Agricultural Biotechnology and Rural Development in Latin America and the Caribbean

Implications for IDB Lending

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Foreword

This working paper, prepared by the Rural Development Unit with the assistance of several experts and after a series of regional consultations, tackles one of the key issues in agricultural development facing the region. Agriculture biotechnology has the potential of being a key instrument for agricultural research in Latin America and the Caribbean.

The paper concentrates on the potential for biotechnology research to benefit consumers and producers of food in the region, including its contribution to reducing poverty, protecting the environment, providing food security and improving food safety. It also addresses biosafety considerations and consumer acceptance issues.

The study analyzes the need to increase investments in agricultural research as well as to strengthen biosafety and intellectual property. It includes policy suggestions regarding agricultural biotechnology issues in IDB funded programs.

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Summary

A substantial activity in the implementation of the IDB's agriculture development strategy involves designing best practice studies to define the Bank's procedures and financing instruments in priority investment areas and to support decision-making by the governments of the region. The agriculture development strategy document highlights the need to strengthen agricultural research investments by the public and the private sectors, as well as the management of research resources at the national and regional level. Biotechnology is an important tool for agricultural research, while intellectual property rights and biosafety regulations are starting to influence the management of agricultural research in the region.

This report concentrates on the potential for biotechnology research to benefit consumers and producers of food in Latin America and the Caribbean. Its objective is to provide general guidance to IDB lending for agriculture development. The study includes policy suggestions regarding agricultural biotechnology issues in IDB-funded programs. Special attention is given to the problems and opportunities of biotechnology for developing agriculture in LAC; the implications of biotechnology for public research organizations, including aspects of regional funding for research; biotechnology's potential contribution to reducing poverty, protecting the environment and providing food security.

In this report, biotechnology is broadly considered to encompass those applications to agriculture that are based on our expanding knowledge of the genetic code of life. The broad array of discoveries could be classified into three groups: (i) molecular tools for plant breeding, including such specific techniques as marker-assisted selection; (ii) recombinant DNA discoveries which lead to the creation of transgenic crop varieties or genetically modified organisms; and (iii) diagnostic techniques.

Agricultural biotechnology comprises a set of tools that, when incorporated into the agricultural research and development process, may improve R&D efficiency and effectiveness in producing new technologies. At the present stage of development, biotechnology can improve and complement, but not replace conventional approaches to technology generation. Consequently, when attempting to evaluate potential impacts it is important to do so in the context of existing agricultural research systems and investments that continue to form the critical link for technology delivery.

For ethical, political and practical reasons, the reduction of poverty must be a priority for any development strategy. Given its natural resource endowment and the importance of agriculture in most of the region's economies, agricultural development is not only a precondition for economic growth, but it is called to play an important role in the future evolution of global food security.

The application of biotechnological approaches to the agricultural industry opens a wide scope of potential benefits, yet many of these benefits may not be achieved if a number of important issues are not resolved. Some of these issues are related to the organization of technology and innovation systems, as well as the scientific basis of biotechnology and its interface with traditional agricultural research, others refer to biosafety considerations and consumer acceptance. There are also issues emerging from the proprietary nature of the new technologies and those that relate to the characteristics of the technology delivery mechanisms involved.

Biotechnology's most important contributions will probably be allowing the expansion of production in some of the region's major crops without increasing the pressure on fragile environments. It is also likely to be important in

connection with the increased opportunities for agro-industrialization that may arise from increased production and diversification. The importance of this contribution will depend on the accuracy of current food production and demand projections and on the capacity of conventional research approaches to develop the technologies needed to sustain the estimated increases in crop yield.

Biotechnology holds potential for improving the competitiveness of regional agricultural production in world markets, as well as reducing the incidence of urban and rural poverty (given that the nutritional and income status of the poor are highly dependent on the efficiency of staple food crop production). Biotechnology can be expected to improve yield potential and stability (increasing tolerance to adverse effects) in both temperate and tropical crops. It could also improve agricultural sustainability by increasing disease and pest resistance and supporting integrated pest management efforts, thereby lessening the use of toxic pesticides; and by reducing the pressure to expand cultivated areas to forest and marginal areas. Finally, it could improve the nutritional value of food crops (including the enhancement of vitamin and micronutrient contents of foodgrains) and expand the potential uses of agricultural processes and products (for instance utilizing non-edible substances of food crops to produce medicinal products, fuel alcohol, and industrial oil, thereby increasing employment and incomes).

A warning is, however, in order. There is no doubt of the potential of the new technologies. They are already taking research into uncharted territory, making possible objectives that only a few years ago were considered impossible, eliminating species barriers, and expanding production frontiers. They also have a wide coverage including all crops, forestry, livestock and aquaculture, and in well endowed as well as poorer ecosystems. The potential is there, but serious questions remain concerning the correct strategies for realizing this potential given the region's human, financial and institutional constraints. That there have been concerns and controversy about the potential environmental and human health risks from the very early stages of development of biotechnology should come as no surprise. The nature of biotechnology alters technological possibilities, particularly in the field of genetics. In some cases it creates new ethical dilemmas, many of which still remain to be made fully discussed and resolved.

Advances in agricultural biotechnology, which are driven in part by advances in medical biotechnology, are producing a revolution in the knowledge about how plants and animals grow and produce useful products. These developments in science are starting to show up as useful technologies for farmers in Latin America. To date, however, there is little going on in terms of agriculture biotechnology delivery in spite of significant scientific capabilities. There has been little effect on either farmers or consumers in Latin America and the Caribbean, and what *is* happening is concentrated on just a few countries (Argentina, Mexico, Uruguay), on temperate events (herbicide and insect resistance) and on three essentially temperate crops (soybeans, maize and cotton). On a worldwide basis however, more than 50 million hectares were planted with "genetically modified" crops in 2001, a 20 percent increase over the previous year.

The pipeline for the next few years does not promise much change; that is, the evolution of agricultural biotechnology in Latin America and the Caribbean will continue at the rhythm of what happens in the more developed countries. This leaves open the question about what will happen with tropical events. Only Brazil seems to have enough capacity to develop some products, but even that appears to be limited when set in the context of R&D investments on temperate events, and the additional fact that the scientific base for tropical agriculture is not nearly as deep as it is for temperate agroecologies.

The agricultural biotechnology situation in LAC can be summarized around two remarks. First, the region has a significant level of biotech research capacity covering a wide range of production constraints, crops and livestock species. This capacity has evolved in and is limited by a very restrictive R&D funding environment. In a few countries public research capacity is supported by an appropriate biosafety and intellectual property rights (IPR) environment. The second observation is that in terms of actual commercial applications, biotechnology is still at a very early stage of development. Commercial use is mostly of cell biology and diagnostic techniques. Genetic engineering applications are concentrated in two countries, are mostly within temperate production environments, and are events that were developed by multinational corporations outside the region.

Taking that into account, this report analyzes the main challenges to increase investments in agricultural research, focusing on the following issues: the institutional infrastructure is still not in place; biosafety and IPR institutions are still in the making and in many of the countries where they are in place enforcement capacities are a problem; and the technology delivery system (small seed markets) is weak. Even if the bulk of investments and innovations will come from private sector investments and will be subject to IPR protection, public sector research institutions will continue to be essential (i) to develop and implement strategies to access proprietary technologies of importance for the country (joint ventures, licensing within market segmentation agreements, etc), (ii) to assure the applications of the new technologies for a more efficient and effective provision of private goods (i.e. epidemiology and areas related to natural resource management and conservation) and (iii) to make it more attractive for the private sector to invest in research in areas that would not otherwise attract enough investment due to market size or risk. Cases such as sunflower in Argentina, or tropical crops in general are examples of the type of interactions needed. There is ample potential for the countries of the region to work together in defining common strategies to deal with joint funding and execution of research that in a great number of situations are of a transboundary nature.

This study proposes specific areas for Bank support, such as capacity development; creating an enabling environment for biosafety, IPR, public awareness (to assure the safe transfer of products developed outside the region and also for local developments where good public opinion is critical); and technology delivery infrastructure (seed markets and identity preservation). The IDB has traditionally financed the strengthening of national and international agricultural research systems via loans and grants and is currently financing some agricultural biotechnology activities as components of projects. Based on country characteristics there are ample opportunities to continue and increase this support at the national level. In addition, because of scale issues there is a large potential impact of agricultural biotech investments in the context of the regional integration of several national research efforts.

I. Introduction

Advances in agricultural biotechnology, which are driven in part by advances in medical biotechnology, are producing a revolution in the knowledge about how plants and animals grow and produce useful products. Genetic maps of major species now have markers for many important genes. For a few plants the complete genomes have been sequenced.[1] At the same time functional genomics is identifying the role of the plant genes. Functional genomics research is growing rapidly, financed largely by the major agricultural input companies that are hiring medical biotech companies and start up companies from universities to identify genes. Functional genomics is also financed by government organizations like the Department of Agriculture (USDA) and the National Science Foundation (NSF) in the United States and similar organizations in Europe.[2]

Another set of breakthroughs has taken place in scientists' ability to transform plants using genetic engineering. The first successful insertion of genes from another plant was reported in 1983. By 1990 there were published reports of transformed tobacco, cotton, soybeans, and maize. These methods have been rapidly improved, reducing the cost of transformation. Transformation is now financially possible for many public and private institutions in developing countries.

These advances in basic science and the development of biotechnology tools have been useful to many applied scientists. Plant breeders can use molecular markers to reduce the cost and increase the speed of breeding new varieties. They can use the completed map of *arabidopsis* to locate similar genes in canola, tobacco, and soybeans or use the rice genome information to find useful genes in *monocots*, including the major grain crops, sugarcane, and orchids. They can also use transformation techniques to add characteristics to crops that cannot be found in the genome of those crops.

Scientists working on pest control can also use these advances in biotechnology. Chemists, who are working to develop safer and more effective pesticides, can test their chemicals against many new targets. These targets will come from the functional genomics of plants that are to be protected and the genomes of important insect and disease pests. Integrated pest management specialists will then have new diagnostic kits that could be very useful to them.

Important advances in livestock genetics and genomics as well as animal cloning and a better understanding of the molecular basis of genetic variation will result in more productive and disease resistant genotypes, vaccines and diagnostic tools to control diseases. In addition, agbiotech together with significant advances in informatics, including geographic information systems, and computing capabilities enable the development of models and methods that can address the complexities of the livestock component of agricultural systems, and the introduction or more sustainable land use practices.

[1] The completed sequence of *arabidopsis*, a small weedy relative of canola seed, was published in November 2000, and in January 2001 it was announced that Syngenta and Myriad Genetics had completed sequencing the rice genome. The maize genome is under intensive study.

[2] Of interest for LAC is the announcement that a new consortium involving the Institute for Genomic Research, the International Plant Genetic Research Institute (IPGRI), and institutes from Australia, Belgium, Brazil, the Czech Republic, France, French West Indies, Germany, India, Mexico, Nigeria, Great Britain, and the United States will sequence the genome of banana (the third plant to have its genome sequenced) over the next five years.

Modern biotechnology based on molecular biology is strengthening the capacity to change the genetic makeup of crops and livestock. These developments in science are starting to show up as useful technologies for farmers in Latin America. To date, however, biotechnology has had little effect on either farmers or consumers in Latin America and the Caribbean, apart from providing some benefits from the use of herbicide resistant soybeans in Argentina and Brazil and insect resistant crops in Argentina and Mexico.

Despite the potential of biotechnology, several issues need to be address, including biosafety and food safety, bioethics, and accessing proprietary science for the benefit of the poor[3]. Although the development of biotechnology rests upon the scientific capacity and the level of commercialization of agriculture in each country, all countries are challenged to develop public sector research capacity and appropriate regulatory frameworks to access new knowledge. If this potential is to be realized, regional and international alliances and public/private partnerships will be important (Byerlee, Alex and Echeverría 2002).[4]

Biotechnology is an important tool for agricultural research, while intellectual property rights and biosafety regulations are starting to influence the management of research in the region.[5] For the purpose of this report, biotechnology is broadly considered to encompass those applications to agriculture that are based on expanding knowledge of the genetic code of life (National Academy Press 2000).

Box 1
Definitions of Biotechnology and its Component Technologies

Biotechnology is any technique that uses living organisms or substances derived from these organisms to make or modify a product, improve plants or animals or develop micro-organisms for specific uses (Cohen 1994). Modern biotechnology refers to the applications of new developments in recombinant DNA technology, advanced cell and tissue culture techniques and modern immunology.

The key components of modern biotechnology are:

- *Genomics*: The molecular characterization of all species;
- *Bioinfomatics*: The assembly of data from genomic analysis into accessible forms;
- *Transformation*: The introduction of single genes conferring potentially useful traits into plants, livestock, fish and tree species that are then called transgenic or genetically modified organisms;
- *Molecular Breeding*: The identification and evaluation of desirable traits in breeding programs by the use of marker assisted selection;
- *Diagnostics*: The use of molecular characterization to provide more accurate and quicker identification of pathogens;
- *Vaccine Technology*: The use of modern immunology to develop recombinant DNA vaccines for improving control of lethal diseases.

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[3] See the U.N. Human Development Report (2001) where special emphasis is given on how to make new agricultural technologies work for human development, and how developing countries may achieve high benefits from new technologies while facing challenges in managing the risks.

[4] See Echeverría (1998) For an overview of agricultural research policy issues in Latin America; and Byerlee and Echeverría (2002) For an analysis of financing and organizing agricultural research in an era of privatization including public-private partnerships in conducting research.

[5] See definition of agricultural biotechnology in box 1.

We divide the broad array of discoveries into three groups of technologies: (i) molecular tools for plant breeding, including such specific techniques as marker-assisted selection, (ii) recombinant DNA (rDNA) discoveries which lead to the creation of transgenic crop varieties or genetically modified organisms (GMOs), and (iii) diagnostic techniques. [6]

The discussion of the use of biotechnology, particularly the use of GMOs has become polarized. Anti-GMO viewpoints emphasize the potential environmental and health risks and the concentration of products in the hands of a few of multinational firms. Support for the use of GMOs is argued from the standpoint of the potential of biotechnology innovations to help meet future food needs, to reduce the use of dangerous pesticides, and to continue providing the economic benefits that agricultural research has delivered to farmers and consumers in the past decades.

The role of biotechnology research is of concern to many national and international agencies. In preparing this document, we have drawn on recent reports from the World Bank (1999), the Asian Development Bank (2000), the CGIAR (2000), IFPRI (2001) and others. This study complements the Bank's agriculture development strategy (IDB 2000) which underlines agricultural research as one of the priority investment areas in the region, emphasizing the need to strengthen public and private research investments, as well as the management of research resources at the national and regional level.

The focus of this study is to assess the potential of biotechnology research to deliver benefits to consumers and producers of food in LAC, with the objective of providing guidance to investments in agriculture biotechnology development. The report is skewed toward plants, with little detail offered on the capacity, unique challenges and prospects for biotechnology to contribute to animal husbandry research. This is partially rationalized by our belief that the impact of applications of biotechnology to animal research will occur further in the future and are more uncertain than will be the case for plants, but is also because the authors were unable to do justice to both animal and plant applications within the resource constraints of this study.

The study includes policy suggestions regarding agricultural biotechnology issues in IDB-funded programs. The document focuses on issues such as: What are the problems and opportunities for biotechnology for developing agriculture in Latin America and the Caribbean? How does the trend toward the privatization of agricultural research affect the Bank's actions with regard to biotechnology lending? What are the implications of biotechnology for public research organizations, including aspects of regional funding for research? Can biotechnology contribute to reducing poverty, protecting the environment and providing food security? What could the IDB emphasize regarding lending to strengthen biotechnology research?

[6] As used here, a GMO is an organism (plant, animal, microorganism) into which a segment of nucleic acid has been introduced and stably incorporated into the genome through a deliberate procedure and with the purpose of obtaining a defined phenotype; the introduction being performed in such a way that the nucleic acid could not have been acquired by the organism through mutations, recombinations or other genetic transfer phenomena recognized as mechanisms which operate in nature without human intervention.

II. Population, Poverty, Productivity and Biotechnology

By 2025, the world's population is expected to rise to slightly over 8 billion at a rate of just over 800 million per decade. Based on a population-increase-only projection, world cereal production must rise from around 1.92 billion tons in 1990 to about 2.68 in 2025 to match this demand (Dyson 1999). Over the next 50 years or so, the challenge will be not only to feed more people, but also to do so, while at the same time taking into account that:

- There will be less arable land because the combination of over plowing, overgrazing and deforestation will have caused soil erosion to exceed soil formation.
- Technologies will be needed to minimize extraction and provide for longer-term sustainability because there will be fewer resources available, particularly nonrenewable resources such as phosphorous and potassium.
- There will be less water, and the quality of the remaining water will be reduced as demand increases.
- The rate of increase in cereal yields in both developed and developing countries is slowing from yields recorded during the 1970s, partially due to reduced use of inputs and falling cereal prices, but also because productivity potentials are already getting close to their genetic ceilings for several of the major staples (Pinstrup-Anderson et al. 1999).
- Fewer people will be engaged in primary agriculture in both developed and developing countries (Kishore and Shewmaker 1999).
- The demand for meat and milk will more than double over the next two decades in developing countries.

These projections for food demand assume that consumption remains at present income levels, where more than one billion people survive on less than $1 per day (World Bank 1999). The task ahead grows even larger if the world poverty situation improves and the demand for food increases. By 2025, the population of Latin America and the Caribbean is expected to grow to 690 million people, up from 440 million in 1990. As a result of the increase in population alone, cereal consumption will increase from 117 million metric tons, to 183 million metric tons. If income increases are also taken into consideration, cereal consumption is expected to rise to 218 million metric tons. The combination of population growth, changes in diet and increasing urbanization will increase the demand for food of animal origin. The demand in LAC for meat and milk is expected to grow at 2.8 percent and 3.3 percent per year, respectively. The total demand and consumption of beef, poultry, pork and milk in LAC is expected to double (in average), with concomitant increases in requirements for food grains. Grass-fed beef will continue to be the most important meat in LAC (Pinstrup-Andersen and Babinard 2001).

Poverty is a critical problem in Latin America and the Caribbean. The poor make up close to 50 percent of the population, and their number has increased from about 136 million people in 1980 to 204 million in 1997 (ECLAC 1999).[7] For ethical, political and practical reasons, poverty reduction must be a priority for any development strategy. Given its natural resource endowment and the importance of agriculture in most of the region's economies, agricultural development is a precondition for economic growth, and it is called to play an important role in the future evolution of global food security. Biotechnology holds potential

[7] Although the largest share of the total population living in poverty are in urban centers; poverty is, in relative terms, still a rural phenomenon in the region since more than half of rural households live in poverty and close to a third live in extreme poverty conditions (Echeverría 2000).

for improving the competitiveness of regional agricultural production in world markets, as well as reducing the incidence of urban and rural poverty because the nutritional and income status of the poor are highly dependent on the efficiency of staple food crop production.

Biotechnology can be expected to improve yield potential and stability in both temperate and tropical crops.[8] It is also expected to improve agricultural sustainability, as well as the nutritional value of food crops. Biotechnology can also expand the potential uses of agricultural processes and products, thereby increasing employment and incomes. Some specific benefits may include the following (Asian Development Bank 2000):

- Increasing productivity and, as a result, increase food production without the need to increase the area of cultivated land, thereby reducing the pressure to expand cultivated areas into forest and marginal areas.
- Increasing crop quality and nutritional quality, including the enhancement of vitamin and micronutrient contents of foodgrains, benefiting consumers who survive on limited and poor diets and who cannot afford to buy supplementary vitamins and micronutrients.
- Increasing disease and pest resistance and improved integrated pest management efforts, thereby lessening the use of toxic pesticides.
- Broadening tolerance of the existing high yielding varieties to drought, flooding, salinity, heavy metals and other abiotic and biotic stresses, which can stabilize and improve the yields of crops grown in rainfed areas.
- Increasing productivity and quality of farm animals and reduced environmental impact of the increased industrialization of animal products.
- Increasing the development of vaccines and the diagnosis of diseases for livestock and aquaculture.
- Utilizing non-edible substances from food crops to produce medicinal products, fuel alcohol, and industrial oil.

A warning is, however, in order. There is no doubt of the potential of the new technologies. They are already taking research into uncharted territory, making possible objectives that only a few years ago were considered impossible, eliminating species barriers, and expanding production frontiers. They also have a wide coverage including all crops, forestry, livestock and aquaculture in well endowed as well as poorer ecosystems. The potential is there, but serious questions remain concerning the correct strategies for realizing this potential given the region's human, financial and institutional constraints.

