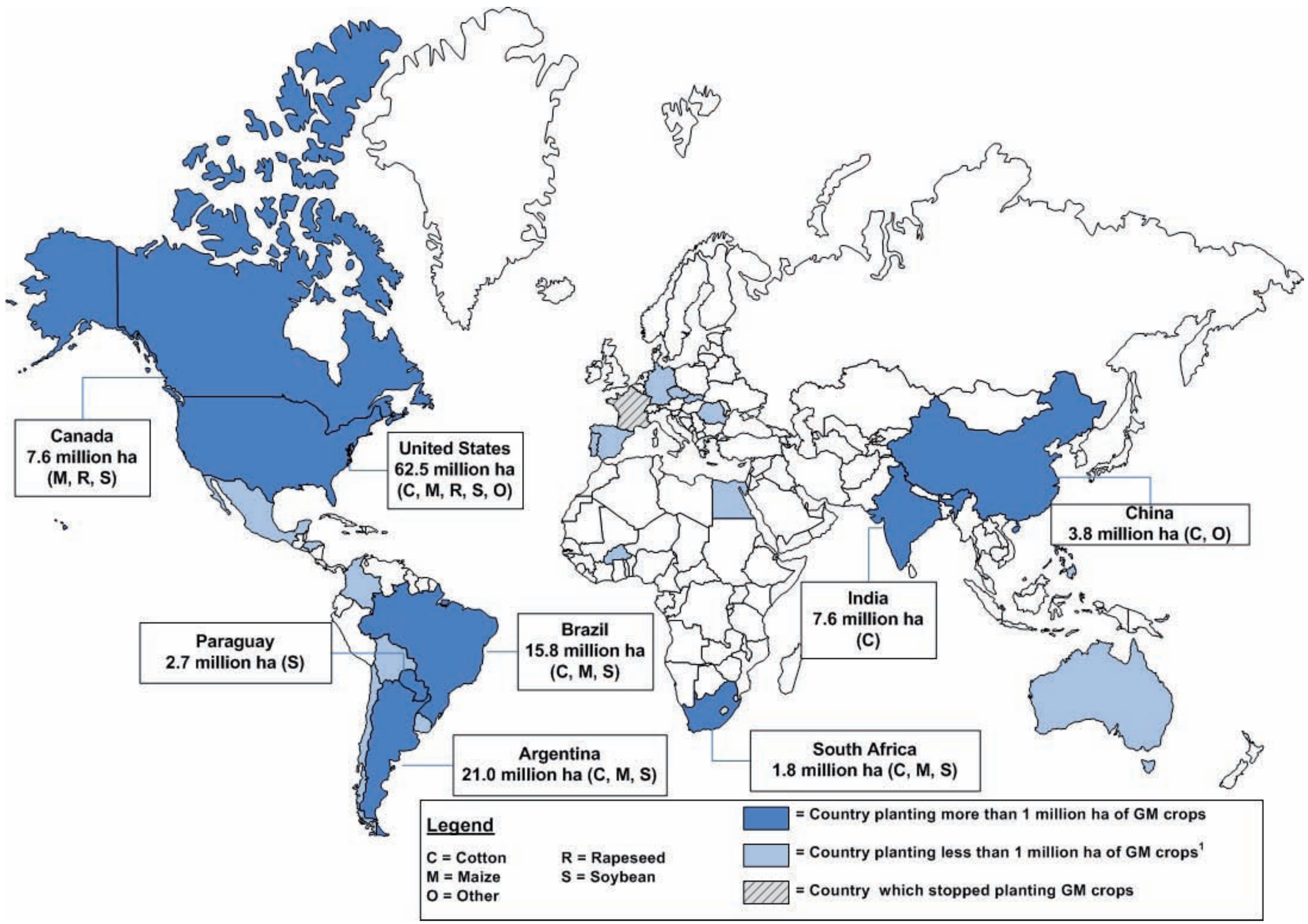


Source: Authors, based on USDA (2009a).

Note: HT = herbicide tolerance, HT-IR = combined herbicide tolerance and insect resistance, VR = virus resistance, PQ = product quality trait, AG = agronomic trait, MS = male sterility.

Although GM varieties of over a dozen different plant species have received regulatory approval somewhere in the world, the large majority of GM plantings are for cotton, maize, rapeseed (canola), and soybeans. Uptake in many regions of the world, in both OECD and non-OECD countries, has been rapid, with GM crops planted in 10 OECD countries and in 15 non-OECD countries in 2008. France, which planted GM maize in 2007, discontinued all GM plantings. Figure 3 displays all the countries that had approved biotech crop plantings in 2008 and highlights the eight countries (two OECD and six non-OECD) that planted a minimum of 1 00 000 hectares. Globally, 125 million hectares were planted with GM crops in 2008, accounting for approximately 10.3% of global hectares planted with all crops. GM varieties accounted for 70.3% of all hectares planted with soybean, 23.3% of maize hectares, 47.0% of cotton hectares, and 18.5% of all rapeseed hectares in 2008 (see the section on “Forecasting for GM crops).[18]

Figure 3. **Approved GM crop plantings, 2008**



Source: Salim Sawaya, based on data from James (2008).

Note: Countries planting less than 1 000 000 hectares in 2007 include: Australia (200 000 ha), Bolivia (600 000 ha), Burkina Faso (<50 000 ha), Chile (<50 000 ha), Colombia (<50 000 ha), Czech Republic (<50 000 ha), Egypt (<50 000 ha), Germany (<50 000 ha), Honduras (<50 000 ha), Mexico (100 000 ha), Philippines (400 000 ha), Poland (<50 000 ha), Portugal (<50 000 ha), Slovakia (<50 000 ha), Spain (100 000 ha), Romania (<50 000), and Uruguay (700 000 ha).

GM field trials

Field trials of GM traits have been conducted in over 130 plant species. The 25 species with the highest number of trials is given in Table 8 and account for 94.4% of all field trials. Maize accounts for almost 40% of all trials. In total, one or more varieties from 13 of the plant species in the top 25 for the number of trials (shaded rows) have been approved or pending in the United States for commercial (unregulated) use as of August 8, 2009 (see Table 7). In addition, several plant species have been approved for use after less than 50 field trials: chicory (42 trials), flax (43 trials), papaya (39 trials), plum (11 trials), and rose (8 trials). An example of GM field trials in a specific type of crops, forage crops (grasses and clovers), are given in Box 2.

Table 8. **Total field trials by plant species: leading 25 plants, as of end 2008**

Species	Number of field trials	Percent of total[1]	Cumulative percent
Maize	8 170	38.1	38.1
Rapeseed	2 120	9.9	48.0
Soybean	1 770	8.2	56.2
Potato	1 628	7.6	63.8
Cotton	1 242	5.8	69.6
Wheat	921	4.3	73.9
Tomato	770	3.6	77.5
Alfalfa	685	3.2	80.7
Beet	540	2.5	83.2
Tobacco	462	2.2	85.3
Rice	331	1.5	86.9
Creeping bentgrass	203	0.9	87.8
Poplar	202	0.9	88.8
Mustard	200	0.9	89.7
Melon	164	0.8	90.5
Pine	156	0.7	91.2
Barley	107	0.5	91.7
Grape	101	0.5	92.2
Lettuce	97	0.5	92.6
Sugarcane	77	0.4	93.0
Squash	72	0.3	93.3
Apple	64	0.3	93.6
Safflower	61	0.3	93.9
Eucalyptus	58	0.3	94.2
Sunflower	56	0.3	94.4

Source: Authors, based on UNU-MERIT (2009).

Notes: 1. The UNU Merit database contains a total of 21 464 plant field trials conducted from 1987 to end 2008.

2. Shaded rows indicate a plant species for which a GM variety has been approved or is pending approval for commercial use in the United States.

3. See Annex A for a description of the UNU-Merit field trial database.

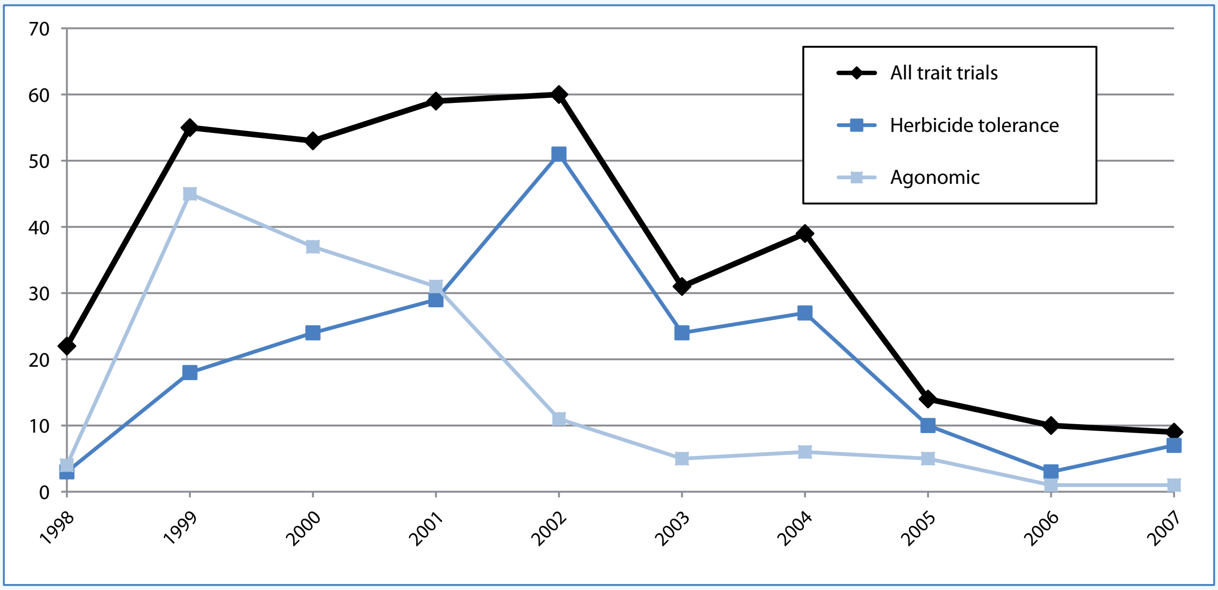
The total number of plant field trials over time is highly variable, as shown in Figure 4. The total reached a peak of 2 244 trials in 1998, declined to 1 139 in 2003, before increasing again to 1 507 trials in 2007. The variation in trials is partly due to the rapid decline in field trials in the EU after 1999, but most of the decline is caused by the completion of specific breeding projects. The decline after 1998, for example, is due to the successful completion of projects on herbicide tolerance and pest resistance using the *Bt* gene. Similarly, new research projects can cause a sudden increase in trials that can extend over several years.

Box 2. **GM field in forage crops**

Grasses and clovers have also been the subject of significant GM R&D. As shown in the figure, there were over 50 trait trials per year for grasses and clovers between 1999 and 2002. Interest has declined after 2004. The focus also shifted after 2001 from agronomic traits to herbicide tolerance.

While it is difficult to determine if interest in developing new GM varieties of grasses and clovers will continue to decline, interest in fibrous crops as a feedstock for lignocellulosic biofuels may spur interest. It may also be that interest is declining because few grass and clovers varieties have sufficiently large markets to justify the research cost. Research into GM grasses has been concentrated in a small number of species. Creeping bentgrass has been the target of nearly 60% of all grass and clover field trials and it is the only grass which has been approved for use in the United States.

GM field trials for forage grasses

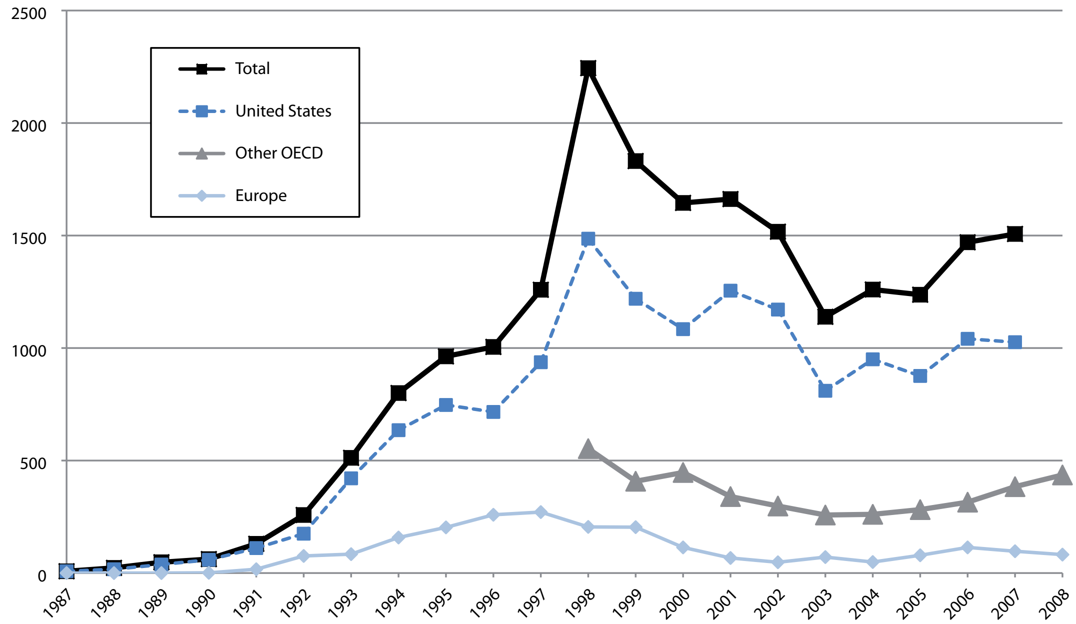


Source: Authors, based on UNU-MERIT (2009).

Notes: 1. Includes bahiagrass, clovers, bermuda grass, canary seed, ryegrasses, St. Augustine grass, switchgrass, tall fescue, and velvet bentgrass.

2. See Annex A for a description of the UNU-Merit field trial database.

Figure 4. **Number of GM field trials of plant varieties by region: 1987 to 2008**



Source: Authors, based on UNU-MERIT (2009).

Notes: 1. See Annex A for a description of the UNU-Merit field trial database.

2. Data for 2008 is not shown due to possible incomplete records for the United States.

Forecasting for GM crops

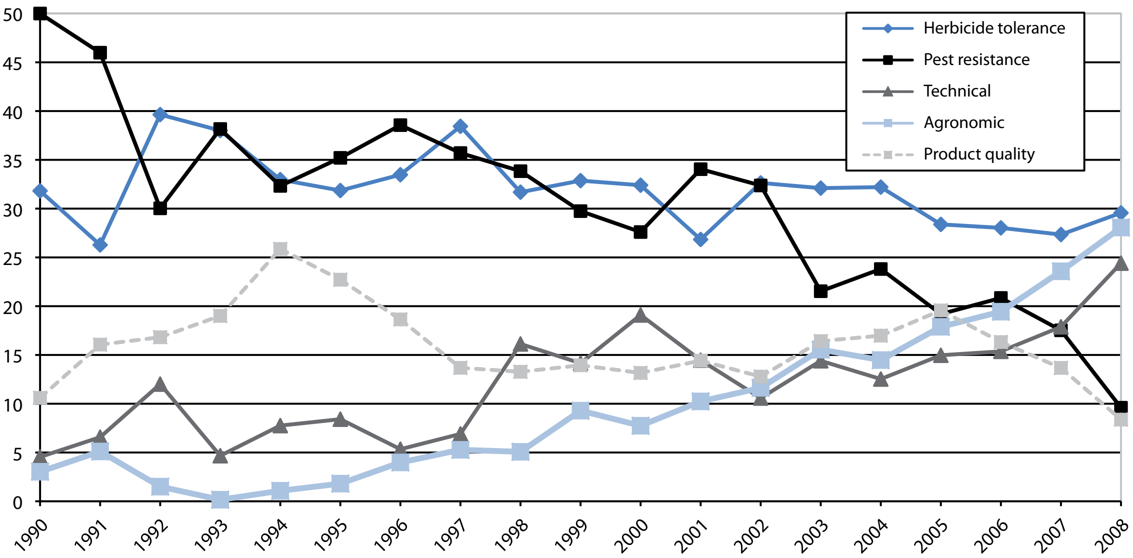
The development of a new plant variety takes between eight to twelve years. The initial steps begin in the laboratory with a search for valuable genetic traits, followed by small trials in greenhouses. The final stage, which can require several years, consists of open field trials under natural climatic conditions. Due to the time lag between field trials and commercialisation, field trial data can be used as leading indicators of the types of GM plant varieties and traits that are likely to reach the market by 2015, as well as indicators of research trends. However, field trial data can only provide a rough estimate of future trends because firms can abandon a research project after the failure of a series of field trials or decide not to apply for market approval. The estimates from the GM field trials are therefore corroborated with data on GM R&D derived from the annual reports of the world's largest seed firms. The two sets of data provide comparable forecasts up to 2015.

A second forecast uses past trend rates in GM plantings of four main GM crop varieties to estimate the future share, in hectares, of GM varieties for each of these crops. Unfortunately, there are no available data for estimating the future marketing of new crop varieties developed through the use of non-GM biotechnology.

Forecasting using GM requires examining traits in specific crops. A field trial can test more than one trait, due to stacking more than one GM trait in a plant variety. Traits can be stacked within a trait category, for example when a GM variety includes traits that confer resistance to two types of herbicides or several types of pests, or they can be stacked across categories, as when a GM plant includes a gene that confers herbicide resistance and insect resistance. The analyses given only identify trait stacking across categories, which will underestimate the actual total. Out of the total of 21 464 plant trials, 6 168 (28.7%) included stacked genes in more than one trait category.

Figure 5 gives the percentage of all 28 025 trial-trait combinations of GM trials for plants by category, based on counting trait categories. The results measure research interest in specific category types. The share of herbicide tolerance out of all trials has remained at around 30% since 1990. Conversely, pest resistance trials have declined steadily from 50% of all trials in 1990 to around 10% in 2008. Over the same time period, the share of agronomic traits increased tenfold from 3% in 1990 to nearly 30%, and the share for technical traits increased five-fold from 5% to almost 25%. Product quality traits saw a large increase in interest in the early 1990s followed by a decline and a gradual increase to 2004, followed by a second decline. Overall, these results show a shift in GM crop development from a focus on first generation herbicide and pest resistance traits to second generation agronomic traits.

Figure 5. **Share of GM plant field trials by trait category (share of total trait trials)**



Source: Authors, based on UNU-MERIT (2009).

Notes: 1. See Annex A for a description of the UNU-Merit field trial database.

2. The shares exclude unknown traits (approximately 1% of the total).

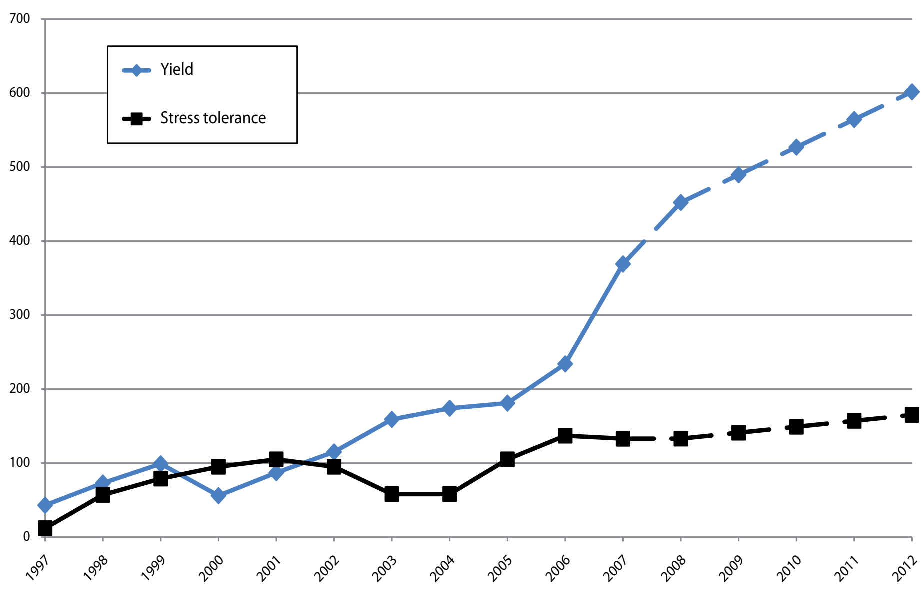
The data do not provide clear answers as to whether or not seed developers will continue to actively pursue product quality traits as a main focus of their R&D programmes. Graff *et al.* (2009) analysed 558 experiments with GM product quality traits and noted a similar decline in research interest and a shift from research into traits for consumer appeal to industrial processing traits. They suggest that one cause of the decline in interest was the European moratorium on GM crops in the late 1990s, which may have reduced consumer interest in quality traits in many other markets as well.

Field trial data do not provide accurate estimates of specific plant varieties that will reach the market over the short term future, due to the poor correlation between the number of trials and new marketed varieties. For example, there have been 921 field trials of wheat, 202 field trials of poplar, 164 field trials of melon, 97 field trials of lettuce, and 101 field trials of grape, without any GM varieties of these species given regulatory approval for commercial use in the United States as of August 2009.

Field tested varieties of GM plants can fail to proceed to market approval because of technical failures, the need for more field tests, or the firm did not apply for market approval. For example, GM wheat is ready for commercialisation, but the lack of a pending application for release is probably due to concerns over its acceptance in major export markets outside North America.[19] In addition, the number of required field trials to develop a commercial new variety is highly variable, ranging from a low of seven trials for a viral resistant plum to several hundred trials to alter the ripening characteristics of a tomato variety.

Yet even with these constraints, field trial data can provide useful insights into the focus of research programmes. This permits approximate forecasts for the types of GM plant varieties and types of traits that are likely to reach the market in the future. The time required between the first field trials and commercial approval varies depending on the maturity of the research programme, but it could range between two and ten years. Consequently, field trial data back to 1998 are used to estimate the types of product categories that could reach the market between 2007 and 2015 and data back to 2000 are used to estimate specific plant species that could reach the market.

Figure 6. **Observed (to 2007) and forecast (2008-2012) field trials by agronomic trait**



Source: Authors, based on UNU-MERIT (2009).

Notes: 1. Dotted lines give extrapolations based on the observed data series for the number trials per year. The start year for extrapolations is 1997 for stress tolerance and 2000 for yield. A total of 2685 agronomic traits were field tested from 1997 to 2007. Of these, 161 trials, or 6.0% of the total, were assigned to "other", which includes traits with an unknown agronomic purpose. No results are given for this category.

2. See Annex A for a description of the UNU-Merit field trial database.

Forecasts for agronomic traits

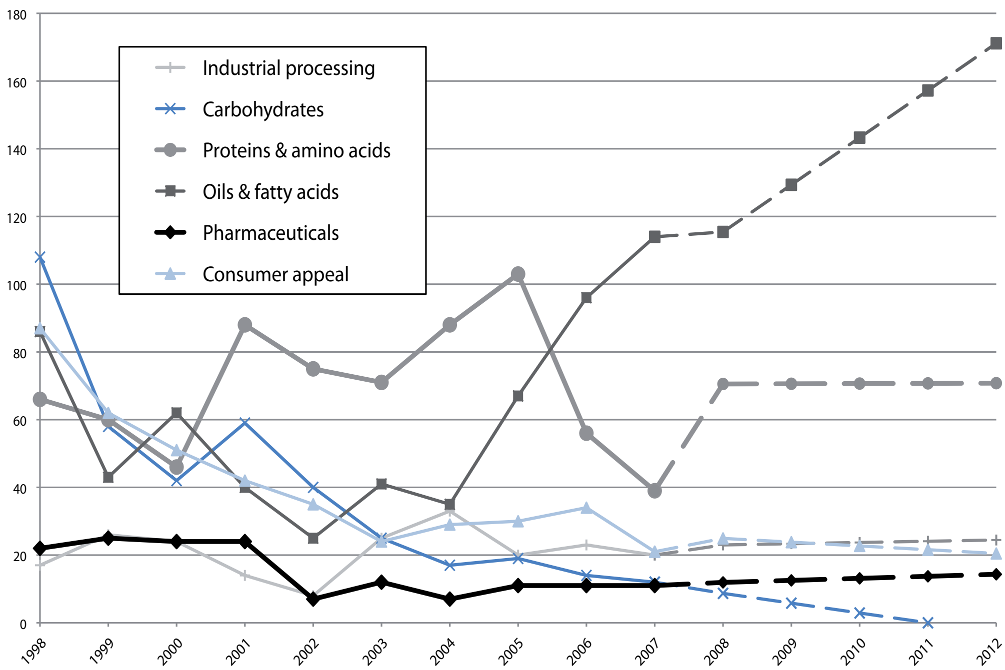
As shown in Figure 5, the focus of GM research has shifted gradually over time to second generation agronomic traits, but as of August 2009 no plant varieties with GM agronomic traits have been approved for commercial use in the United States, although two varieties are pending.

Agronomic traits are divided into two main categories: stress tolerance and yield. Figure 6 shows that there has been a constant increase since 2000 in the number of field trials for yield improvements, while the number of trials for stress tolerance has not been increasing as rapidly.

