Part 1 The Challenge

Throughout history, innovation has driven progress and helped people address the problems of their Age. This progress has not been achieved without pain and controversy. At times, war, famine, and pestilence thwart our best endeavors. Despite setbacks, people the world over continue to strive to understand the natural world, to pursue truth and beauty, and to create a better world for themselves and their children.

Science has a role to play in all these pursuits. However, the very power of the new discoveries in the biological sciences raises fears that these discoveries will not be used wisely. Many believe that they will accelerate the destruction of the natural environment, damage human health, concentrate too much power in the hands of a few global companies, and widen the gap between the rich and the poor, within and between nations.

The task of the Promethean scholars of today is to analyze where modern science can lead to technical innovations and how these can be used wisely to improve agricultural productivity, conserve natural resources, and create wealth especially for poor people in developing countries.

Global Food Security

> *A world of food-secure people is within our reach, if we take the necessary actions.*

The World Food Summit recognized that eradication of poverty is a critical step in improving access to food. Food security covers both the availability of food at the household level as well as access in terms of purchasing power (FAO 1996). *Most people who are undernourished either cannot produce enough food or cannot afford to buy it.* Reduction and elimination of poverty is therefore an integral part of the provision of sustainable global food security.

Poverty in a Time of Plenty: A Paradox

Although the annual world agricultural growth rate has decreased from 3 percent in the 1960s to 2 percent in the last decade, projections indicate that, given reasonable initial assumptions , world food supply will continue to outpace world population growth, at least to 2020 (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1999). Worldwide, per capita availability of food is projected to increase around 7 percent between 1995 and 2020, and for developing countries, by 9 percent (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1999).

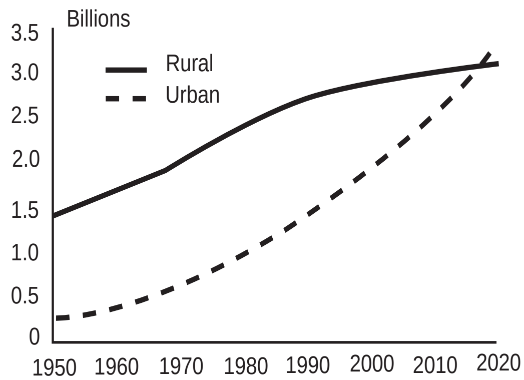
The paradox is that despite the increasing availability of food, *there are about 840 million people, or 13 percent of the global population, who are food insecure.* These people are among the 4.5 billion inhabitants of the developing countries in Asia (48 percent), Africa (35 percent), and Latin America (17 percent). Of these 840 million, at least 200 million are malnourished children.

It is also paradoxical that food insecurity is so prevalent at a time when global food prices are generally in decline. World cereal production doubled between 1960 and 1990, per capita food production increased 37 percent, calories supplied increased 35 percent, and real food prices fell by almost 50 percent (McCalla 1998).

> *The basic cause of the paradox is the intrinsic linkage between poverty and food security. Simply put, people's access to food depends on income.*

Poverty is both a rural and an urban phenomenon. Over 1.3 billion people in developing countries are absolutely poor, with incomes of US$1 per day or less per person, while another 2 billion people are only marginally better off (World Bank 1997). Malnutrition kills 40,000 people each day. Children and women are most vulnerable to dietary deficiencies, with 125 million children affected by vitamin A deficiency. Many of the poor today live in the low-potential rural areas of the world. With increasing urbanization, a higher proportion of poor people will be living in the cities of the developing countries. The rate of increase of the urban population in the developing countries will be approximately six-fold that of rural areas (Figure 1). Ensuring their access to sufficient nutritious food at affordable prices is also an important component of global food security strategies. *Agricultural research needs to respond to both of these challenges, so as to improve the livelihood of the rural poor and ensure the increased availability of nutritious food at affordable prices for the urban poor.*

Figure 1 Urban and rural population levels in developing countries, 1950–2020



Source: United Nations, World Urbanization Prospects: The 1996 Revision (New York: UN, 1996).