Agricultural biotechnology comprises a set of tools that, when incorporated into the agricultural research and development process, may improve R&D efficiency and effectiveness in producing new technologies. At the present stage of development, biotechnology cannot be considered to be an independent paradigm, but rather an instrument which can improve and complement, but not replace, conventional approaches to technology generation. Consequently, when attempting to evaluate potential impacts it is important to do so in the context of existing agricultural research systems and investments that continue to form the critical link for technology delivery.

Biotechnology's most important contribution in the region will probably be to allow the expansion of production in some of the major crops without increasing the pressure on the fragile environments. Increased opportunities for agro-industrialization may also arise from production growth and diversification. The importance of this contribution will depend on

[8] Anderson et al.(2001) report significant potential economic welfare gains from adopting GMO (oilseeds and cereals) technology in Latin America.

the accuracy of current food production and demand projections and on the capacity of conventional research approaches to turn out the technologies needed to sustain the estimated increases in crop yield.

Biotechnology can help reduce poverty in a variety of ways. The urban poor will benefit from lower food prices resulting from improved efficiency in food production and, eventually, from improved nutritional and health characteristics of their food. For the rural poor, benefits will concentrate on those small holders in the better endowed areas who are already in the market for technological inputs and who, to some extent, are already benefiting from conventional technological improvement opportunities. Some benefits will also come from improvement in cash crops like cotton, cacao and coffee, where small farmers are also involved.

The rural poor could also benefit if biotechnology is used to improve specific landraces and non-commercial varieties of crops used by rural communities. Improvements may take the form of insect and disease resistant varieties to decrease crop losses and plants with enhanced nutritional value. In principle, these types of crop improvements should contribute not only to alleviating poverty and enhancing health, but should also provide tools and incentives for maintaining a broad genetic base by promoting the use of native germplasm.[9]

In sum, a significant share of the rural poor, especially landless or subsistence farmers on land without much agricultural potential will get little direct benefits from biotechnology except through the employment multiplier effect resulting from increased activities in the better endowed areas.[10]

The magnitude of the benefits will depend on how much of the research effort is focused on improving the characteristics and production conditions of the crops they produce and how much consideration is given to the ecological constraints they confront. To date, the main priorities in biotechnology have been to reduce production costs in agricultural areas that already have high productivity levels or increase their value added by improving quality, or other traits (Chrispeels 2000). This is often viewed as a "natural" evolution of the R&D investment cycle with areas offering higher return addressed in early development phases and those with lower or longer term returns coming on line at a later time. It is clear, however, that the direction and intensity of public investments in biotechnology will play a critical role in how benefits reach small producers.

[9] In their study of Bt cotton in Mexico, Traxler et al. (2001) found that small farmers (9 ha average farm size) were able to increase their income by reducing the use of chemical pesticides to control 'pink bollworm.' There are also examples of small farmers in Colombia who have benefited from disease resistant banana and cassava planting material that was produced through tissue culture. Small commercial farmers in the Northeast of Brazil would reap major benefits if biotechnology could develop a means of controlling 'witches broom' disease of cacao, which conventional technology has not been able to control.

[10] Some benefits could also be expected from some simpler technologies such as tissue culture, which could have important impacts on subsistence crops such as bananas and cassava. However for this to happen the new development must be able to reach them, and that is still a major hurdle that remains to be solved both for the traditional as well as the new technologies.

III. The Environment, Food Safety and Consumer Acceptance

That there have been concerns and controversy about the potential environmental and human health risks from the very early stages of development of biotechnology should come as no surprise. The nature of biotechnology alters the technological possibilities, particularly in the field of genetics and in some cases creates new ethical dilemmas, many of which still remain to be fully discussed and resolved.[11]

In the Latin American context some of these concerns are of particular importance. First, of the eight centers of origin of crop species in the world, three are in the region. Mexico and Central America are the source of maize, common bean, lima bean, chayote, sweet potato, and pepper. South America gave rise to progenitor species of potato, peanut, tomato, pumpkin, pepper, cassava, papaya, cocoa, and pineapple. In addition, the world's richest concentration of plant and animal biodiversity (about 90% of the Earth's species) can be found in the region, particularly in the Andean countries of Bolivia, Colombia, Ecuador, Peru and Venezuela. Given this situation the release of GMOs into the environment cannot be overlooked. A second set of considerations is associated with the importance of agriculture and food production for the economies of the region and the impact that biosafety issues may eventually have on consumer behavior and the sale of LAC agricultural products in the international markets.

One of the several paradoxes of the early experiences with GMOs is that in the face of persistent opposition from environmental groups, first generation GMOs have generated considerable positive environmental effects. Significant reductions in insecticide use have accompanied the diffusion of Bt cotton in Mexico, China and the United States.[12] In Argentina and the Untied States, the use of herbicide tolerant soybean varieties has facilitated farmer adoption of reduced tillage methods and the use of more toxic herbicides has been replaced by the application of environmentally benign glyphosate. Given the large amount of R&D being devoted to insect, virus and disease resistance, future biotechnology products hold great potential for providing additional environmental benefits through reduced pesticide use.

Assessments of Risks

As early as 1987, the National Academy of Sciences of the United States (NAS), undertook a study of the safety of biotechnology that concluded: "(i) there is no evidence that unique hazards exist either in the use of rDNA techniques or in the movement of genes between unrelated organisms; (ii) risks associated with the introduction of rDNA-engineered organisms are the same in kind as those associated with the introduction of unmodified organisms and organisms modified by other methods; (iii) assessment of risks of introducing rDNA-engineered organisms into the environment should be based on the nature of the organism and the environment into

[11] By environmental, food safety and consumer acceptance issues we are referring to genetic engineering and GMOs, because the other main techniques (tissue culture, diagnostics and genetic markers) raise few serious biodiversity, consumer or ethical concerns.

[12] The average amount of pesticide active ingredient in Coahuila, Mexico, fell from 13.1 kg/ha in the 1980s to less than 2 kg/ha. in the late 1990s (Traxler et al. 2001). Cotton pesticide use in China has been reduced by at least 15,000 million tons (Pray et al. 2001). In the United States, a total of 5.3 million less insecticide treatments have been saved on cotton (Gianessi and Carpenter 1999.).

which it is introduced, not on the method by which it was produced."

These conclusions are fully supported by empirical evidence. In 2001 there were more than 50 million has planted with transgenic crops of more than 10 species, a 20 percent increase over the previous year (James 2001). No environmental or health problems associated with its commercial cultivation or ingestion have been identified. Concern, however remains, as the diversity of genes that have been manipulated increases along with the ease with which they can be inserted into cultivated species.

In 2000, the United States National Research Council, convened a formal committee to review the biotechnology situation in general and the genetically modified pest-protected plants in particular. Based on the available data, the committee fully supported the findings of the 1987 NAS study and concluded that "with careful planning and appropriate regulatory oversight, commercial cultivation of transgenic pest-protected plants is not generally expected to pose higher risks and may pose less risk than other commonly used chemical and biological pest-management techniques." The committee also agreed with the earlier report in that reviews should focus on the properties of a given GMO, and not the process by which it was produced.

The NRC committee went into a more detailed analysis of issues regarding health concerns, ecological considerations and aspects related to the agronomic risks of virus resistant crops. Regarding potential health risks, it concentrated on the allergenicity of GMOs, and indicated that it "was not aware of any evidence that foods on the market are unsafe to eat as a result of genetic modification." Similarly, regarding toxicity, it reported that "information in peer reviewed studies indicates that plant-expressed Bt protein are probably without human health risk." From the ecological point of view, the committee considered the effects on non-target species, the effects of gene flow, and evolution of pest resistance to pest-protected plants. In general, it stated that "both conventional and transgenic pest-protected crops could have effects on non-target species, but these potential effects are generally considered to be smaller than the effects of broad-spectrum synthetic insecticides. Therefore, the use of pest-protected crops could lead to greater biodiversity in agro-ecosystems where they replace the use of those insecticides."

In the case of the effects on non-target organisms, including that of pollen ingestion, the committee noted that while detrimental effects have been reported as regards feeding of monarch butterfly larva, such studies have not documented actual negative impact on population densities of butterflies in the wild. With regard to gene flow, it was agreed that pollen dispersal could lead to gene flow, but that only trace amounts are dispersed more than a few hundred feet. However, the committee found that, "the transfer of either conventionally bred or transgenic resistance traits to weedy relatives potentially could exacerbate weed problems, but such problems have not been observed or adequately studied." Therefore, a number of steps were recommended to monitor the effects of dispersed Bt pollen on populations of non-target organisms, and to assess gene flow and its potential consequences with regard to the spread of pest resistance genes among weed populations.

In connection with agronomic risks and virus-resistant crops, a number of potential risks were considered when looking at the use of transgenic-mediated pest-protection against viruses. Such concerns include potential for creation of new viral strains, introduction of new transmission characteristics, or changes in susceptibility to heterologous viruses. The committee found that "most virus-derived resistance genes are unlikely to present unusual or unmanageable problems that differ from those associated with traditional breeding for virus resistance."

Needed Research and Capacity Building

The NRC committee has found no evidence that GMOs may pose risks that are significantly different from those of their conventional counterparts (National Academy Press 2000). However, it has also cautioned about the need to continue to gather scientific evidence (improving testing protocols regarding possible health implications and the need for field based research on the dynamics of Bt effects on non-target organisms), and to strengthen and clarify regulatory policies and processes, stressing the need to reduce regulatory costs for small biotechnology startup companies, small to medium size seed companies, and public sector breeders by providing flexibility with respect to data requirements, considering fee waivers wherever possible, and helping understand the regulatory systems.[13]

The biosafety issue has also been taken up at the international level as part of the Convention for Biological Diversity, which has established a formal Biosafety Protocol. Under the Protocol every signatory country is committed to undertake the needed actions to ensure the safe use of biotechnological approaches, especially when movement across boundaries are involved. Following as a general guideline the precautionary principle (PP), defined in the Preamble to the Convention with the statement that "when there is a threat of significant reduction or loss of biological biodiversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat." To deal with the implications of the PP, and recognizing the precarious institutional and scientific capacities existing in many countries, the Protocol also calls for an important effort of capacity building to help member countries comply with its provisions (Biotechnology and Development Monitor 2000).

A particular concern expressed in all cases, is how to take advantage of the tremendous wealth of information emerging from the large numbers of trials that have been conducted, to start evaluating what the long-term environmental and health implications of GMOs could be since, "until better data are available, it will be necessary to rely on general ecological and agricultural knowledge to predict the consequences of commercial-scale, crop-to-wild gene flow from pest-protected plants" (National Academy Press 2000). In achieving this, policymakers and regulators confront the need to strike a very delicate balance because the development of the information needed requires significant cost and time, and comparatively few resources are provided for it, either by governments or commercial producers.[14]

Biosafety Regulation

In accordance with the above views, the United States and most of the OECD countries have developed and set in place biosafety regulations and risk evaluation mechanisms designed to accompany the product development process from the laboratory level (safe handling guidelines) through the field and commercial scale trial levels. Every event intended for eventual commercial release is required to go through these processes as well

[13] Other studies (Virginia Polytechnic Institute 1999) have reached similar conclusions about the general safety of GMOs, but also stress the continued need to improve the scientific data needed to base risk evaluations and biosafety regulatory frameworks.

[14] Currently, regulatory agencies acquire information specifically needed to fulfill their review and environmental assessment obligations. Regulators carefully consider calls for further, more extensive data or longer-term studies that are not officially necessary to complete their review procedures. Limiting data and information required help keep regulatory costs down (where possible), minimize regulatory delays, and confronts the fact that there is little willingness to cover the costs of more extensive environmental and health safety testing. On the other hand, improving information availability on all related issues is an essential component of the transparency that everybody agrees is critical for the development of informed public perception about the technologies.

as through an evaluation of its safety for human and animal consumption.[15] In most cases, biosafety evaluation processes have been made the responsibility of already existing environmental protection and food safety agencies. In general, there is broad agreement in the scientific community that: (i) these systems should be directed to the assessment of the potential health and/or environmental risks associated with the introduction of a given organism into the environment and/or the food supply; (ii) the process be based on the nature of the organism and the environment into which it is introduced and not on the method by which it was produced; and (iii) they should be supported by a continued body of new biological and ecological research to generate basic information for the improvement of risk evaluation processes and methodologies as well as to monitor the behavior of GMOs after their introduction into the environment. The normal approval for a crop release involves a process extending from four to six years, depending of the complexity of the issues involved (degree of novelty of the traits, ecological considerations, etc.).

Consumer Acceptance

In a number of developed countries a relatively large proportion of the population report seeing "the trend toward biotechnology as negative and the need to be better informed on the subject." Europe and Japan, where people express the most concern, are major export markets for LAC agricultural production whose sentiments may have an impact on trade. A growing list of countries is requiring labeling of food produced using biotechnology. Therefore, development of a proper identification and segregation system should be a building block of any national biotechnology policy and strategy. A clear indication of the importance of this issue is the agreement reached in the framework of the Convention for Biological Diversity to attach a "may contain" label to GMOs intended for environmental release or human consumption beginning in the year 2004.[16]

The willingness of consumers to accept food products containing GMO grain is of concern to countries such as Brazil, Argentina and Paraguay that export significant shares of their production of maize and soybeans. Several food chains in the European Union have refused to market GMO-derived food products, leading to the fear that export markets could be lost, or that discounts could be applied to grain exported from countries growing GMOs. Brazil has moved slowly on approving the planting of GMO crops, in part as an attempt to position itself as a supplier of GMO-free soybeans. Nonetheless, at present most consumers are willing to consume GMO foods, and price differentials between GMO maize or soybeans and their conventional counterparts are rare (Hartke 2001). This seems likely to remain the case as long as consumers are willing to consume meat products from animals fed on GMO soybean meal or maize.

It is clear that there is a need for impartial information based in facts; and also to take into account developing country perceptions and interests on agricultural biotechnology.[17]

[15] For a description of the U.S. and European systems see OECD (2000).

[16] The EU has established a mandatory labeling policy regarding GMOs. Brazil, Japan, South Korea, Australia, and New Zealand, have approved internal labeling regulations that are not yet in effect, while Canada and Argentina are studying the implications of introducing such policies. The U.S. has regulations mandating labeling only in those cases where the products are not equivalent to their conventional counterparts.

[17] See "Biotecnology and food: voices from a Southern perpective" (Biotechnology and Development Monitor 2001)

IV. Status of Agricultural Biotechnology Research in Latin America and the Caribbean

Although no comprehensive data are available on the institutional, human and financial resources being invested in biotech activities, it is possible to piece together a fairly comprehensive picture based on a variety of sources. An ISNAR report (ISNAR 2000) commissioned as a background document for this study (Table 1) and provides an institutional map and some measures of available research capacity. The ISNAR study covered 292 organizations in 13 countries: Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Jamaica, Paraguay, Peru, Trinidad and Tobago, Uruguay and Venezuela.[18]

Seventy-six percent (76%) of the responses received were from Argentina, Brazil, Chile and Colombia, indicating the relative importance of the biotechnology community in these four countries. Most agricultural biotech R&D is conducted in public universities (44%), followed by public R&D centers (26%) and private firms (20%). This is in line with figures reported by other authors and earlier studies (IICA 1992 and 1993, Jaffé and Infante 1996, FAO 1998, Trigo 2000). The institutional distribution of agricultural biotech research is, however, quite different from other agricultural research in Latin America, which is concentrated in public R&D centers with limited amounts of research being carried out at universities and private firms (Echeverría, Trigo and Byerlee 1996).

The institutional distribution of one of the most applied types of biotech research (field trials of GM varieties) is dominated by the private sector, particularly multinational input firms. Seventy-five percent (75%) of the trials in Mexico, Argentina and Brazil have been conducted by multinational firms (see Table 2). Local input firms play a major role in Mexico. The large Mexican firm SAVIA, which owns the vegetable seed company Seminis and the biotech firm DNAP in the United States, is active in a number of Latin American countries. Local food processing (e.g. the sugar industry) and paper companies also play a role, particularly in Brazil. The government plays a minor role in Argentina and Brazil and a somewhat larger role in Mexico. For the region as a whole, public institutions conducted just nine percent of the trials, a share similar to that of the public sector in U.S. trials.

Although biotechnology research investments in Latin America are insignificant when compared to other countries, when measured by LAC agricultural research investment standards, there is a relatively important amount of money and human resources dedicated to biotechnology research in the region. Table 3 shows ISNAR's estimates of expenditures and number of scientists by country.[19] The largest expenditure is registered in Colombia, in large part because the International Center for Tropical Agriculture (CIAT), which invested $1.6 million in 1999, is located there. It is followed by Brazil, Argentina, Chile, and Peru. Peru's fifth-place position is explained by expenditures made by the International Potato Center (CIP), which invested $1.5 million (98% of the country's total). Mexico, which was not covered by the ISNAR survey but which was the subject of an earlier survey by Falconi (1999), also is making large investments in biotech on the order of the investments in Brazil and Argentina.

[18] The sources used for identifying the institutions, include the most reliable available national and regional biodirectories such as REDBIO-FAO (all countries), CamBioTec (Argentina, Chile, Colombia, Cuba), Foro Argentino de Biotecnologia (Argentina), Fundaçao Osvaldo Cruz and EMBRAPA (Brazil), INIA (Chile), Colciencias (Colombia), and BioMundi (Cuba). Eighty-five organizations responded the questionnaire.

[19] The figures underestimate research expenditures since not all costs of research have been included and not all of the institutes provided information. For example, Avila et al. (2001) using more complete accounting methods, indicate that EMBRAPA alone spent about $14 million on biotech research in 2000. This compares with the $3.4 million reported by the ISNAR study. In addition, FAPESP in São Paulo was spending at least $15 million over three years on agricultural biotech research.

Table 1

Number of Research Organizations Included in the ISNAR Survey, 2000

Country	Public R&D Center Lab	Public University Lab	Private University Lab	Private Firm	International Center	Total (*)
Argentina	5	10	-	2	-	17(41)
Brazil	4	13	-	1	-	18(68)
Chile	4	3	1	1	-	9 (31)
Colombia	3	4	3	10	1	21(45)
Costa Rica	1	1	-	1	1	4(13)
Ecuador	1	2	-	-	-	3(25)
Guatemala	-	-	1	1	-	2(10)
Jamaica	-	-	-	-	-	- (2)
Paraguay	-	1	-	-	-	1(16)
Peru	1	-	-	1	1	3(21)
Trinidad & Tobago	-	-	-	-	-	- (3)
Uruguay	-	-	-	-	-	- (7)
Venezuela	3	3	-	-	1	7(20)
Total	**22**	**37**	**5**	**17**	**4**	**85(292)**

Notes: (*) Figures in parentheses indicate the number of questionnaires sent to each country.
Source: ISNAR (2000).

Table 2

GMO Field Trials by Type of Institution in Three Large Latin American NARS, 2000

	Argentina		**Brazil**		**Mexico**		**Total**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
U.S./Europe Agricultural Input Firms.	247	78	77	52	193	87	517	75
L.A Agricultural Input Firms.	55	17	34	23	0	0	89	13
Food/Paper Companies	0	0	7	5	9	4	16	2
Government Institutes or Universities	14	4	29	20	20	9	63	9

Source: Biosafety committees.

In addition, the International Center for Research on Maize and Wheat (CIMMYT), which is located in Mexico, invests about $3 million annually in biotech. Two small countries with substantial investments are Costa Rica (at least $500,000 annually) and Cuba (data not available).

Table 3

Financial and Human Resources Invested in Biotechnology R&D In Selected Countries of Latin America, 1999

Country (number of responses)	Financial Resources (US$)[a]		Number of Scientists			
	Country Total	Institute Average	Ph.D.	M.Sc.	B.Sc.	Total
Argentina (13)	2,945,000	226,538	56	57	144	257
Brazil (16)	3,363,255	210,203	150	102	183	435
Chile (7)	2,154,716	307,817	35	22	36	93
Colombia[b] (17)	5,808,614	263,038	44	55	152	251
Costa Rica (4)	453,245	113,311	8	9	12	29
Ecuador (2)	160,000	80,000	1	2	6	9
Guatemala (2)	55,600	27,800	1	3	6	10
Mexico[c]	n. a.	n. a.	127	49	62	238
Peru[d] (3)	1,496,338	13,169	10	5	19	34
Venezuela (6)	214,475	35,746	18	11	13	42
TOTAL	**16,651,243**		**323**	**268**	**571**	**1,398**

Notes: (a) exchange rates of December 1999; (b) financial resources for country total includes CIAT 1999 investments while institute average excludes CIAT; (c) Mexico data are for 1997; (d) financial resources for country total includes CIP 1999 investments while institute average excludes CIP.
Sources: ISNAR (2000) and Falconi (1999).