Forecasts for product quality traits

The UNU-MERIT database divides product quality traits into eight main categories, using information available from the original sources: industrial processing, improved carbohydrate content (sugar and starches), improved proteins and amino acid content, improved oils and fatty acids, the production of pharmaceutical proteins, consumer appeal (altered storage, taste, appearance or nutrition), animal feed, and an "other" category which includes trials for which insufficient information is available to assign the trait to one of the other seven categories.[20] Figure 7 gives the number of trials over time, with forecasts

Figure 7. **Observed (to 2007) and forecast (2008-2012) field trials for product quality traits**



Source: Authors, based on UNU-MERIT (2009).

Notes: 1. Dotted lines give extrapolations based on the observed number of trials per year. The start year for the extrapolations is 1998, except for carbohydrates (2003), pharmaceuticals (2002), oils and fatty acids (2001) and consumer appeal (2002). Different start dates are used for the latter three classes of product quality traits due to a shift in previous trends, such as the increase in trials of product (consumer) appeal from 2003.

2. See Annex A for a description of the UNU-Merit field trial database.

to 2012, for six of the eight product quality categories. No results are given for the "other" category and for feed, since both of these categories are infrequent, stable over time, and overlap with other categories.

Due to limited information in the original field trial data, several of the product quality categories can overlap. The category of "industrial processing" includes traits for both food product processing (starch quality of potatoes, etc.) and industrial inputs (fibre quality, lignin content, etc). However, the category of industrial processing traits could also overlap with other categories. Some of the improvements in fatty acids that are designed for industrial applications could have been assigned to "Oils and fatty acids", while some of the trials in the animal feed category could be due to improved proteins or carbohydrates.

The main focus of trials for product quality traits has been for oils and fatty acids. This category is projected to account for more than double the trials of any other type of product quality in 2012. Trials for proteins and amino acids are expected to remain around 70% per year despite the large drop off in 2006 and 2007. Consumer appeal and industrial processing applications has been comparatively steady and are expected to remain so in the future. There may also be some increased interest in pharmaceutical traits, as interest has picked up in recent years. In contrast, the number of trials for improved carbohydrates has been declining and is forecast to reach zero in 2011.

Forecasts by plant varieties from field trial data

Table 9 provides approximate estimates for when new plant varieties with specific traits could reach the market, using the field trial record.[21] The forecasts are limited to plant species with 25 or more field trials since 2000. The forecasts are subjective and also approximate. The estimated year gives an approximate date for when a new variety should reach the market: 2008/9 indicates mature research programmes for varieties that should reach the market within the next year or so, 2010 identifies varieties that will take several years longer, and 2015 is used for varieties that are farther off in time, but based on intensive research programmes. The estimated years also refer to when a research programme should be completed and not the actual year of commercialisation, which can vary because of a delay in the approval process or a decision on the part of the firm that developed the variety to delay commercialisation. The criteria for estimating the approximate year of completion for a research programme are as follows:

2008/9: Sufficient field trials over the previous seven years to have already produced a new variety. The number of "necessary" field trials is less for well-known traits for herbicide tolerance and pest resistance than for product quality and agronomic traits. In many cases the end of a research programme is also visible by a recent and marked drop in the number of trials. For example, the number of trials for herbicide tolerance in alfalfa dropped from 67 in 2005 to 13 in 2006.

2010: The annual number of trials between 2000 and 2006 is sufficient but relatively stable over all years, with no sign of the end of a research programme.

2015: Most field trials were conducted in the latter half of the 2000 to 2006 period, with no sign of a decline in the number of trials. In many cases the number of trials continues to increase over time. This is particularly common for product quality and agronomic traits.

Abandoned (a): Field trials ended by 2003 or earlier, with no request for commercialisation pending in the US.

Unknown (?): Field trials have been continuing over time, but at a low level. This could be a sign of the need for few field trials (as for the development of virus resistant plum) or a sign that the research programme has not yet fully developed, with commercialisation far off into the future.

Three main conclusions can be drawn from the results in Table 9. First, herbicide tolerance technology is well established, with 10 of the 13 plant varieties with active research programmes likely to end in a commercial product in 2008 or 2009, and the remaining three appearing by 2010. Pest resistance traits are in second place, with 11 expected by 2010, and only four research programmes possibly not reaching completion until 2015.

Table 9. **Approximate estimated date of commercialization for new GM crops by trait using field trial data for 2000 to 2006 inclusive**

	Total field trials	HT	PR	PQ	AG
Corn	4 508	2008	2008	2008	2010
Rapeseed	965	2008	2010	2008	2008
Soybean	834	2008	2008	2008	2010
Wheat	650	2008	2010	2015	2015
Cotton	608	2008	2008	2015	2015
Alfalfa	486	2008	-	2015	a
Potato	341	2010	2008	2008	2010
Rice	212	2008	2010	2008	2010
Tobacco	170	?	?	2010	?
Beet	160	2008	2010	-	-
Tomato	155	a	2010	2010	2015
Creeping bentgrass	149	2008	2008	-	2010
Safflower	73	2010	-	2010	-
Poplar	70	?	?	?	2015
Barley	68	2010	2015	2015	-
Sugarcane	60	a	2015	a	-
Kentucky bluegrass	53	2008	-	-	2015
Lettuce	50	a	a	2015	a
Eucalyptus	48	a	-	2015	2015
Pine	46	-	-	2015	2015
Flax	39	a	-	a	a
Grape	38	a	2015	a	a
Pea	36	2010	a	-	-
Petunia	33	a	-	2010	?
Apple	31	-	2015	2015	-
Lentils	26	a	-	-	-
Peanut	26	-	2010	-	-
Sunflower	26	a	a	a	a

Source: Authors, based on UNU-MERIT (2009).
HT = herbicide tolerance, PR = pest resistance, PQ = product quality, AG = agronomic.
– = no field trials for the specific trait, a = abandoned, ? = insufficient data to predict.

Notes: 1. See Table 7 for approvals pending as of 2009.
2. See Annex A for a description of the UNU-Merit field trial database.

Considerably fewer research programmes for product quality and agronomic traits are likely to be completed by 2008 or 2009, with over half estimated to reach the market in the last time period of 2015.

Second, new GM varieties are still most likely to appear in the main GM crops to date. However, GM varieties should appear by 2015 in several plants that do not yet have any commercial GM varieties on the market: safflower, poplar, barley, sugarcane, Kentucky bluegrass, lettuce, eucalyptus (one variety is already pending), pine, grapes, peas, apples, and peanuts.

Third, a large number of traits appear to have been abandoned, either due to technical failure or lack of commercial markets. In several cases the number of field trials for a specific trait, such as herbicide tolerance in grapes, suggests that the research programme was either successful or close to success. These cases may have been abandoned because of concerns that consumer opposition could have made the variety commercially unprofitable. Alternatively, a variety could be commercially unprofitable because of competitive alternative solutions to the same goal, such as managing pest infestations through pesticides or integrated pest management programmes.

Forecasting using company data

The websites of the nine largest seed firms in terms of the number of GM trials were searched in 2007 for information on their future product pipelines.[22] Four firms provide product pipeline data on their websites: Monsanto, DuPont Pioneer Hi-Bred, Syngenta, and Dow Agrosciences. These four firms account for 66.8% of all field trials of plant varieties between 2000 and 2008 inclusive. All four firms rank their pipelines by product phase, with Monsanto also giving data on the "Estimated time to Market". The information was used to develop an approximate time to market for all four firms (see Annex C for the methodology). The results are given in Table 10 for an approximate middle year of each product phase that matches the time periods used in Table 9.

The four firms report developing 112 new crop-trait combinations, 96.4% of which were in four crops: maize (42.9%), soybeans (33.0%), rapeseed (12.5%), and cotton (8%). These are the four largest GM crops to date in terms of hectares planted. They are also in the top five leading crops in terms of the number of field trials after 2000 (see Table 8). Three remaining crops in Table 10 (alfalfa, sugar beets and rice) account for 4% of the total new crop trait combinations.

Pest resistance accounts for 25 research programmes (22%) and herbicide tolerance for 24 research programmes (21%). However, the main GM firms are moving into both second generation product quality traits (34 research programmes or 30% of the total) and agronomic traits (24 research programmes or 21% of the total). There are also six research programmes under pest resistance into the more technically difficult traits for resistance to nematodes and fungi.

The expected completion dates for the research programmes corroborate the results in Table 9 based on the field trial record. An exception is pest resistance, where the company data show that almost half of the pest resistance trials (14) are not expected by be completed until the third time period, whereas the field trial record shows a peak completion time in the second time period. Conversely, the results for the other three trait categories are similar. Using both data sources, the peak time period for herbicide tolerance is in the first time period, product quality in the middle and last time periods, and agronomic traits in the last time period.

Forecasting using past GM plantings

Table 11 gives the number of hectares planted with GM varieties for each of the four main GM crops between 1996 and 2006 and the GM share of global hectares planted to each crop. Figure 8 graphically illustrates the change in GM shares over time. Data are not available for output in tonnes or USD (which would require yield data), but hectares planted provides an estimate of production and of the potential environmental benefits from reduced tillage or pesticide use.

The data from 2009 to 2015 are based on extrapolating past growth rates in the number of hectares planted to GM and the expected growth in the total number of hectares planted to each crop, based on past trends between 1995 and 2007. The forecasts assume there are no major changes in policy or regulation related to GM crops that would affect uptake.

The number of hectares planted to GM is forecast to increase for all four crops to 2015 while the GM share is forecast to continue to increase for three crops. The fastest uptake of GM technology has been for soybeans, with GM varieties accounting for just over 70% of global cultivation in 2008. This is estimated to increase to over 88.2% of all hectares planted to soybeans in 2015. This is partly driven by a large increase in soybean production

Table 10. **Estimated commercialization dates of trait categories from company website**

Crop	Trait Category	Estimated commercialization date			Total
		2008 (2007-2009)	2010 (2009-2012)	2015 (2012-2018)	
Maize	Herbicide tolerance	7	2	-	9
	Pest resistance	9	-	6	15[1]
	Product Quality	4	3	5	12
	Agronomic	-	2	10	12[2]
Soybean	Herbicide tolerance	3	1	1	5
	Pest resistance	1	3	5	9[3]
	Product Quality	4	8	4	16
	Agronomic	2	2	3	7[4]
Rapeseed	Herbicide tolerance	-	4	1	5
	Product Quality	-	4	1	5
	Agronomic	-	4	-	4[5]
Cotton	Herbicide tolerance	1	1	2	4
	Pest resistance	1	1	2	4
	Agronomic	-	-	1	1[6]
Alfalfa	Herbicide tolerance	-	-	1	1
	Product Quality	-	1	-	1
Sugar beets	Herbicide tolerance	1	-	-	1
Rice	Pest resistance	-	-	1	1
Total		*33*	*36*	*43*	*112*

Source: Authors, based on various sources.

Notes: 1. Includes two traits for fungal resistance (1 expected by 2008, 1 by 2015); others for insect resistance.
2. Includes five traits for drought resistance (1 by 2010, four by 2015), seven traits for yield/improved nitrogen efficiency (1 by 2010, 6 by 2015).
3. Includes three traits for nematode resistance (1 by 2010, 2 by 2015), 1 for fungal resistance (by 2015).
4. One trait for drought resistance by 2015, six for yield (2 by 2008, 2 by 2010, 2 by 2015).
5. All four traits for improved yield by 2010.
6. Drought resistance by 2015.
7. See Annex C for the methodology and sources.

in South America (see Annex D). GM cotton also sees a substantial increase in its global share from about 47% in 2008 to nearly 73% in 2015. Maize will increase from approximately 23% to nearly 30% by 2015. The number of hectares planted to GM rapeseed is forecast to increase from 5.9 million in 2008 to 8.7 million in 2015, but the GM share of all hectares planted to rapeseed is forecast to increase only slightly from 18.5% to 21.3%.

The lower forecasts for the share of GM rapeseed (canola) and maize are mainly due to major producing countries, such as Brazil and China, not yet planting GM varieties of these two crops.[23] Brazil approved GM maize in late 2007 for planting during the 2008 harvest (Reuters, 2008), so the GM share of maize and rapeseed should increase faster in the future than estimated in Figure 8. Adoption of GM maize and rapeseed in Brazil, China and India would substantially increase the estimated GM share for these crops because 33% of global maize hectares and over 50% of rapeseed hectares are found in these three countries.

Other GM crops planted commercially during this time include alfalfa, papaya, potato, rice, squash, tobacco, and tomato. None of these crops, however, account for a significant percentage of world hectares. In addition, time series data are too limited to permit forecasting future growth rates.

Table 11. **Observed (to 2008) and forecast (2009-2015) global hectares planted with GM crops, by year**

	Soybean		Maize		Cotton		Rapeseed	
	Million of GM hectares	GM as % of hectares	Million of GM hectares	GM as % of hectares	Million of GM hectares	GM as % of hectares	Million of GM hectares	GM as % of hectares
1996	0.5	0.8%	0.3	0.2%	0.8	2.3%	0.1	0.5%
1997	5.1	7.6%	3.2	2.3%	1.4	4.2%	1.2	5.1%
1998	14.5	20.4%	8.3	6.0%	2.5	7.6%	2.4	9.3%
1999	21.6	30.0%	11.1	8.1%	3.7	11.7%	3.4	12.3%
2000	25.8	34.7%	10.3	7.5%	5.3	16.9%	2.8	10.9%
2001	33.3	43.4%	9.8	7.1%	6.8	20.1%	2.7	12.0%
2002	36.5	46.2%	12.4	9.0%	6.8	22.7%	3	13.1%
2003	41.4	49.5%	15.5	10.7%	7.2	23.3%	3.6	15.4%
2004	48.4	52.9%	19.3	13.1%	9.9	28.9%	4.3	17.1%
2005	54.4	58.9%	21.2	14.4%	9.8	29.7%	4.6	16.7%
2006	58.6	61.7%	25.2	17.0%	13.4	40.6%	4.8	17.1%
2007	58.6	65.0%	35.2	22.3%	15	45.5%	5.5	17.9%
2008	65.8	70.4%	37.3	23.3%	15.5	47.1%	5.9	18.5%
2009	73.7	76.0%	35.5	21.9%	16.3	49.5%	6.2	18.9%
2010	79.1	78.7%	38.2	23.4%	17.6	53.4%	6.6	19.4%
2011	84.6	81.1%	41.0	24.8%	18.8	57.2%	7.0	19.9%
2012	90.0	83.3%	43.8	26.2%	20.1	61.0%	7.4	20.3%
2013	95.4	85.6%	46.5	27.5%	21.3	65.0%	7.8	20.7%
2014	100.8	86.8%	49.3	28.8%	22.6	68.8%	8.2	21.0%
2015	106.3	88.2%	52.1	30.1%	23.8	72.7%	8.7	21.3%

Source: Authors, based on world hectare data from the FAO (2009) and GM plantings from James (various years).

Notes: 1. Shaded rows represent forecasts.
2. FAO data for cotton only goes to 2005, for all other crops data is for 2007.
3. Projection assumes there are no major changes in policy or regulation related to GM crops that would affect uptake.

As expected, the increase in area and the percentage of global area planted with GM crops begins to slow over the projection period. This is a result of saturation of the available market for GM crops.

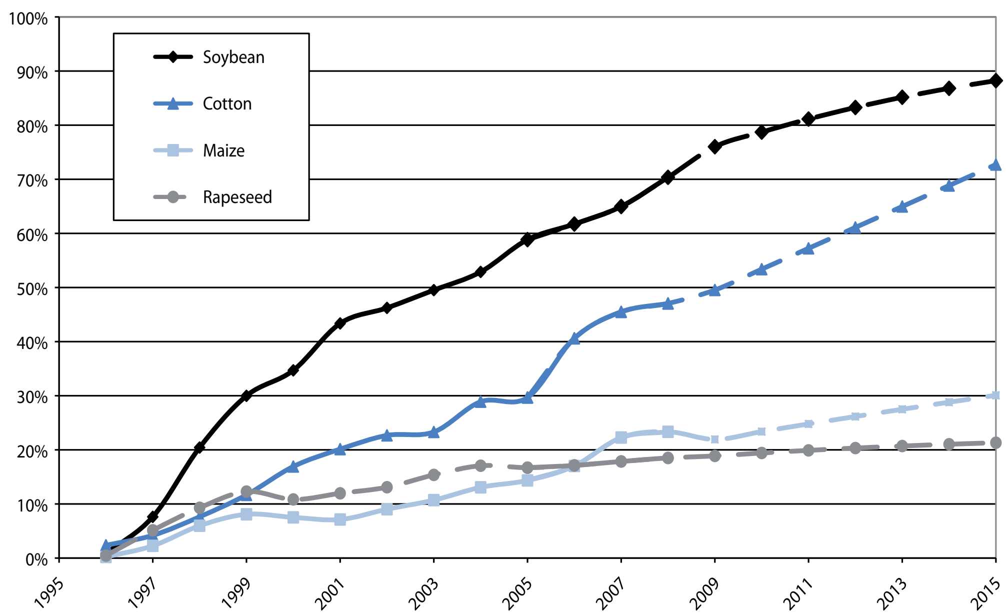
In the United States, the share of hectares planted to GM for three main crops is already close to saturation, with a GM share in 2009 for total hectares plant to each crop of 91% for soybeans, 88% for cotton, and 85% for maize (see Figure 9).[24]

Potential trends

The maximum contribution of biotechnology to the food, feed and industrial feedstock sector would be reached when 100% of crops are based on varieties developed through biotechnology. This is unlikely to occur for any crop because of demand for organic or traditional varieties, but GM varieties of soybeans could be responsible for the vast majority of total plantings by 2015. Most of the remaining new varieties of major food crops are likely to be developed using MAS and related biotechnologies.

A second estimate assumes that all crops with either GM varieties on the market or GM field trials underway will be grown using either GM or MAS varieties. The estimate gives the share of total world and OECD hectares potentially planted to "biotechnology" crop varieties and total world and OECD production prices from these varieties. The number

Figure 8. **Observed (to 2008) and forecast (2009-2015) global GM share of total hectares planted (%), by year**

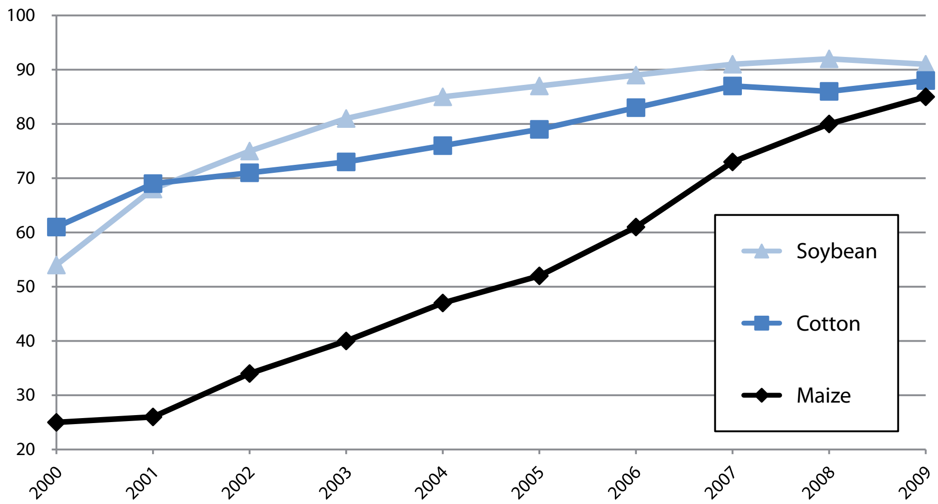


Source: Authors, based on world hectare data from the FAO (2009) and GM plantings from James (various years).

Notes: 1. FAO data for cotton only goes to 2005, for all other crops data is for 2007.

2. Projection assumes there are no major changes in policy or regulation related to GM crops that would affect uptake.

Figure 9. **Share of acreage planted to GM crop varieties in United States, by crop**



Source: Authors, based on USDA Economic Research Service (2009).

Note: Data includes insect-resistant, herbicide-tolerant, and stacked crop varieties.

of hectares planted is an indicator of potential environmental impacts. Producer prices estimate the potential economic output of biotechnology.[25] This does not take into account subsidies that may skew production prices in certain countries.

Current crop varieties based on biotechnology could potentially contribute to crops accounting for USD 164.1 billion in production prices within the OECD and USD 410.9 billion globally (see Tables 12 and 13), equivalent to 46.7% of total OECD production prices of USD 351.8 billion and 41.5% of total global production prices of USD 985.7 billion. In addition, current biotechnology crops could account for 59.2% of global crop hectares[26] and for 68.1% of crop hectares within the OECD.

The third group ("other crops" in Tables 12 and 13) consists of crops where there are no GM varieties on the market. These include many high value-added crops including vegetables, nuts, most fruits, olives and wine grapes that account for 53.4% of production prices within the OECD, although only 41.4% of hectares planted. The rate at which varieties based on biotechnology are adopted in this group will depend on the cost of GM and MAS. As many of these varieties are also sold directly to consumers, acceptance of GM could be a greater issue than for crops such as maize or soybeans that are mostly used in either processed foods (where they are less visible) or as animal feed.

Table 14 gives the yield in tonnes per hectare for each main biotechnology crop, plus the change in yield. The main biotechnological traits to date in these crops are for insect resistance and herbicide tolerance, with no agronomic traits that directly influence yields. Nevertheless, it is interesting that worldwide the yields of the four main GM crops (cotton, maize, rapeseed and soybeans) have increased at an average rate of 13.8% over the period 1995 to 2005, compared to a rate of 7.0% for the other GM crops that account for a much smaller percentage of total output of each crop. This could be due to better yields from lower insect infestations in the GM varieties or possibly because farmers growing more

Table 12. **World production of main GM and other crops (2005)**

A. WORLD	Hectares (thousand)	% of total	Production Price USD million)[5]	% of total
Main GM Target Crops				
Alfalfa	15 119	1.25%	N/A	N/A
Cottonseed	33 026	2.72%	16 950.94	1.72%
Flaxseed	2 510	0.21%	524.46	0.05%
Maize	144 990	11.94%	69 512.94	7.04%
Papaya	381	0.03%	3 056.72	0.31%
Plum1	2 343	0.19%	2 720.20	0.28%
Potatoes	18 816	1.55%	52 171.91	5.28%
Rapeseed[2]	28 261	2.33%	9 350.84	0.95%
Rice, paddy	153 860	12.67%	97 638.01	9.89%
Soybeans	92 113	7.59%	40 397.62	4.09%
Squash[3]	1 507	0.12%	2 644.83	0.27%
Sugar beet	5 456	0.45%	10 388.28	1.05%
Tobacco	3 909	0.32%	N/A	N/A
Tomatoes	4 620	0.38%	27 062.30	2.74%
Wheat	220 394	18.15%	78 464.53	7.95%
Other crops[4]	502124	41.35%	576 526.29	58.39%
Total	1 214 310	100%	985 698	100%

Source: Authors, based on FAO (2009). See table 13 for notes.

Table 13. **OECD production of main GM and other crops (2005)**

B. OECD	Hectares (thousand)	% of total	Production Price (USD million)[5]	% of total
Main GM Target Crops				
Alfalfa	11 724	4.38%	N/A	N/A
Cottonseed	7 052	2.64%	5 228.05	1.49%
Flaxseed	781	0.29%	284.66	0.08%
Maize	45 000	16.82%	35 348.07	10.05%
Papaya	20	0.01%	261.13	0.07%
Plum[1]	190	0.07%	1 225.18	0.35%
Potatoes	2 810	1.05%	16 614.62	4.72%
Rapeseed[2]	11 526	4.31%	5 313.20	1.51%
Rice	4 641	1.73%	21 571.24	6.13%
Soybeans	30 657	11.46%	18 873.37	5.36%
Squash[3]	149	0.06%	1 417.77	0.40%
Sugar beet	3 031	1.13%	8 053.85	2.29%
Tobacco	514	0.19%	N/A	N/A
Tomatoes	871	0.33%	15 500.25	4.41%
Wheat	75 128	28.07%	34 438.07	9.79%
Other crops[4]	85 233	31.85%	187 701.22	53.35%
Total	267 602	100%	351 831	100%

Source: Authors, based on FAO (2009).

Notes: 1. Plums include sloes.
2. Rapeseed includes mustard seed.
3. Squash includes pumpkins & gourds.
4. See Annex E for a list of other crops.
5. Production price data is from 2003.