Food Security

Food security is a complex issue that involves:

- Not just *production*, but also *access*
- Not just *output*, but also *process*
- Not just *technology*, but also *policy*
- Not just *global*, but also *national*
- Not just *national*, but also *household*
- Not just *rural*, but also *urban*
- Not just *amount*, but also *content*.

Food production is a necessary but not sufficient condition for food security. Focusing on improving the livelihood of smallholder farmers in developing countries is key to environmental protection, poverty reduction, and food security. The need is to produce differently, not to produce less.

Global Food Base

Humanity has a narrow food base. Twelve crops account for 95 percent of the plant food base. These are banana/plantain, cassava, *corn (maize), groundnut, millets, oil crops, potato, rice, sorghum, soybean, sweet potato, and wheat.*

There is also an increasing demand for milk and meat in the developing countries, as dietary preferences change, with increasing urbanization. Indeed, some consider that a "livestock revolution" is taking place in global agriculture that has profound implications for human health, livelihoods, and the environment. Population growth, urbanization, and income growth in developing countries are fueling a massive increase in demand for food of animal origin. These changes in the diets of billions of people could significantly improve the well-being of many rural and urban poor (Delgado and others 1999). Although some of this increase will be met by local rangeland production, some also requires increased production and/or import of feed grains and more intensive livestock production. FAO has nominated 14 priority species in its global strategy on farm animal genetic resources. The most important of these for food production are cattle, sheep, goats, pigs, and chickens. Fish are also an increasingly important component of the diet in developing countries (FAO 1999).

World Food Production Challenge

Production Trends

Yields of maize, wheat, and rice in developing countries increased from 1.15 to 2.76 tons/hectare between 1961 and 1998. In Africa, they increased from 0.81 to 1.22 tons/hectare over the same period. This presents a significant opportunity to raise cereal production in Africa through yield increases. Globally, meat production increased from 71 million tons in 1961 to 226 million tons in 1999. For developing countries, it increased from 20 million tons to 122 million tons over the same period (Delgado and others 1999).