Brazil has the highest number of scientists working in biotech (435), followed by Argentina with 257, Colombia with 251, and Mexico with 239. Brazil also has the highest number of PhDs and MScs. Mexico had the next highest number of PhDs as well as the highest proportion of PhDs. In Argentina, PhDs (56) and MScs (44) make up more than 40 percent of all the country's scientists. Although the number of responses was limited, the academic level of scientists in other countries (such as Costa Rica, Peru and Venezuela) appears consistent with the overall level of scientific development. However, it is quite low in Ecuador and Guatemala where BScs represent 60 percent of the total number of scientists involved in biotechnology R&D.

Table 4 shows survey responses of the existing technical capacity in the region. Cell biology techniques appear as the most used by research groups in all countries: 259 times (29.2%), followed by genetic marker techniques with 239 times (26.9%), then diagnostic techniques with 176 times (19.8%), genetic engineering techniques with 124 times (14.0%) and lastly microbial techniques with 90 times (10.1%). It is not surprising that cell biology, which in general require lower levels of investment and less human capital, is the most commonly used technique, while genetic engineering is one of the least used techniques. What is somewhat surprising is that molecular markers are used almost as extensively as cell biology techniques.

Table 4

Biotechnology Tools Applied in Selected Latin America and Caribbean Countries, 2000

No	Technique Involved	Country													Total
		AR	BR	CH	CO	CR	EC	GU	JA	PR	PE	TT	UR	VE	
	Cell Biology Techniques														**259**
1	Micropropagation	13	9	13	39	8	5	3	-	2	11	-	-	11	114
2	Anther culture	3	2	3	9	-	1	-	-	-	1	-	-	2	21
3	Embryo rescue	4	1	4	6	1	-	-	-	-	-	-	-	3	19
4	Protoplast fusion	-	1	-	2	-	-	-	-	-	-	-	-	-	3
5	In vitro germplasm conservation & exchange	5	3	3	14	4	2	-	-	-	1	-	-	10	42
6	In vitro insemination	-	2	-	1	-		-	-	-	-	-	-	-	3
7	Embryo manipulation & exchange	3	5	-	1	-	-	-	-	-	-	-	-	2	11
8	Animal cell cloning	-	3	-	1	-	-	-	-	-	-	-	-	-	4
9	Other - cell biology	3	3	5	21	3	1	-	-	-	-	-	-	6	42
	Genetic Engineering Techniques														**124**
10	Agro bacterium mediated	11	12	6	7	4	-	-	-	-	7	-	-	4	51
11	Micro-projectile bombardment	4	11	7	6	3	1	-	-	-	-	-	-	5	37
12	Electroporation	-	7	1	1	-	1	-	-	-	-	-	-	4	14
13	Microinjection	-	4	-	1	-	-	-	-	-	-	-	-	-	5
14	Other genetic engineering	7	5	2	2	1	-	-	-	-	-	-	-	-	17
	Genetic Marker Techniques														**239**
15	RFLP	7	9	3	10	-	2	-	-	-	2	-	-	2	35
16	RAPD	15	24	11	14	2	6	-	-	-	4	-	-	5	81
17	Micro satellite markers	13	10	8	12	3	1	-	-	-	4	-	-	-	51
18	AFLP	13	6	7	8	1	1	-	-	-	4	-	-	-	40
19	Others	6	9	10	4	-	1	-	-	-	-	-	-	2	32
	Diagnostic Techniques														**176**
20	ELISA	6	12	3	13	-	2	-	-	2	2	-	-	3	43
21	Monoclonal antibodies	1	5	2	4	-	1	-	-	2	1	-	-	1	17
22	Nucleic acid probes	1	5	1	1	-	-	-	-	-	1	-	-	4	13
23	PCR	10	29	12	11	-	1	-	-	-	1	-	-	4	68
24	Others	-	5	5	20	2	2	-	-	-	-	-	-	1	35
	Microbial Techniques														**90**
25	Design-delivery biocontrol agents	1	3	2	7	-	-	5	-	-	-	-	-	-	18
26	Design-delivery biofertilizers	2	2	-	2	-	-	-	-	-	-	-	-	1	7
27	Fermentation, food processing	2	4	-	17	-	1	-	-	-	-	-	-	-	24
28	Animal growth hormones	2	2	-	-	-	-	-	-	-	-	-	-	-	4
29	Rumen manipulation	-	1	-	-	-	-	-	-	-	-	-	-	-	1
30	Design-delivery - vaccines	5	-	-	1	-	-	-	-	-	-	-	-	-	6
31	Other – microbiology	6	1	2	17	2	1	-	-	-	-	-	-	1	30
TOTAL		**143**	**195**	**110**	**252**	**34**	**30**	**8**	**-**	**6**	**39**	**-**	**-**	**71**	**888**

Source: ISNAR (2000).

Table 5

Production Constraints Addressed by Biotechnology Research Institutions in LAC

Country	Production Constraint or Need Targeted*								Total
	PP	PH	AP	AH	GR	FP	GE	OT	
Argentina	26	20	10	23	22	-	1	-	**102**
Brazil	16	30	15	2	23	8	2	3	**99**
Chile	20	15	3	4	24	1	-	4	**71**
Colombia	39	35	4	14	21	10	-	4	**127**
Costa Rica	12	-	-	-	14	2	-	-	**28**
Ecuador	2	3	3	2	9	-	-	1	**20**
Guatemala	2	5	-	-	-	2	-	-	**9**
Jamaica	-	-	-	-	-	-	-	-	**-**
Paraguay	2	1	-	-	-	-	-	-	**3**
Peru	7	8	-	-	2	1	-	-	**18**
Trinidad & Tobago	-	-	-	-	-	-	-	-	**-**
Uruguay	-	-	-	-	-	-	-	-	**-**
Venezuela	12	9	-	-	9	-	-	-	**30**
TOTAL	**138**	**126**	**35**	**45**	**124**	**24**	**3**	**12**	**507**

Notes: (*) **PP**=Plant Production (plant breeding, cloning, productivity, abiotic stress, other); **PH=** Plant Health (protection, diseases, diagnostics, other); **AP=**Animal Production (reproduction, productivity, other); **AH**=Animal Health (protection, diseases, vaccines, diagnostics, other); **GR**=Genetic Resources (characterization, variability, selection, conservation); **FP**=Food and Pharmaceutical Needs (nutritional quality, functional food, drugs, enzymes); **GE**=Genomics; **OT**=Other (industrial/energy purposes, other)

Source: ISNAR (2000).

According to Table 5, biotech research focused on plant production constraints (27%), followed by genetic resources (25%) and plant health (25%). The combined interest in animal production and health (16%) also reflects the importance of livestock in most countries of the region. The interest in food production/pharmaceutical applications (5%) and in other industry and energy applications (2%) reflects the fact that there is an emerging industrial demand for innovation, quality and competitiveness in some Latin American economies.

The relative distribution of the crop-livestock species as the subject of research shows a wide and even distribution of interests ranging from the top 20 percent for fruit trees and forestry species, to the bottom 5 percent for other animals and microorganisms. Table 6 shows that the Latin American research community is studying almost all types of crop and livestock species according to the particular needs of the individual country economies. However, each country is represented in almost every category, with, perhaps, some regional specialization toward wheat and cereals in Southern Cone countries and potato, roots and tuber crops in Andean/tropical countries. At the country level, Argentina concentrates its efforts on cereals and oilseeds, cattle and other livestock (57% of responses); Brazil places more emphasis on horticulture/legumes, cattle and other livestock (63%); in Chile horticulture/legumes/berries and fruit and forest represent 57% of the total effort; and in Colombia, there is a much wider and more even distribution except for the high importance given to industrial crops (23%).

Table 6
Biotechnology Research Focus in LAC 2000

Country	Crop / Livestock Breed Involved x Times*									Total
	WH	PO	HO	FF	MP	IC	CA	OL	OA	
Argentina	25	10	16	13	6	3	27	18	5	**123**
Brazil	13	10	37	14	6	5	13	19	7	**124**
Chile	11	6	18	29	8	1	6	2	2	**83**
Colombia	14	23	31	39	13	42	15	12	9	**198**
Costa Rica	-	7	3	9	8	5	-	-	3	**35**
Ecuador	1	13	-	2	2	-	-	-	9	**27**
Guatemala	1	-	5	-	2	1	-	-	3	**12**
Jamaica	-	-	-	-	-	-	-	-	-	**-**
Paraguay	-	-	-	3	-	-	-	-	-	**3**
Peru	-	11	9	12	-	1	-	-	-	**33**
Trinidad & Tobago	-	-	-	-	-	-	-	-	-	**-**
Uruguay	-	-	-	-	-	-	-	-	-	**-**
Venezuela	7	9	4	18	14	14	-	-	-	**66**
TOTAL	**72**	**89**	**123**	**139**	**59**	**72**	**61**	**51**	**38**	**704**

Notes: (*) **WH=**Wheat, Barley, Maize and other Cereals (inc. grasses); **PO**=Potato, Roots and Tubers; **HO**=Horticultural, Oilseeds, Legumes, Berries and Ornamental plants; **FF**=Fruit trees and Forestry Species; **MP=**Medicinal, Tropical and Native plants; **IC**=Industrial Crops (Coffee, Sugarcane,Tobacco, Palm, etc); **CA**=Cattle (Bovine, beef and dairy); **OL=**Other Livestock species (Swine, Goats, Sheep; also Horses and Poultry); **OA**=Other Animals and Microorganisms (Aquatic Animals, Dogs, Birds, Insects, etc)

Source: ISNAR (2000).

Table 7
Sources of Funds for Biotech Research in Colombia and Mexico, 1985-87

Source	1985	1989	1993	1997
	% of expenditure			
Colombia				
Government	23	5	32	47
Sale Products	0	33	33	25
Donors	18	13	7	13
Levies	59	50	27	14
Contracts	0	0	0	0
Mexico				
Government	69	60	64	59
Sale Products	0	1	4	9
Sale Services	11	0	0	3
Contracts	0	0	3	4
Donors	20	37	28	24
Levies	0	0	0	3
Others	0	2	1	0

Sources: Colombia (Torres and Falconi 2000); Mexico (Qaim and Falconi 1998).

Conventional Plant Breeding Research Capacity

The development of a new variety involves many steps, from the collection of unimproved landraces and wild species, to germplasm storage and characterization, creation and crossing of advanced lines, testing of advanced lines in targeted release areas and, finally, to the release of adapted varieties. Genetic resource improvement is a continuous process. The development of a finished variety may take twenty or more years to complete. It is difficult to capture or even to measure, the benefits produced at any research point prior to the final step of releasing and distributing a commercial variety.

Prior to 1960, there was no formal system in place that provided plant breeders access to germplasm available beyond their borders. The current system for sharing crop improvement results is relatively young. It evolved in the 1970s and 1980s, when financial resources were expanding and plant IPR laws were weak or nonexistent. International access to research from other public institutions remains generally open and without charge. The exchange of germplasm is largely based on a system of informal exchange among plant breeders. To date, the effect of reduced investment in plant breeding has been felt more keenly than have been changes in IPR regimes.

The region has a wealth of ex-situ and in-situ genetic resources. The largest in-situ collections are held by national centers in Brazil and Mexico and in the three CGIAR centers in the region. Overall, approximately 13 percent of the world's accessions for the crops listed in Table 7 are held in genebanks in the region. The value of these materials as a source of the genetic building blocks for future biotechnology research is potentially very large. Yet, nearly all of the collections are underutilized as inputs into conventional plant breeding at present. Many of the genebanks face serious problems of underfunding and risk deterioration of materials in storage. Support for the conservation and improvement of germplasm in the region is an activity that strongly complements other biotechnology activities.

National and International Biotechnology Support Programs

Detailed data on the sources of funding of agricultural biotechnology are available for only two countries (Mexico and Colombia) but the evidence from them and our case studies and experience indicates that central governments and donors are the major sources of funding. Provincial governments and the private sector are important in some countries. Donors have also played a role also in both countries.[20] Table 7 shows that the government is the largest supporter of agricultural research.

Much of the capacity reported in the previous section has evolved as part of support programs for the development of scientists implemented both at the country, regional and subregional levels. In general these programs have concentrated on the creation and/or consolidation of the general local R&D base, and biotechnology support was only a part of the efforts that combined funding for R&D and infrastructure development with human resources training.

In most cases, the bulk of these efforts were funded through loan projects from either the IDB or the World Bank (Table 8). In recent years, many projects were designed to support R&D activities in general, usually within the framework of competitive grant funding schemes.[21] Although there is no comprehensive data on the importance of the share of biotechnology related projects in the total funding provided through these schemes, partial evidence from some countries (Chile, Argentina, Brazil, Venezuela) indicates that biotechnology related research captured a significant share from the beginning.

[20] According authors' experience, a similar analysis in other LAC countries would yield similar results to those of Colombia and Mexico.

[21] Venezuela (CONICYT); Chile, National Fund for Scientific and Technological Research (FONDECYT), National Fund for Technological Development (FONTEC) and National Fund for Development Promotion (FONDEF); Uruguay, National Council for Scientific and Technological Research (CONICYT); Argentina National Fund for Science and Technology (FONCYT) and Argentinean Fund for Technology Development (FONTAR), among other initiatives.

Table 8

Governmental Programs in Support of Biotechnology Development

in Selected LAC Countries (1980 - 2001)

Country	Program	Executing Agency	Objectives	Budget (Millions U$S)
Argentina	Programa Nacional de Biotecnología	Department of Science and Technology (SeCyT)	Promotion and funding of Biotechnology R&D	3.8
	Programa de Moderni-zación Tecnológica I (IDB 1993)	Department of Economic Planning and Programming / Department of Science and Technology	Support for general Sc.&Tech research and for increased private sector participation in R&D activities, through loans and risk sharing mechanisms.	91.0
	Programa de Moderni-zación Tecnológica II (IDB 1999)	Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT)	Support for Sc. &Tech research in general and grants for private sector involvement in R&D activities	280.0
Brazil	Programa Nacional de Biotecnología (1981)	National Research Council (CNPq) and national Fund for the promotion of Scientific and Technological Research (FINEP)	Funding of biotechnology R & D	3.3
	PADCT/ Biotecnología (World Bank 1984)	Ministry for Science and Technology	Human Resources and Infrastructure in biotechnology related scientific fields	12.9
	Biotechnology Parks	Ministry for Science and Technology	Infrastructure and services for start-up firms	
	Science and Techno-logy Promotion Pro-gram (IDB 1991)	Ministry of Science and Technology, CNPq	Grants for scientific and technological research in R & D public and private sector institutions. Support for risk sharing initiatives in the private sector.	100.0
	Science and Technol-ogy Reform Support (World Bank 1997)	Ministry of Science and Technology	Improve the quality of advanced research and training and promote cooperative R & D between public and private institutions and private investments in R & D	360.0
	Genome Project	Sao Paolo Science and Technology Foundation (FAPESP)	Infrastructure and research by Universities, Research Institutes, and Private Firms	30.0

(continued)

Table 8 (Cont.)

Governmental Programs in Support of Biotechnology Development in Selected LAC Countries (1980 - 2001)

Country	Program	Executing Agency	Objectives	Budget (Millions U$S)
Chile	National Biotechnology Committee (1983)	National council for Scientific and Technological Research (CONICYT)	Human Resources Development/ Promotion and Coordination of R&D	N/A
	Programa de Ciencia y Tecnología (IDB 1994)	CONICYT and the Coorporación de Fomento, CORFO	Promotion of Sc.&Tech research in general and portion of private sector involvement in R&D activities through risk sharing mechanisms	94.0
	Programa de Desarrollo e innovación Tecnológica (IDB 2000)	Economics Ministry	Promotion of public and private R&D for improving the competitiveness of production sectors, with special emphasis on the use of biotechnological approaches	200.0
Colombia	Biotechnology Program (1984)	Instituto Colombiano para el Desarrollo de la Ciencia y la Tecnología (COLCIENCIAS)	Planning, Coordination and Funding of R&D	N/A
	Programa de Desarrollo Científico y Tecnológico (IDB 1995)	COLCIENCIAS	General support for scientific and technological research and technological innovation in strategic sectors	100.0
México	Programa Nacional de Desarrollo Científico y Tecnológico, PRONDETYC (1984)	Consejo Nacional de Ciencia y Tecnología, CONACYT	Funding support for biotechnology research in Universities and other public research centers	N/A
	Apoyo al Desarrollo Científico y Tecnológico (IDB 1993)	Consejo nacional de Ciencia y Tecnología, CONACYT	Infrastructure and funding support for Sc.&Tech research and direct funding for pre-competitive R&D in small and medium private enterprises	150.0
Venezuela	Programa Nacional de Ingeniería Genética y Biotecnología (1986)	Consejo Nacional de Investigaciones Científicas y Tecnológicas, CONICyT	Funding of R&D	0.5
	Programa Nuevas Tecnologías (IDB 1992)	CONICIT	General support for R&D (human resources, infrastructure and R&D expenditures)	30.0
	Segundo Programa de Ciencia y Tecnología (IDB 1999)	CONICIT	Support for Sc.&Tech. research and promotion of private sector involvement in R&D activities, through a grants program	200.0
	Programa de Tecnología Agropecuaria (IDB 2001)	Instituto Nacional de Investigaciones Agropecuaria, INIA	Increase agricultural productivity through the modernization of INIA to generate technologies and provide efficient services.	45.0
Uruguay	Programa de Desarrollo Científico y Tecnológico (IDB 1991)	Consejo Nacional de Investigaciones Científicas y Tecnológicas, CONICYT	General support for R&D (human resources, infrastructure and R&D expenditures)	35.0

Source: the authors, based on Jaffé and Infante (1996), IDB SDS/RUR database and personal communications.

In Argentina, almost 30 percent of the more than 1100 projects approved by FONCYT in 1997 and 1998 can be categorized as biotechnology R&D.

Another important development is that these initiatives include significant funding (soft loans and grants) for (i) the development of better links between public scientific institutions and the productive sector, and (ii) technological modernization and innovation at the individual firm level. The most recent projects implemented in Argentina, Chile, Uruguay, Brazil and Venezuela, offer co-funding to allow R&D institutions (public and private) to establish business units to improve their capacities to provide technological services, and to promote joint ventures between firms and research institutions in R&D activities as well as direct funding for R&D and innovation initiatives by commercial firms.

In Argentina, biotechnology related projects (both general and agricultural) appear prominently on the list of projects funded since the inception of these new modalities. All these initiatives have been developed with funding assistance from the IDB, and represent not only critical support for research activities, but also for technology transfer. They do not replace the venture capital for start-up developments, but represent an important step toward facilitating the linkage between scientific and technology exploitation capacities.[22]

International cooperation programs have also played a significant role in the development of biotechnology in general and agbiotech in particular, especially in the smaller countries (Table 9). The most relevant programs include the Regional Biotechnology Program of the United Nations funded by United Nations Development Program (UNDP), the United Nations Education and Science Organization (UNESCO) and the United Nations Industrial Development Organization (UNIDO). The Program pioneered the process of diffusion of the basic techniques in a large number of the regional research institutions through the funding of cooperative projects involving institutions in different countries. It also worked on the creation of a number of "national biotechnology commissions" to establish the basis for coordinating national efforts in the area.

Other initiatives to create basic research capacities include the recently created Biotechnology Consultative Group for Latin America and the Caribbean (BIOLAC), a program of the United Nations Industrial Development, organization (UNIDO) and the agricultural biotechnology network of the FAO (REDBIO). Both initiatives represent important coordination and exchange mechanisms for Latin American researchers and research centers.

At the subregional level there are several programs designed to develop cooperative research on issues of common interest to the participating countries, the sharing of information and technology transfer. The most important is the *Centro Argentino Brasileño de Biotecnología* (CABBIO), which has been in operation since 1985 and has funded about 70 projects, a good proportion of them in agricultural and food related areas. CABBIO started as a binational initiative and was later expanded to all the MERCOSUR countries and Chile. Human resource development and technology transfer are the two most important outputs of CABBIO to date, but there are significant R&D results in a number of areas that are rapidly maturing into the product development stage.