Table 14. **Yield and % change (1995-2005) for world and OECD, by crop**

	Yield Rate (tonnes / hectare)			
	World		OECD	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Alfalfa	30	-2.90%	32	-2.76%
Cottonseed	1	13.47%	2	20.45%
Flaxseed	1	29.62%	2	24.35%
Maize	5	18.20%	8	18.63%
Papaya	17	5.38%	37	14.58%
Plums[2]	4	0.51%	9	21.94%
Potatoes	17	5.81%	32	15.36%
Rapeseed[3]	2	14.20%	2	14.98%
Rice, paddy	4	7.70%	7	3.26%
Soybeans	2	9.38%	3	2.75%
Squash[4]	13	2.45%	22	8.41%
Sugar beet	46	20.86%	57	11.91%
Tobacco	2	3.24%	2	-4.99%
Tomatoes	27	1.99%	50	6.82%
Wheat	3	2.74%	3	3.16%
Other crops[5]	N/A	N/A	N/A	N/A

Source: Authors, based on FAO (2009). For notes, see Table 13.

expensive GM varieties take better care of their crops. The alternative explanation is that the increase is simply part of a general trend for improved yields, with yields of conventional varieties of these four main crops also increasing rapidly.[27]

Plant diagnostics

Biotechnology can provide accurate and efficient diagnostics to identify specific plant diseases before the disease causes significant economic damage, allowing the farmer to either treat the affected crop with pesticides or to prevent the spread of disease to unaffected crops.[28] Plant pathogens can cause the loss of between 16% and 18% of the crop (Pinstrup-Andersen, 2001). Estimates of the economic losses from plant disease vary widely depending on the underlying assumptions. In the late 1980s, plant diseases were estimated to result in global crop losses of USD 8 billion in maize, USD 10 million in potatoes, USD 33 billion in rice, and USD 14 billion in wheat. Estimates for the United States vary between a total of USD 9.1 billion per year (Fermin-Munoz *et al.,* 2000) and USD 33 billion per year (Pimentel *et al*., 2005). The developing countries suffer greater relative crop losses than developed countries, due to the economic importance of agriculture and the high cost of plant protection products.

There is a large variation in the amount of crop damage done by specific pathogens. *Fusarium* fungi species can cause crop losses of 25% to 60% for potatoes (Michigan State University, 2009) and between 18% and 95% among different lettuce varieties (ISID, 2003). Nematodes can destroy between 20% and 70% of potato crops (ISID, 2004).

As of February 2008, the American Phytopathological Society (APS) has identified 97 plant varieties suffering from 6 169 infectious diseases (APS, n.d.): 60.6% of the diseases are fungal, 15.5% are viral, 11.5% are caused by nematodes and other parasitic diseases, 5.7% are bacterial, and the balance are caused by a range of other diseases and disorders. Some pathogens are at the root of many diseases, such as the fungus *Rhizoctonia solani*, which causes 106 different diseases. New plant pathogens are continually discovered, with eight new pathogens and 10 new strains of identified pathogens identified in 2007 (ISID, 2007).

Genetic sequencing of plant pathogens permits the development of molecular diagnostics for the pathogen. As of 14 January 2008, DPVweb (2009), had catalogued the sequences of 22 542 strain of 1 185 different viruses and 672 strains of 137 fungi or protozoa. Some of these sequenced pests caused substantial crop losses. For instance, *phytophthora sojae*, which causes USD 1 billion annually in losses from stem and root rot of soybeans, was successfully sequenced in 2004 (GenomeWeb, 2004).

Current status of plant diagnostics

Two types of molecular diagnostics are widely used to detect plant pathogens: ELISA and PCR.[29] Tests are frequently carried out in the laboratory and require specific skills. Diagnostics are available for most important pathogens of developed countries (Ward, 2004). Diagnostics are available for 954 plant diseases (1,402 diagnostics are available in total). Most diagnostics either use PCR (40.4%) or ELISA (53.9%). Table 15 gives the class of pathogen targeted by diagnostics for at least 954 plant diseases. Half of the diagnostics were for the identification of viral diseases.

Forecasting for plant diagnostics

The goal for diagnostics is to develop real-time tests for multiple diseases that can be used by farmers in the field. Twenty-four real-time PCR methods are currently available,[30] but they can only detect single pathogens. An example is a test, introduced in 2007, that can identify nematodes in pine trees (INRA, 2007). Real-time PCR methods are fast but not widely used because they do not include enough assays to get a wide range of diagnoses (Ward *et al.*, 2004). The best technology is a DNA microarray that detects the genomes of plant pathogens, but none are beyond the developmental stage, such as a microarray that can test for 24 potato pathogens (EC, n.d.).[31] The method is still costly and difficult to achieve.[32]

Table 15. **Estimate of plant diagnostics by the class of plant disease tested, as of 2007**

Types of plant diseases	Number of diseases with diagnostics	Percent of total
Bacterial diseases	125	13.1
Fungal diseases	275	28.8
Miscellaneous diseases and disorders	4	0.4
Nematode and parasitic diseases	18	1.9
Phytoplasmal and spiroplasmal diseases	55	5.8
Viral and viroid diseases	477	50.0
Total	954	100.0

Source: Authors based on diagnostic from various companies.

Note: This table may not be complete, due to the difficulty in identifying all plant diagnostics.

Animal farming

Animal farming includes the breeding and raising of livestock (animal husbandry), poultry, fish and bees. It includes all biotechnology applications to farmed species in the Animalia Kingdom, consisting of heterotrophs that feed off other organisms. In addition, biotechnology has some applications to the exploitation and conservation of wild animal populations such as fish.

Livestock accounts for approximately 40% to 50% of the value of agricultural production in OECD countries. The main outputs are dairy products, eggs, meat, and fibre (wool, hair, etc). Global prices are not comparable. As an alternative, Table 16 gives the output of farmed animal products measured in tonnes. In 2005, total production of meat was 288.6 million tonnes, dairy 629.1 million tonnes, and eggs 64.0 million tonnes. The fastest growth rates for animal products between 1995 and 2005 are for poultry, eggs, and pork. Beef production grew by 3.8% globally but declined by 5.2% in the OECD.

Up to 2015, biotechnology has three main applications for livestock, poultry and aquaculture: breeding, propagation, and health (diagnostic and therapeutic) applications. The identical set of biotechnologies used in plant breeding can be applied to animal breeding, including transgenic GM, MAS, cisgenesis, and gene shuffling, etc. In addition, diagnostics can be used to identify serious inherited diseases and to remove afflicted animals from the breeding population.

Table 16. **Animal production (in thousand tonnes)**

	World		OECD	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Animal Fats	8 113	3.74%	5 368	1.59%
Bird Eggs	64 004	30.51%	18 050	10.18%
Bovine	63 982	3.81%	27 307	-5.21%
Dairy	629 053	14.94%	289 097	4.32%
Fibres[2]	3 635	-6.83%	988	-21.64%
Natural Honey	1 384	18.36%	474	8.19%
Other[3]	16 762	6.30%	6 210	-2.52%
Pig	104 630	24.23%	36 706	10.61%
Poultry[4]	82 394	38.01%	37 206	21.94%
Sheep and goat	12 768	19.23%	2 849	-8.39%

Source: Authors, based on FAO (2009).

Notes: 1. To avoid anomalies from variable growing conditions, the percent change was determined from the average production output between 1995 to 1997 and 2003 to 2005.
2. Only includes fibres of animal origin.
3. Other includes edible offal, equine meat, rabbit meat, and meat not included elsewhere.
4. Poultry includes chicken meat, turkey meat, and duck, goose, or guinea fowl.
5. See Annex F for data on the European Union, North America, and South America.

Current status of biotechnology

In contrast to plant biotechnology, there are only a few publicly available databases on animal biotechnology. These are for approved health products. There is no equivalent of the GM field trial databases for animals, nor have any GM varieties of food animals been commercially approved within the OECD.[33]

Livestock and poultry breeding

The largest current commercial application of the use of biotechnology in animal breeding is the application of MAS to conventional breeding programmes. MAS improves the accuracy and speed of breeding programmes. A study by Menrad *et al.* (2006) evaluated the use of MAS in European pig breeders and found that markers or gene assisted selection for genetic problems such as the halothane gene are already widely used to remove defective stock. MAS is not as widely used, however, to identify the presence of desirable genes, partly because of a lack of adequate knowledge of possible markers. Markers are currently available for the halothane gene plus genes linked to meat quality, intramuscular fat, tenderness, resistance to *E.coli*, appetite, growth rate, male infertility, and litter size. Menrad *et al.* (2006) estimate that "MAS contributed to the breeding of around 40% to 80% of breeding females". Similar rates for the use of MAS could apply to other valuable livestock, such as cattle and dairy cows.

Breeding in aquaculture

Table 17 gives production results for marine animals. Fish (mostly wild varieties) account for 59.7% of global production by weight, but fish catches have fallen by 5.2% over the past decade. Conversely, production of molluscs and other marine resources has grown, partly because molluscs and crustaceans are increasingly farmed. Globally, aquaculture produced 45.5 million tonnes of marine products with a market value of approximately USD 63.4 billion (FAO, 2006).

Biotechnology is used to develop improved varieties of shrimp, fish and molluscs for aquaculture. The firm Aqua Bounty, for instance, has developed a GM Atlantic salmon (AquaAdvantage™) that grows much faster than non GM salmon used in fish farming. The growth hormone gene that causes faster growth has also been included in Tilapia, trout and

Table 17. **Marine animal production (in thousand tonnes)**

	World		OECD	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Fish[2]	23 390	-5.20%	9 325	-15.19%
Molluscs[3]	4 821	14.60%	3 751	11.73%
Other[4]	10 967	2.07%	4 116	-18.69%

Source: Authors, based on FAO (2009).

Notes: 1. To avoid any anomalies due to unusual environmental conditions etc., the percent change was determined from the average quantity of the periods 1995 to 1997 and 2003 to 2005.
2. Fish includes freshwater and diadromous fish; and demersal, pelagic, and other marine fish.
3. Molluscs include clams and oysters.
4. Other includes aquatic plants, mammals, and other animals; cephalopods (squid), and crustaceans (shrimp, prawns, lobsters etc).
5. See Annex G for data on the European Union, North America, and South America.

flounder. Aqua Bounty submitted AquaAdvantage™ salmon to the US FDA for approval in 2003, but as of August 2009 the variety has not yet been approved for commercial use. Even if approved, it may not be in commercial use by 2015, due to public opposition (Mulvaney, 2007). To date, the only transgenic fish approved for use within the OECD is a fluorescent gold fish for home aquariums.

MAS has been used in breeding programmes for oysters, salmon and trout for culture. Varieties developed using MAS are estimated to account for 30% of salmon and trout breeding in the European Union, with MAS estimated to contribute to 15% of European Union fish farming turnover (Zika *et al*., 2007).

Breeding of insects

Biotechnology has applications for reducing the viability of insect pests and for improving the health and survival of valuable insect pollinators such as honey bees. Biotechnological applications for insect pollinators and pests are only in the research stage.

Research into pests aims at reducing pest populations and infestations. This can be accomplished by developing male only strains or strains that pass a fatal genetic trait to offspring.

Research on honey bees includes developing insecticide resistant and disease resistant honey bee strains and identifying the cause of honey bee diseases or die off (Pew Initiative on Food and Biotechnology, 2004).[34] The honey bee genome was sequenced and published in October 2006 (Honeybee Genome Sequencing Consortium, 2006).

Therapeutics and diagnostics

The global market for animal heath products is estimated at approximately 3% of the market for human health products, or approximately USD 24.1 billion in 2008 (Elder, 2008), about two-thirds of which are products for farm animals and the remaining third is for companion animals (household pets).

Therapeutics

Biotechnology can be used in the development of animal therapeutics and vaccines. However, very few bio-pharmaceuticals have yet to receive approval for animal use. The FDA's Center for Veterinary Medicine publishes a list of approved drugs for animals in its Green Book.[35] The January 15, 2008 version, only listed one bio-pharmaceutical: bovine somatotropin for use in dairy cows (not approved in the EU).[36] Porcine somatotropin is approved for use in Australia, Mexico, Malaysia and Vietnam to encourage growth and lean meat in pigs. The lack of more bio-pharmaceuticals is probably due to poor cost effectiveness in livestock or a lack of applications in valuable animals such as family pets and racehorses. The most common drugs for livestock are vaccines and anti-infectives.

The only recombinant vaccine approved for the United States for livestock as of December 2006 is a vaccine for West Nile Virus (USDA, 2006), although recombinant rabies vaccines are approved for wild racoon populations and for cats. Otherwise, all vaccines use live or killed infective agents. In Europe, recombinant and live rabies vaccines have been used for the control of rabies in wild foxes. A recombinant vaccine has been available in Europe for pseudorabies (Aujeszky's Disease) which affects pigs, but this vaccine has not so far been used in the United States (Menrad *et al*., 2006). The advantage of the recombinant vaccine over live or killed virus vaccines for this disease is that the recombinant version permits the identification of vaccinated versus infected animals. Europe appears to lead the United States in the development of recombinant vaccines and could have additional recombinant vaccines for animal use either on the market or under development.

Diagnostics

The animal diagnostics sector largely depends on methods that have been developed for the human diagnostic industry, with minor variations. There are two main markets: companion animals (pets) and farm animals. There are two types of molecular or biotechnological tests. Genetic tests target DNA or RNA while immunological tests target protein. Table 18 gives examples of both types of animal diagnostics.

Gene based diagnostic tests for disease detection (or gene probes) permit the identification of the presence of a pathogen, rather than antibodies to a pathogen (the most common form of animal diagnostics). Genetic tests are available for swine fever, Mycobacterium paratuberculosis, and Mycoplasma gallisepticum. In addition, monoclonal antibodies are available for the detection of canine heartworm and feline leukaemia virus in household cats.

Table 18. **Types of animal diagnostics**

Type	Description	Disease target[1]
Genetic tests	Target: DNA/RNA	
Nucleic Acid Sequence Based Amplification	Method to amplify RNA sequences.	Avian influenza Foot-and-mouth disease
DNA microarray	A glass slide or bead containing microscopic DNA samples in an orderly pattern are treated with complimentary-DNA and used to detect the relative expression level of each gene.	Canine heartworm
Fluorescent In Situ Hybridization	A procedure involving the use of fluorescent DNA probes to locate in a tissue section specific regions of DNA in the chromosomes.	Pneumocystis carinii pneumonia
Polymerase Chain Reaction (PCR)	A specific sequence of nucleotides within a double-stranded DNA is amplified to test for disease and detect rare mutations.	Mycobacterium Paratuberculosis Classical Swine Fever Virus
Real-time Polymerase Chain Reaction (real-time PCR)	A laboratory technique based on polymerase chain reaction, which is used to amplify and simultaneously quantify a targeted DNA molecule. It enables both detection and quantification (as absolute number of copies or relative amount when normalized to DNA input or additional normalizing genes) of a specific sequence in a DNA sample.	bovine rotavirus Feline Leukemia Virus
Immuno-diagnostics	Target: proteins (antibody, antigens…)	
Dot Blot	Detection of organic molecules.	Canine Parvovirus Chronic Wasting Disease
Enzyme-Linked ImmunoSorbent Assay (ELISA)	The measurement of specific biochemical substances that depends upon the specificity and high affinity shown by suitable antibodies for their complimentary antigens, which are labelled with an enzyme as an indicator.	Bovine Spongiform Encephalopathy
Competitive Enzyme-Linked ImmunoSorbent Assay (competitive ELISA)	A use of ELISA through competitive binding.	Caprine Arthritis-Encephalitis Virus Bluetongue Virus
Indirect Immuno-Fluorescence Assay	An antigen or antibody is linked to a fluorescent dye that fluoresces when exposed to the complimentary antibody or antigen in a sample.	Babesia Bovis Infection

Source: Authors, definitions from a range of sources.

Notes: 1. The list is not exhaustive.
2. Not all diagnostics for each target are available on the market.

In the United States, animal diagnostic kits for veterinary use to identify diseases are under the control of the United States Department of Agriculture (USDA). This organization ensures that the tests are not harmful or dangerous.[37] In contrast, tests to diagnose genetic traits of animals are not regulated. These tests exist for companion and other animals, for example to identify purebreds, and for livestock and pet breeders (Harmon, 2007). The diagnostic market for companion animals is particularly valuable because pet owners are willing to spend more on healthcare per animal than livestock growers. In 2006, Americans spent USD 19 billion on all forms of pet healthcare (Bellingham, 2007). The time to develop an animal diagnostic (up to market entry) is estimated at half the time required for human diagnostics (Gallagher, 1998).

Estimates of the global market for animal diagnostics vary widely. One report estimated the market for animal diagnostics in 2007 at USD 474 million, (Elder, 2008) but Animal Pharma estimated the market in 2002 at USD 1 100 million (Animal Pharma Report, 2003).[38] The market is attractive for firms already involved in the development of human diagnostics.

Table 19 provides an estimate of the 2002 distribution of sales by diagnostic type. Genetic tests have a 4% market share, while immunodiagnostic tests have 40% of the market.

Table 19. **Estimate of diagnostic sales by type of product – 2002**

	2002 Sales (USD millions)	Share of total diagnostic sales
Immuno-diagnostics	440	40%
Genetic testing	44	4%
Others	616	56%
Total	1 100	100%

Source: Animal Pharma Report, 2003.

Table 20 lists companies that develop and manufacture animal diagnostics and gives the share for each company of all diagnostics that have been licensed by the USDA Center for Veterinary Biologics (2007). The top ten firms produce over 80% of the licensed products, with two firms producing more than half of all animal diagnostic products (57.5%). While not all of these diagnostic tests are biotechnology based, many are, and the table shows the level of concentration present in the animal diagnostic market.

In addition to farmed animals, biotechnological diagnostics can be used to manage wild fish, mollusc and other marine stocks. This is based on DNA fingerprinting to distinguish between different stocks of migrating fish. The technology can be used to set fishing quotas or close fisheries of endangered stocks. DNA fingerprinting can also be used to determine the factors that improve survival of wild fish species released from hatcheries (ETEPS, 2006).

Aquaculture diagnostics and therapeutics

Diagnostics in aquaculture are used to determine the health status of aquaculture species or to determine the cause of illness. Some diseases of aquatic animals can be transmitted through water, causing high infection rates in aquaculture. For example, the viral yellowhead disease in tiger prawns (Penaeus monodon) can kill up to 100% of the affected population (OIE, 2006). In Japan, economic losses due to fish diseases are estimated to fall between USD 97 million and USD 195 million per year (The FishSite, 2005). In 2005, aquaculture production in the United States alone had a value of USD 1.1 billion, of which fish species accounted for 62% of total sales (JAVMA, 2005).

Aquatic animals can be affected by four main families of pathogens: bacteria, fungi, parasites and viruses. As shown in Table 21, there are currently 63 known pathogens that affect aquatic animals. Almost half are parasites (47.6%), one-third are viruses, 15.9% are bacteria, and 3.2% are fungi. While all aquatic species are vulnerable to disease, the vast majority of pathogens target fish. The number of known pathogens for both aquaculture and wild aquatic species is increasing over time.

Table 20. **Number of animal diagnostics, by company, licensed by the USDA (as of June 2009)**

Company	Licensed products	Share of total products (%)	Cumulative percentage (%)
IDEXX Laboratories, Inc	52	29.5%	29.5%
Synbiotics Corporation	40	22.7%	52.3%
VMRD, Inc.	14	8.0%	60.2%
Affinitech, LTD	10	5.7%	65.9%
Veterinary Diagnostic Technology, Inc.	7	4.0%	69.9%
Bio-Rad Laboratories	6	3.4%	73.3%
Intervet, Inc.	5	2.8%	76.1%
Heska Corporation	5	2.8%	79.0%
Meridian Bioscience, Inc.	4	2.3%	81.3%
Prionics USA, Inc.	3	1.7%	83.0%
Charles River Laboratories, Inc.	3	1.7%	84.7%
Trace Diagnostics, Inc.	2	1.1%	85.8%
Tetracore, Inc.	2	1.1%	86.9%
Pierce Chemical Company	2	1.1%	88.1%
Pfizer, Inc.	2	1.1%	89.2%
LMD Agro-Vet LLC	2	1.1%	90.3%
Diagnostic Chemicals Limited (USA)	2	1.1%	91.5%
Colorado Serum Company	2	1.1%	92.6%
Chembio Diagnostic Systems, Inc.	2	1.1%	93.8%
United Vaccines, Inc.	1	0.6%	94.3%
United Biomedical, Inc.	1	0.6%	94.9%
SA Scientific, Inc	1	0.6%	95.5%
Quadraspec, Inc.	1	0.6%	96.0%
Prion Developmental Laboratories, Inc.	1	0.6%	96.6%
Modern Veterinary Therapeutics, LLC	1	0.6%	97.2%
Lohmann Animal Health International	1	0.6%	97.7%
Inverness Medical Innovations	1	0.6%	98.3%
Immucell Corporation	1	0.6%	98.9%
Idetek, Inc.	1	0.6%	99.4%
Abbott Laboratories	1	0.6%	100.0%
TOTAL	176	100	---

Source: Authors, based on USDA (2009b).

Table 21. **Pathogens involved in aquatic animal diseases, by pathogen family – 2008**

	Pathogens	Share of the total
Bacteria	10	15.9
Fungus	2	3.2
Parasite	30	47.6
Virus	21	33.3
TOTAL	63	100.0

Source: Authors, based on AAPQIS (2009).

The World Organisation for Animal Health (OIE) identifies 23 notifiable diseases for aquatic animals, based on their negative economic impacts. Seven affect crustaceans (none is parasitic), nine affect fish (one is parasitic) and seven affect molluscs (all but one are parasitic) (see Table 22). According to the OIE, commercial molecular diagnostics are available for four crustacean, two fish and one mollusc disease. With the exception of a test for the parasite *Bonamia exitiosa,* all detect viruses.[39] There are no data on the exact value of the diagnostic market for aquatic animals.

Biotechnology has the potential to significantly improve aquatic animal diagnostics (McIntosh, 2004) by increasing the speed and sensitivity of diagnosis. However, very few of the currently available diagnostics for aquaculture are based on biotechnological methods such as ELISA PCR, or DNA microarrays. In Japan and in the United Kingdom, research has focused on the use of microarrays. The Japanese Fisheries Research Agency has developed a chip diagnosing 23 different bacterial infections in one test (The FishSite, 2005). A consortium of three UK universities is developing a DNA microarray for hundreds of salmon genes (University of Aberdeen, n.d.). The goal is to determine the genetic causes of poor health in salmon (Science Daily, 2006).

There is a lack of effective therapeutic products to prevent or manage aquatic animal diseases. Only two viral diseases listed by the OIE can be prevented by a vaccine: infectious haematopoietic necrosis (for which a recombinant vaccine has been developed) and red sea bream iridoviral disease. Other vaccines are available for bacterial infections, particularly for salmonid species, but none of them appear to have been developed using advanced biotechnology (Sommerset *et al.*, 2006). As of August 2009, 12 vaccines were available for use in farmed fish in the United States. Globally, five companies dominate the fish vaccine market: Intervet International, Novartis, Schering Plough, Pharmaq, and Bayer.

Propagation

The main advanced propagation biotechnology is cloning. Other propagation methods such as *in vitro* fertilisation (IVF) and embryo transfer are often included under animal biotechnology (ETEPS, 2005), but these technologies do not require genetic knowledge and have been available for decades (the first use of embryo transfer was in 1890).

Nuclear transfer (NT) cloning, based on using embryonic and somatic cells as nuclei donors, is an expensive technology that has been used commercially to reproduce high value individuals, such as breeding bulls. It is also combined with GM to produce animals that express valuable pharmaceuticals in their milk, since conventional breeding of GM stock could result in the loss of the genetic trait that produces the pharmaceutical. Although the FDA has accepted cloning in principle for food animals, cloned animals are unlikely to directly enter the food chain in OECD countries due to their cost. Instead, the most feasible use of cloning is to produce breeding stock, with their progeny possibly entering the food supply. Even here, market opportunities are currently limited by public opposition to food products from cloned animals.[40]

Forecasting

Forecasting for breeding

Up to 2015, the most widespread application of biotechnology to animal breeding is likely to be the use of MAS and related biotechnologies in valuable commercial livestock species such as pigs, cattle, dairy cows, and sheep.

Table 22. **Notifiable OIE diseases for aquatic animals**

	Pathogen type	Molecular tests commercially available
Crustacean Diseases		
Crayfish plague (Aphanomyces astaci)	fungus	no
Infectious hypodermal and haematopoietic necrosis	virus	yes
Spherical baculovirosis (Penaeus monodon-type baculovirus)	virus	yes
Taura syndrome	virus	yes
Tetrahedral baculovirosis (Baculovirus penaei)	virus	yes
White spot disease	virus	no
Yellowhead disease	virus	no
Fish diseases		
Epizootic haematopoietic necrosis	virus	no
Epizootic ulcerative syndrome	fungus	no
Gyrodactylosis (Gyrodactylus salaris)	parasite	no
Infectious haematopoietic necrosis[1]	virus	no
Infectious salmon anaemia	virus	no
Koi herpesvirus disease	virus	yes
Red sea bream iridoviral disease[1]	virus	no
Spring viraemia of carp	virus	yes
Viral haemorrhagic septicaemia	virus	no
Mollusc diseases		
Abalone viral mortality	virus	---[2]
Infection with Bonamia exitiosa	parasite	yes
Infection with Bonamia ostreae	parasite	no
Infection with Marteilia refringens	parasite	no
Infection with Perkinsus marinus	parasite	no
Infection with Perkinsus olseni	parasite	no
Infection with Xenohaliotis californiensis	parasite	no

Source: Authors, based on OIE (2007).

Notes: 1. For those two diseases, there is a vaccine available and accepted by the OIE. For all the other diseases there is no vaccine or it has not been proven to be useful.
2. Data are not yet available for the abalone viral mortality disease.