Consumption Patterns

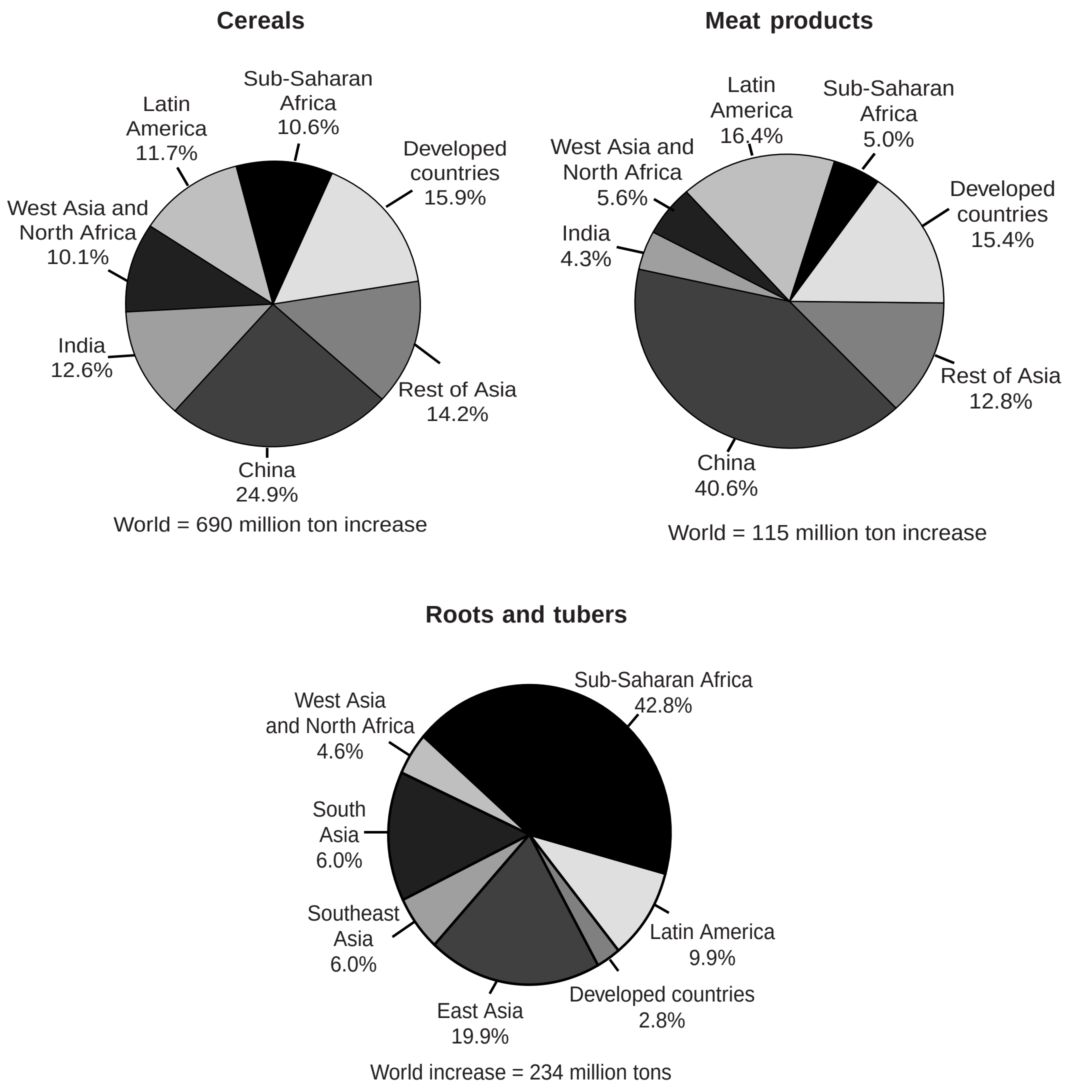
Demands for food in developing countries are met by both local production and imports. Currently the developing world is a net importer of 88 million tons of cereals/year at a cost of US$14.5 billion. Since the 1970s the developing countries have become large net importers of milk and meat as demand for livestock products increasingly exceeds supply. Net meat imports by developing countries will increase eightfold between 1995 and 2020.

Forecasts of future demands for plant and animal products that will drive the production/import requirements of the various regions of the developing world will need to take into account: (a) changes in dietary composition of both food and livestock products; (b) use of cereals as food and feed; and (c) the balance between production and import of plant and animal commodities.

Future Demands

IFPRI projects that global demand for cereals will increase by 40 percent between 1995 and 2020, with most of the increase in demand coming from developing countries. This will include a doubling in demand for feed grains in the developing world. Net cereal imports by developing countries will almost double by 2020 to meet the gap between production and demand (Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1999) (see Figures 2 and 3).

Figure 2 Share of increase in global demand by region, 1995–2020



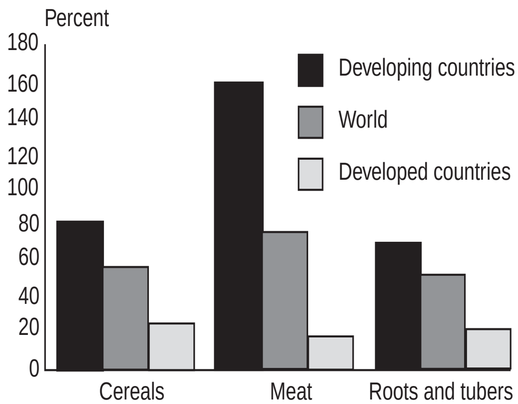
Source: IFPRI IMPACT simulations, July 1999.