The Cooperative Agricultural Research Program for the Southern Cone (PROCISUR), which links the Southern Cone countries (Chile, Argentina, Uruguay, Brazil, Paraguay and Bolivia), is also an important initiative in terms of its impact on national programs, as well as the level of support that it has been able to obtain from the participating countries and international assistance organizations.

[22] In Argentina, FONTAR has funded projects with biotechnology firms and provided support for the establishment of biotechnology based service units at national agricultural research institute (INTA) in areas related to genetic and sanitary quality assurance of planting materials in fruit trees (citrus, prunes, olives, grapes) and horticultural crops (garlic, potatoes, etc), livestock improvement and animal health (diagnostic kits, vaccine development, embryo transfer), and forestry (improved planting materials) among other areas.

Table 9

Regional Biotechnology Cooperation Programs in LAC

Program	Focus	Administrative / Funding Agency	Coverage	Budget (U$S)
Centro Argentino Brasileño de Biotecnología, CABBIO (1985, continues)	Joint research project funding, through competitive mechanisms	Independent Agency / Member Countries	All scientific areas / Argentina and Brazil, since 1993 all the MERCOSUR countries (Chile requested to be included in 2000)	14.000.000 since its creation
Programa Regional de Biotecnología (1988-93)	Promotion of coop. research projects focused on human resources development and diffusion of basic technologies	UNDP/UNESCO/ UNIDO	All scientific areas / Regional	5.000.000 (Program)
BIOLAC (1988, continues)	Training through national and multi country research projects	University of the United Nations	All areas, emphasis on basic techniques / Regional	150.000 200.000/year
Latin American Plant Biotechnology Network, REDBIO (1990, continues)	Networking of researchers and research institutions	FAO	Focused on plant biotech. / Regional	60.000/year
Programa Andino de Biotecnología (1988-93)	Training and technology transfer in strategic areas	Corporación Andina de Fomento	All scientific areas / Andean Region Countries	2.000.000 (Program)
Políticas para Biotecnología Agrícola (1988-1994)	Biotech policy / promotion of biosafety regulatory mechanisms	CIDA Canada / IICA	Agricultural bio-technology / Re-gional	800.000/year
Programa de Biotecnología (1988, continues)	Training, some research projects	Organization of American States (OAS)	All scientific areas / Regional	300.000/year
Programa de Biotecnología del Cono Sur (1992, continues)	Cooperative research, training, technology transfer,	Programa Cooperativo de Investigación agrícola del Cono Sur (PROCISUR) /IICA/IADB/Member Countries	Agricultural biotechnology / Argentina-Brazil-Chile-Uruguay-Paraguay-Bolivia	120.000/year
CamBioTec (1996, continues)	Promoting biotechnology development through Canadian-Latin America partnerships (both public and private)	IDRC, CIDA and national partners	All areas / Canada, Argentina, Chile, Colombia, Cuba y México	N/A

Source: the authors on the basis of Jaffé and Infante (1996) and personal communications.

In the recent past, PROCISUR has conducted several regional cooperation programs in agricultural biotechnology, as well as an agenda for subregional biotechnology research (Carneiro, 2001).

Other cooperation efforts worth mentioning are CAMBIOTEC, a Canadian (CIDA and IDRC funded) initiative to promote business ventures in Latin America by promoting biosafety regulations and public awareness, as well as the establishment of links between Latin American and Canadian R&D capacities and firms.

In Central America, the biotechnology programs and activities of the International Agricultural Research Centers, particularly CIAT, CIP and CIMMYT and the Tropical Agricultural Research and Education Center (CATIE) have also lent critical support for the development of the biotechnology, both through the diffusion of strategic technologies and through human resources formation. The IARCs have developed an extensive network of research collaboration with advanced research institutes, public and private, in industrialized countries and developing countries. Their efforts are mainly focused on conducting biotechnology research for tropical crops and animal species, and building research capacity in developing countries, including Latin America and the Caribbean. The 16 IARCs together invest approximately $25 million annually on biotechnology, representing around 8 percent of the total CGIAR budget. Of the $25 million, about 27 percent is related directly to livestock (primarily animal health). Roughly 15 percent of the total expenditures go to genetic engineering (Morris and Hoisington 2000).

Although their combined R&D investments in agricultural biotechnology may be small compared to leading private sector companies, the IARCs play an extremely important role as an access mechanism to basic knowledge for the countries of the region. Beyond that general role, they are also important for their direct research contribution as well as to strengthen national capacities through their networking and training activities. As an example of the nature and extent of the activities of CGIAR Centers, Table 10 summarizes the biotechnology related activities that are carried out by CIMMYT, CIAP and CIP, as well as their collaborative interactions with other research institutions.

Table 10

Biotechnology Research Capacity at CIMMYT, CIAT and CIP, 2000

Crop	Activities	Techniques	Collaborating Institutes
CIMMYT			
Maize	Resistance to maize stem borers	RFLP, RAPD, AFLP Agrobacterium-mediated transformation Micro projectile bombardment	
	Resistance to rootworm	RFLP, RAPD, AFLP	
	Resistance to Fusarium ear rot	RFLP, RAPD, AFLP	
	Resistance to maize streak virus	RFLP, RAPD, AFLP	
	Resistance to mosaic virus	RFLP, RAPD, AFLP	
	Tolerance to drought	RFLP, RAPD, AFLP	
	Tolerance to acid soils	RFLP, RAPD, AFLP	
	Nutrient-enriched maize	RFLP, RAPD, AFLP	
	Apomixis	RFLP, RAPD, AFLP Wide hybridization	Institut de Recherche pour le Developpement (France); Pioneer Hi-Bred (USA); Groupe Limagrain (France); Novartis Seeds (USA)
Wheat	Resistance to leaf rust	RFLP, RAPD, AFLP	
	Resistance to stripe rust	RFLP, RAPD, AFLP	
	Resistance to Fusarium head bligh	RFLP, RAPD, AFLP	Japan International Research Center for Agricultural Sciences
	Resistance to barley yellow dwarf virus	RFLP, RAPD, AFLP	
	Resistance to Septoria diseases	RFLP, RAPD, AFLP	
	Resistance to Septoria diseases	RFLP, RAPD, AFLP	
	Tolerance to drought	RFLP, RAPD, AFLP	
	Tolerance to aluminum toxic soils	RFLP, RAPD, AFLP	
	High yielding wheat	RFLP, RAPD, AFLP	

(continued)

Table 10 (Cont.)

Biotechnology Research Capacity at CIMMYT, CIAT and CIP, 2000

Crop	Activities	Techniques	Collaborating Institutes
CIAT			
Beans	Resistance to bacterial blight	Embryo rescue	
	Tolerance to low P	Genetic markers	University of Michigan (USA)
	Tolerance to golden mosaic virus	Genetic markers	CORPOICA (Colombia); Novartis (USA); Plantek (Japan)
Cassava	Mapping resistance genes to mosaic disease	Micro satellite markers	IITA; Clemson University (USA)
	Mapping resistance genes to whitefly	Micro satellite markers AFLP	University of Florida (USA)
	Genetic resistance to bacterial blight	RFLP	IRD, Montpellier (France)
	Resistance to stem borer	Agrobacterium-mediated transformation	CORPOICA (Colombia)
	Production of clean planting material	Micro propagation	University of Louvain (Belgium)
	Long-term conservation	In vitro conservation	Rutgers University (USA); IDEA (Venezuela); Empresa Polar (Venezuela)
	Root physiological deterioration	Micro satellite markers PCR	Corporacion BIOTEC (Colombia)
Rice	Resistance to *hoja blanca* virus	Mediated-mediated transformation Micro projectile bombardment	Bath University (UK)
	Improving grain quality and yield	RFLP	Cornell University (USA)
	Resistance to blast	RFLP Micro satellite markers	Purdue University (USA); Paradigm Co. (USA)
CIP			
Potato	Resistance to potato tuber moth	Agrobacterium-mediated transformation	Michigan State University (USA); Aventis-PGS (Belgium); Unicrop (Finland)
	Resistance to potato viruses	Agrobacterium-mediated transformation	John Innes Center (UK)
	Resistance to late blight	Agrobacterium-mediated transformation RFLP, RAPD, AFLP Micro satellite markers	Max Planck Institute (Germany); Centre de Recherché Public (Luxembourg); Molecular Plant & Protein Biotechnology (Germany); Federal Institute for Plant Research (Germany); IRD (France); University of California (USA); USDA; Oregon State University (USA); Clemson University (USA); Smart Plant International (USA)
	Diagnostic kits for viruses and viroids	ELISA Monoclonal antibodies Nucleic acid probes PCR	
	Reduction of natural toxicants	Agro bacterium-mediated transformation	USDA

(continued)

Table 10 (Cont.)

Biotechnology Research Capacity at CIMMYT, CIAT and CIP, 2000

Crop	Activities	Techniques	Collaborating Institutes
CIP			
Sweet potato	Resistance to weevils	Mediated-mediated transformation RFLP, RAPD, AFLP Micro satellite markers	Laval University (Canada)
	Resistance to viruses	Agrobacterium-mediated transformation RFLP, RAPD, AFLP Micro satellite markers	North Carolina State University (USA); Austrian Research Centers (Austria)
	Improvement of flour quality	Agrobacterium-mediated transformation	IACR Long Ashton (UK)
Potato & sweet potato	Germplasm DNA fingerprinting	RAPD, AFLP Micro satellite markers	Scottish Crop Research Institute (UK); University of Wisconsin (USA); Cornell University (USA)
Root and tubers	Germplasm conservation	In vitro conservation	University of Wisconsin (USA)

Source: the authors based on ISNAR (2000) and personal communications.

The Output of Latin American Agricultural Biotech Research

Biotechnology research conducted in Latin America produced new knowledge, new tools, and new technology. However, the major advances in technology that are in use by farmers (GM soybeans, maize, and cotton) and in the pipeline are the result of genes and tools developed by companies based in the United States and Europe.

Additions to Knowledge

The FAPESP genome program in São Paulo, Brazil, has had the most well publicized successes in basic biotech research. In July 2000 it was the first group to completely sequence a plant pathogen; namely, *Xylella fastidiosa*, the pathogen that causes citrus variegated chlorosis, an important citrus disease. Since then it has completed sequencing the organism that causes citrus canker, *Xanthomonas citri*. In April 2001 scientists supported by FAPESP and local sugar cooperatives finished sequencing the sugarcane genome. Another FAPESP-industry consortium is starting to work on the Eucalyptus genome (Rohter 2001).

Brazilian researchers have also developed technologies to improve the efficiency of biotechnology research and have obtained the right to commercialize transgenic crops that they have produced. They have developed a unique system for transforming soybeans in which the embryonic axes of soybeans are bombarded with plasmid DNA (Avila et al. 2001). The frequency of transformation (number of transgenic plants/number of bombarded embryonic axes) varies from 5 to 20 percent, depending on the cultivar. At least four elite soybeans lines that were transformed in this way grew into plants that produced viable seed.

Biotech scientists at these institutes are also publishing research results in international and national journals. Table 11 provides a crude measure of publication output in biotechnology (the number of publications abstracted in biological abstracts). The dominance of Brazil and its growth in recent years is important to note. Another interesting fact is the relatively large number of publications from Costa Rica, a country with a small research system. In addition, the unique technologies that Latin American research has developed is indicated by the number of patents issued in the United States and Europe even though these inventions cannot be patented in their own countries.

Table 11
Publications Abstracted in CAB Biological Abstracts By Country of Publication

	1991	1995	1999
Argentina	25	23	26
Belize	0	0	0
Bolivia	0	68	0
Brazil	175	104	550
Chile	8	11	1
Costa Rica	41	27	47
Cuba	4	0	1
Guatemala	0	2	0
Mexico	98	15	43
Peru	24	17	75
United States	3596	3983	4384
Uruguay	2	13	0

Source: CAB Abstracts search using Ovid search engine. (June 2001).

Another measure of the output of applied biotech research is field trials on new genetically modified crops. A total of 880 GMO field trials were conducted in the region from 1987 to 2000 (Table 12). This comprises approximately 20 percent of the world field trials conducted outside of the United States. These field tests have been concentrated in Argentina, Brazil, and Mexico, three countries that account for 84 percent of LAC trials. Argentina, Brazil, and Mexico rank fourth, sixth and ninth worldwide, respectively, in terms of total number of field trials conducted. During 1998-99 only two countries, the United States and Canada, conducted more field trials than Brazil or Argentina (James 2001).

Field tests in the region have been concentrated in the private sector, particularly the multinational input firms. Local input firms play a major role in some countries (e.g. Mexico). Some (mostly local) food processing (e.g. sugar industry) and paper companies also play a role. The government plays a minor role in Argentina and Brazil and a somewhat larger role in Mexico. For the region as a whole, public institutions conducted just nine percent of the trials, a share similar to that of the public sector in U.S. trials. The number of institutions conducting GMO field trials is an indication of the diffusion of biotechnology research capacity and of the potential for competitive markets for GM products to evolve. In Argentina, for example, 32 different organizations have conducted GMO field trials. In 1999, 11 of them conducted trials in maize alone. (Table 13).

The GMO Pipeline

Three GMOs, Roundup Ready® (RR) soybean, Bt maize and Bt cotton, have been commercialized in Latin America and the Caribbean. More than 95 percent of the GMO area in the region is sown with RR soybean (Table 14). By the 1999 growing season, more than 6 million ha; that is, 80 percent of the soybean area, were planted to HT soybeans in Argentina and an estimated 1 million ha were being grown in Brazil. Small areas of RR soybeans have been introduced in Mexico and Uruguay. Bt maize provides resistance to certain Lepidopteran insects, the European maize borer in the United States, and the sugar cane borer in Argentina. Bt maize holds significant potential and has been introduced in Mexico and Argentina, but has been planted in a total of only 327,000 ha. The third GMO to be commercialized in the region is Bt cotton, which is resistant to certain Lepidoptera insects. Bt cotton has been grown in Mexico and Argentina, but in relatively small areas.

Field tests provide an indication of the type of GM technology in the pipeline. Field tests have been conducted in the region on a total of 24 different crops, but testing has focused on herbicide tolerance (HT) and insect resistance (IR) traits (Table 15) in the main commercial crops (maize, soybeans, cotton and sunflower). These four crops constitute 80 percent of all LAC trials (Table 16), while herbicide tolerance and insect resistance (in all crops) also account for 80 percent of all trials. The product quality (PQ) trials that have been conducted to date are dominated by delayed ripening in tomatoes in Mexico. Trials of disease (DR) and virus resistant (VR) crops are becoming more frequent.

Table 12

GM Field Trials in LAC, 1987 - 2000

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total[a]	% of Total
Argentina					3	7	9	18	32	38	67	71	76	0	**321**	37
Brazil											25	88	110	24	**247**	28
México		1				4	6	7	10	27	36	31	23	21	**166**	19
Chile	1					4	7	6	21				16		**55**	6
Uruguay												29			**29**	3
Cuba				1	1	2	4	5	5						**18**	2
Costa Rica					1	4		2	10						**17**	2
Bolivia					3	1		1	1			2			**8**	1
Colombia														7	**7**	1
Belize						4	1								**5**	1
Guatemala			1					1	1						**3**	0
Peru								2							**2**	0
LAC Total	**1**	**1**	**1**	**1**	**8**	**26**	**27**	**42**	**80**	**65**	**128**	**221**	**225**	**52**	**878**	
World Total w/o USA	1	10	37	48	74	156	222	351	476	532	681	815	813	514	4730	
World Total	100	10	3	2	11	17	12	12	17	12	19	27	28	10	19	

Notes: (a) Field trial totals refer to the number of applications for transgenic crops that have been approved in each country.
Sources: for Argentina, CONABIA (2001); for Brazil, CTNBio (2001); for Peru, Guislain (2001); for Mexico, SAGAR (2001); for Chile, Hinrichsen (2000) and James and Kratigger (1996); for Colombia, Artunuaga-Salas (2001); for Belize, Bolivia, Costa Rica, Cuba, and Guatemala, James and Krattiger (1996); and for Uruguay, Blanco (1998). World data compiled from Courtmanche, Pray, and Govindasamy (2001).

Table 13

Number of Institutions Conducting GMO Field Trials

In Argentina, 1991 - 99

	1991	1992	1993	1994	1995	1996	1997	1998	1999
Alfalfa							1	1	
Cotton	1	2	1	1	4	1	2	3	3
Rice								1	1
Canola		1	2	1	2	1			
Sunflower				1		2	3	5	5
Maize	1	2	5	6	10	10	12	13	11
Potato					1	1	2	3	1
Sweet Beet		1							
Soy	1	1	1	3	7	4	4	5	4
Tomato				1			1		
Wheat			1		1	1	2	2	1
Total	3	6	6	10	15	11	17	19	16

Source: CONABIA 2001.

The immediate pipeline of transgenic crops then is dominated by herbicide tolerance, and insect resistance that have been added to new varieties of maize, soybeans, and cotton.

These products can be expected to extend the area of these GM crops beyond its current boundaries. In Brazil, for example, GM soybean varieties developed by EMBRAPA as part of a commercial agreement with Monsanto for most of the major soybeans regions are now moving through the regulatory process. The other technologies that are in the pipeline are resistance to pests, herbicides and virus that have been added to crops other than maize, soybean and cotton, including sugarcane, sunflowers, rapeseed (canola), and others. Adapted varieties of these crops are also waiting for regulatory approval. In Mexico, in addition to pest and disease resistance, there has been some work on product quality of tomatoes and other vegetables.

In summary, the biotechnology sector in LAC is one of considerable scientific potential and presents a significant opportunity for biotechnology to contribute to improving agricultural productivity and providing enhanced products to consumers. Scientific capacity is concentrated in the region's large countries, particularly in Brazil, Argentina and Mexico. Even within these countries, capacity is concentrated in a few world-class institutions and linkages to applied research are largely lacking. At the other end of the spectrum, most LAC countries lack biotechnology capacity at both the basic and applied levels. For this large group of countries, marshalling the technical expertise to even implement functional biosafety and patenting systems will require a sustained effort over a period of years, and a significant commitment of new financial resources. There is a similar disparity in the potential for the private sector to lead the introduction of biotechnology innovation. Again Brazil, Argentina and Mexico hold great promise, while seed markets in other countries are handicapped by size and underdeveloped infrastructure.

Table 14

Area Under Commercial Production of GM Crops 1999 (ha)

Country	Soybeans	Corn	Cotton	Others
Argentina	6,400,000	260,000	10,000	
Brazil	1,000,000			
Chile		20,000		
Mexico	500	47,000	20,000	Tomato, squash, melon
Uruguay	5,000			
Total	7,405,500	327,000	30,000	

Sources: Argentina and Mexico from James 2000; Brazil – estimates from seed industry; Chile from ISNAR 2000 (for seed export to U.S.); Uruguay personal communication Roberto Diaz, INIA, Uruguay, July 11, 2000.

Table 15

GM Field Trials by Trait, 1987-2000*

	Argentina	Belize	Bolivia	Brazil	Chile	Colombia	Costa Rica	Cuba	Guatemala	Mexico	Peru	Uruguay	Total No.	Total (%)
HT	104	3	2	112	21		11			30		19	302	35
IR	106	2	2	95	6	2	4	10		52		10	289	34
HT/IR	58			10	6					10			84	10
PQ	15		1		14	1	1		2	36			70	8
VR	7			6	3	1	1	6	1	26			51	6
DR	22				1			1		1			25	3
MG	1		1		1			1		10			14	2
AP	4		2							2			8	1
Unident						3	1				2		6	1
HT/AP	1												1	0
HT/DR	1												1	0
HT/MG					2								2	0
HT/VR					1								1	0
VR/IR	1												1	0
Other	1							2					3	0
Totals	321	5	8	223	55	7	18	20	3	167	2	29	858	100

Notes: (*) Not all countries include year 2000 data.
Sources: for Argentina, CONABIA (2001); for Brazil, CTNBio (2001); for Peru, Guislain (2001); for Mexico, SAGAR (2001); for Chile, Hinrichsen (2000) and James and Kratigger (1996); for Colombia, Artunuaga-Salas (2001); for Belize, Bolivia, Costa Rica, Cuba, and Guatemala, James and Krattiger (1996); and for Uruguay, Blanco (1998). World data compiled from Courtmanche, Pray, and Govindasamy (2001).

Table 16

GM Field Trials[a] by Crop, 1987-2000.