Up to 2015, the largest potential for biotechnology in marine applications are for wild stock management, for diagnostics and therapeutics for aquaculture, and the use of MAS and related non-GM biotechnologies for breeding aquaculture fish, mollusc and crustacean varieties. Within the OECD, environmental concerns are likely to block the use of GM aquaculture in open waters, limiting this technology first to enclosed pens. Even then, firms could be reluctant to adopt GM fish and other farmed aquaculture animals due to concerns over public opposition.

The most probable developments for insects include *(1)* insecticide and pest resistance varieties of honey bees, developed using MAS or possibly GM technology (more likely to appear towards the end of the time period 2012 to 2015), and *(2)* more extensive diagnostic tests for pathogens that attack honey bee hives. The latter should appear continuously over time.

The development of GM or other modified insects that are agricultural pests is constrained by alternative technologies such as insect resistant crop varieties and insecticides. Consequently it is unclear how many modified pests will be able to successfully move from the current laboratory stage to commercial use. One exception is honey bee pests such as mites, where insecticides could kill both the pest and the honey bee.

Forecasting for diagnostics and therapeutics

Therapeutics

Research is underway to develop a few additional bio-pharmaceuticals for livestock. Examples include Babesia bovis L-lactate dehydrogenase as a potential treatment for parasitic bovine babesiosis (Bork *et al.*, 2004) and recombinant porcine interferon-alpha/gamma to treat classical swine fever (Xia *et al.*, 2005). These products could reach the market by 2015 and porcine somatotropin could be approved by 2015 for use in the United States. Otherwise, the high manufacturing costs of biopharmaceutical therapeutics severely constrain their potential use for chronic disease in livestock. Future applications are limited to three applications: growth or meat quality enhancers (bST and porcine somatotropin), economically expensive infective diseases for which other treatments are not available, and for companion animals. In the future, pharmaceutical companies that develop biotherapeutics for humans could market similar or identical products for the companion animal market (Bellingham, 2007).

Recombinant vaccines offer several advantages over conventional vaccines based on live or killed infective agents, such as improved immunity, plus the vaccinated animal will never develop the disease, which can happen following the administration of conventional vaccines in rare cases. A disadvantage is that they often require more frequent booster shots than for conventional vaccines. Additional recombinant vaccines could reach the market for livestock applications by 2015, but uptake is likely to be much slower than for human applications, where recombinant vaccines should almost entirely replace live and killed vaccines by 2015.

Diagnostics

The diagnostic market is growing rapidly. Between 2002 and 2007, 54 new animal diagnostics (most not based on biotechnology) were launched in the United States, accounting for 33.8% of the 160 diagnostics on the market in 2007 (USDA, 2007).

Over the short term, the most important application of biotechnology is likely to be for diagnostics for animal genetic conditions. This field has been growing rapidly. Some DNA-based microarrays for animal genetics are already commercially available. For example, GeneChip Porcine Genome Array, developed by Affymetrix through its expertise in similar products for the human diagnostic market, contains 20 201 genes (Affymetrix, 2009).

Genetic diagnostics for animal diseases hold great promise, but only a few are currently available. As with plant diagnostics, the goal is to develop microarrays that farmers can use in the field to detect a variety of animal pathogens. One study predicted that farmside genetic testing for disease would be widely available for livestock by 2010, but this is probably optimistic, given the small number of genetic diagnostics for disease that have reached the market so far (NZ MORST, 2005). However, this technology could be widely available by 2015.

Forecasting propagation

Due to public opposition to animal cloning, this technology is unlikely to be commercially applied to develop breeding stock for food animals within the OECD by 2015. The most probable application of animal cloning is to develop GM animals to produce high-value pharmaceuticals. The first commercial use of cloning for meat or dairy production could occur in non-OECD countries, where public opposition to meat derived from cloned animals could be less important, although this claim is based on what appear to be unverified assumptions about attitudes to animal cloning in China.

Forestry

Biotechnology applications in forestry include the use of MAS and GM in breeding programmes and new micropropagation technologies, particularly somatic embryogenesis.[41]

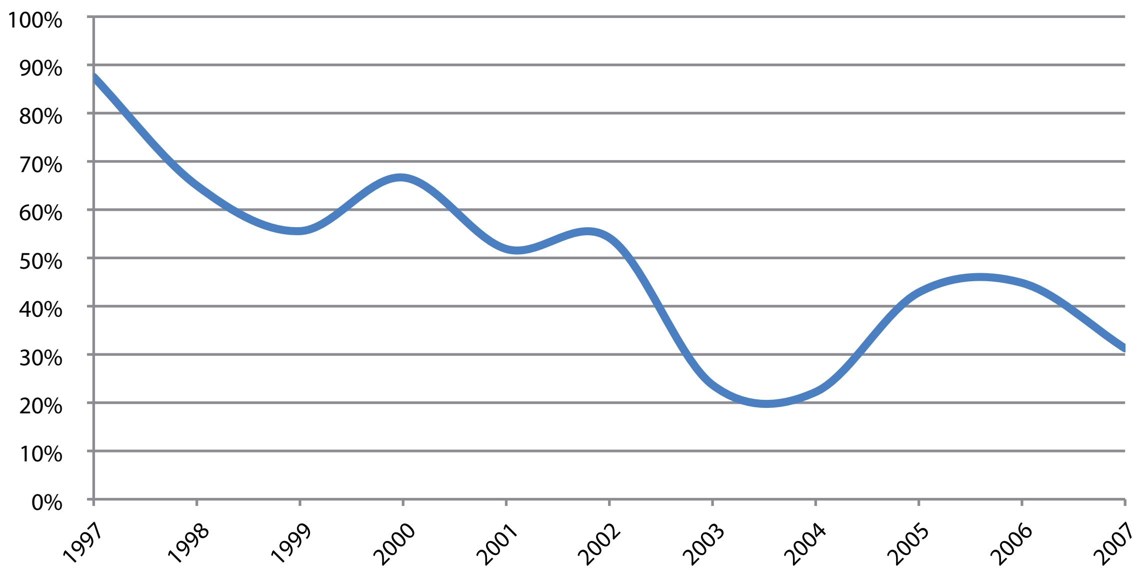
Current status of biotechnology for forestry

Biotechnology research for trees is undertaken by a mix of private and public research entities. As shown in Figure 10, the public sector conducted the majority of GM tree field trials from 1997 to 2002. In 2003, however, the number of field trials conducted by private entities surpassed public entities. This trend has continued, and the private sector conducted nearly 70% of all GM tree field trials in 2007.

Breeding

Research to develop new tree varieties covers many of the traits that are the focus of crop research: pest resistance, product quality, and agronomic traits, particularly yield. Faster growing tree species for timber, pulp and paper, and biofuel is another important goal. Product quality traits concern processing characteristics, particularly for paper production. Biotechnology

Figure 10. **Share of GM tree field trials conducted by the public sector**



Source: Authors, based on UNU-MERIT (2009).

Note: See Annex A for a description of the UNU-Merit field trial database.

can potentially reduce costs by producing tree varieties with modified lignin that is more suitable for paper manufacture, or types of wood that are suited for specialty papers, such as for high quality colour printing. An alternative is to reduce paper costs (both economic and environmental) by developing better ligninolytic enzymes to break down lignin.

Most biotechnology activity is in the research stage, such as identifying markers or sequencing the genome of a few genera such as *populus* (aspen and poplar), *pinus* (pine species), *eucalyptus* species, *betulaceae* (birch) and *picea* (spruce). Compared to breeding programmes for annual crop plants, tree breeding is in an early stage. The only commercial GM tree plantation is in China for a poplar species and one variety of GM eucalyptus is pending approval in the United States (see Table 7).

As shown in Table 23, the most frequent GM trials for tree species concern technical traits, followed by agronomic characteristics, quality applications, herbicide tolerance and pest resistance. Trials for herbicide tolerance fell after 2000, with no herbicide tolerant variety obtaining market approval. Since 2000, almost all GM trials have focused on technical traits (identification of markers), agronomic traits and product quality traits (primarily lignin content). Trials for agronomic (mostly growth) traits increased from 3 in 2001 to 77 in 2007. Based on the field trial record by species, a higher growth variety of pine and possibly poplar could be ready for commercialisation by 2012 and a reduced lignin variety of poplar for paper making (or bioethanol) by 2015.

Table 23. **GM field trials for forestry tree species by trait**

Trait	1993-1999	2000-2007	Total	Percent total
Herbicide tolerance	36	33	68	11.0%
Pest resistance	16	32	48	7.7%
Product quality	10	63	73	11.7%
Technical	24	216	240	38.4%
Agronomic	3	192	195	31.2%
Total	89	536	625	100%

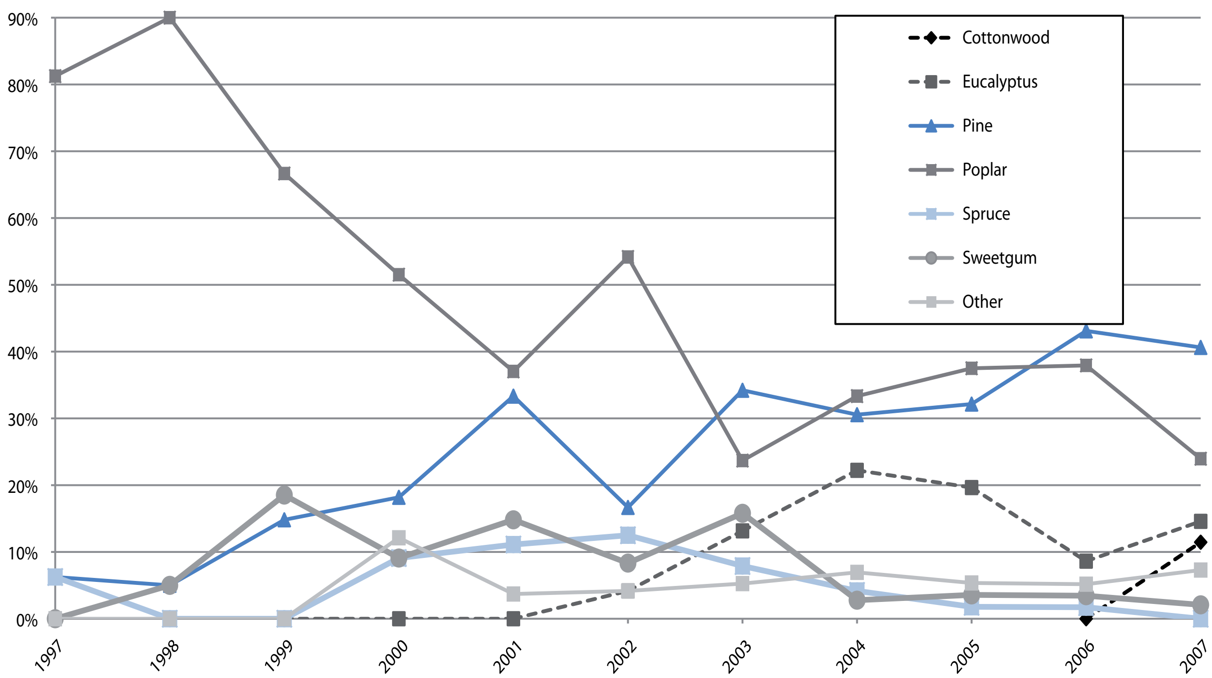
Source: Authors, based on UNU-MERIT (2009).

Notes: 1. Based on trail-trait combinations for 484 field trials conducted from 1993 to 2007.
2. See Annex A for a description of the UNU-Merit field trial database.

Although there has not been a large increase in GM research programmes in pest resistance, this is a major potential application of biotechnology to forestry, both for important wood and fibre tree varieties (pine) and in ornamentals and street trees (elms, chestnuts, California oaks) that have been damaged by introduced pests. The gene coding for *Bt* has been experimentally introduced into poplar varieties to control leaf-eating insects.

GM research has targeted a range of tree species. As shown in Figure 11, GM tree field trials were dominated by poplar species from the late 1990s through 2003. It was then surpassed by field trials for GM pine species, which in 2007 accounted for approximately 40% of all GM tree field trials. Sweetgum and spruce varieties both accounted for around 10% to 15% of all field trials from 2000 to 2003, but interest appears to have waned with no field trials for spruce and only two for sweetgum in 2007. Eucalyptus has also been the subject of field trial activity, accounting for between 10% and 20% of field trials every year since 2003. The first field trials for GM cottonwood began in 2007 and made up 11.5% of trials for that year.

Figure 11. **Share of GM tree field trials, by species**



Source: Authors, based on UNU-MERIT (2009).

Notes: 1. See Annex A for a description of the UNU-Merit field trial database.
2. Other includes American Chestnut, American Elm, Aspen, and Birch.

Micropropagation

Micropropagation covers in vitro methods of vegetative multiplication of large numbers of clones through root cuttings, organogenesis, and somatic embryogenesis. Root cutting techniques are widely used for angiosperms (broadleaf trees) but are not part of modern biotechnology. It is more difficult to use this technique for conifers. One result is that there is a greater chance of commercial success in developing new varieties of broadleaf species. An option for conifers is somatic embryogenesis (SE) which has attracted a lot of research attention as a method of propagation, although the technology has not been commercialised, since many technical problems have not been solved.

A major potential use of SE (with or without MAS) is to speed up tree breeding programmes. Tree varieties often need to be grown for six or more years before it is known if desirable traits are expressed, resulting in 15 to 20 years to develop a new variety, compared to about 8 to 12 years for an annual crop plant. At six years of age, the tree is too old for use in vegetative propagation. Different varieties developed by SE can be both grown and some clones frozen. The clones for the successful varieties can then be thawed and propagated, significantly reducing the time required to develop a new tree variety.

Trends to 2015 in forestry

As noted, two GM varieties of faster growing tree species could be ready for commercialisation by 2012 and an altered lignin variety for pulp or bioethanol production by 2015. MAS should also be widely used in breeding programmes, particularly in countries such as Canada and New Zealand where forestry is a major industry based on a limited number of tree species and active tree replacement programmes. Under these conditions, there is a large commercial potential for improved tree varieties, particularly for pest resistance.

The main growth area for wood and fibre is in humid tropical and semi-tropical regions, where biomass production is many times greater than in the temperate forest zones of the EU. As an example, one hectare of plantation in the tropics produces 40 cubic metres of wood per year, with a harvest age at six years. In contrast, a hectare of forest in Sweden produces 2 cubic metres with a harvestable age of 60 years. Not surprisingly, there is far greater interest in breeding new varieties of fast-growing short rotation trees such as pine and Eucalyptus for wood and fibre in high growth tropical and sub-tropical zones such as Florida (Sedjo, 2005). Second, many northern OECD countries have a surplus of wood. This reduces incentives to invest now in new plantations, although the balance should turn negative by 2050 due to the exploitation of northern forests for pulp and paper and for structural timber. The net result is that there has been less private sector interest for developing new wood and fibre tree varieties for temperate zones, with the exception of poplar species. It is possible that once current temperate forests have been fully exploited, most production of fibre and an increasing level of production of wood will shift to warm humid regions. Although climate change could result in a shift in the location of the best growing regions for commercial tree species, the focus of tree breeding programmes will likely remain on optimal humid and warm environments.

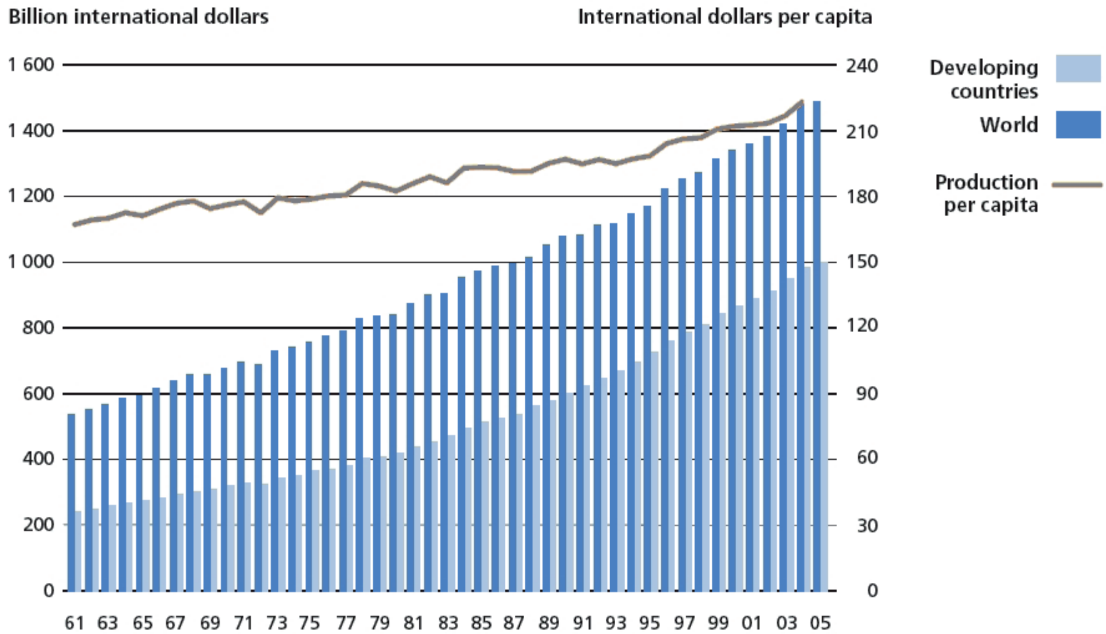
Agricultural biotechnology in developing countries

Agriculture is of vital importance to developing economies. With 80% of the world's population, these regions are the largest overall consumers of food. Hunger and malnutrition remain significant problems, and demand for agricultural products is expected to grow significantly due to increasing populations and income levels. This is likely to be particularly noticeable for animals and animal feed as meat consumption is expected to grow by nearly 1.7% per year from 2007 to 2016 after having increased by 2.7% per year over the previous decade (OECD-FAO, 2007). Meat consumption in developed countries is also expected to increase, but by only 0.7% per year.

Agriculture plays a much larger role in developing, compared with developed, economies both in terms of production and employment. The potential land area that could be dedicated to agriculture is also much larger in the developing world. Given these factors, the application of biotechnology to agriculture in the developing world could have a major impact on people, environments, and economies.

In the early 1960s, developing countries accounted for approximately 45% of global agricultural production (see Figure 12). The developing world's share has increased steadily

Figure 12. **Total and per capita agricultural production**



Source: FAO, 2007.

Note: International dollars are an international commodity price unit, average 1999-2001.

to around 70% in 2005, while at the same time, global agricultural production has risen. Agriculture accounts for an average of 13.4% of the GDP of many developing countries compared to 1.7% of GDP for developed countries. In larger developing countries the share ranges from around 5% in Brazil and Russia, to 11% and 16.6% in China and India respectively (see Table 24).

Table 24. **GDP, agricultural GDP, and agricultural labour force for selected countries and region**

	GDP[2] (billions)	Agriculture[3] (% GDP)	Agricultural Share of GDP (billions)	Agricultural Labour Force[3] (millions)
High-income countries[1]	38 081	1.7%	641	38
Argentina	245.6	6.0%	14.7	0.2
Brazil	1 269	5.1%	64.7	20
China	2 879	11.0%	316.7	345
India	894.1	16.6%	148.4	310
Russia	1 251	4.6%	57.5	6
Other, not high-income	5 740	13.4%	771	487
World Total	50 360	4.0%	2 014.4	1 206

Source: Authors, based on CIA (2008).

Notes: 1. High income countries include all OECD and EU countries. This excludes a number of other small high income countries such as, *inter alia*, Israel and Singapore that would not have a major impact on global agriculture statistics.

2. GDP is the estimated amount for 2007 and calculated using official exchange rates.

3. Data varies from 1999 to 2006.

The number of agricultural workers, which accounts for about 40% of the global labour force, is also much larger in the developing world than it is in developed countries. While high-income countries have 38 million agricultural workers (about 3.1% of the world total), developing countries have over 1.1 billion (see Table 24). Both China and India have more than 300 million workers each in agriculture, accounting for over 50% of the world's agricultural labour force.

The developing world also contains more than 70% of the world's agricultural and forest lands (see Table 25). Agricultural land, as a share of surface area, is almost identical (around 38%) for developing and developed countries, but this is strongly influenced by Russia which has a very large land area and little agricultural land. If Russia is excluded, the share of potential agricultural land in developing countries rises to 44%. The share of forest land is similar for developing and developed countries (around 29.5%). Brazil and Russia have large swathes of forest that account for approximately half of their surface area. These two countries combined account for nearly a third of the world's forests.

There are a number of social, economic, and environmental drivers that point to an increase in the application of biotechnology to agriculture in developing countries by 2015. This could lead to a massive increase in the number of workers, land area, and global agricultural production that are influenced by biotechnology. Indeed a number of developing countries have already adopted biotechnology in much of their agricultural sector. Several developing countries are also making substantial investments in biotechnology research, which should increase their future use of biotechnology.

Table 25. **Area of agricultural and forest lands for selected countries and regions**

	Surface area (1000 sq. km)	Agricultural land[2] (% of land area)	Agricultural land[2] (1000 sq. km)	Forest area[3] (% of land area)	Forest area[3] (1000 sq. km)
High-income countries[1]	35 536	37.5%	13 312	29.6%	10 534
Argentina	2 780	47.0%	1 308	11.9%	330
Brazil	8 515	31.2%	2 653	56.1%	4 777
China	9 598	59.5%	5 710	20.6%	1 973
India	3 287	60.6%	1 992	20.6%	677
Russia	17 098	13.2%	2 251	47.3%	8 088
Other, not high-income	57 027	42.2%	24 083	22.9%	13 047
World Total	13 3841	38.3%	51 309	29.5%	39 426

Source: Authors, based on World Bank (2007).

Notes: 1. High income countries include all OECD and EU countries. Although this excludes a number of small high income countries, such as Israel and Singapore, the exclusions do not have a major impact on global land area statistics.

2. The FAO defines agricultural land as "land area that is arable, under permanent crops, and under permanent pastures. Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded. Land under permanent crops is land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee, and rubber. This category includes land under flowering shrubs, fruit trees, nut trees, and vines, but excludes land under trees grown for wood or timber. Permanent pasture is land used for five or more years for forage, including natural and cultivated crops."

3. The FAO defines forests as "land under natural or planted stands of trees, whether productive or not."

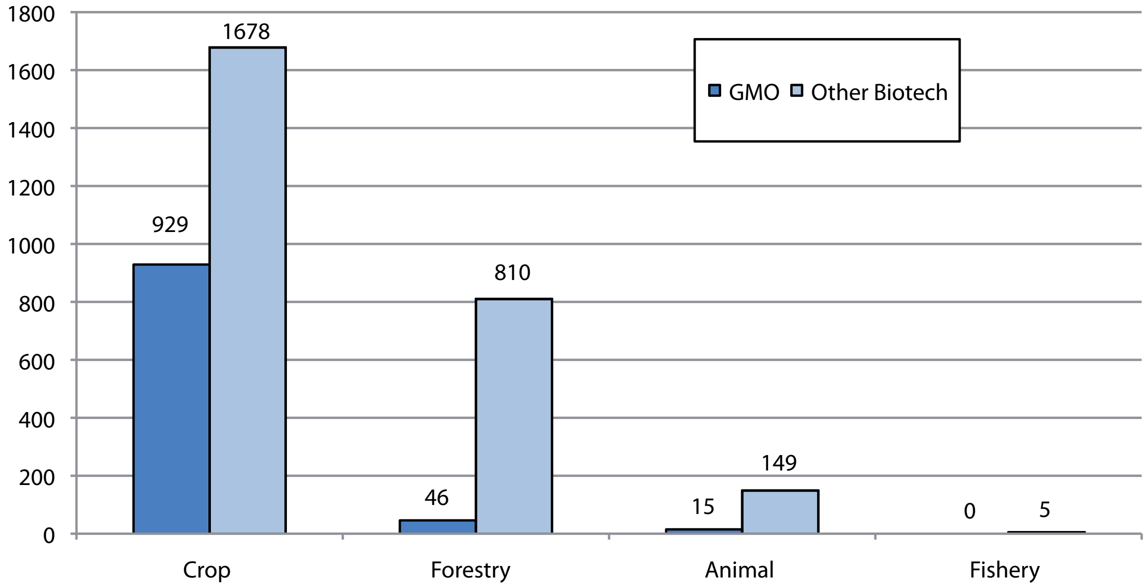
The FAO-BioDeC database, which was launched in April 2003, contains information on "state-of-the-art crop biotechnology products and techniques, which are in use, or in the pipeline in developing countries (FAO, n.d.)." There are more than 2 000 entries for 70 developing countries. They cover projects to develop biopesticides, biofertilisers, diagnostics, fermentation processes, plant breeding, micropropagation methods, other forms of propagation, and a range of other techniques. While the database is unlikely to cover all agricultural biotechnology in use or development, it provides a good indication of the location and types of biotechnology projects in developing countries. As shown in Figure 13, biotechnology in the developing world is primarily applied towards crops, followed by forestry, animal, and fishery applications. In all four application areas non-GMO techniques and products predominate.