Beyond the Green Revolution

The food production increases over the past 40 years have been achieved by increasing productivity of cereals, expanding the area of arable land, and massive increases in fertilizer use.

The key element in improving food security during 1960-99 was government policies reflecting a belief that investments in improving agricultural productivity were a prerequisite to initiating the process of economic development. These policies were supported by both the public and private sectors of the international community. The successful implementation of these policies led to the Green Revolution. Attention was given to the following issues: research and development; technology transfer; human resource development;

Figure 3 Projected increase in total demand for food, 1990–2020



appropriate provision of credit; supply and distribution of inputs (seed, water, fertilizer, pesticide); appropriate pricing policies for inputs and outputs; and infrastructure.

The scientific basis for the green revolution stems from joint national and international research programs, which led to the development and distribution of new, high-yielding varieties, primarily of wheat and rice. These varieties gave improved yields, especially when grown in favorable environments with the addition of fertilizer and pesticides.

Plant breeding was carried out with multiple sites worldwide, north and south of the equator. These trials were associated with comprehensive production training programs for scientists and technicians from national agricultural research systems. Informative data on the performance of the genetic materials were provided back to the coordinating center. Local breeding and selection programs were later initiated by the national agricultural research systems, based on the international breeding materials crossed with locally adapted material. This increased the availability of locally adapted varieties for different ecosystems.

The international agricultural research centers also undertook the collection and conservation of the germplasm of their mandate crops, established and maintained large ex situ collections of this genetic material, and undertook its partial phenotypic characterization. Some hundreds of thousands of accessions are now held in trust by the CGIAR Centers, under the auspices of the FAO Commission on Plant Genetic Resources.

Doubly Green Revolution

To meet the food security needs of the world's people in the decades ahead and to create wealth, there is a need to increase agricultural productivity on the presently available land while conserving the natural resource base (Conway 1997). Such a revolution would involve:

- Increasing productivity of the major food crops
- Reducing chemical inputs of fertilizers and pesticides and replacing these with biologically based products
- Integrating soil, water, and nutrient management
- Improving the productivity of livestock.

Double Shift in the Research Paradigm

The challenge now is how to use new developments in modern science, communications technology, and new ways of managing knowledge to make complex agricultural systems of smallholder farmers more productive in a sustainable way.

These issues make for a complex research agenda to improve food security and create wealth. *This new research agenda needs to combine traditional wisdom with modern science.*

There is a double shift in the research paradigm: firstly, the need for greater contextualization of research, to be undertaken in the context of the deeper understanding of the suatainable management of the environment and the socioeconomic and gender issues that affect the livelihoods of poor people in rural and urban areas. This research will need to seek synergies within the farming systems of smallholders, who integrate crop agriculture, livestock, agroforestry, and aquaculture in complex farming systems.

The second shift is the need to mobilize the new revolution in genetics and biotechnology to improve the productivity of agroecological systems and the crops, livestock, fish, trees and other species important to poor people and developing countries.

Without minimizing in any way the vital importance of the first shift, this monograph is devoted to a discussion of the second shift, the challenge of harnessing of the new findings in biotechnology for the benefit of the poor and the environment.

Role of Agricultural Research

The annual rates of return to investment in agricultural research average 50-80 percent. Thus well directed agricultural research and development programs remain a wise investment of public funds (Alston and others 2000).

There have been several forces that have resulted in the restructuring, downsizing, and refinancing of agricultural and natural resources research systems in industrial and developing countries over the past decade. They include increasing privatization and competition amongst research providers. These changes are also having a significant impact on donor perceptions, policies, and financial support for national and international agricultural research.

There is a trend toward decreasing public sector investments in research and development. This is partially offset by increasing private sector investments largely aimed at generating new products and processes through biotechnological advances. There is also an increasing use of *participatory processes* involving farmers, civil society, and other stakeholders in the financing, planning, and conduct of research and technology transfer. These approaches seek to enhance successful delivery of useful products and decision-support systems to farmers and consumers.