	Argentina	Belize	Bolivia	Brazil	Chile	Colombia	Costa Rica	Cuba	Guatemala	Mexico	Uruguay	Total No.	Total %
Maize	173	3		205	21	1	2			34	13	460	47
Soybean	50	1	1	62	9		11			15	15	164	17
Cotton	28	1	3	36		1	3			38		110	12
Sunflower	44											44	5
Tomato					6				2	30		38	4
Potato	7		4	2	2	1		7		5		28	3
Canola	8				11			1		2		22	2
Other Veg.								5	1	13		19	2
Sugarcane				14				3				17	2
Wheat	7				1					5		13	1
Fruit				2	1		1			15		19	2
Tobacco				2	1			3		4		10	1
Rice	3			3		1	1			1		9	1
Other				4		2				3	1	10	1
Sugar Beet	1				3			1				5	1
Flowers						1				1		2	0
Alfalfa										1		1	0
Total	**321**	**5**	**8**	**330**	**55**	**7**	**18**	**20**	**3**	**167**	**29**	**971**	

Notes: (a) Field trial totals refer to the number of applications for transgenic crops that have been approved in each country.
Sources: for Argentina, CONABIA (2001); for Brazil, CTNBio (2001); for Peru, Guislain (2001); for Mexico, SAGAR (2001); for Chile, Hinrichsen (2000) and James and Kratigger (1996); for Colombia, Artunuaga-Salas (2001); for Belize, Bolivia, Costa Rica, Cuba, and Guatemala, James and Krattiger (1996); and for Uruguay, Blanco (1998). World data compiled from Courtmanche, Pray, and Govindasamy (2001).

V. Challenges for Accessing the Benefits of Biotechnology

The application of biotechnological approaches to the agricultural industry opens a wide scope of potential benefits, yet many of these benefits may not be achieved if a number of important issues are not resolved. Some of these issues are related to the organization of technology and innovation systems and the scientific basis of biotechnology and its interface with traditional agricultural research. Others refer to biosafety considerations and consumer acceptance. There are also issues emerging from the proprietary nature of the new technologies as well as relating to the characteristics of the technology delivery mechanisms involved.

Chronic Underinvestment in Agricultural Research vis-à-vis Large Investment Requirements and Long Time Lags for Biotech Research

The novel character of the science involved and the relatively long periods required to get products into the markets (Figure 1) converge to make the biotechnology industry an expensive one. The cases of the U.S. Agricultural Research Service (ARS), the Rockefeller Foundation's International Rice Biotechnology Program and China's efforts in the field, are good examples of the long lags and substantial investment involved.

ARS has placed significant emphasis on biotechnology research for more than a decade, with an annual budget of at least $110 million,[23] an amount equal to some estimates of the biotech expenditure of all national agricultural research systems worldwide (Horstkotte-Wesseler and Byerlee 2000). ARS has conducted nearly 100 GMO field trials. Its research complements applied technology development by private companies and state agricultural universities in the United States. However, no ARS biotechnologies are being used by farmers.

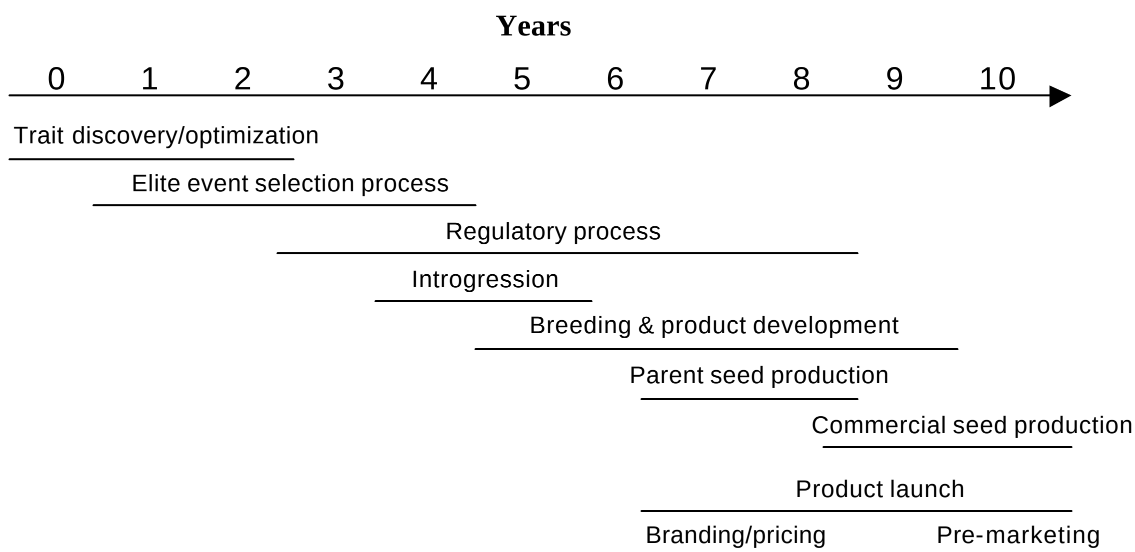
The *Rockefeller Foundation*'s experience with the International Rice Biotechnology Program is similar. After more than 15 years and over $100 million invested, transgenic rice varieties are just starting to be field tested in Asia, due to problems in obtaining biosafety permits and public resistance in some countries, as well as the complexities of negotiating the proprietary rights associated with several genes and processes incorporated into the new varieties so that they can be used commercially (Horstkotte-Wesseler and Byerlee 2000). In both cases, the research represents impressive scientific accomplishments and has made important contributions to human resource development, but its direct impact on production is still very limited, in spite of large and sustained investment efforts.[24]

The small returns of these biotech programs result from the need to identify useful genes and develop techniques for inserting them into plants. The creation of a useful GMO combines the products of two distinct scientific undertakings: a biotechnology step and a plant breeding step. The biotechnology step produces a genetic event or gene transformation that is useful in solving an economically important agricultural problem. The gene must then be combined with an adapted crop variety to create a viable commercial GMO. Once the biotechnology step has been successfully completed, the development of an adapted cultivar is accomplished using conventional plant breeding techniques. The plant breeding step is scientifically routine, but for a GMO to be successful requires that the genetic event be placed in a variety with the agronomic traits desired by farmers. Farmers will not accept a GMO unless it is packaged in a genetic background with acceptable performance. Achieving farmer acceptance and access to improved varieties, GMO or conventional, remains

[23] Personal correspondence (Paul Heisey). See also Heisey et al. (2002) for a recent discussion of the privatization of plant breeding in developed countries.

[24] China's experience is also one of modest impacts in spite of a quite serious level of investment commitments. China was spending about $90 million annually in the late 1990s and is now spending over $100 million on agricultural biotechnology (Huang et al. 2001). The major benefits for farmers and consumers have been the diffusion of Bt cotton, which they likely would have obtained from Monsanto and Delta and Pineland varieties even if the public sector had not developed competing varieties.

Figure 1. Discovery and development process of a transgenic crop variety



Source: Covenent (2000).

an unmet challenge for most crops in most LAC countries.

If public or private breeding programs can obtain useful genes like Bt, the plant breeding step is likely to have a high payoff. An institution can be a successful provider of GMOs without possessing any biotechnology research capacity. For example, Delta and Pineland Seed Company (D&PL) is a modest size seed company with just eight U.S.-based cotton breeders and three breeders in other countries, and has never had significant biotechnology research capacity.[25] Yet, through the use of licensing agreements with Monsanto, it has become one of the world's largest marketers of GMO crop seeds, selling GMOs in six countries including Mexico and Argentina. The implication is that LAC countries can obtain access to GMOs without possessing the capacity to produce genetic events. At present, the capacity of public institutions in LAC, or anywhere in the world, to produce useful genetic events is limited. Industrialized countries have invested heavily in agricultural biotechnology research.

According to Kalaitzandonakes (2000) public sector investment in the European Union was approximately $100 million annually during the mid-1990s, and Japan invested $260 million in 2000. Data on the size of private sector biotechnology expenditures are sketchy, but the available evidence suggests that investments are substantial. Table 17 is a partial listing of some 100 bilateral research agreements between product firms such Pioneer and Monsanto and research providers that were announced between 1997 and 2000. Only a dozen of these agreements include information about contract values, which range from $20 million to $218 million and total $838 million. Nonetheless, after two decades and several billion dollars invested, only a handful of products have reached the market, and only three have been widely adopted (RR soybeans and Bt cotton and Bt maize).

[25] D&PL's first investment in biotechnology research occurred in 1998. By 1999 one scientist was operating a small lab focussing on identifying useful markers.

Table 17

World Research Agreements in Agrobiotechnolgy, 1996-2000

Company	Company	Research Area	Year	Contract Value
AgrEvo	GeneLogic	Disease resistance	1998	$45 million
AgrEvo	Netgenics	Bioinformatics	1999	NA
American Cyanamid	Hyseq	Genomics	1999	$60 million
Aventis	Lynx	Functional genomics	1999	NA
BASF	SunGene	Plant biotechnology	1999	NA
BASF	Metanomics	Plant biotechnology	1999	NA
BASF	Incyte	Genomics	1996	NA
Bayer	Arqule	Library screening	1999	$30 million
Bayer	Exclixis	Chemical screening	2000	$200 million
Bayer	Paradigm Genetics	Herbicide development	1998	$40 million
Ceres	Genset	Gene sequencing	1999	NA
Dow Agro	BioSource Technologies	Functional genomics	1997	NA
Dow Agro	Integrated Genomics	Product development	1999	NA
Dow Chemicals	Diversa	Novel enzyme	2000	$80 million
DuPont	Maxygen	Novel genes	1999	NA
DuPont	Lynx	Gene identification	1998	$60 million
FMC	Xenova	Novel insecticides	1998	NA
Hitachi	Myriad Genetics	Proteomics	2000	$26 million
Monsanto	Paradigm Genetics	Functional genomics	1999	NA
Monsanto	Genetracer	Plant-animal genomics	1997	NA
Monsanto	Millenium	Plant genomics	1997	$218 million
Monsanto	Molecular Applications	Function of novel proteins	1999	NA
Novartis	Myriad Genetics	Cereal genomics	1999	$34 million
Novartis	Chiron	Combinatorial chemistry	1997	NA
Novartis Agribus	Diversa	Novel enzymes	1999	NA
Novartis Institute	Invitrogen	Functional genomics	1999	NA
Paradigm Genetics	Lion BioSciences	Genomics	2000	NA
Pioneer	CuraGen	Genomics	1998	NA
Pioneer	Maxygen	Gene performance	1999	NA
Pioneer	Oxford GlycoSciences	Protein analysis	1998	NA
RhoBio	Celera AgGen	Corn genes	1999	NA
RhoBio	CSIRO	Gene expression	1999	NA
Rhone Poulene	Agritope	Functional genomics	1999	$20 million
Rhone Poulene	Inst. Of Molecular Biology	Rice genomics	1999	NA
Zeneca	John Innes Centre	Wheat genomics	1998	NA
Zeneca	Maxygen	Input-output traits	1999	$25 million

Source: Kalaitzandonakes (2000).

Another emerging constraint is that ag-biotechnology products demand long development time until a product is ready for marketing (usually more than 10 years). Given that investments to continue to upgrade equipment are becoming scarce or even unavailable, it is difficult to finish potential pipeline products.

Private research investment levels in LAC are also below those of other regions. While in the United States, Australia and Canada, private R&D has risen significantly, in LAC it still represent a very small proportion of total investments. With the exception of plant breeding research in some cereals and oilseeds in Argentina, Brazil and Mexico, and in some plantation tropical crops such as coffee and sugarcane in Brazil, Colombia and Central America, the evolution of private R&D has followed essentially the same direction as public funding.[26] This investment trend reflects the fact that potential markets in LAC are not of sufficient size to support significant R&D efforts. Large potential markets exist for only a few crops in Argentina, Brazil and Mexico (Table 18).

Table 18
Estimated Value of the Commercial Markets for Seeds and Planting Materials in some LAC Countries, 2000

Country	Value (Mill $ US)
Brazil	1200
Argentina	810
Mexico	350
Chile	120
Paraguay	70
Colombia	40
Bolivia	35
Ecuador	12
Dominican Republic	7

Source: developed by the authors based on misc. USDA and American Seed Trade Association publications.

Together these three countries account for more than 80 percent of the total cropped area in LAC, and more than 85 percent of the area under the main commercial crops of maize, soybean, and cotton (Table 19).

A key question facing national agricultural research systems with limited funds is how much should they invest in developing the capacity to perform basic biotechnology research. Without biotechnology capacity spillover benefits from research can be accessed through effective plant breeding if useful events are available from other sources. However, the main reason for supporting gene discovery capacity at the local level is that it will increase the availability of events targeted at regionally important agricultural problems. Without that capacity, the availability of GMO products will be dominated by temperate events developed by transnational companies for agriculture in other countries, principally the United States.

The Potential Integration of Biotechnology and Agricultural R&D at Universities and Research Institutes

Universities and Research Institutes

Biotechnology is not an alternative type of research that should be conducted separately from traditional agricultural research technologies. Conceptually, biotechnology transforms and greatly extends the scope of technological possibilities of agricultural research, but should still be considered as a set of tools which complements traditional research approaches, making them more efficient and effective.

The nature of this complementarity is evident in areas such as crop breeding and epidemiology. In crop breeding, biotechnological approaches – (genomics and modern genetic engineering) can make breeding more efficient and effective in time and focus. Biotechnology also provides technological alternatives that were not possible just a few years back, allowing the design of completely "new" products. Once the new constructs are available there is still the need to backcross the new GM varieties into the broad germplasm basis of existing commercial varieties, and undertake the large-scale field evaluations to adapt the new products to local ecological conditions and cultural practices. This step is still to be done through conventional crop breeding and agronomic work and through the type of public/private collaborations on which agricultural technology development systems have been based until now.[27]

[26] Private investments in agricultural research the U.S. have nearly tripled in real terms from 1960 to 1995 to about $3.5 billion, representing almost 60% of total expenditures (Fuglie et al. 1996). For LAC, no estimate places private research over 15% of expenditures (Ardila 1999; Trigo 2000)

[27] See Morris and Ekasingh (2002) for a recent discussion on the roles for the public and private sector plant breeding research in developing countries.

Table 19
Area Harvested with Major Crops in Latin America Average 1997-99 (1,000 ha)

Countries	Maize	Soy	Wheat	Beans	Rice	Sunflwr	Cassava	Veg	Cotton	Banana	Potato	Plantain	Oats	Sweet Potato	Canola	Total
Brazil	11,592	12,585	1,399	3,958	3,322	75	1,574	428	714	524	174	-	196	55	17	**36,615**
Argentina	3,067	7,171	5,607	267	242	3,454	16	203	802	8	115	-	279	17	3	**21,252**
Mexico	7,479	99	727	1,819	99	3	1	563	199	69	64	-	72	2	1	**11,196**
Paraguay	365	1,064	172	63	28	54	232	44	160	3	0	-	-	10	-	**2,196**
Colombia	528	33	20	131	409	-	190	100	54	51	167	385	-	-	-	**2,067**
Bolivia	283	580	169	13	132	111	36	111	51	3	13	15	5	3	-	**1,678**
Peru	440	3	123	98	273	-	77	170	81	-	263	115	5	15	-	**1,663**
Ecuador	456	20	28	59	336	0	26	78	8	204	62	63	1	0	-	**1,341**
Guatemala	611	18	5	130	13	-	5	39	2	24	8	7	-	-	-	**862**
Venezuela	373	3	1	42	158	6	44	64	37	52	18	61	-	2	-	**860**
Chile	93	-	380	34	22	4	-	99	-	-	62	-	88	1	21	**804**
Haiti	273	-	-	58	58	-	73	37	4	42	1	45	-	56	-	**647**
Uruguay	60	9	215	5	178	104	-	17	-	-	9	-	42	6	-	**645**
Honduras	409	2	2	91	11	-	1	27	1	22	2	13	-	1	-	**582**
Cuba	90	-	-	47	131	-	73	85	-	17	14	55	-	44	-	**555**
Nicaragua	245	14	-	176	71	-	5	11	2	2	2	4	-	-	-	**533**
El Salvador	317	1	-	79	13	-	2	8	1	6	1	3	-	0	-	**431**
Dom. Rep.	27	-	-	33	111	-	19	30	-	31	2	31	-	7	-	**291**
Costa Rica	18	-	-	39	66	-	6	14	0	48	4	8	-	-	-	**204**
Panama	62	0	-	8	89	-	5	8	-	19	1	10	-	-	-	**203**
Guyana	3	-	-	-	139	-	2	1	-	2	-	5	-	-	-	**152**
Suriname	0	0	-	-	55	-	0	2	-	2	-	1	-	0	-	**60**
Jamaica	2	-	-	0	0	-	1	13	-	16	1	2	-	2	-	**36**
Belize	18	-	-	5	5	-	-	1	-	4	-	-	-	-	-	**33**
Martinique	-	-	-	-	-	-	0	2	-	11	-	1	-	0	-	**14**
Puerto Rico	0	-	-	0	-	-	0	6	-	2	-	5	-	0	-	**14**
FrGuiana	0	-	-	-	9	-	2	1	-	1	-	0	-	-	-	**13**
S. Lucia	-	-	-	-	-	-	0	0	-	9	-	0	-	0	-	**10**
Trin&Tob	2	-	-	-	2	-	0	2	-	1	-	1	-	0	-	**8**
Guadelpe	-	-	-	-	-	-	0	2	-	6	-	1	-	0	-	**8**
S.Vin/Gren	1	-	-	-	-	-	0	0	-	4	-	0	-	1	-	**6**
Dominica	0	-	-	-	-	-	0	1	-	3	0	1	-	0	-	**5**
Barbados	1	-	-	-	-	-	0	2	-	0	-	-	-	1	-	**3**
Bahamas	0	-	-	-	-	-	0	2	-	0	-	-	-	0	-	**3**
Grenada	0	-	-	0	-	-	0	0	0	1	-	0	-	0	-	**2**
Anti&Barb	0	-	-	-	-	-	0	0	1	0	-	-	-	0	-	**1**
Montserrat	0	-	-	-	-	-	-	0	0	0	0	-	-	0	-	**0**
Cayman Is.	-	-	-	-	-	-	0	0	-	0	-	-	-	0	-	**0**
S.Kitt&Nev	-	-	-	-	-	-	-	0	0	-	0	-	-	0	-	**0**
BrVirgin Is	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	**0**
LAC total	**26,814**	**21,601**	**8,847**	**7,155**	**5,975**	**3,812**	**2,391**	**2,174**	**2,117**	**1,222**	**1,100**	**833**	**688**	**225**	**42**	**84,996**
% Area	**32**	**25**	**10**	**8**	**7**	**4**	**3**	**3**	**2**	**1**	**1**	**1**	**1**	**0**	**0**	**100**

Source: FAO

A critical issue for biotechnology is that many countries have convinced new institutions to conduct basic biological research that is relevant to agricultural research, but these new institutions are not often closely linked to agricultural research and technology transfer organizations.

While traditional agricultural technology has been developed within "dedicated" institutional settings (national institutes, specialized agricultural research centers, agricultural colleges), biotechnology is linked to the basic science environment. Traditional agricultural R&D has a vertical structure, where the development of the basic knowledge and its applications to technology generation are closely interrelated, usually undertaken within the same organization. Biotechnology development, on the other hand, is of a horizontal nature. The discovery of rDNA and the principles of genetic engineering are applicable across a broad range of subject matters in health, environment, industry and agriculture. Biotechnology capacities are of a generic nature and its natural institutional environment is the basic science department of the universities and the advanced research institutions, which at present are not linked to the technology delivery systems of the region.

According to an FAO survey of the early 1990s (Villalobos 1997) more than 1000 researchers were working in biotechnology related areas in the region; the majority of them in universities. Agricultural research institutes accounted for about 35 percent, and private firms for the remainder. Scientific production indicators also support the greater diversity of institutional participation in the biotechnology development. According to CABI, in the mid-1990s about 65 percent of scientific publications concerning intermediate biotechnologies and close to 70 percent of those involving modern or advanced technologies belong to university researchers. The ISNAR survey mentioned before shows that universities are the most active actor, with public agricultural research institutes presence only in the case of the larger countries.

Table 20 shows that most organizations involved in biotechnology do so as part of extensive networking arrangements involving institutions in their same countries (45.5%), other LAC countries (13%), Europe (21.2%), the United States (18.8%) and elsewhere. This greater diversity of actors has significant implications for scientific and technological policy-making. One implication is that since organizational cultures and incentives vary significantly from institution to institution, special programs and incentives are needed to persuade biologists and agricultural scientists to work together. [28]

The second implication is that while in the traditional environment public policy toward agricultural research and technology development was largely determined by direct investments (budgetary allocations) and priorities set in the public agricultural research institute, in this more diversified institutional environment, institutional allocations become less relevant as instruments of public policy compared with other mechanisms, such as competitive funds.