Non-GM crop biotechnologies in developing countries

The FAO-BioDeC database contains a total of 1678 non-GM crop projects. Figure 14 shows the breakdown of these projects for three phases: experimental work, trials, and commercialisation. The distribution of each phase by region and type of technology is also shown.

Of the 1 678 projects, 142 (8.5%) have been commercialised, 313 (18.7%) are in trials, 1041 (62%) are in the experimental phase, and 182 have no status specified. Sub-Saharan Africa has commercialised 34% of the 142 projects that have reached this phase, followed by Asia and South America with 24% and 22% respectively. South America has a large majority (64%) of all trials, dominated by Venezuela with 69 trials, followed by Brazil, Chile, and Ecuador with approximately 30 each, Argentina with 18, Peru and Uruguay with 8, and Paraguay with 1. Experimental R&D is led by Asia with 30% of the total. This

Figure 13. **Number of entries in the FAO-BioDeC database**



Source: Authors, based on FAO (n.d.).

experimental research is spread widely over a number of Asian countries with no one country accounting for more than 10% of the total, except Armenia which is undertaking 18% of all experimental projects in Asia.

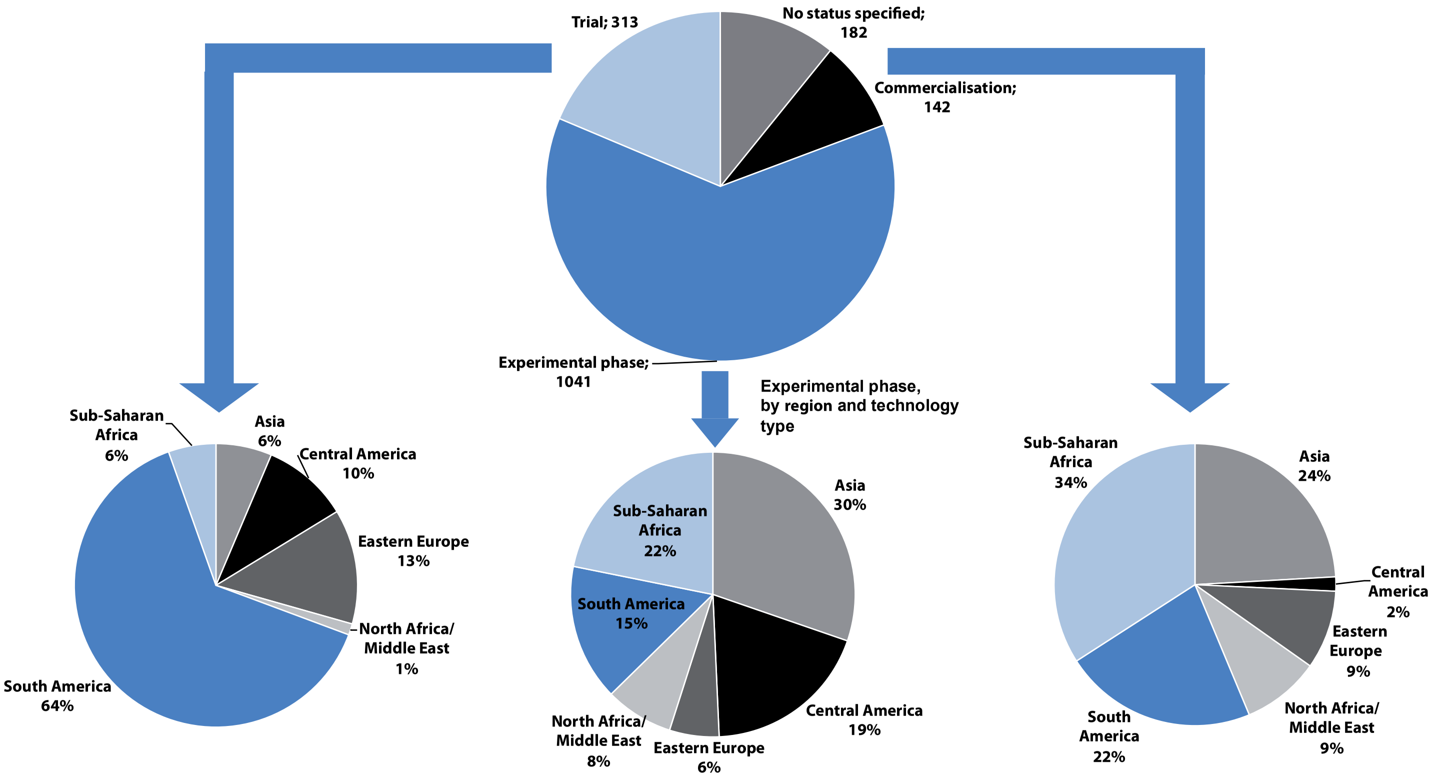
Within each project phase, the prevalence of technology categories is similar and parallels the non-GM plant biotechnology group as a whole. In all cases, plant breeding and micropropagation make up the large majority of all projects. Diagnostics and biopesticides/biofertilisers are the next most studied areas.

GM crops in developing countries

As shown in Figure 15, there are is a significant amount of GM crop activity in the developing world. The FAO-BioDeC database contains a total of 929 GM crop projects: 58 (6.2%) in the commercialization phase, 254 (27.3%) in field trials, 535 (57.6%) in the experimental phase, and the remainder (82) unspecified. In all three specified activities, the Asian region is dominant with 54% of all commercialised GM varieties, 33% of field trials, and 73% of all projects in the experimental phase. South America follows closely with 27% of field trials, but is a distant second in both commercialisation and experimental projects. Sub-Saharan Africa also contains 17% of all the commercialised GM varieties and 11% of all trials, but is only responsible for 5% of all projects in the experimental phase. Central America includes 16% of all field trials, 5% of all experimental GM varieties, and no commercialised GM crops. This large share of trials, however, is heavily influenced by the inclusion of Mexico,[42] which accounts for over 80% of all field trials in Central America.

The large share of GM projects undertaken in Asia, South America, and sub-Saharan Africa is mainly due to the contribution of a few large countries that dominate their respective regions. Table 26 shows the total number of GM projects undertaken in these regions along with the breakdown of the large regional players. In the Asian region, China, India, Indonesia and the Philippines account for more than 85% of all commercialised GM

Figure 14. **Number of non-GM applications of biotechnology to agriculture in developing countries, by phase and technology type**



Trials

Type of Technology	Number
Biopesticides/biofertilizers	22
Diagnostic	15
Fermentation, food process.	5
Other	48
Plant Breeding	113
Propagation, micro	81
Propagation, other	29

Experimental

Type of Technology	Number
Biopesticides/biofertilizers	49
Diagnostic	53
Fermentation, food process.	19
Other	235
Plant Breeding	432
Propagation, micro	247
Propagation, other	6

Commercialisation

Type of Technology	Number
Biopesticides/biofertilizers	5
Diagnostic	6
Fermentation, food process.	11
Other	8
Plant Breeding	15
Propagation, micro	97
Propagation, other	0

Source: Authors, based on FAO (n.d.).

Note: See Annex H for a list of countries by region.

varieties and field trials, and nearly 60% of all projects in the experimental phase. In South America, GM projects are even more concentrated with Argentina accounting for more than 93% of all commercialised varieties, and Argentina and Brazil undertaking more than 90% of all field trials and 40% of all experimental projects. South Africa accounts for all GM varieties commercialised in sub-Saharan Africa and more than 82% of all field trials.

Table 26. **GM projects in selected developing countries and regions, by phase**

	Commercialization	Field Trial	Experimental
Asia	31	83	390
China	10	27	28
India	8	31	114
Indonesia	0	9	54
Philippines	9	4	29
South America	15	68	57
Argentina	14	35	9
Brazil	0	27	14
Sub-Saharan Africa	10	28	25
South Africa	10	23	4

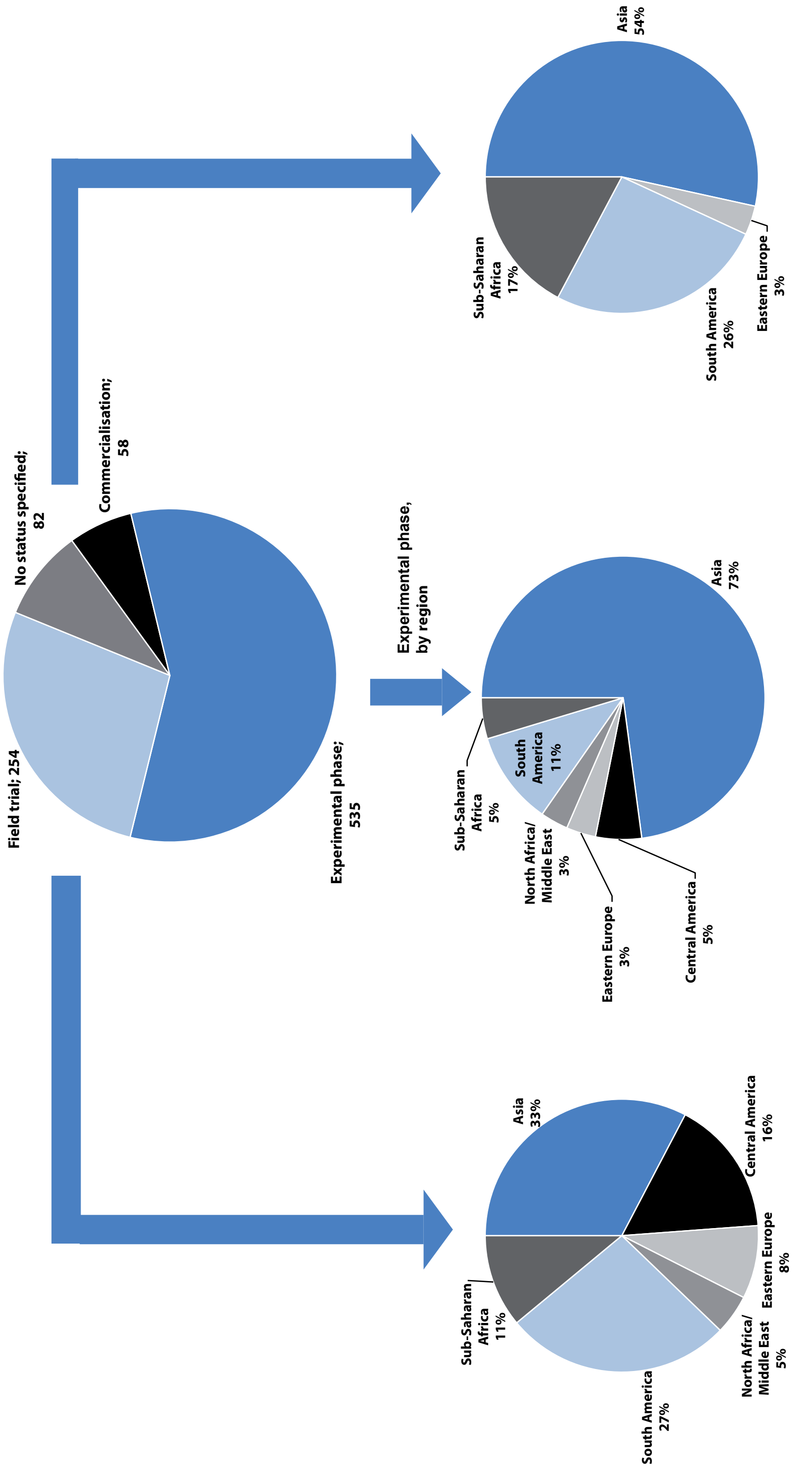
Source: Authors, based on FAO (n.d.).

Almost all of the major commercialised GM varieties and GM field trials in the developing world are for the same crops as in developed countries: cotton, maize and soybeans. In addition, a single variety of the following crops have also been commercialised: orchid, sweet pepper, petunia, green pepper, and red lettuce and field trials have been conducted for sugarcane (10 trials), sunflower (5), cauliflower (4), and cabbage (3) and in a wide variety of other plants. Roughly 60% of all GM varieties in the experimental phases target the main GM crops, while about 4% target sugarcane, and the other 40% span a wide range of plants. Some of the species receiving the most attention are barley, bananas, coffee, eggplant, oil palm, pineapple, sweet potato, and various beans and peas.

Despite the dominance of Asia in GM projects, this has not translated into an equivalent level of technology adoption. Table 27 shows commercial plantings of GM crop varieties in 14 developing countries in 2008. South America accounts for roughly 75% of all GM plantings, while Asia and Africa make up approximately 21.5% and 3.5% respectively. In addition to the plantings listed, a number of other GM crops have received regulatory approval (and are possibly being grown) in developing countries but these tend to be high value crops that are not grown over large areas. For instance, China has commercially approved GM varieties of tomato, sweet pepper and petunia (Cantley, 2006). The FAO-BioDeC database also includes a commercialized variety of GM rice in the Philippines, but there is no evidence that it is being cultivated on a large scale.

This discrepancy between the number of GM projects and adoption rates in Asia and South America could be caused by several factors. First, negative consumer opinion towards GM crops in Asia could be more prevalent that in South America. This is suggested by the adoption of GM cotton in China and India, but no GM human food crops, although pest resistant eggplant is in the final stages of market approval in India.[43] However given the large number of Asian projects for GM rice, which is the regions primary staple crop, GM rice varieties could be approved before 2015. In Asia, rice accounts

Figure 15. **Number of GMO plant variety projects in developing countries, by phase**



Source: Authors, based on FAO (n.d.).

Note: See Annex H for a list of countries by region.

Table 27. **GM plantings in developing countries, by crop for 2008**

Country	Millions Hectares Planted in 2008	Cotton	Maize	Soybean	Other
Argentina	21.0	♦	♦	♦	
Brazil	15.8	♦	♦	♦	
India	7.6	♦			
China	3.8	♦			♦[1]
Paraguay	2.7			♦	
South Africa	1.8	♦	♦	♦	
Uruguay	0.7		♦	♦	
Bolivia	0.6			♦	
Philippines	0.4		♦		
Chile	<0.1		♦	♦	♦[2]
Columbia	<0.1	♦			
Honduras	<0.1		♦		
Burkina Faso	<0.1	♦			
Egypt	<0.1		♦		

Source: Authors, based on James (2008).

Notes: 1. China also cultivates GM poplar, papaya, petunia, sweet pepper, and tomato.
2. Chile also cultivates GM rapeseed.

for 73 out of 390 (18.7%) projects in the experimental phase and for 14 of 83 (16.9%) field trials. Indeed, rice accounts for over two and a half times more experimental projects than tomatoes, which are the second most studied edible plant species in Asia. James (2006) also notes that approximately 20% of China's governmental crop biotechnology budget, or USD 24 million (USD 115 million in PPP), was devoted to rice. This makes China's investment in biotech rice, "undoubtedly … the largest in the world (James, 2006)."

Concerns regarding trade ties between these regions and important markets, such as Europe, Japan, and Korea, that have very strict regulations concerning the consumption of GM crops and adventitious presence, could also play a role in the decision to avoid GM crops. Table 28 presents mixed evidence regarding the influence of trade on the adoption of GM crops. For crops such as maize and soy that are primarily exported as animal feed, trade factors seems to have little if any effect on the decision to grow GM varieties. Between 85% and 92% of the total soy imported by the EU-15 and Switzerland, Japan, and Korea comes from Brazil and the United States, where 55% of the 2006/2007 (James, 2006), and 87% the 2005 soy crop was GM (Fernandez-Cornejo and Caswell, 2006), respectively.

The case is similar for maize, where Argentina and the United States provide over 17% of the EU-15 and Switzerland's maize imports, and the United States alone supplies more than 65% and 95% of Korea and Japan's maize imports respectively. Although the adoption rate of GM maize has been slower than that of soy, 35% of maize cultivated in the United States in 2005 (Fernandez-Cornejo and Caswell 2006) and over 65% in Argentina in 2006 was GM (James, 2006), indicating that trade concerns have not prevented plantings of GM maize.

Table 28. **Maize, rice, and soybean trade between various regions and Europe, Japan, and Korea in 2006**

	EU-15 + Switzerland (as % of total imported value[1])			Japan (as % of total imported value[1])			Korea (as % of total imported value[1])		
Exporting Country	Maize	Rice	Soy	Maize	Rice	Soy	Maize	Rice	Soy
Africa, excl. S. Africa	0.1%	6.2%	0.0%	0.0%	N/A	N/A	0.0%	N/A	N/A
Argentina	14.6%	1.3%	0.6%	0.5%	N/A	N/A	0.3%	N/A	0.0%
Brazil	11.7%	3.9%	63.4%	0.0%	N/A	8.1%	10.1%	N/A	44.4%
Canada	0.1%	0.0%	4.0%	N/A	N/A	9.2%	0.0%	N/A	N/A
China	0.0%	0.3%	0.3%	2.8%	17.8%	6.2%	22.2%	57.5%	7.4%
India[2]	0.0%	1.7%	0.0%	N/A	0.0%	N/A	0.0%	0.0%	0.0%
Indonesia	0.0%	0.0%	0.0%	0.1%	N/A	N/A	0.2%	N/A	N/A
Philippines	0.0%	0.0%	N/A	0.0%	N/A	N/A	N/A	0.2%	N/A
South Africa	0.1%	0.0%	0.0%	0.0%	N/A	N/A	0.1%	N/A	N/A
United States	3.0%	23.6%	23.1%	96.2%	52.5%	76.5%	66.3%	26.9%	48.0%

Source: Authors, based on OECD (2006).

Notes: 1. Value is measured in current USD
2. Data for India is only for Switzerland as EU-15 data was not available.
3. Shaded rows indicate countries cultivating more than 50 000 hectares of GM food/feed crops.

This may not be the case with rice. As noted in the section on "Food, feed, and industrial feedstock crops", it seems that wheat, which is primarily used as human food and widely traded, has not been commercialised despite successful R&D programs due to consumer perception concerns. This trend may also affect rice, which is a staple food for much of the world. As demonstrated, much of the rice imported to the various GM sensitive regions comes from the United States, the world's leading GM crop cultivator. However despite the development and approval of a herbicide tolerant variety of rice, it has not been adopted commercially in the United States, and there is evidence that this is due to fears of jeopardizing GM sensitive export markets.[44]

As noted, much research is going into rice and the commercialisation of a GM variety in China and/or India may significantly alter the picture. These two countries have significant internal demand for rice and make up 10% and 17%, respectively, of the value of all American rice exports.[45] However, China also has a large share of the Japanese (17.8%) and Korean (57.5%) import markets, which could influence the adoption of GM technology for this crop.

Many observers have also pointed to strict GM regulations in the European Union as hindering the uptake of GM crops in Africa due to a fear of losing export markets.[46] Yet with the exception of rice, sub-Saharan Africa is not a significant exporter of agricultural commodity products and therefore consumer opposition to GM in developed country markets is unlikely to have a significant direct effect on the decision to adopt GM. African maize, rice, and soybean exports (excluding South Africa) account for roughly 0.1%, 6.2%, and 0.0% of the total market value of imports for these products to the EU-15 plus Switzerland. The expectation of future markets could influence African countries not to permit GM crops, but Europe already imports animal feed crops from high GM regions, so it is difficult to see how future expectations could play a role. An alternative explanation is that European resistance to GM for human food could influence the policies of African Governments towards GM via professional links between politicians and regulators or by influencing public opinion. It is also important to note that cultural, distribution, and geographic factors could hinder the adoption of GM crops in Africa.

Finally, the similarity in the types of GM crops and GM traits cultivated in North America, South America, and South Africa seems to play a role in the strong adoption of GM crops. The success of maize and soybean as GM food crops has been strongly influenced by the United States. As shown in Table 29 the United States cultivates both maize and soybean on roughly 30% of the total crop hectares planted in the country. This large reliance on these crops and the market acceptance of GM crops in the United States played an important role in the development of a large number of GM varieties available for these two crops.

The United States shares this major reliance on soybean and maize with Argentina, Brazil, and South Africa where the two crops account for well over half of all hectares planted. Argentina grows more soybeans than any other field crop and was one of the first adopters of GM soybean in 1996, followed by maize in 1998 (Argenbio, 2008). Brazil, where agriculture is also highly dependent on soybeans and maize, began planting GM soybeans in 1997 and adopted GM maize in 2008. South Africa, where maize alone accounts for more than 50% of all hectares planted, began cultivating GM maize in 2000 (Brookes and Barfoot, 2006). The approval of these GM varieties was probably heavily influenced by the availability of this technology from American seed firms.

In the major Asian countries listed, rice is the major field crop. While GM herbicide tolerant rice has been developed, other GM varieties such as *Bt* and stacked traits are not yet available for rice. Maize is a relatively important crop to China as well, but GM maize has not been adopted. Some possible reasons for this could be food security considerations (*i.e.* not wanting farmers to rely on multinational firms for seed supplies) and China's own extensive GM R&D programme. The government could be waiting for Chinese research institutes or firms to develop GM varieties.

Table 29. **Maize, rice, and soybean cultivation shares of total crop cultivation in selected countries, 2007**

Country	Total Ha Planted (1000 Ha)	Maize (% of total Ha planted)	Rice (% of total Ha planted)	Soybean (% of total Ha planted)
Argentina	32 795	9.2%	0.5%	51.7%
Brazil	61 140	22.0%	4.6%	32.9%
Canada	26 368	5.0%	0.0%	4.3%
China	164 185	17.8%	17.6%	5.4%
India	181 432	4.2%	23.5%	4.8%
Indonesia	30 575	10.3%	34.4%	1.3%
Philippines	12 717	19.8%	31.9%	0.0%
South Africa	5 996	50.8%	0.03%	3.6%
United States	99 350	35.1%	1.1%	26.1%

Source: Authors, based on FAO (n.d.).

Animal biotechnology in developing countries

Livestock and poultry

The FAO-BioDeC database contains 149 non-GM animal biotechnology projects occurring in the developing world. As shown in Table 30, a large majority of these (more than 60%) are dedicated to cattle and other large animals such as buffalos, camels, and horses. Pig and poultry account for nearly 10% of all projects and sheep and goats for about 6% each.

Table 30. **Non-GM animal biotechnology projects, by animal type**

Animal	Number	Percentage
Cattle and other large animals	90	60.4%
Pig	16	10.7%
Poultry (incl. Chicken)	14	9.4%
Sheep	10	6.7%
Goat	9	6.0%
Wildlife & game animals	2	1.3%
Domestic animals	1	0.7%
Other	7	4.7%
TOTAL	149	100.0%

Source: Authors, based on FAO (n.d.).

Nearly 80% of all projects are for animal breeding (see Table 31) while diagnostics and vaccines account for about 5% each.[47] Eighteen biotechnologies have been commercialised: seven in animal breeding (three of which are classified as artificial insemination which may not use modern biotechnology), one diagnostic, six vaccine production techniques, and four others that are mainly focused on cryopreservation. Field trials are almost exclusively being undertaken in animal breeding but there is one diagnostic being tested for Porcine Cysticercosis (Pork Tapeworm), and one hormone (somatotropin) being tested in cattle. Projects in the experimental phase are also largely dominated by animal breeding, but there are six diagnostics being developed for *E. coli*, *chlamydophila abortus*, *bovine pestvirus*, and eight other projects.

Table 31. **Type of animal biotechnologies being studied in the FAO BioDeC database, by number and share**

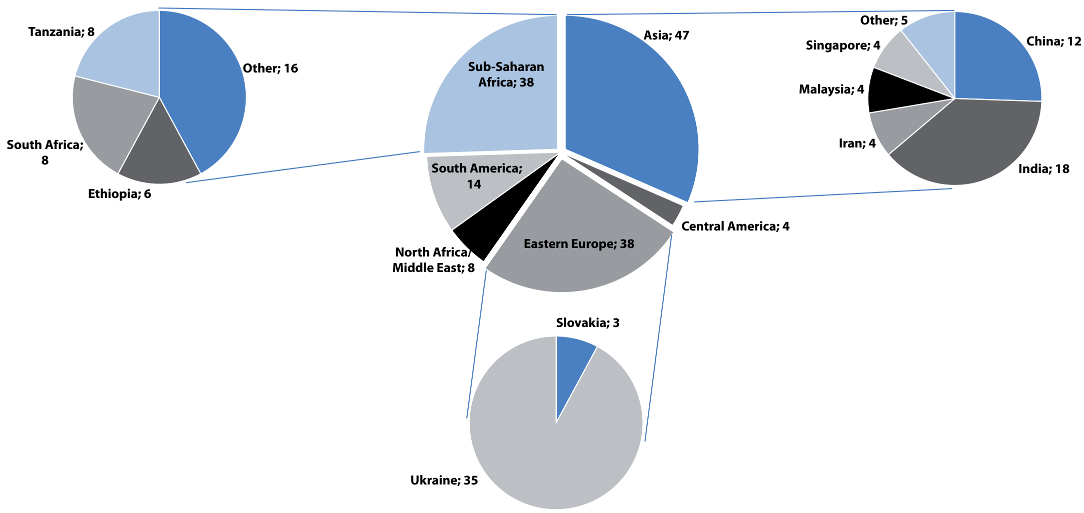
Type of Technology	Total Number	Number in Experimental Phase	Number in Field Trials	Number commercialised
Animal Breeding	118	100	11	7
Diagnostic	8	6	1	1
Vaccine production	8	0	0	6
Other	15	8	1	4
TOTAL	149	114	13	18

Source: Authors, based on FAO (n.d.).