The coming into force of several international treaties and conventions have also increased the pressure on national governments to meet international obligations.

New Modalities

New developments in modern biotechnology, information technology, and geographic information systems are revolutionizing global research and development in agriculture and natural resources research. Partnerships between national agencies and international groups may often be the most effective means of developing and delivering new agricultural research technologies of a public goods nature.

These programs need to involve various combinations of national agricultural research systems, nongovernmental organizations, the private sector, farmer groups, advanced research organizations, and the international agricultural research centers.

This challenge requires the CGIAR to work with more partners, in a wider array of environments, with a broader range of commodities, often grown in mixed systems, and with concern for maintaining the physical and genetic resource base.

The Genetic Imperative

Rapid progress is being made in understanding the genetic basis of living organisms, and the ability to use that understanding to develop new products and processes useful in human and animal health, food and agriculture, and the environment.

There is now increasing use of modern molecular genetics for genetic mapping and marker-assisted selection as aids to improve crops, livestock, fish, and tree species. Other biotechnology applications such as tissue culture and new diagnostics and animal vaccines are being widely adopted.

Harnessing the full power of the genetic revolution requires going beyond these early applications of modern biotechnology, and recognizing the power of the new revolution in genomics and associated technologies as aids for genetic improvement. The new technologies will enable greatly increased efficiency of selection for valuable genes, based on knowledge of the biology of the organism, the function of specific genes, and their role in regulating particular traits. This will enable more precise selection of improved strains at the molecular as well as the phenotypic level.

Challenge of Biotechnology

Biotechnology (see Box 1) offers both promise and perils for the world community. In human health, it offers new ways to understand the genetic basis of diseases, and to develop improved diagnostics, drugs, and vaccines for their treatment. In agriculture and forestry, it promises new ways to harness and improve the biological potential of crops, livestock, fish, and trees, and improved ways to diagnose and control the pests and pathogens that damage them.

The perils lie in the profound ethical issues surrounding the control and use of

Box 1 Biotechnology defined

Biotechnology is any technique that uses living organisms or parts thereof to make or modify a product, improve plants or animals, or develop microorganisms for specific uses. All the characteristics of any given organism are encoded within its *genetic material*, which consists of the collection of *deoxyribonucleic acid (DNA)* molecules that exist in each cell of the organism. The complete set of DNA molecules in an organism comprises its *genome*. The genome is divided into a series of functional units, called *genes*. Typical crop plants contain 20,000 to 25,000 such genes. The genome contains two copies of each gene, one having been received from each parent. The collection of *traits* displayed by any organism (*phenotype*) depends on which genes are present in its genome (*genotype*). The appearance of any specific phenotype trait also will depend on many other factors, including whether the genetic information responsible for the trait (or genes) associated with it is turned on (*expressed*) or off, the specific cells within which the genes are expressed, and how the genes, their expression, and the gene products interact with environmental factors (genotype x environment effects).

these powerful new technologies, and the assessment and management of risks to human health and the environment associated with specific applications. These issues have led to rising public concerns in some countries about various applications of biotechnology. The concerns have been stimulated by an activist campaign against the use of genetically improved organisms in food and agriculture and their release into the environment. *Modern biotechnology raises profound issues, but it also offers enormous promise for dealing with previously intractable problems.*

Key Issues

The key policy issues that will affect the application of new developments in modern biotechnology for the public good are ethics, food and environmental safety, economic concentration, and intellectual property management.

Ethics

A wealth of scientific and popular discussion exists about the benefits and risks of genetic engineering and biotechnology. Confusion surrounds the issue of biotechnology's risks and benefits. What are the social and ethical issues surrounding the use of biotechnology to improve food security and alleviate poverty? Current public debate about the "gene revolution" often does not sufficiently differentiate between risks inherent in a technology and those that transcend it. This differentiation is important in any attempt to reason out the social and ethical implications of biotechnology (Leisinger 2000).