Public and Private Sector

The biotechnology and the plant breeding research steps for GMOs grown commercially today have only occasionally taken place in the same institution, and need not occur in the same country. In fact, at present nearly all GMOs grown commercially anywhere in the world are the result of genetic events produced in the United States, and with few exceptions based on

[28] An example of what can be done is the virtual genome institute financed by FAPESP (the State of São Paulo Research Foundation, www.fapesp.org.br). This program brought together biologists from 30 general universities, medical schools, agricultural universities, agricultural research institutes and private sector research programs to sequence the plant pathogen *Xylella fastidiosa* . It provided money for equipment, research supplies, buildings, and the excitement of working as a group on the cutting edge of science. The result was that they were the first group in the world to completely sequence a plant pathogen.

Table 20

LAC Biotechnology Collaboration with Advanced Research Institutes, 2000

Surveyed Country	**Country of the Advanced Institution**													**Total**
	SA	AR	BR	CU	MX	LA	US	CA	UK	FR	SP	OE	OD	
Argentina	44	-	-	-	2	-	14	-	2	1	5	10	4	**82**
Brazil	62	1	-	-	2	3	16	1	1	11	7	4	5	**113**
Chile	47	2	2	3	5	8	16	1	2	1	3	5	4	**99**
Colombia	56	1	4	6	1	10	30	2	1	8	2	19	6	**146**
Costa Rica	14	-	-	-	5	2	4	-	2	6	1	9	-	**43**
Ecuador	9	-	-	-	-	10	4	-	1	-	-	10	-	**34**
Guatemala	9	-	-	-	-	1	-	-	-	-	-	-	-	**10**
Jamaica	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Paraguay	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Peru	3	2	1	2	-	1	14	1	3	2	-	9	-	**38**
Trinidad & Tobago	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Uruguay	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Venezuela	36	-	-	1	-	7	7	-	-	-	1	2	-	**54**
TOTAL	**280**	**6**	**7**	**12**	**15**	**42**	**105**	**5**	**12**	**29**	**19**	**68**	**19**	**619**

Notes: US = United States of America; CA = Canada; UK = United Kingdom; FR = France; SP = Spain; OE = Other European countries; OD = Other Developed countries; SA = Same Country; AR = Argentina; BR = Brazil CU = Cuba; MX = Mexico; LA = Other Latin American countries

Source: ISNAR (2000).

biotechnology science performed by multinational companies.[29] The commercial arrangements between the firms providing genetic events and the seed companies are varied, with licensing and royalty arrangements being the most commonly used. To date, the multinationals have proven willing to provide access to genetic events to virtually any interested company. Based on experiences in LAC and the rest of the world, it is clear that through the use of licenses, an institution can be a successful provider of GMOs without possessing any biotechnology research capacity.

The private sector generated no more than $20 million in revenue from GMO seed sales in LAC in 2000, and perhaps half that amount in developing countries in other parts of the world. The slow rate at which political, biosafety and intellectual property obstacles to GMO use are being resolved suggests that the private sector will move slowly in making large investment commitments in Latin America and the Caribbean. Until then, private interest is likely to continue to focus on adapting events already developed for U.S. agriculture, and on a few high value plantation crops whose marketing chain favor IP capture. Hence, we should expect to see GMOs developed and marketed for maize and cotton in Brazil, Argentina and Mexico and for coffee and sugarcane in several countries. The private sector cannot be expected to make significant investments in developing events for pure line crops such as wheat, rice, and beans; it will most likely be unwilling to finance the large investments required to conduct research targeting LAC events until the business climate becomes more certain.

[29] The exceptions are 400 ha of virus resistant papaya in Hawaii developed by Cornell University (James 2001) and approximately 100,000 ha planted to China Academy of Agricultural Sciences' Bt cotton (Pray et al. 2001). In LAC, the Bt cotton transformation was accomplished by Monsanto and was introduced into Mexico and Argentina in a Delta & Pineland variety, DP33b, the same variety used to introduce Bt cotton in the US. RR soybeans, the biggest commercial GMO is also based on a gene from Monsanto.

Thus, to get access to these proprietary technologies for smaller crops or pureline crops, public sector organizations will have to work with private companies. In some cases, private firms may be willing to donate the technology if they are assured that it will not be used to compete against them and will be used in a way that will not lead to public relations or liability problems for them. Public organizations could purchase these technologies for a lump sum payment or for royalties. In a few cases the public sector might have technology or germplasm that they could use to barter to get access to technology. The public sector might get access to the technologies through an international center such as CIMMYT or IRRI and/or an organization like ISAAA working as intermediary. Finally, there is the possibility of longer term research collaboration with private firms that would give the public sector not only access to specific technologies, but also access to some of the scientific knowledge and tools controlled by private firms. At present there are no public organizations in the region making more than occasional use of proprietary research inputs from other institutions, public or private. Missing in the region is a means to institutionalize the search for useful technologies, and to negotiate their use.

Technology purchases and public/private research collaboration require new attitudes and policies; including the willingness to work with private sector scientists, the capacity to negotiate with firms and deal with IPR issues, and be concerned about the bottom line.

A Credible Capacity for Biosafety Oversight

Modern biotechnology offers a wide array of benefits for agricultural development and for consumers. However, because of the novel characteristics of some of its components, particularly GMOs, biotech raises a number of concerns regarding their safety for human health and the environment that have been addressed by a relatively large number of studies, panels and committees.[30] In spite of the general agreement about the safety of the new technologies, because of the novelty involved and the lack of solid scientific evidence in some fields (mostly relating to ecological consideration about gene transfer into related species and biodiversity impacts). Public willingness to accept biotechnology products is closely tied to their faith in the integrity and scientific validity of regulatory bodies. Therefore, a competent, apolitical and transparent regulatory system is a necessary condition for the development of the biotechnology industry. This is a condition that is satisfied in few countries in the world.

Table 21 summarizes biosafety regulations in Latin America and the Caribbean. The overall picture is one of extreme weakness. Only a few countries (Mexico, Costa Rica, Cuba, Brazil and Argentina) have operational systems, with most of the rest presenting very recent or partial frameworks (Colombia, Peru, Bolivia, Paraguay, Chile, Uruguay), or having no formal mechanism in place. Even in the case of the more advanced systems, some recent evaluations indicate that regulatory frameworks require in-depth analysis and strengthening, particularly with regard to their autonomy of operation and the access and availability of scientific information to support the risk assessment process. An ISNAR study of Argentina –(probably the most advanced country in terms of the commercial use of GMOs) concluded that the existing mechanisms need improvement in at least four areas (i) the clarification of the institutional roles and responsibilities of the different administrative, technical and political levels involved in the evaluation and approval process, (ii) the scope and depth of the scientific base available to support the decision-making process, (iii) the efficiency and transparency of the review processes, and (iv) public awareness and acceptance.[31]

Biosafety concerns revolve around several key issues, including out crossing and gene flow from

[30] For a summary of the findings of the different studies see ISNAR (2001).
[31] Burachik and Traynor (in press).

GMOs to related and wild species, disease and insect resistance changes, and effects on non-target organisms (e.g. earthworms, microorganisms, leaf litter breakdown, non-target arthropods including pollinators and beneficial arthropods, grazing birds and mammals). These are areas that have not been of major interest prior to the appearance of genetic engineering techniques. Subsequently, relatively little accumulated knowledge or scientific capacity exists in the region. Gene flow, pest resistance and non-target effects are all issues requiring studies that include a breadth of geographic and temporal coverage, hence requiring a significant commitment of human and financial resources.

Another key scientific capacity needed for regulation of transgenic technology is the capacity to conduct food safety (health) evaluations. Credible health evaluations will be a key contributor in securing consumer confidence in biotech products. Two levels of food safety capacity can be identified. The first level applies to transgenic products such as RR soybeans that have already been approved in another country. Approval would require the capacity to evaluate the health trials conducted in the country of first approval and to identify any relevant scientific gaps.

The second, more sophisticated level, is the ability to conduct the laboratory analyses needed to generate the nutritional data (Nutrients (proteins, amino acids, calories, vitamins and proximate composition: ash, moisture content, crude protein, crude fat, crude carbohydrates) as well as the capacity to conduct evaluations of allergen city (homology to allergens), natural toxicants (homology to toxicants), anti-nutritional effects, and protein digestibility.

Finally the capacity to devise, monitor and enforce pest resistance management strategies is an important, and untested area. Current resistance management plans rely on maintaining sufficient refuges of conventional crops to foster populations of non-resistant insect strains that can then cross-breed with resistant populations should they develop. Plans for Bt cotton in Mexico, for example, require farmers to plant no more than 80 percent of their cotton area with transgenic varieties. Monitoring compliance in small farmer agricultural settings will be extremely difficult. The level of compliance even in the United States is unclear.

Table 21
Summary of Status of Biosafety Regulations in LAC Countries, 2000

Country	Existence Formal Mechanism	Level of the norm	Coverage	Comments	Operational Experience
Argentina	Yes	Ministerial Resolution (1991)	Only plants and microorganisms for veterinary use (norm concerning animals is under consideration; there have been voluntary evaluation about animals)	Advisory Commission. Procedure includes health and environmental evaluations; commercial risks of introduction of GMOs also evaluated.	More than 500 field trials, including commercial releases in maize, soybeans, cotton, sunflower, potatoes, canola, wheat, rice, and sugar beets. Commercial releases in soybeans, maize, cotton.
Chile	Yes	Ministerial Resolution (1993)	Covers only plants	Advisory Mechanism based on adaptation of seeds law. Emphasis is on "winter nursery", situations now extended to cover local releases.	Field trials conducted in maize, soybeans, tomatoes, canola, wheat, tobacco and sugar beets.
Uruguay	Yes	Ministerial Resolution	Covers only plants	Advisory Mechanism based on adaptation of seeds law. Emphasis is on "winter nursery", situations now extended to cover local releases. It does not cover laboratory experimentation only field experiments.	Field trials conducted in several species. Commercial releases approved in soybeans and maize.
Paraguay	Yes	Ministerial Resolution	Covers only plants	Advisory Mechanisms for executive decisions.	No operational experience.
Brazil	Yes	Law (National Biosafety Law # 8974 of 1995)	Wide coverage (plants, animals, microorganisms) of health, agriculture and the environment	Executive mechanism includes sanctions to infractors.	Large number of field trials, no commercial approvals, in maize, soybeans, cotton, potatoes, sugarcane, fruits, tobacco and rice.
Bolivia	Yes	Ministerial Resolution	Covers only plants	Advisory Mechanisms for executive decisions.	Limited experience with field trials in cotton and potatoes. No commercial releases.
Perú	Yes	Law (1999)	Wide coverage (plants, animals and microorganisms)	The mechanism is of an advisory nature and is part of the biodiversity protection law. Specific procedures applicable to the agricultural sector are still under. review.	

(continued)

Table 21(Cont.)
Summary of Status of Biosafety Regulations in LAC Countries, 2000

Colombia	Yes	Ministerial Resolution (1998)	Covers only plants	Advisory mechanisms, it does not cover laboratory work; only field evaluations.	Limited experience with field trials in flowers and cotton. No commercial releases approved.
Venezuela	Approved, in process of organization	The Biological Diversity Law, passed on May 2000 includes a chapter on biosafety, which served as the basis for the system been set in place (expected to be in operation 2nd semester 2001)	Covers all GMO an its derivatives	The system been organized is based on an Advisory Commission on Biosafety which will operate in the Ministry of the Environment, while monitoring and control functions are to be implemented by the different sectorial Ministries (Agriculture, Health, etc.)	
English Speaking Caribbean	There is no region wide framework.			Some countries (Jamaica, T&T) have regulations for the import of GM plants; their coverage is for laboratory and field trials. In Jamaica they are been applied to TG papaya.	
Cuba	Yes	Decree Law #190 on Biological Safety	Wide application (plants, animals and microorganisms)	Follows the guidelines of the Con-vention on Biological Diversity.	Field trials approved in potatoes, canola, vegetables, sugarcane and tobacco. No commercial releases.
Costa Rica	Yes	Nat.Tech.Advisory Committee on Biosafety (Crop Protection Law N°7664)	Only plants	Normative emphasis in the control "winter nurseries" situations.	Field trials in maize, soybeans cotton, and wheat
Mexico	Yes	Mexican Federal Norm (1995)	Wide coverage (plants, animal, microorganisms)	Resolutions of obligatory applications.	Field trials approved in maize, soybeans, cotton, tomatoes, vegetables, canola, wheat, fruits, tobacco, rice and alfalfa.

Note: Ecuador, Dominican Republic, Panama, Nicaragua, Honduras, El Salvador, Guatemala do not report any formal mechanism in operation
Source: the authors based on information from ISNAR (2000), Regulatory Agencies Web Sites and personal information and communications with regulatory authorities.

The Proprietary Nature of the New Technologies

By comparison with conventional research approaches, the new biotechnologies bring about a displacement of the "technological space" toward the private dimension. It is not only that a large proportion of the final products are subject to intellectual property protection mechanisms. Proprietary claims are also rapidly enveloping the tools that researchers use to develop new products. It is this characteristic –(which sets the stage for the possibility of protecting and recouping R&D investments) that has provided the incentive for the private sector to mobilize large sums of money and invest in agro-biotechnology research and development. This trend, however, has a number of important implications for research organization and management, as well as for the public/private roles in technology development.

First, the growing importance of enforceable property rights, covering both the tools as well as the products of research, requires that the public sector re-examine its role in agricultural research and development activities, including the management and funding mechanisms. In part, the whole issue of public goods should be carefully reviewed since the existence of potentially enforceable property rights makes the distinction between public and private goods not as clear as before. With the possibility of enforcing property rights in areas that were previously in the public domain, the whole legitimacy of public subsidies to research in these areas is being challenged and is in need of revision, particularly in the context of the perpetual and dramatic underfunding of most public research institutions. At the same time, if the process is left to market forces alone, there will most probably be a tendency to focus research on those areas where IPR protection could be more effective and profitable, sometimes leading to a monopolization of key technologies. Strong public sector research institutions can serve as effective instruments of market regulation to prevent monopolistic behavior by input suppliers. By providing alternate sources of biotechnology products, or pre-competitive technologies, NARSs can help make markets contestable by lowering barriers to entry to smaller firms that may not be able to absorb all costs of product development.

Even if we accept that the bulk of investments and innovations will come from the private sector and will be subject to IPR protection, public sector research institutions will continue to be essential (i) to develop and implement strategies to access proprietary technologies of importance for the country (joint ventures, licensing within market segmentation agreements, etc), (ii) to assure the applications of the new technologies for a more efficient and effective provision of private goods (i.e. epidemiology and areas related to natural resource management and conservation) and (iii) to make it more attractive for the private sector to invest in research in areas that would not otherwise attract enough investment due to market size or risk. Cases such as sunflower in Argentina, or the tropical crops in general are good examples of the type of interactions needed.

A second issue is that IPRs cause research management to grow in complexity and cost. Researchers now have a much more powerful set of tools to work with, but they must learn to manage the highly complex IPR instruments that control their availability. Long established patterns of intellectual communication essential to the functioning of academic institutions are already being disrupted, with noticeable delays in publication due to IP concerns. Intimidation of potential users of biotechnology because of complexity of IP issues and lack of experience of small companies and public sector is a real risk. Management of IPR is a key skill for all research institutions. New skills and expertise including negotiation, prioritization, freedom to operate evaluation, and assessing relevant patent claims are underdeveloped in all public sector institutions. This is an urgent skill after January 1, 2002 when patented technologies will be registered in all countries.

The growing relevance of IPRs in germplasm is already proving to be a problem for public plant breeders, who report increasing problems in gaining access to genetic stocks from both private and public sources. If it can be said that negotiating access to private sector technology has been difficult, it must also be recognized that no good model exists for sharing proprietary technology between public sector institutions. As an example of the complications involved, third party transfers between U.S. and LAC public sector institutions can be obstructed even if the U.S. institution has ownership in the United States, because proprietary technologies licensed to develop the product may not be transferable. The international sharing of technology among public sector institutions is therefore rare. This is a critical issue that needs to be resolved because the future rate of technological progress generated by public sector institutions may depend nearly as much on their ability to negotiate access to existing component technologies as it does on the scientific capacity to assemble the components. No institution will be able to act as if they are "technologically autarkic."

Beyond the issue of access to knowledge and materials, there is also the increased complexity involved in managing the IPR required for some biotechnological work. Private sector research is much better positioned to maneuver in these situations both due to their organizational flexibility and greater financial strength to absorb the costs involved in gaining access to what rights are needed in each case. Given this situation, public research organizations need to develop specific capacities and strategies to access the knowledge and technologies they need to carry out their work, but this is not proving to be an easy task because it implies a drastic departure from the organizational cultures of most NARS organizations.

Third, IPR issues are an integral part of trade agreements. According to the Agreement on Trade Related Aspects of Intellectual Protection Rights (TRIPS) signed in the context of World Trade Organization (WTO), member countries are obliged to provide at least some level of patent protection for any invention in all fields of technology for a minimum of twenty years and for plant varieties in the forms of patents and/or by a an effective sui generis system.[32] In the case of biotechnology innovations it is clear that innovations arising from microorganisms and microbiological processes are within the norm, but the definition of "discovery" is not clear in the case of genes. Developing countries in general were given until 2001 to comply with this requirement (the least developed countries were allowed eleven years to bring their systems up to compliance). The discussion about the impact of these requirements is still very much open. The main issues now under consideration are how to protect the rights of indigenous persons and farmers, and the ethical considerations of the potential increase in concentration of the supply side of the technology systems. The most direct implications, however, are for export oriented agricultural systems that are, in many cases, those who are in a better position to exploit the new technologies. Without proper IPR frameworks these countries may find themselves excluded from market access.

Finally, the private sector's experience with protecting intellectual property outside of North America has not been encouraging, and difficulties will remain even in the presence of legislation. As measured by area of adoption, herbicide resistant soybeans in Argentina and Bt cotton in China have been the industry's two greatest GMO successes. Nonetheless, it appears that the GMO developers have not been able to capture revenue from even half the planted area in either case because of seed piracy.

[32] For an extensive discussion of the issue see Lele, Lesser and Horstkotte-Wesseler 2000.

Table 22

Situation of IPR Protection in Agricultural Biotechnology Related Areas in LAC, 2000

Country	Discovery	Biol. Process	Plants[c]	Plant Varieties[d]	Animals (Breeds)	Microorganisms	Genes
Argentina	no	yes	yes	yes	yes	yes	yes
Chile	no	yes	?	yes	no[e]	yes	?
Brazil	no	yes	no	yes	no	no	no
Uruguay	no	no	no	yes	no	yes	no
Paraguay	no	no	no	yes	no	?	?
Bolivia[a]	no	no	no	yes	no	?	?
Peru[a b]	no	no	no	yes	no	?	?
Ecuador[a]	no	no[f]	yes	yes	no	yes	yes
Colombia[a]	no	no	no[g]	yes	no	yes	?
Venezuela[a]	no	no	no	yes	no	yes	yes
México	no	no	yes	yes	no	yes	?
Costa Rica	no	no	no	no	no	?	?

Notes: **no** means no protection, **yes** means there is protection; **?** means not clear in the national regulations.
(a) Legislation is under the scope of Decision 344 of the Cartagena Agreement.
(b) Two patent applications for genes are filed (No. 262710.95 and No. 273859.95) but not yet approved.
(c) UPOV 78 and/or 91.
(d).Genetic modification.
(e) Animal races are explicitly excluded from patentability (law 19.039, Art. 37b) but not animals as such.
(f) Yes to obtain plant varieties, No for animals.
(g) Not defined. WIPO document reports no exclusion for plants from patentability but at the same time it is apparently not possible to obtain a patent for a plant per se.

Source: developed by the authors on the basis of ISNAR (2000), IICA (1993), World Bank (1999) and WIPO 2001.

The situation regarding IPR frameworks in the countries of Latin America and the Caribbean is quite dismal. Table 22 summarizes the status of IPR legislation for those countries for which information is available. Honduras, El Salvador, Guatemala, the Dominican Republic, and the English-speaking countries of the Caribbean do not report any formal IPR system coverage, either for plants or for other types of inventions.

The most important point, however, is that in those cases where legislation is available, coverage is unclear, and it could be said that no countries comply in full with the TRIPS agreement. A recent ISNAR report on the matter rightly highlights that these are new and complex issues and in many cases, terms and conditions are just being discussed. It will be some time before they are settled and legally defined (Salazar et al. 2000).