Notes: 1. Columns may not sum to total due to projects where phase is unknown.
2. See Annex I for complete information.

As shown in Figure 16, Asia accounts for 31.5% of all non-GM animal projects and Eastern Europe and sub-Saharan Africa are both undertaking 25.5% of all projects. Within all three of these regions, a small number of countries account for a majority of projects. In Asia, China and India account for over 63% of all projects, with 12 and 18 projects respectively. Ethiopia, South Africa, and Tanzania account for more than 57% of all projects in sub-Saharan Africa.

Figure 16. **Non-GM animal biotechnology projects, by region and selected countries**



Source: Authors, based on FAO (n.d.).

The database also contains 15 projects involving GM animals. Thirteen of these are from Asia (seven in Korea, five in China, and one in Malaysia) and the other two are from Eastern Europe (one each in Slovakia and Ukraine). Ten are in the experimental phase while five are in unspecified phases. Six of these are for producing therapeutic proteins such as human lactoferrin, human granulocyte-colony stimulating factor (G-CSF), hEPO protein, h-tPA protein, and human clotting factor VIII in animals. Other projects study molecular systems and structural gene expression and one project is attempting to develop cattle resistant to mad cow disease.

Fisheries and aquaculture

The FAO-BioDeC database contains five biotechnology projects for fisheries. None of these are identified as using GM techniques. Of the five, two are taking place in Singapore (using unidentified technologies) and the remaining three, in the Ukraine, are for cytogenetic techniques, DNA markers, and isozymes.

Biotechnology could increasingly be used in developing countries to develop new aquatic animals, diagnostics and therapeutics, due to the demand for and economic importance of fisheries and aquaculture. From 1970 to 2006, average annual growth in aquaculture production has been highest in the Latin America and the Caribbean region (at 22%), followed by the Near East region (20%) and Africa (12.7%). In 2006, China alone accounted for 67% of global aquaculture production and 49% of its total value (FAO, 2008).

Forestry in developing countries

In addition to their importance as a building material, forest products are widely used as fuel in developing countries. Forestry is also a very important industry in many developing countries. As shown in Table 32, developing economies provide nearly 35% of all forestry imports to the United States and over half of all imports to the European Union-15 and Japan. Trees are also increasingly being used to solve environmental problems such as desertification.

Table 32. **2006 import value1 and share of forestry product imports to selected markets (in billion USD)**

	United States	European Union-15	Japan
High-income countries[2] (% of total)	19.49 (65.6%)	11.83 (44.0%)	6.00 (43.5%)
Non high-income countries (% of total)	10.21 (34.4%)	15.08 (56.0%)	7.78 (56.5%)

Source: Authors, based on OECD (2006).

Notes: 1. Value is measured in current USD
2. High income countries include all OECD and EU countries. This excludes a number of other small high income countries such as Israel and Singapore that would not have a major impact on forestry statistics.

Non-GM forestry biotechnologies

Developing countries are undertaking a lot of projects to apply biotechnology to forestry. The FAO-BioDeC database contains 810 non-GM forestry projects. As shown in Table 33, micro-propagation is the most used technology, followed by biotechnology based plant breeding, biopesticides and biofertilisers, and diagnostics.

Table 33. **Number of non-GM forestry projects**

Type of Technology	Number
Biopesticides/biofertilisers	42
Diagnostic	15
Other	70
Plant Breeding	267
Propagation, micro	413
Propagation, other	3

Source: Authors, based on FAO (n.d.).

Research is concentrated on a few tree species. The top ten studied tree varieties make up about 54% of all projects underway, while the top five varieties (acacia, eucalyptus, populus, pinus, and mahogany) make up more than 43% (see Table 34). The remaining projects are in a variety of other trees, many of which are region specific.

Only five non-GM forestry biotechnologies have been commercialised in the developing world: two in Malaysia and one each in Nepal, Tunisia, and Burundi. Of these, detailed information is available for four, all of which use micro-propagation. Two of these are for *Acacia* species and promote auxiliary budding and the other two are for *Prunus* and mulberry. There are also 67 forestry products in field trials, 34 of which are in Asia, followed by 23 in South America, 7 in Eastern Europe, 2 in sub-Saharan Africa, and one in Central America. India, Argentina, Chile, and Bangladesh are the leading countries with 20, 11, 7, and 6 field trials respectively. Surprisingly, China, despite a large share of experimental projects (see Figure 17), does not have any reported field trials.

Table 34. **Number and share of non-GM biotech projects, by tree type**

Tree type	Number of Non-GM Biotech Projects	Percent of Total Non-GM Biotech Projects
Acacia (*thorntree, wattle*)	96	11.9%
Eucalyptus	89	11.0%
Populus (*poplar, aspen*)	76	9.4%
Pinus	62	7.7%
Mahogany	28	3.5%
Teak	24	3.0%
Quercus (*Oak*)	22	2.7%
Picea (*Spruce*)	15	1.9%
Ulmus (*Elm*)	13	1.6%
Dalbergia (*sheoak, beefwood*)	12	1.5%

Source: Authors, based on FAO (n.d.).

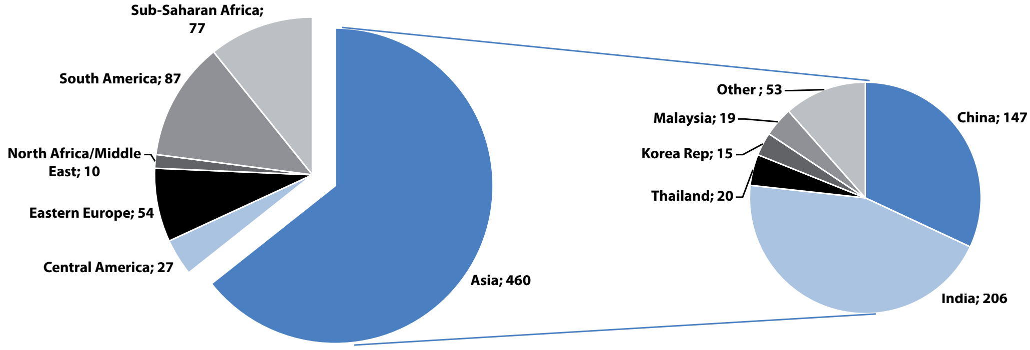
Note: Italics represent commonly known species within the tree genus.

715 of the 810 non-GM forestry projects in the FAO database are in the experimental phase and nearly 65% of those are in Asia (see Figure 17). In Asia, India and China are very dominant with 206 (45% of Asian experimental projects and 28% of the total) in India and 147 (32% of Asian experimental R&D and 20.5% of total). South America has 87 experimental forestry projects with the majority in Brazil (49), Argentina (19), and Chile (16). Sub-Saharan Africa also has a lot of experimental forestry activity (77 total projects) with South Africa under taking 23 of these projects, nearly four times as many as the next largest sub-Saharan African country.

GM forestry biotechnologies

The FAO-BioDeC database also contains 46 GM projects related to forestry. As shown in Table 35, over 50% of these are focused on poplar species, 10% on Eucalyptus and teak, nearly 9% on pine, and the remainder on cocoa, birch, walnut, mulberry, and several other unspecified varieties. A large majority of all projects (over 80%) are in the experimental phase, but there are four poplar, two eucalyptus, and one birch variety in field trials.

Figure 17. **Non-GM forestry projects in the experimental phase, by region (and country for Asia)**



Source: Authors, based on FAO (n.d.).

Table 35. **Number and share of GM biotech projects, by tree type**

Tree type	Number of GM Biotech Projects	Percent of Total GM Biotech Projects	Number in Experimental Phase	Number in Field Trials
Populus (*poplar, aspen*)	25	54.3%	20	4
Eucalyptus	5	10.9%	3	2
Teak	5	10.9%	5	0
Pinus	4	8.7%	4	0
Other	7	15.2%	5	1

Source: Authors, based on FAO (n.d.).

Notes: 1. Italics represent commonly known species within the tree genus.
2. Number of experimental projects and field trials do not sum to total for populus and other because of a project with unspecified status.

Table 36 provides the type of traits being researched in forestry. Over 41% of all GM projects are for insect resistance, followed by 13% for bacterial and fungal resistance, nearly 11% for salinity tolerance, and 4% each for male sterility and wood quality/lignin content.

Table 36. **GM forestry projects, by trait**

Trait	Number of GM Biotech Projects	Percent of Total GM Biotech Projects
Insects resistance	19	41.3%
Bacterial/fungal resistance	6	13.0%
Salinity resistance	5	10.9%
Male sterility	4	8.7%
Wood quality/lignin content	4	8.7%
Other or not specified	8	17.4%

Source: Authors, based on FAO (n.d.).

Forecasting for developing countries

About 97% of global population growth to 2030 is expected in developing countries (UN, 2006). This population growth, coupled with rising income levels and the associated demand for animal products, will have a massive impact on global agriculture in the coming years.

Though developing countries are increasing their investment in R&D for agriculture and related biotechnologies, it is very unlikely that their R&D capacity will equal that of the developed world by 2015. Therefore, as was the case with GM maize and soybeans, the uptake of agricultural biotechnologies in developing regions will probably continue to be influenced by the development of biotechnology in OECD countries. For example, agronomic traits such as drought and salinity tolerance, which are the focus of several research programmes within the OECD, could have a major beneficial impact on large areas of the developing world. If robust strains of important local crops are developed with these traits, adoption is likely if the benefits outweigh the extra cost of GM seed. As long as regulatory conditions and consumer acceptance are favourable, the sheer size of the agricultural market in Brazil, China, India, Argentina and other developing countries will continue to attract the interest of seed firms based in OECD countries.

Conversely, the development of crop varieties with improved micronutrient levels to address chronic malnutrition in some developing regions is unlikely to attract the interest of seed firms based in OECD countries, due to the inability of poor farmers to pay for new seed varieties. The development of nutrient-enhanced varieties of crops such as sorghum or rice is likely to depend on investment by the public sector in developing countries (OECD, 2009).

Many observers have also pointed to non-technological reasons for the slow adoption of GM food crops in some developing countries such as India, China and sub-Saharan Africa. These include weak regulatory capacity, high regulatory costs, consumer mistrust or opposition, persistent fears of a negative effect on export markets, and inadequate public funds for agricultural biotechnology research. Efforts to address these problems could significantly improve the adoption of biotechnology in developing countries.

Without solid data for developing regions on the average time spent in various development phases and average success rates, it is impossible to accurately predict the types of crop and tree species that will come out of the R&D pipelines in developing countries pipelines by 2015. There are however a very large number of crop and forestry projects (both GM and non-GM) in the experimental phase and some in field trials. This indicates that a significant number of these technologies could be commercialised by 2015, including GM rice and poplar varieties and non-GM varieties of aquatic animals for aquaculture.

Conclusions

Table 37 summarizes the main developments in biotechnology for agriculture, fishing and forestry that are expected to be ready for commercialisation by 2015. Of note, there is a marked shift in GM research since 2000 towards agronomic traits, especially for increased yield. Research into product quality traits also appears to be achieving results. Seed firms extensively discussed these developments in the late 1990s, but there was no data at that time to back up this shift. Today, both the field trial results and company data confirm the move away from a focus on herbicide tolerance and pest resistance (based on the *Bt* gene) towards environmentally beneficial stress tolerance and higher value-added quality traits. In addition, GM crops with improved fungal and nematode resistance should appear on the market by 2015.

The short-term trends covered in this article also highlight the impact of public opposition to GM products. This is by no means limited to Europe. Concern over a lack of markets in many OECD countries, including the United States, could be reducing private sector investment in developing GM varieties of fish, forest trees, honey bees, and food animals. In crops, the main application of GM technology has been for animal feed crops and for crops that are used in food processing. Neither produce agricultural products that are directly eaten by consumers. The number of apparently abandoned GM research programmes for crops such as grapes, plus the decision of Monsanto not to commercialise GM wheat in Canada and the United States (due to opposition of wheat farmers concerned about export markets), suggests that GM still faces a difficult future in many markets.

Two issues for the future are the role of MAS and other non-transgene biotechnologies in breeding programmes and public acceptance of these technologies. Continued opposition to GM could shift breeding methods to non-transgene technology. The extent of any such shift will also depend on the relative cost of GM versus alternatives such as MAS and gene shuffling. To date, the public does not appear to be concerned about the use of MAS or gene shuffling, but this could be based on ignorance about their use. Greater public awareness could lead to a negative association between MAS and GM. Alternatively, greater awareness could lead to a decline in opposition to GM, since the boundaries of technologies such as gene shuffling or cisgenesis overlap with that of GM. For example, cisgenesis uses the same technology as GM, but transfers genes between two plant varieties that could interbreed under normal conditions. If the public accepts cisgenesis, they might be increasingly likely to accept GM technology. How public opinion develops on this issue is clearly of importance to agricultural, forestry, and fisheries policy.[48]

Developing countries have become heavily involved in the use and development of agricultural biotechnologies. This is driven to a large extent by the economic importance of agriculture to their economies (in terms of share of GDP and employment) and by increasing demand from growing populations and incomes. Although this initial wave of agricultural biotechnology uptake in the developing world was mainly driven by technologies developed in OECD countries, developing countries are increasingly conducting their own research using biotechnology. The emergence of major agricultural biotechnology research programmes in developing countries could also have a major impact on future technology developments.

Two major impacts are likely. First, R&D programmes in developing countries are likely to focus on new varieties of local crops and crops that are adapted to local conditions, which would extend the range of crops affected by biotechnology. Second, competition from developing countries could serve to reduce some of the extreme concentration that has caused a large reduction in the number of firms active in agricultural biotechnology. This "competition" could also push governments in developed countries to boost investment in agricultural R&D.

Table 37. **Indicative short-term trends in biotechnology for agriculture and related natural resources**

	Expected by 2010-2012	Expected by 2015
Food, feed & industrial feedstock crops	Almost all varieties of major crops such as maize, cotton, rapeseed and soybeans in OECD countries developed using some form of biotechnology (GM, MAS, etc).	Almost all varieties of alfalfa, potatoes, sugar beet, tomatoes, rice, wheat, barley, rye and oats in OECD countries developed using some form of biotechnology (GM, MAS, etc).
		GM varieties of safflower, poplar, barley sugarcane, Kentucky bluegrass, lettuce, grapes, peas, apples and peanuts become available.
	Some agronomic GM traits available for stress resistance and improved yield available for rapeseed, maize, soybean, potato, rice, and turf grasses.	Some agronomic GM traits available for wheat, cotton, tomato, poplar, many traits for maize, and a few additional traits for soybeans.
	Some product quality GM traits available for tomatoes, rapeseed and safflower.	Large increase in product quality GM traits, with traits available for the main GM target crops.
	New forms of GM pest resistance that are not based on bT in maize, rapeseed, soybeans, potatoes, wheat, sugar beets and tomatoes.	A few major crop varieties with GM resistance to nematodes and fungi.
		Worldwide, GM varieties account for 88% of all soybean plantings, 73% of cotton, 30% of maize, and 21% of rapeseed.
Animals	Commercial use of GM cloned animals that express valuable pharmaceuticals in their milk.	Cloned food animals in non-OECD countries.
	MAS used in OECD countries in all major breeding programmes for pigs, cattle, dairy cows, and sheep.	
	Increase in recombinant vaccines, particularly in Europe.	A few new therapeutic bio-pharmaceuticals for livestock for economically expensive and infective diseases.
	New diagnostics for undesirable genetic conditions.	New genetic diagnostic products for livestock diseases.
Fish, molluscs, crustaceans	New genetic diagnostic and therapeutic products for diseases.	
	Expansion of use of DNA fingerprinting to manage wild fish stocks.	
	Widespread use of MAS in breeding programmes for aquaculture.	GM fish in aquaculture in non-OECD countries.
Forestry	Widespread use of MAS in breeding programmes.	
	Use of GM varieties of pine, eucalyptus and other broadleaf varieties in sub-tropical and tropical plantations for paper and timber.	MAS combined with somatic embryogenesis for cool climate conifers.
Insects	New diagnostics for pests that attack honey bees	Insecticide and pest resistance strains of honey bees, developed using GM or MAS

Notes

1. The figure uses the United Nations median variant.

2. The FAOSTAT database shows that globally there were 1 280 780 hectares of arable land in 1961 and 1 413 425 ha in 2005. This refers to "land under temporary crops … temporary meadows for mowing or pasture … and land temporarily fallow … abandoned land resulting from shifting cultivation is not included".

3. Approximately ten times as much water is required to produce 1 kg of beef as 1 kg of wheat (FAO as cited by BBC, 2008).

4. Many forms of plant tissue culture are not part of advanced biotechnology.

5. The field trial database used in this report is constructed from publicly available information, in English. It does not contain GM field trial results for Korea, Norway and Turkey. This may be because no GM field trials have been conducted in these two OECD countries, or because their field trial data are not publicly available in English. See Annex A for more information.

6. All analyses of the patent data are by the authors.

7. The two main industrial classifications systems are NACE (used in Europe) and ISIC (International). The NAFTA countries use NAICS, but the three systems are generally comparable for the ANR sectors. For both NACE and ISIC (3rd revision), the ANR sectors are covered under sections A and B (at the NACE two-digit level, sectors 01, 02, and 05).

8. Total gross value-added (GVA) is similar to GDP and equals output values minus subsidies and input costs (at producer or purchaser prices). GVA at the sector level is intended to measure the sector contribution to GDP. National differences in the method of calculating sector value added can introduce variability of 5% to 10% in the estimate of the sector contribution to total GDP. See *www.oecd.org/dataoecd/53/21/34464010.doc*.

9. OECD estimate excludes Iceland, Luxembourg, and Norway.

10. Monsanto, Syngenta, and Bayer CropScience reported over 15 000 employees in 2006, but this included employees active in plant protection divisions that manufacture pesticides.

11. The number of patent applicants will underestimate the number of firms using biotechnology in plant breeding. Although the USPTO and the EPO receive many applications from firms based in other OECD countries, the number of applicants from Japan, Korea or Australia is likely to be smaller than the number of firms in these countries that use biotechnology. Firms can also use biotechnology without applying for a plant patent. Conversely, some firms that apply for a plant patent are not involved in plant breeding.

12. A complete patent application record for the USPTO is not available because the USPTO did not start publishing patent applications until 2001. This explains why the USPTO data are for grants until 2004, followed by patent applications.

13. The share of field trials attributed to a firm includes wholly owned subsidiaries plus purchases of other firms. Field trials by a purchased firm are assigned to the new owner from the year after the purchase. For example, Monsanto's share during 1995 to 1999 includes field trials registered to firms purchased by Monsanto, including Agracetus and Asgrow. Since it is difficult retrospectively to identify all subsidiaries, the concentration measures are probably underestimated.

14. Field trials are assigned by the location of the firm's head office and not by the location of the field trial. For example, field trials conducted by European firms such as Syngenta, Bayer CropScience or their subsidiaries in the United States are assigned to Europe.

15. Although some public sector institutions in non-OECD countries apply for an EPO plant patent or received a USPTO plant patent grant, they only accounted for 4.3% of EPO and 5.9% of USPTO patents.

16. See pages 119 – 122 of Menrad *et al*. (2006).

17. Analyses by the authors. The names of all 41 firms were searched in the UNU-MERIT field trial database, with 25 listed as applying for one or more GM field trials.

18. The FAOSTAT database shows that globally 1 214 310 000 hectares were planted in 2006. Data for 2008 were not available at the time of writing.

19. There is more concern over public acceptance for crops used as human feed than for animal feed. More than 80% of wheat is used as human food in OECD countries. In 2009, Monsanto announced that, despite opposition, it would refocus attention on developing GM wheat (Gillam, 2009).

20. A total of 2853 product quality traits were field tested from 1998 to 2007. Of these the feed category accounts for 4 trials (less than 0.1% of total) and the "other" category accounts for 376 trials (13.3% of total). Data for 2008 are not used in the trends because it may be incomplete.

21. The field trial data are not useful for estimating the commercialisation date of high value crops that could be grown entirely in enclosed greenhouses, such as plants to produce pharmaceuticals.

22. The firms include Monsanto, Bayer Crop Science, Du Pont Pioneer Hi-Bred, Syngenta, Targeted Growth, Dow Agrosciences, Scotts, ArborGen and BASF. The websites for major subsidiaries were also checked: Plant Genetics (part of Bayer) and Seminis, Calgene and Asgrow (part of Monsanto).

23. Due to differences in yields both within and across countries, the GM share of global hectares planted is only an approximate measure of the GM share of total production in tonnes.

24. The United States is not a major producer of rapeseed, accounting for only 1.5% of global hectares planted in 2007 (FAO, 2009).

25. Value added data are not available. Producer prices cover costs from pesticides, fertilizers, seeds, etc.

26. When permanent crops are included, total world arable land increases to 1.54 billion hectares, of which biotechnology varieties could account for 46.1%.

27. A recent comprehensive review of GM crops and yield (Brookes and Barfoot, 2006) reports no effect on yield from the GM trait for herbicide tolerance, but in most countries (with the exception of Australia) GM crop varieties with insect resistance traits increased yields by over 5% in corn and over 3% in cotton.

28. There are approximately 50 000 plant pathogens in the United States, although many cause little economic damage (Pimentel *et al*., 2004).

29. Some variants of these methods are also used. For example, the Reverse Transcription-PCR (RT-PRC) method, or the Double-Antibody Sandwich-ELISA (or DAS-ELISA) method are used to detect the Verticillium sp. pathogen (van de Koppel and Sebots, 1995).

30. An example is a diagnostic for nematodes in potatoes (Bates *et al*., 2002). FLASHKIT tests developed by the firm Agdia are ELISA-based and can be performed in the field. Most identify viruses, but a few tests can identify bacteria.

31. There are 15 viruses and virus-like organisms, six nematodes, one fungus and two bacterial diseases (EC, n.d.).

32. The European Commission has launched the Diag Chip project to develop a chip that can recognize 275 harmful pathogens. These pathogens are listed in the EU directive 77/93/EEC.

33. GM laboratory animals for research, primarily mice, are widely used.

34. Possible viral and pathogen causes of the 2006-2007 "colony collapse disorder" have been identified using high throughput screening for viruses (Science Daily, 2007).

35. The Green Book list of approved products is available at *www.fda.gov/AnimalVeterinary/Products/ApprovedAnimalDrugProducts/ucm042847.htm*. In the EU, the EMEA's Committee for Veterinary Medicinal Products approved recombinant interferon-omega in 2001 for the treatment of canine parvovirosis in dogs and cats in 2004.

36. The green book includes biologics such as porcine insulin, chorionic gonadotropin, follicle stimulating hormone, polysulfated glycosaminoglycan and serum gonadotropin. These are obtained from biologic extracts from animals or humans. Some can also be produced using recombinant technology, but none of the examples in the Green Book appear to be recombinant versions.

37. The control applies to diagnostics which are produced in the United States and for imports.

38. According to Arundel and Sawaya (2009), the total in vitro diagnostic market for humans was estimated at 27.6 billion USD. The market for animal diagnostics is therefore approximately 2% to 4% of the human diagnostic market.

39. The company AquaBounty markets diagnostic systems using PCR that identify five shrimp and salmon viruses (SybrShrimp and SybrSalmon), see *www.aquabounty.com*. Aquatic diagnostics have also been used as a research tool (McIntosh, 2004).

40. In many countries, public opinion surveys have found the lowest level of support for cloned animal food products out of all agricultural biotechnology applications. This has been found as recently as 2007 for Australia (Eureka, 2007), consistently for Europe (Gaskell, 2000), and also in the United States, where a 2006 survey found that 64% of Americans were 'uncomfortable with animal cloning' (Mellman Group, 2006). Less is known about public attitudes in Asia. A survey in Zheijiang Province found a generally utilitarian and positive attitude to agricultural biotechnology, although there were no specific questions reported for animal cloning (Lu, 2007).

41. See Forest Resources Development Service (2004) and Mccord and Gartland (2003).

42. While Mexico is included in the FAO-BioDeC database, it has been excluded from the developing country category throughout the rest of the report.

43. Approval was expected by the end of 2009 (*http://gmopundit.blogspot.com/2008/06/gm-brinjal-moves-forward-in-india.html*). If approved, this would be the first GM crop for human consumption approved in India.

44. See *http://calriceproducers.org/BCI_executive_summary.pdf*.

45. The 2006 value of all rice imports to the United States was USD 368.3 million of which China and India accounted for USD 37.9 million and USD 62.8 million respectively.

46. For examples see *www.nuffieldbioethics.org/fileLibrary/pdf/gm_crops_summary.pdf* and *www.goldenrice.org/Content4-Info/Info10_GM+development.html*.

47. There are no data on whether or not these vaccines and diagnostics are based on advanced biotechnology.

48. As of October 2009, cisgenesis is regulated in Europe as transgenic crops, but the status of cisgenesis has been under review.

References

Affymetrix (2009), GeneChip Porcine Genome Array, *www.affymetrix.com/products_services/arrays/specific/porcine.affx*, accessed 18 August 2009.