Since the early 1970s, recombinant DNA technology has enabled scientists to genetically modify plants, animals, and microorganisms and introduce a greater diversity of genes, including genes from distantly related species, into organisms than traditional methods of breeding and selection. Organisms genetically modified in this way are called *living modified organisms*. Concerns exist about the potential risks posed by living modified organisms. The principles and practices required for assessment of technology-inherent risks are well established and draw on the experience of individual countries and regional and international organizations. From an ethical perspective, risks disallowed in industrial countries should not be exported to developing countries. If genetically engineered organisms and biotechnological procedures are used in developing countries, state-of-the-art quality management that takes local ecological conditions into account must be practiced. Such risk assessments allow governments, communities, and business to make informed decisions about the benefits and risks inherent in using a particular technology to solve specific problems.

Technology-transcending risks emanate from the political and social context in which a technology is used. These risks stem from both the course the global economy takes and country-specific political and social issues. The most critical fears have to do with the potential aggravation of the prosperity gap between industrial and developing countries and growing disparities in the distribution of income and wealth within and between developing countries. The gap in prosperity between industrial and developing countries may grow because of the possible substitution of genetically engineered products for tropical agricultural exports and because the industrial world may not adequately compensate the developing world for exploiting its indigenous genetic resources.

Widespread fear exists that private enterprises and research institutes could gain unremunerated control of the genes of plants native to the developing world and use them to produce superior varieties that would then be sold back to developing countries at high prices. The successful implementation of the Rio Convention on Biological Diversity so that it becomes clear who should compensate whom for what and for how much needs unequivocal regulation. Simple and effective ways need to be found to establish fair compensation.

In assessing the potential impact of biotechnology on food security and povertty alleviation, the interpretation of data is subject to the interests and value judgments of a variety of stakeholders. Identical information can lead some to consider agricultural biotechnologies to be amongst the most powerful and economically promising means of ensuring food security, while others perceive them as a threat to development in poor countries. Differing realities and pluralism of opinion exist. Biotechnology involves a number of economic, social, and ecological risks. But these risks are not a consequence of the technology per se. They arise from particular social settings, transcending the nature of the technology employed within those settings. There are also ethical issues involved in *not* pursuing the use of new technologies that may contribute to improving the productivity and sustainability of agriculture, especially in developing countries (Nuffield Council on Bioethics 1999). All these issues need to be openly debated, and choices made by individuals and nations.

Food Safety

An open, transparent, and inclusive food safety policy and regulatory process is required, which takes account of public concerns about genetically improved foods. Many consumers in North America, Europe, and China have been eating genetically improved food over the past several years, without any demonstrated adverse effects on human health. The concept and practice of risk assessment, including consistent approaches to the use of substantial equivalence and the precautionary principle, are valuable tools but need to be kept under review.

Food labeling, whether mandatory or voluntary, could be used to provide information about specific products and enable consumers to make informed decisions about their use. The potential long-term impact of genetically improved foods on human health, worker safety, and the environment is unknown, and requires monitoring and research. Methods are available to test allergenicity and toxicity of novel genetically improved foods in humans. Post-market monitoring of such foods may be possible in some markets but impractical in others.

The Organization for Economic Cooperation and Development will report in mid 2000 to the G8 Summit on key issues, including:

- Factual points of departure where there is agreement and disagreement
- Benefits versus risks, which differ for different countries and environments
- Management of genetic modification technologies
- The role of stakeholders
- An international program of activities to inform the public debate and policymaking.

Environmental Risks

When addressing risks posed by the cultivation of plants in the environment, six safety issues need to be considered (Cook 2000; NRC 2000). These are

- gene transfer to wild relatives
- weediness
- trait effects
- genetic and phenotypic variability
- expression of genetic material from pathogens
- worker safety.

Review of these issues is inherent in the regulatory systems in place today (Doyle and Persley 1996).