The situation is somewhat different regarding the protection of plant varieties because plant breeders' rights have a longer history in the region. Argentina, Chile and Uruguay have had legislation in this area for about 20 years, even though full implementation has only been in force since the mid-1980s. Since then, Mexico, the Andean Pact countries, and Brazil have also adopted legislation. In Brazil, the enactment of plant variety legislation has had a major impact on investment in the seed industry, but the impact in other countries has been minor.

However, Jaffé and van Wijk (1995) showed that the impact of this legislation is low, even in those countries that have had it for a long time. They also show, however, that it has had an important indirect impact through the strengthening of local breeding programs (especially in open pollinating species) and by improving local industry access to advanced varieties. This latter impact appears to be of greatest importance for fruits and flowers (see Banchero 1999).

This is an area where there is ample potential for the countries of the region to work together to define common interpretations and strategies to deal with resources and opportunities that in a great number of situations are of a transboundary nature. At the research organization level, IPR issues are also very poorly understood and managed. According to an ISNAR (2000) study covering five countries of the region, in 33 percent of the cases where researchers were using protected technologies, they had no information on the means of protection and most respondents were unaware of the principles of territoriality of patents or of the potential consequences for their research. Most of the cases where formal were reported were of the material transfer agreements type, allowing the use of the technologies for research, but restricting their use by third parties and the eventual commercialization of the resulting products. However, a majority of the research centers (70%) did not anticipate problems from the dissemination of final products from their biotechnology research, even though the survey reports high expectations about protecting these products; out of the 50 expected products reported, 74 percent are expected to be protected, either by patents or by plant variety protection (Salazar et al. 2000).

In summary, this situation clearly highlights the extreme confusion that characterizes this age of transition and the difficulties that traditional agricultural research organizations confront in accessing and exploiting the tools of the new technologies. Institutional and management innovations are needed if they are going to be able to be part of the new R&D scenario that is emerging. The definition of institutional policies –(which may or may not include the creation of IPR units) and the training of researchers in the handling of IPR related matters appear as minimum common steps that all organizations must undertake. This is another area where there might be economies of scale that justify a regional or subregional approach to some issues to complement national activities.

The Technology Delivery Infrastructure

R&D capacities alone are not sufficient to exploit the potential benefits offered by biotechnology. Most of the relevant products of the biotechnological approaches to R&D, are technologies of the "embodied" type that must be packaged either in seeds or in other physical inputs (such as diagnostic kits, vaccines or yeast and other industrial inputs) before they can deliver their potential benefits. Consequently, the capacity to develop prototypes and scale them to industrial production and marketing are critical components for developing the biotechnology sector.

In this context the existence of a functioning (in terms of variety turnover) germplasm market and industry is probably the most critical issue because it is through the seed that most of the input efficiency and product innovations are incorporated into the food and fiber systems. The strategic importance of the seed sector is well substantiated by what has happened to its structure over the past ten years and the emergence of the "life sciences" industry. Seed industry support would likely be primarily in the form for strengthening of key market

Institutions (such as IP legislation/enforcement, streamlining legislation controlling seed importation and variety registration) and for the seed trade associations. Other areas where industrial capacities are needed are those of tissue culture, diagnostics and veterinary products. In general, these capacities are inbred in "knowledge-based" startups that are actively involved in the R&D process, in some cases through joint ventures with research institutions, but very frequently having significant in-house research programs. This trend is strengthened by the fact that in many biotechnology areas the boundary between basic and applied research is not clear, as many basic research efforts have potentially important commercial applications. This justifies direct private investment and makes the traditional public/basic, private/applied allocation of responsibilities in the technology development process less clearly defined than was previously the case.

Technology delivery mechanisms –(or, in other words, the existence of an active technological input market) are important not only for what they mean for the organization of the R&D process, but also because under these conditions public policy and promotional instruments, in addition to research related instruments, must also consider actions and instruments in relation to the development of the input industry. In the case of seeds, only a few countries in the region appear to have effective crop breeding programs and a seed market with sufficient turnover to support an active pipeline of biotechnology based innovations. The situation regarding other areas where opportunities exist does not seem to be very different. Most sources point to the existence of only a handful of firms actively involved in the development and commercialization of plant and animal biotechnology products. The majority of these efforts are in the simpler, more traditional areas (tissue culture and diagnostics) with only a few using molecular biology and genetic engineering as part of their core business.

ISNAR (2000) reports that about 35 firms in Argentina, 45 in Brazil, 30 in Chile and 25 in Mexico are involved in manufacturing or service activities in the biotechnology area.[33] In general, tissue culture and micropropagation applications are the more diffused technologies in use; however, there are also important experiences in animal and plant health products, but not in the more advanced technologies. As a whole, the weakness of private sector developments at this level is one of the more substantive limitations for the future development of the system. The root of this weakness does not appear to be linked to scientific capabilities, but to other restrictions affecting the creation of startups and private investments in R&D. The weakness of the local capital markets and the absence of risk and venture capital mechanisms in most countries are clearly key factors and potential areas of future intervention.

Another set of issues related to countries' ability to exploit the benefits of the new technologies are the capacity of marketing systems to handle GMOs and other products of biotechnology separately from their conventional counterparts. This refers to the logistical infrastructure required to run "identity preservation" systems throughout the marketing chain and to comply with the labeling requirements that are emerging in many markets. At the present time these infrastructural requirements appear to be a barrier to technology diffusion as price differentials do not seem to justify their development, and producers have been reluctant to support initiatives to do so. However, up to now the labeling discussion has been approached mainly from the negative side (to protect consumers' right to know

[33] Other sources reported in Trigo (1999) also identify a very small number of firms operating in countries such as Uruguay, Colombia, Costa Rica and Venezuela. Cuba is also commercializing a relatively important number of biotechnology products, including recombinant animal vaccines, plant antibodies and transgenic crops, as well as tissue culture and micropropagation commercial scale applications.

about a potentially "harmful" event). When the issue is set in a longer-term perspective the relevance of this discussion changes direction. The need for identity preservation and segregation of GMOs within the food supply chain becomes a critical aspect for the future development of the technology, not because the present consumer protection and/or rights related aspects but as an essential instrument to justify and/or protect investments in the area.

As biotechnologies form what is usually referred to as the second and third waves, when product quality traits become available, it is the producers who are interested in identifying the GMO origin of the product. In either case, today thinking about environmental and consumer protection or tomorrow making possible differentiation opportunities, the limiting factor for exploiting the potential benefits (lower costs of production, or the new quality characteristics of the products) is the capacity of the logistical system to segregate GMOs from the non-GMO crops.

In most LAC countries, the logistical and marketing systems, particularly in grains, oilseeds and other staples, have developed to exploit economies of scale in situations in which identity preservation of individual lots brought no aggregate value. In the case of the new GMOs, segregation becomes the critical issue for adoption and diffusion, as it is only through segregation that markets will be able to adjust their price signals in favor of the new products, if in fact consumers are willing to pay a higher price for the quality characteristics offered. The needed private investments for the new logistical infrastructure will only become available if institutional innovations are brought about in the present contractual and market regulatory systems.

VI. Utilizing Agricultural Biotechnology Opportunities

The agricultural biotechnology situation in LAC can be summarized around two observations. First, the region has pockets of high quality biotech research capacity in molecular transformation techniques, but with important weakness both geographically and in area of research. What is lacking is a strategic vision and the ability to formulate priorities and coordinate the components of the innovation system, covering a wide range of production constraints, crops and livestock species. This capacity has evolved in and is limited by a very restrictive R&D funding environment. In a few countries public research capacity is supported by an appropriate biosafety and IPR environment. The second observation is that in terms of actual applications at the commercial level, biotechnology is still at a very early stage of development. Commercial use is mostly of the cell biology and diagnostic techniques. Genetic engineering applications are concentrated in two countries, are mostly within temperate production environments, and are events that were developed by multinational corporations outside the region.

These biases should not come as a surprise, as with all novel technologies initial diffusion patterns tend to reflect the science base and market sizes and, to date, most of the scientific efforts in the field are of more direct application to temperate agricultural production situations. The relevant questions, however, concern how biotechnology is expected to evolve, whether it can serve society's needs, and how policy initiatives by the countries of the region can increase their access to technologies that can improve agriculture and the environment. In the remainder of this section we concentrate first on the possible scenarios for the development of the technologies and then look into the policy alternatives that different countries may want to consider. Special attention is given to issues where IDB interventions can be of assistance.

Scenarios for the Evolution of Biotechnology

In discussing the evolution of biotechnology, two types of considerations have to be taken into account. One is the possible evolution of the science, based on the type of research that is being undertaken and the likelihood of that research being successful. The second type of consideration is related to non-science aspects of biotechnology that may affect the flow of resources to research and the eventual acceptability of research results.

Taking into account just the first type of considerations, Table 23 presents what the R&D pipeline will have to offer in the near and medium term. From this information, the potential benefits for the countries of Latin America and the Caribbean is quite evident because the pipeline covers most of the region's major crops. This evidence also reflects, however, a significant "temperate" bias in the current orientation of industry research. The main events that have reached the market to date are essentially temperate events and so are the majority of those close to commercialization. This should not come as a surprise as it is in temperate agricultural situations where the R&D capacity, market size and the technology delivery infrastructure come together. However, it is also clear that potential for biodiversity exploitation as well as from improving socioeconomic conditions, lies in tropical agriculture. Industry's temperate product development bias will not change in the short to medium term as neither scientific capacities, market size nor technology delivery infrastructures appear to be adequate for significant events to be developed. With the sole exception of Brazil and plantation crops such as coffee, cocoa, bananas and sugarcane, no country in the region has the scientific depth to undertake the required efforts combined with sufficient market area to attract the level of private effort needed to fill the gap.

Table 23

Summary of Near and Medium Term Trait Pipeline

Near Term (1-5 years)	**Input Traits** ▪ Herbicide tolerance extended to cotton[ab], maiz[a], rice[a], sunflower[a], wheat[b], potato[a], lupin[b], clover[b], pea[b], fodder beet, sugarbeet, sugarcane[a], alfalfa[a], tomato, lettuce, sunflower, eucalyptus[a], canola[ab], and soybean[a]. ▪ Insect resistance in alfalfa[a], rice, soybean[a], sunflower[a], tomato[ab], sugarcane[a], sweet potato[a], peas[b], apple, cabbage[a], tobacco[a], and poplar. ▪ Durable insect resistance using multiple Bt & other genes in cotton[ab], sunflower[a], and maiz[a]. ▪ Virus resistance in wheat[a], potato[ab], lupins[b], white clover[b], tomato, sweet pepper, sugarcane[ab], barley[b], papaya[ab], tobacco[a], melon[a], and squash[a]. ▪ Bacteria/Fungus resistance corn, wheat[a], bananas, sunflower[a], rice, potato[a], canola[b], carnation[b], and tobacco[a].
	Output Traits ▪ Healthier/more nutritional food and feed in maiz[a], soy[a], canola[a], wheat[ab]. ▪ Remedies for vitamin deficiencies – Golden Rice[b]. ▪ Enhanced microelements – iron levels in rice[b]. ▪ Improved chemical structure – better flavor, color, taste, storage in potato[a], tomato[a], carnation[a], canola[b], banana[a], and pineapple[ab]. ▪ Improved fiber quality in wheat[b].
Medium Term (5-10 years)	Yield increase of wheat through hybridization.

Notes: (a) In trial in one or more LAC country; (b) In trial in countries outside of LAC. Field trial information included from the following countries: LAC: Argentina, Belize, Brazil, Bolivia, Chile, Colombia, Costa Rica, Cuba, Guatemala, Mexico, Peru, and Uruguay. Non-LAC: US, Austria and Australia.

Sources: James (2000), James (1996), Brazil CTNBIO Ministerio da Ciencia e Tecnologia, INIA of Chile, Colombia Agricultural Institute, SAGAR Direcion General de Sanidad Vegetal de Mexico.

From a broader perspective, Table 24 presents three alternative scenarios for the development of the biotechnology sector, adding to the existing information about the R&D pipeline and likelihood of product availability under different potential investment behaviors, public awareness and demand conditions. The *optimistic* scenario assumes the consolidation of the technology and its transformation into the dominant force for technical change in the food and fiber sectors. It also assumes that current levels of investment are maintained and that most current expectations about product development are met. It is the "high benefits" scenario.

On the other extreme, the *pessimistic* view assumes a deterioration of the present public acceptance situation, that due to the occurrence of negative human health or environmental impacts R&D fails to deliver according to expectation or, most probably, a mixture or both situations. In this scenario there are no additional benefits other than those to be obtained from conventional approaches.

The third alternative represents the projection of the current situation with a progressive leaning toward the optimistic scenario, and is the one we propose to use to evaluate the opportunities offered by the new technologies. Two types of considerations are relevant. One is the development of credible biosafety and risk evaluation mechanisms, and the continued accumulation of scientific evidence favorable to the application of the new technologies as an increasing number of GMOs are released in the environment without negative consequences.

Table 24

Three Alternative Scenarios for the Development of Biotechnology in the Next 20 years

	Optimistic	Steady	Pesimistic
General	Biotechnology becomes dominant technological paradigm in agricultural and food systems.	Current situation. Ag. biotechnology continues to rise controversy and R&D inversion become stagnant and mostly directed to non-human consumption related areas.	Increased virulence in opposition to GMOs by environment and consumer groups, spreads into the US. Labeling generalizes. There is a reduction in R&D investments.
Demand Side	There is increasing consumer acceptance in Europe, Japan and the US. China becomes a major player in the industry. Sales in 2010 reach $ 25 billion.	Europe and Japan allow GMOs to be used in animal feed and there is a slow and gradual increase in consumer acceptance due to lack of major environmental or health problems and labeling.	European markets close to GMOs, labeling generalizes.
Pipeline 2005	• Tissue culture and other cellular approaches are widely used to produce improved planting materials, as well as biological byproducts. • Diagnostic kits based on molecular approaches are available for a wide range of plant and animal health and food quality applications. • Herb. tolerance spreads to most major crops. • Genomic research spreads to cover most of major crops and becomes a standard tool. • Virus & fungus res. Starts to spread. • Yield increases due to hybrids in rice and corn. • Improved quality oils and protein spread and become major sources of revenue. • Natural health supplements from plants become available.	• Tissue culture and other cellular approaches are widely used to produce improved planting materials, as well as biological by products. • Diagnostic kits based on molecular approaches are available for a wide range of plant and animal health and food quality applications. • Herbicide tolerance and BT spread to most major crops but with less impact on productivity. • Disease resistance virus resistance and fungus resistant crops spreads. • Yield increases due to improved hybrids in canola. • Genomic work advances but at a low rate. • Improved quality oils and improved protein in maize minor sources of increased profits (many substitutes and cost of segregation). • Natural health supplements from plants take small share of supplements market.	• Tissue culture and other cellular approaches are widely used to produce improved planting materials, as well as biological byproducts. • Pest resistance breaks down quickly, other genes not as effective in controlling pests. • Yield increases due to improved hybrids only in canola. • Genomics works become very restricted and limited to research purposes. • Improved quality oils and improved protein in maize give no profits (many substitutes and cost of segregation). • Natural health supplements from plants take small share of supplements market.

(continued)

Table 24 (Cont.)
Three Alternative Scenarios for the Development of Biotechnology in the Next 20 years

	Optimistic	Steady	Pesimistic
Pipeline 2010	Vitamin A rice spreads • Continued dev. of new genes for crop protection • Trangenesis spreads to tropical crops. • Yield increases from hybrids in wheat and other crops. • Quality traits diversify and spread to variety of crops.	• Vitamin A rice spreads slowly because farmers do not like color and taste. • Pest resistance develops to first generation of biotech products continued development of new genes for crop protection. • Yield increased through hybrids of rice, maize, and other crops. • Industrial uses provide only small cost advantage over conventional methods.	• Diagnostic kits based on molecular approaches are available for a wide range of plant and animal health and food quality applications. • Vitamin A rice spreads slowly because farmers do not like color and taste. • Pest resistance develops to first generation of biotech products replacements slow. • Yield increased through hybrids not enough to cover increased costs of production. • Industrial uses provide only no cost advantage over conventional methods.
Pipeline 2020	Improved quality becomes standard • Major yield increases due to increases in the efficiency of the plants. • Development of new chemicals for crop protection and yield enhancement. • Nutraceutical that are clinically proven (cancer, hearth attacks) are approved for human use.	• Major yield increases due to increases in efficiency of the plant. • Continued development of new genes for crop protection. • Development of new chemicals for crop protection and yield enhancement. • Nutraceuticals that are clinically proven to reduce cancer, heart attacks.	• Gradual yield increases due to increases in efficiency of the plant. • More rapid development of new genes for crop protection. • Development of new chemicals for crop protection and yield enhancement. • Industrial uses become practical.

Source: the authors.

To reach these conclusions, a continuing and well designed monitoring system should be in place for at least 5 years when new products are released into the tropical environment. Even thought health impact would be much more difficult to monitor due to many other acting factors, it is relatively easy to select areas for medium-term studies of environmental impact. Releasing these types of data to the public would also help to change public perception.

The second aspect is the beginning of the transition on the product side from input traits to output traits. As consumers become primary beneficiaries of biotechnologies, it would also be appropriate to anticipate a more positive attitude toward biotechnology. This tendency should be reinforced by the growing effort being undertaken to improve public perception of the technologies in a number of countries.[34]

All these elements could act in the same positive direction concerning public acceptance and that, in turn, would feed back into higher investment levels and greater final product turn out.

[34] The recent new EU Directive on GMOs, which implies a lifting of the *de facto* moratorium on GMOs that has been in place since 1998, is an indication of how the discussion is evolving and what kind of policy environment can be expected to emerge as technology development evolves.

Options to Develop Agricultural Biotechnology Opportunities

Future critical issues seem to involve questions of how to access and exploit the technology, rather than consumer acceptance or marketing issues. Experience with GMOs in LAC to date seems to indicate that the crucial strategic links between research and the farmer are the existence of "down-stream" capacities, that is, traditional plant breeding programs and operational seed markets as well as commercial micropropagation undertakings and other types of industrial capabilities (i.e. plant diagnostic and veterinary medicine commercial sectors, etc.), rather than the scientific capacity required to develop the events or products involved. As discussed in Section 5 all GMOs grown commercially anywhere in the world are the result of genetic events produced in the United States, and with few exceptions based on biotechnology science performed by multinational companies.

In general, the countries of Latin America and the Caribbean have ample potential for obtaining biotechnology. They can take advantage of the potential spillover benefits that may accrue from R&D investments already underway in developed countries – (mostly the United States, but also Europe and, increasingly, China. In addition, they can exploit the new technologies in their own research programs to improve the production of public goods and fully exploit the wealth and diversity of their natural resources. It is true, however, that for many of the countries in the region; opportunities are restricted either by the underdeveloped state of their agricultural R&D infrastructure or the scale and nature of their agricultural industry (their markets are too small to support R&D investments and they have undeveloped seed markets). Agricultural biotechnology development strategies should be targeted at four critical areas: (i) creating the enabling environment for the use of the new technologies, (ii) biotechnology capacity development; (iii) supporting the development of industrial and marketing capacities, particularly within the critical seed delivery sector; and (iv) supporting genetic resource collection, conservation and management.

Creating the Enabling Environment for Using the Technology

Two broad areas require particular attentional for the sustainable development of biotechnology investments. The first is related to the attitudes of the policy establishment regarding biotechnology; the second is the existence or not of a functioning biosafety system and IPR framework.

Private firms are reluctant to invest in biotech research and transfer technology unless policymakers are sending a clear signal that biotechnology is welcome. At present policymakers in a number of Latin American countries have not decided what to do about biotech and are making decisions about biotechnology on an ad hoc basis. Policymakers in LAC need some capacity to analyze the costs and benefits of the many policy alternatives regarding biotechnology. At the national level many countries could benefit from a biotechnology strategy in which the best economists and scientists examine the options open to policymakers. After this exercise, policymakers and research funding agencies need to be able to draw on consulting firms or in-house economics and science policy capacity to examine new issues as they arise. Strengthening these capacities, both at the regional and national levels, should be a priority of any initiative aimed at supporting the development of biotechnology in the region.

The existence of a proper and functioning biosafety regulatory system and IPR framework as well as related management capacities constitute the two basic building blocks for the creation of the necessary conditions for the exploitation of new technologies. It is through the existence and proper functioning of these two interrelated institutional developments that the countries will be able to access the needed knowledge and research tools and to develop public acceptance and support for their application to improve food and fiber production.