APS (American Phytopathological Society) (n.d.), Common names of plant diseases, *www.apsnet.org/online/common/toc.asp*, accessed 18 August 2009.

Blank S (2009), *personal communication with the authors,* 20 October 2009.

Bogdanovic S and B Langlands (2003), *Immunodiagnostics and Nucleic Acid Testing Kits for the Veterinary Status and future prospects*, Animal Pharma report, PJB Publications Ltd.

AAPQIS (Aquatic Animal Pathogen and Quarantine Information System) (2009), Aquatic Animal Health E-Governance, *www.aapqis.org/main/main.asp*, accessed 18 August 2009.

Argenbio (2008), Cultivos aprobados y adopción, *www.argenbio.org/h/biotecnologia/11.php*, accessed 18 August 2009.

Arundel A. and D. Sawaya (2009), "Health Biotechnologies to 2015", *OECD Journal: General Papers*, Volume 2009/3, OECD, Paris.

Bates *et al.* (2002), "Determination of relative proportions of globodera species in mixed populations of potato cyst nematodes using PCR product melting peak analysis", *Molecular Plant Pathology,* vol. 3, pp. 153-161.

Bellingham, J. (2007), "Biotech for you companion?", *Nature Biotechnology*, vol. 25, num. 12, pp.1343-1345.

Bendixen, C., J. Hedegaard, and P. Horn (2005), "Functional genomics in farm animals – Microarray analysis", *Meat Science*, vol. 71, pp. 128-137.

BCC Research (2004), Animal Therapeutics and Diagnostics, *www.bccresearch.com/report/HLC034A.html*, accessed 18 August 2009.

Bork S, *et al.* (2004), "Identification of Babesia bovis L-lactate dehydrogenase as a potential chemotherapeutical target against bovine babesiosis", *Molecular Biochemistry and Parasitology* vol. 136, pp.165-72.

BBC (2008), "The Cost of Food: Facts and Figures", *news.bbc.co.uk/2/hi/in_depth/7284196.stm*, accessed 12 November 2008.

Brookes G, and Barfoot P (2006), "Global impact of biotech crops: Socio-economic and environmental effects in the first ten years of commercial use", *AgbioForum, vol.* 9, pp. 139-151.

Cantley, M. (2006), An Overview of Regulatory Tools and Frameworks for Modern Biotechnology: A Focus on Agro-Food, *www.oecd.org/dataoecd/11/15/40926623.pdf*, OECD, Paris.

Caswell M., and J Fernandez-Cornejo (2006), *The First Decade of Genetically Engineered Crops in the United States*, USDA.

CIA (United States Central Intelligence Agency) (2008), CIA World Factbook, *https://www.cia.gov/library/publications/the-world-factbook/.*

Conner AJ, *et al.* (2007), "Intragenic vectors for gene transfer without foreign DNA", *Euphytica*, vol. 154, pp. 341-353.

Dow AgroSciences (2007), Herculex EXTRA, Insect Protection, *www.dowagro.com/herculex/about/heruclexxtra/*, accessed 1 February 2008.

Dow AgroSciences (2007), Plant Genetics & Biotechnology, R&D Pipeline, *www.dowagro.com/pgb/research/pipe.htm*, accessed 1 February 2008.

Dow AgroSciences (2007), Canola and Sunflower Seeds *www.dowagro.com/pgb/platforms/oilover/seeds/canola_sun.htm*

DuPont Pioneer (2007), "Crop Genetics Pipeline" *www.pioneer.com/CMRoot/Pioneer/research/pipeline/DuPont_BG_Pipeline.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), Anthracnose Stalk Rot Resistance, www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/StalkRot.pdf, accessed 1 February 2008.

DuPont Pioneer (2007), Next Generation Insect Control – Corn Rootworm and Corn Borer Resistance www.*pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/insect.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Drought Tolerance www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/Drought.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Fungal Disease Resistance www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/Fungal.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Herculex RW® and Herculex XTRA www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/Herculex.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Increased Ethanol Production www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/Ethanol.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Improved Feed www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/ImpFeed_Corn.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Improved Processing www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/CornProcessing.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Nitrogen Use Efficiency www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/Nitro.pdf,* accessed 1 February 2008.

DuPont Pioneer (2007), *Asian Soybean Rust Resistance www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/Rust.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Cyst Nematode Resistance www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/soycyst.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Soybean Disease Resistance www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/SoyDisease.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Optimum™ GAT™ Glyphosate ALS Tolerance www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/GAT.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *High Oleic/High Stearic Acid Oil www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/HOSoy.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Improved Feed www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/ImpFeed_Soy.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Low Linolenic Oil www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/LowLin.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Increased Yield www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/SoybeanYield.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Doubled Haploids www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/DoubledHaploids.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *EnClass(SM) Technology www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/EnClass.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *FAST Corn www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/FastCorn.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Gene Sequencing www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/genesequence.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Gene Shuffling www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/GeneShuffle.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Marker-Assisted Selection (MAS) www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/MAS.pdf*, accessed 1 February 2008.

DuPont Pioneer (2007), *Seed Production Technology www.pioneer.com/CMRoot/Pioneer/research/pipeline/spec_sheets/PSPTechnology.pdf*, accessed 1 February 2008.

DuPont (2006), DuPont Achieves Regulatory Milestone, *http://vocuspr.vocus.com/VocusPR30/Newsroom/Query.aspx?SiteName=DupontNew&Entity=PRAsset&SF_PRAsset_PRAssetID_EQ=104178&XSL=PressRelease&Cache=*, accessed 18 August 2009.

Elder, M (2008), Animal Therapeutics and Diagnostics, BBC Research, *www.bccresearch.com/report/HLC034B.html*, accessed 26 August 2009.

ETEPS (European Techno-Economic Policy Support Network) (2005), *Consequences, opportunities and challenges of modern biotechnology for Europe (Bio4EU): Task 1 – Mapping of modern biotechnology applications and industrial sectors, identification of data needs and development of indicators,* Final Report, European Commission.

Eureka Strategic Research (2007), *Community Attitudes to Biotechnology: Report on Food and Agriculture Applications*, Biotechnology Australia.

EC (European Commission) (n.d.), DIAG CHIP – Plant health diagnostics on a microchip, *http://ec.europa.eu/research/agriculture/projects_showcase13_en.htm*.

EU KLEMS (European Union Capital (K) Labour (L) Energy (E) Materials (M) Service Inputs (S) Database) (2008), "Growth and Productivity Accounts", database, *www.euklems.net/eukdata.shtml*.

TheFishSite (2005), "Rapid Detection of Bacterial Infection in Farmed Fish through DNA Chip", *TheFishSite Latest News*, 31 January 2005.

Fitzgerald, M. (2006), India's Big Plans for Biodiesel, *www.technologyreview.com/Energy/17940/page1/*, accessed 18 August 2009.

FAO (Food and Agriculture Organization) (n.d.), Biotechnology in Developing Countries, Bio-dec database. *www.fao.org/ biotech/inventory_admin/dep/default.asp*.

FAO (2002), "World Agriculture 2030: Main Findings", *www.fao.org/english/newsroom/news/2002/7833-en.html*, accessed 12 November 2008.

FAO (2009), *FAOSTAT Database*, FAO, Rome.

FAO (2008), State of World Fisheries and Aquaculture, *www.fao.org/docrep/011/i0250e/i0250e00.htm*, accessed 26 August 2009.

FAO (2006), State of World Fisheries and Aquaculture, *www.fao.org/docrep/009/A0699e/A0699e00.htm*, accessed 18 August 2009.

FAO (2007), The State of Food and Agriculture 2007, *www.fao.org/docrep/010/a1200e/a1200e00.htm*, accessed 18 August 2009.

Forest Resources Development Service (2004), *Preliminary Review of Biotechnology in Forestry, Including Genetic Modification*, FAO, Rome.

Fermin-Munoz GA *et al.* (2000), Biotechnology: A new era for plant pathology and plant protection, APSnet, The American Phytopathological Society, *www.apsnet.org/online/feature/BioTechnology/*, accessed 18 August 2009.

Gallagher L (1998), "Captain Prozac is now a vet", www.forbes.com/forbes/1998/0907/6205091a.html, Forbes, accessed 18 August 2009.

Gaskell G (2000), "Agricultural biotechnology and public attitudes in the European Union", *AgBioForum,* vol. 3 pp. 87-96.

GenomeWeb (2004), "JGI Unlocks Genome of Oak, Soy Pathogens", *GenomeWeb Daily News*, *www.genomeweb.com/issues/news/124095-1.html*, accessed 1 February 2008.

Gillam, C (2009), World still wary as biotech wheat advances, Reuters, *www.reuters.com/article/internal_ReutersNewsRoom_BehindTheScenes_MOLT/idUSTRE56G5ZF20090717*, accessed 25 August 2009.

Gonsalves, J (2006), An Assessment of the Biofuels Industry in India, *www.unctad.org/en/docs/ditcted20066_en.pdf*, UNCTAD, Geneva, accessed 18 August 2009.

Graff, GD, Cullen SE, Bradford KJ, Zilberman D, and Bennet AB. (2003), The public-private structure of intellectual property ownership in agricultural biotechnology, *Nature Biotechnology*, Vol. 21, pp. 989-995.

Graff, GD, Zilberman D, and Bennet AB (2009), The contraction of agbiotech product quality innovation, *Nature Biotechnology*, Vol 27, pp. 702-704.

Gullickson, G., (2006) "A glimpse at Monsanto's future crops technology", Crops Technology Editor, *www.agriculture.com/ag/story.jhtml?storyid=/templatedata/ag/story/data/1157465498761.xml*, accessed 18 August 2009.

Harmon, A (2007), "As Breeders Test DNA, Dogs Become Guinea Pigs", The New York Times, 12 June 2007.

Honeybee Genome Sequencing Consortium (2006), "Insights into social insects from the genome of the honeybee Apis mellifera", *Nature, vol.* 443, pp 931-949.

Indian Express Newspapers (2005), "Transgenic Wonders of NBRI", *www.merid.org/fs-agbiotech/more.php?articleID=4943&search=%2Ffs-agbiotech%2Farchive.php%3FdoSearch%3D1%26regions%255B%255D%3DEast%2520and%2520South%2520Asia%2520and%2520the%2520Pacific%26page%3D2%26items%3D15&scorePrecent=100*, accessed 18 August 2009.

INRA (Institut National de Recherche Agronomique) (2007), Un diagnostic moléculaire pour la detection du nématode du Pin, *www.inra.fr/presse/diagnostic_moleculaire_pour_detection_nematode_du_pin*, accessed 18 August 2009.

IPCC (Intergovernmental Panel on Climate Change) (2007), "Climate Change 2007: Synthesis Report: Summary for Policymakers", *www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf*, accessed 12 November 2008.

IEA (International Energy Agency) (2008), R&D Statistics Database, Paris, *www.iea.org/textbase/stats/rd.asp*.

ISID (International Society for Infectious Diseases) (2003a), "Pro/PL > Fusarium wilt, lettuce – USA (AZ): first report", 22 Sept 2003, ProMED-mail, Archive number 20030922.2393, *www.promedmail.org/pls/otn/f?p=2400:1001:282466995230384::::F2400_P1001_BACK_PAGE,F2400_P1001_ARCHIVE_NUMBER,F2400_P1001_USE_ARCHIVE:1001,20030922.2393,Y*, accessed 18 August 2009.

ISID (2003b), "ProMED-mail, Archive number 20030915.2336; Pro/PL > Quarantine pests, new data – EPPO (03)", *http://apex.oracle.com/pls/otn/f?p=2400:1001:674479108843189::NO::F2400_P1001_BACK_PAGE,F2400_P1001_PUB_MAIL_ID:1300,26562*, accessed 18 August 2009.

ISID (2004), "Pro/PL > Plant pests, new data, EPPO (04)", ProMED-mail, Archive number 20040904.2473, *http://apex.oracle.com/pls/otn/f?p=2400:1001:674479108843189::NO::F2400_P1001_BACK_PAGE,F2400_P1001_PUB_MAIL_ID:1300,26562*, accessed 18 August 2009.

ISID (2007), "Pro/PL > ProMED plant disease reports 2007: overview", 31 Dec 2007, ProMED-mail, Archive number 20071231.4190, *www.promedmail.org/pls/otn/f?p=2400:1001:19224::::F2400_P1001_BACK_PAGE,F2400_P1001_ARCHIVE_NUMBER,F2400_P1001_USE_ARCHIVE:1001,20071231.4190,Y*, accessed 18 August 2009.

International Seed Federation (2008), Estimated Value of the Domestic Seed Market in Selected Countries, *www.worldseed.org/cms/medias/file/ResourceCenter/SeedStatistics/Value_of_the_Domestic_Market_for_Seed_in_Selected_Countries_20080601.pdf*, accessed 18 August 2009.

Jacobsen E. and Schouten H. (2007), Cisgenesis strongly improves introgression breeding and induced translocation breeding of plants. *Trends in Biotechnology* Vol. 25, pp. 219-223.

James, C. (2007), "Global Status of Commercialized Biotech/GM Crops: 2007", ISAAA Brief No. 37, Ithaca, New York.

James, C. (2006), "Global Status of Commercialized Biotech/GM Crops: 2006", ISAAA Brief No. 35, Ithaca, New York.

James, C. (2005), "Global Status of Commercialized Biotech/GM Crops: 2005", ISAAA Brief No. 34, Ithaca, New York.

James, C. (2004), "Global Status of Commercialized Biotech/GM Crops: 2004", ISAAA Brief No. 32, Ithaca, New York.

James, C. (2003), "Global Status of Commercialized Biotech/GM Crops: 2003", ISAAA Brief No. 30, Ithaca, New York.

James, C. (2002), "Global Status of Commercialized Biotech/GM Crops: 2002", ISAAA Brief No. 27, Ithaca, New York.

James, C. (2001), "Global Status of Commercialized Biotech/GM Crops: 2001", ISAAA Brief No. 24, Ithaca, New York.

James, C. (2000), "Global Status of Commercialized Biotech/GM Crops: 2000", ISAAA Brief No. 21, Ithaca, New York.

James, C. (1999), "Global Status of Commercialized Biotech/GM Crops: 1999", ISAAA Brief No. 12, Ithaca, New York.

James, C. (1998), "Global Status of Commercialized Biotech/GM Crops: 1998", ISAAA Brief No. 8, Ithaca, New York.

James, C. (1997), "Global Status of Commercialized Biotech/GM Crops: 1997", ISAAA Brief No. 5, Ithaca, New York.

JAVMA (2005), U.S. aquaculture sales surpass $1 billion, *www.avma.org/onlnews/javma/nov06/061115m.asp*, accessed 18 August 2009.

Kamis, R. and M. Joshi (2008), Biofuel Patents Are Booming, *http://media.cleantech.com/2329/biofuel-patents-are-booming*, accessed 11 November 2008.

Klepper, S. (1996), Entry, Exit, Growth, and Innovation over the Product Life Cycle, *American Economic Review*, Vol. 86, No. 3, pp. 562-583.

Lawrence, S. (2004), Patent drop reveals pressure on industry, Nature Biotechnology, Vol. 22, num. 8, pp. 930-931.

Lin and Tanaka (2005), "Ethanol fermentation from biomass resources: current state and prospects, *www.springerlink.com/content/fm9l941r87w26048/fulltext.pdf*, Applied Microbial Biotechnology, vol. 69, pp. 627-642.

Lu L. (2007), Public views on biotechnology applications in China, Presentation to workshop on "Modern Biology and its Social Implications", Xishuanbanna, Yunnan, *www.genomicsforum.ac.uk/documents/pdf/china/04%20Lu.ppt*, last accessed January 7, 2008.

McIntosh D (2004), "Molecular tools for aquatic animal health: past and future perspectives", *Bulletin of the Aquaculture Association of Canada*, vol. 104, num. 2, pp. 79-83.

Mccord S and K Gartland K (Eds) (2003), *Forest Biotechnology in Europe*, Institute of Forest Biotechnology.

The Mellman Group (2006), Memorandum to the Pew Initiative on Food and Biotechnology, *www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Public_Opinion/Food_and_Biotechnology/2006summary.pdf*, accessed 13 November 2008.

Menrad K, Petzoldt M, Feigl S, Hirzinger T, Tait J, Bruce A, Shelley-Egan C, Rosiello A, and Gaisser S. *Consequences, Opportunities and Challenges of Modern Biotechnology For Europe, Task 2: Case studies report: The impact of primary production applications, Annex to Report 3*. ETEPS (European Techno-Economic Policy Support Network, European Commission, 2006.

Michigan State University (2009), "Tuber and Stem Diseases/Conditions of Potato", *www.potatodiseases.org/tuberdiseases.html*, accessed 28 Jan 2008.

Monsanto (2007), Key Crops Corn Products, www.monsanto.com/monsanto/layout/products/seeds_genomics/corn.asp, accessed 1 February 2008.

Monsanto (2007), Key Crops Cotton Products www.*monsanto*.com/monsanto/layout/products/seeds_genomics/cotton.asp, accessed 1 February 2008.

Mulvaney D. (2007), "Containing risk: explaining social resistance to transgenic salmon," Abstract to the 2007 Annual General Meeting, Association of American Geographers, San Francisco.

Nill, K. (2001), Biotech Terms, *http://biotechterms.org*, accessed 26 January 2009.

NZ MoRST (New Zealand Ministry of Research, Science and Technology) (2005), *Biotechnologies to 2025, www.morst.govt.nz/business/biotech-to-2025/.*

Nuffield Council on Bioethics (2006), The Use of Genetically Modified Crops in Developing Countries, London, *www.nuffieldbioethics.org/go/ourwork/gmcrops/publication_313.html,* accessed 18 August 2009.

OECD (Organisation for Economic Co-operation and Development) (2008a), *Economic Outlook*, Vol. 2, p. 6, OECD, Paris, December 2008.

OECD (2008b), *Environmental Outlook to 2030*, OECD, Paris.

OECD (2006), International Trade Statistics Database, OECD, Paris.

OECD-FAO (2008), *Agricultural Outlook 2008-2017*, OECD, Paris.

OECD-FAO (2007), *Agricultural Outlook 2007-2016,* OECD, Paris.

OIE (World organisation for animal health) (2006), "'Yellowhead disease', Manual of Diagnostic Tests for Aquatic animals 2006", *www.oie.int/eng/Normes/fmanual/A_00050.htm,* OIE, Paris.

OIE (2007), "Notifiable diseases", OIE, Paris.

Pehu E. and C Ragasa (2007), *Agricultural Biotechnology: Transgenics in Agriculture and Their Implications for Developing Countries,* World Bank.

Pew Initiative on Food and Biotechnology (2004), *Bugs in the System?* Washington DC.

Pimentel D, R. Zuniga and D. Morrison (2005), "Update on the environmental and economic costs associated with alien-invasive species in the United States", *Ecological Economics*, vol. 52, no. 3, pp. 273-288.

Pinstrup-Andersen, P (2001), *The Future World Food Situation and the Role of Plant Diseases*, APSnet Education Center, The Plant Health Instructor.

Reiss, T., *et al.* (2007), "Consequences, Opportunities and Challenges of Modern Biotechnology for Europe", Task 2 Main Report, Joint Research Centre Reference Reports, IPTS, Seville.

Sawaya D. and Arundel A (2009), “Agbio: a developing story”, *Chemistry and Industry, vol.* 6, 23 March, pp. 16-18.

Science Daily (2006), Special Chip Provides Better Picture of Salmon Health, *www.sciencedaily.com/releases/2006/10/061017085114.htm*, accessed 18 August 2009.

Science Daily (2007), Scientists Identify Pathogens That May Be Causing Global Honey-Bee Deaths, *www.sciencedaily.com/releases/2007/04/070426100117.htm*, accessed 18 August 2009.

Searchinger T. *et al.* (2008), “Use of U.S. croplands for Biofuels Increases Greenhouse Gases Through Emissions for Land Use Change”, *Science*, vol. 319. no. 5867, pp. 1238-1240.

Sedjo, R. (2005), “Will Developing Countries Be the Early Adopters of Genetically Engineered Forests?”, *AgBioForum*, Vol. 8, pp. 205-212.

Sommerset, I., Krossoy, B., Biering E. and Frost, P. (2006), Vaccines for fish in Aquaculture, *www.thefishsite.com/articles/150/vaccines-for-fish-in-aquaculture*, accessed 11 October 2009.

Steenblik, R in OECD/ITF (2007), *Biofuels: Linking Support to Performance*, *www.internationaltransportforum.org/jtrc/RTbiofuelsSummary.pdf*, accessed 18 August 2009.

Stern, N., *et al.* (2006), “Stern Review Report on the Economics of Climate Change”. *www.hm-treasury.gov.uk/stern_review_climate_change.htm*.

Syngenta Research and Development Pipeline (2007), *www.syngenta.com/en/about_syngenta/crop_protection_pipeline.aspx*, accessed 1 February 2008.

TERI (The Energy and Resources Institute) (2008), *Centre for Mycorrhizal Research, www.teriin.org/*, accessed 11 November 2008.

UN (United Nations) (2006), *World Population Prospects: The 2006 Revision*, Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *http://esa.un.org/unpp*, accessed 4 April 2008.

UNU-MERIT (United Nations University Maastricht Economic and social Research and training centre on Innovation and Technology) (2009), *GM Field Trial Database*, Maastricht.

USDA ERS (United States Department of Agriculture Economic research Service) (2009), Adoption of Genetically Engineered Crops in the U.S., *www.ers.usda.gov/Data/BiotechCrops/*, accessed 18 August 2009.

USDA (United States Department of Agriculture) (2009a), Petitions of Nonregulated Status Granted or Pending by APHIS as of August 8, 2009, *www.aphis.usda.gov/brs/not_reg.html*, accessed 19 August 2009.

USDA (2009b), “Veterinary Biological Products”, Center for Veterinary Biologics, *www.aphis.usda.gov/animal_health/vet_biologics/publications/CurrentProdCodeBook.pdf*, accessed 26 August 2009.

USDA (2009c), “Currently Available Biologics for Fish”, *www.aphis.usda.gov/animal_health/vet_biologics/publications/products.pdf*, accessed 26 August 2009.

USDA (2007)The Center for Veterinary Biologics: Ensuring the Availability of Quality Products, *www.aphis.usda.gov/vs/highlights/section4/section4-11.html*, accessed 09 January 2008.

USDA (2006), *Veterinary Biological Products: Licensees and Permittees*, Ames, Iowa

University of Aberdeen (n.d.), *Detailed summary of Salmon Traits*, *www.abdn.ac.uk/sfirc/salmon/summary.shtml*, accessed 18 August 2009.

Vaccari D (2009), "Phosphorus Famine: The Threat to Our Food Supply", Scientific American Magazine.

Ward, E., *et al.* (2004), "Plant Pathogen Diagnostics: Immunological and Nucleic Acid-Based Approaches", *Annals of Applied Biology*, Vol. 145 pp. 1-16.

World Bank (2007), Selected World Development Indicators, *http://ddp-ext.worldbank.org/ext/DDPQQ/member.do?method=getMembers&userid=1&queryId=135*.

Xia C, *et al.* (2005), "Cloning and expression of interferon-alpha/gamma from a domestic porcine breed and its effect on classical swine fever virus", Veterinary Immunology and Immunopathology, vol. 104, pp. 81-9.

Zah R. *et al.* (2007), "Life Cycle Assessment of Energy Products: Environmental Impact Assessment of Biofuels – Executive Summary" EMPA.

Scharlemann J. and Laurance W. (2008), "How Green Are Biofuels?", *Science*, vol. 319, no. 5859, pp. 43-44.

Zika, E., *et al.* (2007), "Consequences, Opportunities and Challenges of Modern Biotechnology for Europe", Joint Research Centre Reference Reports, IPTS, Seville.

Annex A

Description of the UNU-Merit field trial database

In most OECD countries, field trials of new GM plant varieties are registered and the data are publicly available. Field trials cover a comparatively late stage of the development of GM varieties, as they do not include greenhouse and laboratory trials. Consequently, field trials provide evidence of relatively late stage research into new plant varieties that could be ready for commercialization within two to six years. The field trial database is updated annually and currently covers 1987 to December 31, 2008.

Field trial data have many of the advantages and limitations of patents. Both provide a measure of investment in particular lines of research by firms and public sector institutions to develop new plant varieties (field trials) or inventions (patents), but in both cases there is no direct relationship between the number of trials or patents and the outcome in terms of commercialised GM varieties or inventions. A series of trials can be abandoned, with no commercialisation of the GM variety, and there is large range in the number of field trials required to develop a GM variety. For example, several hundred field trials were conducted in the United States to alter the ripening characteristics of a tomato variety whereas only 15 trials were required to develop a virus resistant papaya variety. Furthermore, field trials are not fully comparable across countries, as they can vary by size (number of hectares) and by the number of years for which they are valid. In Canada, the number of field trials is increased by regulatory limits on the size of each individual trial, while in New Zealand a field trial can last for multiple years.