The Cartagena Protocol on Biosafety was agreed to by 130 governments in Montreal in January 2000. The Biosafety Protocol is intended to specify obligations for international transfer of living modified organisms that may threaten biodiversity. It sets out means of risk assessment, risk management, advance informed agreement, technology transfer, and capacity building.

Under the Protocol, governments will signal whether they are willing to accept imports of living modified organisms intended for release into the environment, by communicating their decision via a Biosafety Clearing House. Information on living modified organisms that may be contained in shipments of commodities will also be provided to importing countries.

Advanced Informed Agreement procedures will apply to the introduction of seeds, live fish, attenuated vaccines, and other living modified organisms that are to be intentionally introduced into the environment and which may threaten biodiversity. In all these cases, the exporter must provide detailed information to each importing country in advance of the first shipment, and the importer must then authorize the shipment within a one-year period. The Protocol also outlines general procedures for risk assessment. The aim is to ensure that recipient countries have both the opportunity and the capacity to assess any risks to biodiversity involving the products of modern biotechnology. Capacity building is also an important component of the agreement. The Protocol and the World Trade Organization are intended to be mutually supportive. The Protocol is not to affect the rights and obligations of governments under any existing international agreements.

To ensure the safe use of biotechnology in the environment, there is a need for continuing emphasis on:

- Efficient and cost-effective regulatory systems at the institutional and national levels
- Clear guidelines for field tests and commercial releases of living modified organisms
- Informative labeling of novel products for consumers
- Systematic capacity building
- International support mechanisms for early warning of good or bad developments with living modified organisms
- More scientific research on possible short- and long-term effects of living modified organisms on the environment and risks to biodiversity.

Economic Concentration

The trend toward intellectual property protection in biosciences has had several important structural consequences. The private sector life sciences industry has become increasingly centralized. About six companies dominate what was once an industry in which many more small companies played a major role. The reasons for this are complex. They relate to economic efficiencies in production and marketing, as well as the desire to access specific research and development expertise in smaller companies. Intellectual property protection has contributed significantly to the development of the current biotechnological revolution in agriculture, and to the institutional restructuring that is accompanying that revolution (Barton 1999).

Intellectual Property Management

New scientific discoveries in biotechnology may be protected by plant variety protection, patents, and/or trade secrets. Countries differ in what forms of intellectual property protection may be applied to specific inventions. The 1995 Agreement on Trade-Related Aspects of Intellectual Property Rights requires all members to provide at least a sui generis system of protection for plant varieties.

Industrial country moves toward intellectual property protection of the products of biotechnology have led to developing country moves to protect the genetic sources. This culminated in the Convention on Biological Diversity in 1992. This agreement made it clear that nations could enact legislation protecting the export of genetic resources, by arrangements to share the benefits should there be financial return from the exported genetic resources.

Because the private sector holds many of the advanced biotechnologies, the publicly funded agricultural research community must also develop an effective approach to cooperation with the private sector in research and product development. The public sector needs to develop a policy toward intellectual property protection for its own discoveries. In doing so it should set the example in terms of benefit sharing with poor indigenous farmers, and also to consider the possibility for the public sector to obtain intellectual property protection to have bargaining chips to negotiate strategic alliances with multinational companies.

For national governments, it would be desirable to design Trade-Related Aspects of Intellectual Property Rights-compliant legislation in a way that is beneficial to their agriculture, maintaining the possibility for a multilateral regime for germplasm acquisition and transfer. Legislation should be supplemented with improved capabilities in the courts, the law firms, and the law schools, so that the law can be used effectively. There is a real possibility that an antitrust code can be negotiated and this is almost certainly beneficial for developing countries.

Developing countries could also seek ways to use the intellectual property system to encourage research for their needs by giving incentives, such as market protection, to encourage private-sector research on products of benefit to the developing world, in a manner analogous to the Orphan Drug legislation. All such legislation should be the result of substantive public discussion and be adopted in a transparent fashion.