In the United States, field tests of GM varieties that have already received approval do not need to be registered, which decreases the comparability between Europe and the United States. The UNU-MERIT GM Field trials database used here includes American data for both releases and notifications (an expedited type of release permit). For all countries, the results given in this article exclude non-plant field tests, such as for bacterial pathogens and animals.

The United States provides ten identifiers for the purpose of each trait. These identifiers were used by UNU-MERIT to identify field trials of specific traits for herbicide tolerance, pest resistance, product quality, agronomic characteristics, and other types of traits. Other countries provide information on the trait but do not include an identifier. UNU-MERIT used the data from the United States and other sources to assign each trait in these countries to one of the five main categories. This classification system contains an unknown but small amount of error because some genetic traits can be used for different purposes. In a small number of trials insufficient detail is provided to accurately determine the purpose of a trial. These are assigned to an "other" category.

Ownership is based on the country of the head office of the organisation performing the field trial in the year in which the trial is conducted. Ownership is revised annually to take account of mergers and acquisitions.

All field trials are assigned to either the private sector, public research institutions (universities and research institutes), and to private non-profit research institutes. The public sector is defined as public research institutes and private non-profit institutions. Trials conducted jointly by the private sector and the public sector are assigned to the public sector. There is a small degree of error in the assignment of trials to the public and private sector (estimated at well under 1%), due to a lack of information on the applicant for some trials conducted by Eastern European and Japanese organisations.

Annex B

Definition of plant patents

Patents are assigned by the patent examiner to one or more International Patent Codes (IPC). A single patent can be assigned dozens of IPC codes, depending on the patent claims. In respect to agriculture, the EPO 2004 patent application by Abbot Laboratories for "control of plant cell proliferation and growth" was given 18 IPC codes and covered four major classes: A01H, A01N, C07K, C12N15, of which two (A01H and C12N15) are plant patents.

A plant patent is defined as including at least one of the following IPC classes:

1. **A01H1 to A01H4**: includes processes for modifying genotypes and phenotypes, plus plant reproduction by tissue culture techniques.
2. **A01H5 to A01H17**: includes product patents for varieties of flowering plants, conifers, mosses, algae, fungi, lichens, and symbiotic or parasitic combinations. Many of the patents for plant species other than flowering plants (A01H5) and conifers (A01H7) (with forestry applications could be for uses other than agriculture or other forms of primary production.
3. **C12N15/82, /83 and /84**: includes recombinant DNA or RNA and other technologies, such as vectors, that are part of the genetic modification of plants.

This article excludes patents that are *only* assigned to product IPC classes (group 1 above). Only results for plant patents with an IPC code in either group 1 or group 3 above are included. These are patents for processes or for recombinant technology. Of note, these two groups overlap, since many patents assigned to genetic modification are also assigned to process patents. Consequently, it is not possible to sum different subgroups of plant patents.

Annex C

R&D pipeline review methodology

A web search was conducted of the following firms active in agricultural biotechnology:

- Monsanto
- Bayer Crop Science
- Du Pont Pioneer
- Syngenta
- Targeted Growth, Inc. (private firm)
- Dow Agrosciences
- Scotts
- ArborGen
- BASF

In addition, the websites for five subsidiaries were also checked:

- Plant Genetic Systems (now part of Bayer)
- Novartis (ag-bio now under Syngenta)
- Seminis (now a seed company of Monsanto)
- Calgene (now part of Monsanto)
- Àsgrow (now a seed company of Monsanto)

Of those surveyed, 4 companies had sufficient data to be included in a timeline of what biotechnologies are coming through the pipelines to 2015:

1. DOW Agrosciences
2. Monsanto
3. DuPont Pioneer
4. Syngenta

The companies provide information regarding what products they are developing, and where the products are in their development pipelines. The different products were classified as follows:

- Agronomic
  - Drought
  - Stress resistance
  - Yield
  - Nitrogen efficiency

- Product quality
- Pest resistance
  - Insect
  - Virus
  - Nematodes
  - Fungi
  - Bacteria
- Herbicide tolerance

Each trait was counted as a single instance so that products which stacked two traits, *e.g.* pest resistance and herbicide tolerance, were counted twice.

Some companies also gave an indication of when they believe the product would come to market. When this information was not given, it was either estimated from other company literature or from similar data provided by other companies.

A list of methods by each company is below:

1. **DOW Agrosciences** – Estimated by comparison with Monsanto's pipeline "Estimated Time to Market" (ETM) data.
2. **Monsanto** – Product "phase" data was given in a company pipeline document. In the same document, the ETM is given in ranges. Both high and low limits were taken for each phase.
3. **DuPont Pioneer** – Product "phase" data was given in a company pipeline document. ETM is given for some products, and for those where it was not, ETM is estimated from the other company phase data.
4. **Syngenta** – Product "phase" data and ETM was given in a company pipeline document. This included information about the percentage completed within each phase. The ETM given was a single year, so a (+/-) 1 year buffer was used. The percentage developed, which was provided by the company, was taken into account when classifying into the "OECD phases", which are discussed later.

Given the difficulties in comparing the different research phases of each company, an "OECD classification for use in agriculture projections" was developed to facilitate comparison.

Once the products were classified, they were placed into Table 10.

Table 38. **Description of OECD agricultural biotechnology development phases**

OECD Phase	Estimated Time to Market	Description
Discovery	8 to 12 years	Key Activities: High-throughput screening; Model crop testing Research Focus: grain yield, environmental stress tolerance, pest control, herbicide tolerance, disease resistance, lipid enhancements (increased oil, improved fatty-acid balance), protein enhancements (improved amino-acid balance), carbohydrate enhancements, & bioactive compounds.
I	6 to 8 years	Key Activities: Gene optimization; Crop transformation
II	3 to 6 years	Key Activities: Trait development; Pre-regulatory data; Large-scale transformation
III	1 to 3 years	Key Activities: Trait integration; Fixed testing; Regulatory data generation, Regulatory submission; Seed bulk-up; Pre-marketing

Source: Adapted from the "Monsanto 2007 R&D Pipeline at a glance", and their phases III & IV were combined.

Annex D

Crop production data

Table 39. **Number of hectares planted and % change (1995-2005) for world and major region, by crop (in thousands of hectares)**

	World		OECD		European Union[2]		North America[3]		South America[4]	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Alfalfa	15 119	-4.65%	11 724	-4.06%	2 099	-13.62%	9 421	-3.71%	1 801	0.85%
Cottonseed	33 026	-6.11%	7 052	-14.43%	451	-7.08%	5 688	-14.29%	818	-52.86%
Flaxseed	2 510	-19.00%	781	-7.76%	187	-33.01%	589	0.84%	14	-82.72%
Maize	144 990	4.05%	45 000	4.58%	8 924	3.80%	38 102	3.12%	17 486	-5.83%
Papaya	381	28.47%	20	31.47%	0	0.00%	20	30.97%	68	9.60%
Plums[5]	2 343	31.64%	190	-33.97%	211	-27.09%	59	-13.12%	36	1.91%
Potatoes	18 816	2.17%	2 810	-28.77%	2 254	-32.97%	657	-7.26%	848	-12.64%
Rapeseed[6]	28 261	7.70%	11 526	13.35%	4 901	22.69%	5 962	2.32%	64	91.39%
Rice, paddy	153 860	0.41%	4 641	-9.58%	413	1.21%	1 419	-0.28%	6 111	0.52%
Soybeans	92 113	35.97%	30 657	9.53%	418	-8.77%	30 094	9.93%	40 238	91.87%
Squash[7]	1 507	25.54%	149	-6.58%	41	-20.75%	50	-24.98%	56	-5.53%
Sugar beet	5 456	-25.55%	3 031	-20.66%	2 159	-26.31%	515	-10.01%	32	-38.02%
Tobacco	3 909	-19.67%	514	-35.82%	186	-13.76%	145	-51.53%	602	33.01%
Tomatoes	4 620	34.13%	871	7.50%	343	-5.72%	294	-7.60%	142	-8.34%
Wheat	220 394	-0.30%	75 128	0.14%	26 196	-2.88%	30 811	-7.79%	14 076	51.32%
Total GM Target	727 304	N/A	194 093	N/A	48 784	N/A	123 825	N/A	82 392	N/A
Other crops[8]	502 124	3.00%	85 233	-4.75%	42 996	-7.98%	26 382	-3.26%	33 938	2.49%

Source: Authors, based on FAO (2009).

Notes: See notes at end of Annex D.

Table 40. **Number of tonnes produced and % change (1995-2005) for world and major region, by crop (in thousands of tonnes)**

	World		OECD		European Union[2]		North America[3]		South America[4]	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Alfalfa	454 635	-7.45%	372 842	-6.77%	66 790	-18.24%	296 106	-5.47%	47 839	1.31%
Cottonseed	39 133	6.63%	10 766	3.86%	871	3.24%	7 927	6.77%	230	-42.17%
Flaxseed	2 878	5.28%	1 784	11.96%	194	-34.04%	1 582	22.82%	47	-72.08%
Maize	709 366	22.94%	364 497	23.80%	62 685	3.65%	309 784	26.27%	65 150	26.67%
Papaya	6 614	35.82%	730	51.73%	0	0.00%	724	52.09%	2 212	44.80%
Plums[5]	9 252	32.23%	1 748	-19.24%	1 548	5.09%	491	-23.10%	426	78.37%
Potatoes	316 166	8.08%	88 769	-17.90%	59 488	-24.87%	25 112	2.06%	13 012	-1.93%
Rapeseed[6]	49 477	23.62%	271 59	30.82%	15 656	28.34%	10 596	30.64%	129	111.59%
Rice, paddy	628 198	8.16%	31 709	-6.57%	2 687	10.12%	10 416	16.06%	24 241	23.25%
Soybeans	212 577	48.62%	88 049	12.15%	1 188	-26.08%	86 688	13.11%	95 766	129.26%
Squash[7]	20 212	28.61%	3 319	1.21%	1 206	6.89%	1 011	-17.33%	699	-13.03%
Sugar beet	250 884	-9.83%	171 956	-11.31%	129 182	-15.32%	25 696	-0.21%	2 823	-22.57%
Tobacco	6 572	-17.54%	886	-38.92%	417	-6.47%	349	-51.05%	1 136	41.17%
Tomatoes	122 880	36.74%	43 297	14.90%	17 967	16.83%	14 683	-0.40%	6 367	14.78%
Wheat	622 561	2.44%	255 287	3.36%	133 330	-0.89%	87 070	-3.37%	20 470	29.51%
Total GM Target	3 451 405	N/A	1 462 798	N/A	493 206	N/A	878 236	N/A	280 546	N/A
Other crops[8]	3 583 342	18.61%	544 231	-0.21%	217 521	-4.48%	203 791	0.28%	673 543	22.36%

Source: Authors, based on FAO (2009).

Notes: See notes at end of Annex D.

Table 41. **Yield and % change (1995-2005) for major regions, by crop (in tonnes/ha)**

	European Union[2]		North America[3]		South America[4]	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Alfalfa	32	-5.28%	31	-1.75%	27	0.47%
Cottonseed	2	10.78%	1	23.00%	0	8.15%
Flaxseed	1	-1.05%	3	24.81%	3	135.48%
Maize	7	0.72%	8	22.67%	4	34.41%
Papaya	0	0.00%	37	15.24%	33	32.22%
Plums5	7	43.37%	8	-12.02%	12	73.38%
Potatoes	26	12.16%	38	10.18%	15	12.30%
Rapeseed[6]	3	3.79%	2	26.99%	2	9.26%
Rice, paddy	6	9.20%	7	16.41%	4	21.70%
Soybeans	3	-18.37%	3	3.25%	2	20.37%
Squash[7]	29	40.38%	20	10.01%	13	-7.82%
Sugar beet	60	15.02%	50	10.83%	89	25.17%
Tobacco	2	8.42%	2	2.01%	2	6.19%
Tomatoes	52	23.84%	50	8.17%	45	25.22%
Wheat	5	1.83%	3	3.96%	1	-8.71%
Total GM Target	N/A	N/A	N/A	N/A	N/A	N/A
Other crops[8]	N/A	N/A	N/A	N/A	N/A	N/A

Source: Authors, based on FAO (2009).

Notes: See notes at end of Annex D.

Table 42. **2003 production price for world and major region, by crop (in USD millions, 2003 production price)**

Commodity	European Union[2]	North America[3]	South America[4]
Alfalfa	N/A	N/A	N/A
Cottonseed	560.22	3 316.42	362.82
Flaxseed	47.75	238.07	4.07
Maize	7 911.83	28 749.20	5 458.51
Papaya	0.00	254.66	2 009.74
Plums[5]	946.41	278.58	86.88
Potatoes	10 964.77	4 152.12	2 045.94
Rapeseed[6]	2 931.58	1 915.35	15.45
Rice, paddy	762.29	1 493.18	2 522.59
Soybeans	192.24	18 314.96	14 098.65
Squash[7]	678.97	190.71	131.20
Sugar beet	5 675.80	1 139.40	100.82
Tobacco	N/A	N/A	N/A
Tomatoes	9 244.44	2 300.36	1 361.96
Wheat	14 624.39	10 538.49	2 951.05
Total GM Target	N/A	N/A	N/A
Other crops[8]	N/A	N/A	N/A

Source: Authors, based on FAO (2009).

Notes apply to Tables 39 to 42:

1. To avoid any anomalies due to environmental conditions etc. the percent change was determined from the average quantity from the periods 1995 to 1997 and 2003 to 2005.
2. The European Union includes Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, & the United Kingdom
3. North America includes Canada, Mexico, and the USA
4. South America includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, & Venezuela
5. Plums include sloes.
6. Rapeseed includes mustard seed.
7. Squash includes pumpkins & gourds.
8. Other crops include nuts, tree fruits (except plums), vine fruits (including grapes), vegetables, other root crops (cassava, sweet potatoes, yams), other cereals (barely, oats, sorghum, millet), legumes, spices, plantains, etc. See Annex E for a complete list.

Annex E

Crops included in world acreage total

Almonds; anise, badian, fennel, corian; apples; apricots; artichokes; asparagus; avocados; bananas; barley; beans (including string b.), green; beans (including cow peas), dry; broad beans, horse beans, dry; cabbages and other brassicas; carrots and turnips; cashew nuts; cassava (fresh and dried); cauliflowers and broccoli; cereals, nec; cherries (including sour cherries); chestnuts; chick peas; chillies and peppers, dry; chillies and peppers, green; cinnamon (canella); citrus fruit, nec; cloves; cocoa beans; coconuts (including copra); coffee, green; cranberries, blueberries; cucumbers and gherkins; currants and gooseberries; dates; eggplants (aubergines); figs; fruit, nec (including persimm.); garlic; ginger; grapefruit and pomelo; grapes; groundnuts; guavas, mangoes, mangosteens; hazelnuts; kiwi fruit; leeks, other alliaceous vegeta; legum. veg., nec; lemons and limes; lentils; lettuce and chicory; millet; mushrooms and truffles; natural honey; nutmeg, mace and cardamoms; nuts, nec; oats; oilseeds, nec; olives; onions (including shallots); oranges; other melons (including cantaloupes); palm nuts-kernels (nut equiv.); peaches and nectarines; pears and quinces; peas, dry; peas, green; pepper (piper spp.); pineapples; pistachios; plantains; pulses, nec; raspberries and other berries; rye; sesame seed; sorghum; spices, nec; spinach; starchy roots, nec; strawberries; sugar cane and sugar crops, nec; sunflower seed; sweet potatoes; tangerines, mandarins, clem.; tea and maté; vanilla; vegetables, nec (including okra); walnuts; watermelons; yams.

Annex F

Animal production data

Table 43. **Land animal production data, by region (in thousand tonnes)**

	European Union		North America		South America	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Animal Fats	1 513	-9.09%	3 373	6.01%	1 026	10.27%
Bird Eggs	6 505	-2.46%	8 005	27.69%	3 089	14.10%
Bovine	8 649	-19.07%	14 817	2.62%	13 509	7.65%
Dairy	150 491	-2.44%	98 397	11.80%	48 400	16.90%
Fibres[2]	195	-9.77%	23	-28.81%	158	-29.40%
Natural Honey	199	18.60%	166	-2.60%	133	21.68%
Other[3]	3 093	-9.44%	2 160	2.58%	2 673	25.59%
Pig	21 253	1.80%	13 113	24.04%	4 426	20.84%
Poultry[4]	11 762	11.24%	22 144	27.26%	12 989	70.93%
Sheep and goat	1 204	-11.48%	196	-12.84%	338	-5.98%

Source: Authors, based on FAO (2009).

Notes: 1. To avoid any anomalies due to unusual environmental conditions etc., the percent change was determined from the average quantity of the periods 1995 to 1997 and 2003 to 2005.

2. Only includes fibres of animal origin.
3. Other includes edible offal, equine meat, rabbit meat, and meat not included elsewhere.
4. Poultry includes chicken meat, turkey meat, and duck, goose, or guinea fowl.

Annex G

Marine production data

Table 44. **Marine animal production data, by region (in thousand tonnes)**

	European Union		North America		South America	
Commodity	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)	Total (2005)	% change[1] (1995-2005)
Fish[2]	2 035	-37.66%	2 893	-1.96%	1 733	-18.38%
Molluscs[3]	1 106	4.46%	1 091	26.20%	302	57.13%
Other[4]	460	-19.92%	1 100	0.23%	1 173	15.97%

Source: Authors, based on FAO (2009).

Notes: 1. To avoid any anomalies due to unusual environmental conditions etc., the percent change was determined from the average quantity of the periods 1995 to 1997 and 2003 to 2005.

2. Fish includes freshwater and diadromous fish; and demersal, pelagic, and other marine fish.
3. Molluscs exclude cephalopods.
4. Other includes aquatic plants, mammals, and other animals; cephalopods, and crustaceans.

Annex H

Developing countries, by region

Asia: Afghanistan, Armenia, Azerbaijan, Bangladesh, China, Georgia, India, Indonesia, Iran, Korea Rep, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Vietnam.

Central America: Bahamas, Barbados, Belize, Costa Rica, Cuba, Grenada, Guadeloupe, Guatemala, Honduras, Jamaica, Mexico, Netherlands Antilles and Puerto Rico.

Eastern Europe: Albania, Bosnia Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Lithuania, Macedonia, Moldova Rep, Poland, Romania, Serbia and Montenegro, Slovakia and Ukraine

Middle East/North Africa: Algeria, Egypt, Iraq, Jordan, Kuwait, Morocco, Syria, Tunisia and United Arab Emirates

South America: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Uruguay and Venezuela.

Sub-Saharan Africa: Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Democratic Republic of Congo, Congo, Côte d'Ivoire, Ethiopia, Gabon, Ghana, Kenya, Madagascar, Malawi, Mali, Mauritius, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia and Zimbabwe

Annex I

Non-GM biotechnologies in FAO Bio-DeC

Table 45. **Non-GM crop biotechnologies in the FAO Bio-DeC database**

Technology	Type of Technology	Number	Percentage
AFLP	Plant Breeding	71	4.23%
Anther culture	Plant Breeding	78	4.65%
Bioprospecting	Other	1	0.06%
Bios-pesticide	Biopesticides/biofertilizers	11	0.66%
Design-delivery biocontrol agents	Biopesticides/biofertilizers	33	1.97%
Design-delivery of biofertilizers	Biopesticides/biofertilizers	35	2.09%
ELISA	Diagnostic	69	4.11%
Embryo rescue	Plant Breeding	37	2.21%
Fermentation, food processing	Fermentation, food process.	35	2.09%
Gene cloning	Plant Breeding	4	0.24%
Gene discovery	Plant Breeding	1	0.06%
Genetic engineering	Plant Breeding	2	0.12%
Genetic Transformation	Plant Breeding	11	0.66%
Genome sequencing	Plant Breeding	9	0.54%
In vitro germplasm conservation & exchange	Other	43	2.56%
In vitro regeneration	Propagation, other	35	2.09%
Isozymes	Plant Breeding	8	0.48%
MAS – Marker Assisted Selection	Plant Breeding	19	1.13%
Micropropagation	Propagation, micro	485	28.90%
Microsatellite markers	Plant Breeding	78	4.65%
Monoclonal antibodies	Diagnostic	9	0.54%
Nucleic acid probes	Plant Breeding	1	0.06%
Other – cell biology	Other	94	5.60%
Other or not specified	Other	185	11.03%
PCR	Plant Breeding	51	3.04%
Protoplast fusion and culture	Plant Breeding	23	1.37%
RAPD	Plant Breeding	169	10.07%
RFLP	Plant Breeding	64	3.81%
Somaclonal variation	Plant Breeding	12	0.72%
Somatic hybridisation	Plant Breeding	5	0.30%
TOTAL		1 678	100.00%

Source: Authors, based on FAO (n.d.).

Table 46. **Non-GM animal biotechnologies in the FAO Bio-DeC database**

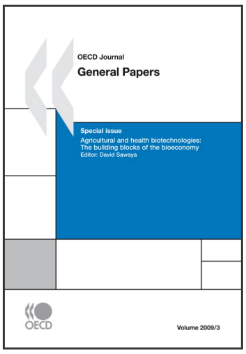
Technology	Type of Technology	Number	Percentage
AFLP	Animal Breeding	2	1.3%
Artificial insemination	Animal Breeding	3	2.0%
Biochemical markers	Animal Breeding	4	2.7%
Blood protein markers	Animal Breeding	4	2.7%
Cell culture	Other	1	0.7%
Cryopreservation	Other	5	3.4%
Cytogenetics Techniques	Other	4	2.7%
DNA markers – unspecified	Animal Breeding	6	4.0%
DNA probes	Diagnostic	5	3.4%
DNA sequencing	Animal Breeding	3	2.0%
ELISA	Diagnostic	3	2.0%
Embryo transfer	Animal Breeding	7	4.7%
Enzymes	Other	1	0.7%
Gene cloning and characterisation	Animal Breeding	1	0.7%
Gene expression	Animal Breeding	2	1.3%
Genome sequencing	Animal Breeding	3	2.0%
Genotyping	Animal Breeding	6	4.0%
Hormones	Other	1	0.7%
in vitro fertilisation	Animal Breeding	3	2.0%
Isozymes	Animal Breeding	3	2.0%
Marker assisted breeding	Animal Breeding	1	0.7%
Microsatellites	Animal Breeding	10	6.7%
Mitochondrial DNA	Animal Breeding	3	2.0%
Other or unspecified	Other	3	2.0%
PCR	Animal Breeding	37	24.8%
PCR – RFLP	Animal Breeding	5	3.4%
RAPD	Animal Breeding	1	0.7%
RFLP	Animal Breeding	1	0.7%
Ribosomal DNA ITS	Animal Breeding	1	0.7%
RT – PCR	Animal Breeding	8	5.4%
RT – PCR & Sequencing	Animal Breeding	4	2.7%
Vaccine production	Vaccine	8	5.4%
Grand Total		149	100.0%

Source: Authors, based on FAO (n.d.).

Table 47. **Non-GM forestry biotechnologies in the FAO Bio-DeC database**

Technology	Type of Technology	Number	Percentage
AFLP	Plant Breeding	18	2.22%
Agrobacterium mediated transformation	Plant Breeding	12	1.48%
Anther and pollen culture	Plant Breeding	2	0.25%
Biofertilizers	Biopesticides/biofertilizers	41	5.06%
Biopesticides	Biopesticides/biofertilizers	1	0.12%
Chloroplast DNA markers	Plant Breeding	11	1.36%
DNA based	Plant Breeding	2	0.25%
DNA chip	Diagnostic	14	1.73%
ELISA	Diagnostic	1	0.12%
Embryo rescue	Plant Breeding	4	0.49%
Expressed Sequence Tags (EST)	Plant Breeding	1	0.12%
Gene expression	Plant Breeding	12	1.48%
Genetic markers techniques	Plant Breeding	4	0.49%
Genetic variation	Plant Breeding	7	0.86%
In vitro germplasm cons. and cryopreservation	Other	9	1.11%
In vitro regeneration	Propagation, other	3	0.37%
Isozymes	Plant Breeding	52	6.42%
MAS – Marker Assisted Selection	Plant Breeding	17	2.10%
Micropropagation	Propagation, micro	413	50.99%
Other or not specified	Other	61	7.53%
PCR	Plant Breeding	2	0.25%
Polyploid induction	Plant Breeding	3	0.37%
Protoplast culture	Plant Breeding	2	0.25%
RAPD	Plant Breeding	79	9.75%
rDNA – ribosomal DNA sequences	Plant Breeding	4	0.49%
RFLP	Plant Breeding	9	1.11%
Sequencing	Plant Breeding	1	0.12%
Microsatellites or SSRs	Plant Breeding	20	2.47%
Transformation	Plant Breeding	5	0.62%
TOTAL		810	100.00%

Source: Authors, based on FAO (n.d.).



From:
OECD Journal: General Papers

Access the journal at:
https://doi.org/10.1787/1995283x

Please cite this article as:

Arundel, Anthony and David Sawaya (2010), "Biotechnologies in Agriculture and Related Natural Resources to 2015", *OECD Journal: General Papers*, Vol. 2009/3.

DOI: https://doi.org/10.1787/gen_papers-2009-5kmjkjtfzztj

OECD