Support for biosafety regulation needs to be directed to three essential areas (i) the development of norms and regulations, (ii) the generation of scientific information of relevance for risk analysis, and (iii) the institutionalization of administrative procedures and enforcement capacities. In addition, it is important to incorporate support for research in ecological risk assessment and risk management linked to the needs identified for LAC, including ecological feasibility studies. In general, cost figures for the implementation and enforcement of biosafety and food/feed safety regulations, best laboratory practices, are unknown at all levels: research and development, and policy-making systems.

IPR legislation is lacking in many countries, but even in those where there is an established IPR framework, research institutions lack the capacity to work within the context of the legislation. Support should include the development of IPR databases, institutional policies and training and even more advanced mechanisms such as IP advisory services and patent "pools."[35]

IPR and biosafety are essentially institution building issues. As such, they should be part of science and technology projects as well as broader institutional development initiatives. They are not stand-alone issues but are part of the broader institutional framework of the country (including both legislation as well as enforcement capacities).

Efforts relating to strengthening biosafety and IPR management represent special challenges for the smaller countries. The research institutes in these countries face both conflict of interest issues (the patent applicants are the only ones sufficiently well trained to judge the patent's novelty and non-obviousness) as well as economies of scale restrictions in bringing together the scientific expertise and the necessary databases. Because of these limitations, special consideration should be given to supporting a process of regional or subregional harmonization of regulatory approaches and the creation of biosafety clearinghouses and risk evaluation facilities. Regional programs in these areas may be the only viable alternative for some small-country regions, such as Central America, the Caribbean and even the Andean Zone, and constitute a logical alternative for supporting economic integration efforts. A common approach to this issues will facilitate regional trade as well as more efficient exploitation of available human and institutional resources and, eventually, the emergence and consolidation of a regional technology market.

Finally, there is the issue of public perception of biotechnology and its products. Environmental groups have been extremely effective in creating a negative image of GMOs and other biotechnology products. Their public campaigns are very much at the heart of the EU moratorium on GMO trials and Mexico's unofficial moratorium on GMO maize (in place since 1999) and similar cases in other countries. There is no doubt that these campaigns are not founded on available scientific evidence and are extremely negative because they increase the risks and costs of already costly regulatory activities.[36] However negative these campaigns may be, it is also clear that the response to them cannot come from official government sources, but must come from industry organizations and other pro-technology groups in society. Government participation should be limited to assuring a transparent and credible regulatory process and making relevant information on actual GMO performance as widely available as possible.

Development of Scientific Research Capacity

It should be stressed that the development of biotechnology will not be independent of the

[35] For specific proposals regarding these type of mechanisms see Krattiger (March 2001).

[36] For instance, CINVESTAV in Urapuato has developed a GM maize variety tolerant to aluminum which could be valuable for reclaiming large areas of the country for maize production, but which cannot be moved to the field trial stage because of the moratorium.

region's NARS and wider science and technology systems. Latin America confronts a long-standing decline in agricultural research and general support for the sciences. This decline must be reversed. This should continue to be the main priority of any strategy and support program. It is, however, important to stress that the sectoral focus used until now may not be the most appropriate for biotechnology support because there is an interest and a need to bring nonagricultural institutions into agricultural biotechnological efforts. The issues to consider when designing new initiatives should be (i) to integrate biotechnological approaches into traditional agricultural research, such as plant breeding and animal and plant health instruments (epidemiology, diagnostics, protection); (ii) increase the interaction between non-agricultural biological sciences capacities (universities, advanced institutes) and agricultural research institutes;[37] and (iii) increase the cooperation and collaboration between public and private biotech research.

A regional approach is also important when considering capacity development. Multicountry (regional or subregional) ventures may serve as the only alternative when addressing problems that are not viable for individual countries, but which become feasible and profitable when funded and executed from a more aggregate perspective. The long-standing regional cooperation experience that exists in LAC, as well as the regional economic integration initiatives, are important assets when considering regional mechanisms which could help set the stage for exploiting the large economies of scale and spillovers that appear to be present in biotechnology research and development.

Networking arrangements to link scientists at different institutions and countries as well as the development of (or support for existing) centers of excellence working on problems that affect many countries in the region are two proven operational mechanisms to work at the supranational level.[38] Each approach has the potential to increase the flow of scientific information, induce scale economies and minimize the duplication of efforts. Networks can be organized with mandates capable of accommodating nearly any scale of financial support, and modern information and communication technologies are rapidly expanding the scope and efficiency of networking possibilities, getting them ever closer to becoming virtual centers, going well beyond the initial information exchange mode.[39]

International centers have proven effective in generating certain specialized critical scientific mass that can be shared by several countries and/or production situations. The CGIAR centers in general and those located in LAC in particular (CIMMYT, CIAT, CIP and to a lesser extent IRRI) are a good example of the kind of benefits that can be obtained from pooling resources behind problems that go beyond national frontiers. Given the nature of the biotechnology challenge, they should be considered as a prime alternative for supporting the advance of biotechnology in the region because they (i) have the potential for generating spillovers for a large number of countries and crops; (ii) have already gained a critical mass –(including operational links to advanced science institutions) that can be mobilized in the short term if resources become available; (iii) have a very extensive germplasm base; (iv) have a long history of training and cooperation with LAC plant breeding programs; and (v) facilitate the transfer and sharing of technology among countries.

[37] This will be particularly important for food and feed safety analysis of GMOs where integration with medical sciences and other non-agricultural partners has became a necessity of the business.

[38] Networking is also an alternative that should be considered as an essential component of any national biotechnology effort. Given the nature of the scientific capabilities required, no institution is in a position to have in-house all the needed resources, and, probably it would make no sense to even attempt to do so.

[39] There are many examples of successful networks, for instance the Rockefeller Foundation's IRBP, CABBIO, and the biotechnology components of the PROCIs. IRBP-funded research projects at 76 institutions on an annual expenditure of $6-9 million (Horstkotte-Wesseler and Byerlee 2000).

Supporting the Development of Industrial and Marketing Capacities

Biotechnology applications need to be supported by a technological input and service sector capable of taking the R&D products to farmers and eventually to the final food and fiber markets. The inputs and services sectors are the critical components for transferring agricultural biotechnology research products. On the input side, this involves not only already established firms but startups as well. Startups have played a critical role in the development of the industry, especially in fields such as veterinary products, plant health, specialty crops genetics, and tissue and cell culture. Needed support involves facilitating the institutional changes for the development of public/private joint ventures and subsidies for private R&D projects. Traditional agricultural research programs as well as science and technology sector programs aim to meet this objective.

Closely related is the need for assistance in the development and consolidation of venture and risk capital mechanisms (which are all but nonexistent in most of the countries of the region) and where loan programs could play a critical role in facilitating the involvement of local financial systems in this field.

On the agricultural products side, there will be an increasing need for improved identity preservation (traceability), quality and certification systems, which could both facilitate the need for proper labeling of product sand serve as a basis for the product differentiation processes, which will emerge as quality traits become available to producers. In part, these will require the revision of norms and the development of new quality systems, but in most cases they will also require specific investments to decentralize storage and handling systems and make them more flexible in terms of lot size throughout the marketing chain. Some of this will be the responsibility of the public sector, but the bulk are private investments. Support for this should probably be incorporated in general agricultural loans aiming at rural development or competitiveness improvement.

Public Sector Roles and Policy Options

Opportunities are not the same for all countries in the region. Capacity to access the technologies as well as the possibilities to exploit the potential benefits are greatly influenced by the strength of the particular NARS, and scientific and technological capabilities in general, as well as the maturity of their agricultural inputs and services sectors, particularly their seed markets. Larger countries are confronted with the whole continuum from basic research and technology development to technology exploitation. Policy options for smaller countries should probably focus on putting in place the proper institutional structures for a safe technology transfer process. Regional initiatives aimed at facilitating basic capacities, training and lowering the costs of biosafety and IPR access and management could play a critical role. Table 25 summarizes public sector roles, policy objectives and instruments in an array of increasing complexity, which could be taken as a continuum going from the minimum that any country should have if it wants to incorporate biotechnological approaches into its technology development systems, to a situation where it is a full player in the industry.

Limited Capacity

At the bottom of the scale, the overriding issues are related to (i) the establishment of technological acquisition capacities and (ii) acknowledging that most technology and investments will come from abroad and largely from private multinational concerns. There are two types of countries in this situation. The first are countries with very weak NARS and no seed distribution systems in place. For these countries biotechnology offers very limited opportunities, as they are probably not even exploiting the benefits from conventional approaches.

Table 25

Public Sector Roles and Policy Options for Biotechnology Development

Country Characteristics	Public Sector Role/Policy Objectives	Capacities Required	Policy Instruments
Small Countries Peru, Honduras, Nicaragua, Paraguay, Dominican Republic, Panama, most of the English Speaking Caribbean • Very weak NARS. • Underdeveloped seed distribution systems unable to make new varieties available at the farm level on a continued basis.	Focus is on the development of conventional capacities, and accessing cellular approaches such as tissue culture and micropropagation technologies.	• Applied and adaptive research capacities in agronomy and conventional breeding. • Tissue culture and micropropagation facilities in strategic crops. • Institutional framework for seed market development. • Minimum biosafety and IPR frameworks and management capacities.	• Support for NARS infrastructure and human resources development. • Seed related legislation. • Regional and/or subregional biosafety/risk evaluation support mechanisms. • Regional and/or subregional IPR information/management support mechanisms.
Intermediate Countries Ecuador, Bolivia, Guatemala, El Salvador • NARS with limited applied research capacities; crop-breeding programs providing germplasm at farm level in some crops. • Active seed markets in some crops	Creating the environment for accessing potential spillover benefits from existing research and development investments.	• IPR framework (minimum PBR) • Biosafety regulatory capacities. • Complementary scientific & technical capacities to orient and support a technology acquisition strategy, including (i) strategy and priority formulation, and (ii) a working plant breeding program able to incorporate desirable traits into commercial varieties. • An operational seed market, with institutional and logistical systems capable of differentiating, throughout the production - marketing chain, biotechnology products from the rest of agricultural production.	• IPR legislation (UPOV, Patents). • Biosafety regulations and enforcement capacities. • Regional and/or subregional biosafety/risk evaluation support mechanisms. • Regional and/or subregional IPR information/management support mechanisms. • Support to NARS and Sci&Tec. Institutions for infrastructure and human resources development. • Funding support (institutional and/or project) for research in areas related to technology and biosafety evaluation. • Seed legislation, support for seed trade associations. • Legislation supporting / permitting new input supplier – producer – processor coordination / integration mechanism. • Quality, certification and identity preservation systems. • Public investments and credit support for private participation in development of logistical infrastructure.

(continued)

Table 25 (Cont.)

Public Sector Roles and Policy Options for Biotechnology Development

Country Characteristics	Public Sector Role/Policy Objectives	Capacities Required	Policy Instruments
Small Advanced Countries Argentina, Uruguay, Chile, Venezuela, Colombia, Costa Rica • One or more strong general science institutions. • NARS with applied research capacities and breeding programs, • Active private seed markets.	Improving public goods production and strengthening/building capacities for technology acquisition and exploitation in plant and animal health related R&D and for targeted transgenic research in important crops.	• Scientific and technological capacities to apply to: • Cellular and molecular approaches in areas related to genetic resources conservation and evaluation, epidemiology and pest and disease control. • Molecular marker technologies and genetic engineering approaches to incorporate (transform) existing gene constructs into new crops. • National commodity programs with strong applied breeding capabilities. • Private sector involvement in product development and commercialization, both in seeds and other agricultural technological input sectors.	• Support to NARS and Sc.&Tech. Institutions for infrastructure and human resources development. • Funding support for research projects that integrate capacities from different institutions, including institutions from abroad. • Mechanisms for facilitating public/private joint ventures in biotechnology related R&D projects. • Public funding for private sector R&D projects (co-financing, subsidized loans, tax credits for R&D). • Promotion of risk and venture capital mechanism.
Large Advanced Countries Brazil, Argentina Countries with a wide science base and large public sector research programs and well developed agricultural inputs and services sectors.	Promotion and support for basic and strategic research directed to improving the efficiency and scope of technology development activities as a whole.	• Basic and strategic transgenic and genomic research capacities in both the public and private sectors. • National commodity programs with comprehensive breeding capacities (wide scope of crops and pre-breeding research).	• **S**upport to NARS and Sc&Tech. institutions for infrastructure and human resources development. • Single and multi-instit. project funding mechanism.

Source: the authors.

The public sector role is to support the development of basic capacities in the NARS. Its role with regards to biotechnology opportunities is essentially limited to tissue culture and micropropagation applications for improved planting materials, probably in a small number of export crops and through ad hoc institutional arrangements.

Modest Capacity

The second groups of countries are potential beneficiaries of spillovers. This includes countries with a NARS with limited but operational capacities (basically crop breeding) and seed distribution systems able to reach farmers with improved materials on a regular basis. The policy objective for these countries is to establish conditions for technology transfer/acquisition process, including the regulatory environment necessary for that to take place; that is, a transparent IPR regime – (which is mandated by the trade agreements that most countries are signatories of) and an operative biosafety mechanism. Without these capacities no country will be able to access the benefits of the new technologies because it is very unlikely that private or public entities able to offer technological capabilities will enter into a technology transfer agreement, either because the lack of IPR protection will endanger the likelihood of recuperating the investment or because without a biosafety mechanism in place there will be no possibilities of a safe movement and environmental release. Beyond these aspects, the absence of a seed system assuring a minimum seed turnover at the farm level will make it impossible for innovative traits of be effectively incorporated into production processes. Most of the actions to establish these conditions are, as stressed above, essentially the same as those needed to promote conventional technologies. However, biosafety and IPR-related capabilities present some differences that should be considered.

Biosafety regulations and risk evaluation approaches, require specific normative and administrative and enforcement capacities as well as a substantive level of scientific inputs (scientific information and judgment) that are quite similar to those needed to use the technologies for product development. For many of the countries in this grouping, this means a critical potential conflict of interest situation because they lack a pool of scientific capacities (people and institutions) large enough to fully separate the regulatory function for the R&D process. Thus, they are unable to avoid the inevitable conflict and loss of transparency that will follow if the same people and institutions that are involved in developing a technology are also providing information and judgement for the risk evaluation and biosafety assurance processes. Under these circumstances, an option to consider is that of promoting regional or subregional mechanisms that by pooling resources could offer information and support to national biosafety regulatory institutions. IPR present problems of a similar nature, although they are not related to potential conflicts of interest, but to the costs of maintaining appropriate databases and advisory capacities for research institutions and the possibilities of creating significant economies of scale in their exploitation if those capacities are developed and made available to several countries rather than on a country-by-country basis.

Medium Capacity

Countries with more developed NARS and agricultural services systems have to take advantage of the new technologies to improve the production of public goods. Their ability to do so will be greatly influenced by the strength of existing traditional capacities and the public sector's support for private sector involvement by lowering the risks/levels of investment needed through public research investments, promoting public/private R&D joint ventures or direct subsidies to private research, and/or promoting venture capital mechanisms to facilitate the development of start-up companies to exploit promising R&D results.

Comprehensive Capacity

The final stage incorporates all the previous components of the public sector role, including promoting development in strategic areas through support for the basic sciences. The nature of policy instruments evolves together with the complexity of the different alternative roles by (i) becoming less dedicated, both in the institutional and sector sense, and more horizontal, that is, more oriented to generic scientific components; and (ii) paying increasing attention to incentives to private sector research and input industry participation.

In summary, in a large number of countries (Honduras, Nicaragua, Panama, Dominican Republic, most of the English-speaking Caribbean, Guatemala, El Salvador, Bolivia and Ecuador[40]) the basic capacities are not in place, hence the efforts should focus on the creation of the basic enabling environment. There is a group of countries (Colombia, Chile, Uruguay, Costa Rica, and to a lesser degree, Venezuela) where there is the confluence of a relatively strong scientific and institutional system and dynamic agricultural export markets, in which there are already signs that the public sector is starting to play additional roles, as well as an emerging private sector involvement at least in the more traditional biotechnologies (tissue culture and plant propagation, immunology technologies and diagnostic kits, etc, are in this stage). Only Brazil, Mexico Argentina and Cuba, go beyond the intermediate level and could potentially be considered full players in the development of the technology and eventual sources of spillover benefits for the rest of the countries.

[40] The first and second categories mentioned in the table are indicative, as the criteria is based on indicators which are difficult to quantify and the transition from one stage to the other is subjective. The classification attempts to highlight a "typical" situation for the country.

Opportunities for IDB Support

Agricultural biotechnology is still in its early stages in most of the countries of Latin America and the Caribbean. However, there is little doubt of the potential that these technologies offer and that, as the technological pipeline consolidates and more of its products become available, they will become the basis of a new technological paradigm. It is also true that many of its potential benefits will not be reachable unless a proper environment is established for accessing and exploiting the technologies. This is a task that must be undertaken at the national level because it requires policy decisions in areas that are the prerogative of national authorities, involving not only resource investment priorities, but also new institutional and legal frameworks. It is also true, however, that many of the issues involved have commonalities across countries that justify the use of regional mechanisms. International agencies, and particularly international financial organizations such as the IDB, have a critical role to play in helping countries set the stage for fully incorporating the new technologies into their productive sectors. Some countries (Brazil, Venezuela) are already executing IDB financed loans, which include strengthening agricultural biotechnology capacity.

The following aspects should be taken into consideration when developing guidelines to support country activities in this area:

- Agricultural biotechnology should be an integral part of the agricultural research and technology development effort and not a separate strategy.

- In terms of the required scientific research capacities, universities and non-agricultural advanced research centers are as important as the traditional agricultural research institutions.

- The following areas are of critical importance for the advancement of plant biotechnology in the region: (i) the capacity to deliver seeds to farmers, (ii) substantial public sector investment in improving germplasm collection and conservation, (iii) conventional plant breeding and (iv) creating conditions favorable to private sector investment in seed development.
- The complexity of the science and the laborious biosafety assurance processes involved in relation to the size of potential markets for the new technologies imply significant economies of scale, highlighting the need for innovative regional and/or subregional collaborative mechanisms, in R&D as well as in other activities.

- The private sector is playing a central role in the development of biotechnology. Most technologies and events relevant to the region's agricultural conditions are now proprietary. As a result, public/private interaction and active IPR management strategies are essential elements in any agricultural biotechnology effort.

- The capacity to modernize the institutional and physical infrastructure supporting product and input markets will be as important to the delivery of the new technologies as the creation of enhanced R&D capacity.

Given this context, the IDB must not only assist individual countries through traditional project and program loans, but must also take an active role in extending the scope of regional and subregional initiatives. Such initiatives will allow all countries to better exploit economies of scale and spillover potentials that are inherent in areas such as biosafety, negotiation for the acquisition of private sector technology and development of the environment for IPR management.

Actions at the Country Level

Most of the policy instruments identified in table 25 are already being considered in agricultural loans or agricultural research and science and technology programs. At this point the issue is not so much the specific instruments to include in project design, as it is about making biotechnology a mechanism of R&D and innovation system support and helping client countries put strategies in place that take advantage of key opportunities and resource constraints. In bringing this emphasis into the design of Bank-supported programs and projects, the areas described below should be given special attention.

Support for Policy Design and Priority Identification. Given the high levels of investment involved, biotechnology efforts must be prioritized in relation to national agricultural objectives (e.g. among types of technologies, crops and livestock species, target beneficiaries, etc.). Technology acquisition strategies must be correctly balanced and sequenced (own R&D vis–à-vis technology imports, strategic alliances with other countries, international organizations, private firms, etc.). The impacts of the introduction of biotechnology strategies into agrifood systems must be anticipated and the eventual logistical and marketing infrastructure investment requirements must be recognized. Assistance for developing information to analyze options and implement monitoring systems, and to develop a public consensus for the selected strategy will be critical because of the many controversial issues that will emanate from the novel character of the technology and its rapidly evolving nature.

Technology Delivery Systems. The delivery of the benefits of plant biotechnology depends critically on the capacity to develop and distribute germplasm. Whether originating in the public or private sector, once genetic events are discovered they must be placed in a variety with the agronomic traits desired by farmers and consumers. Achieving farmer acceptance and access to improved varieties (GMO or conventional) remains an unmet challenge for most crops in most LAC countries. The Bank can offer two critical types of support in this area. The first is support for the strengthening of conventional plant breeding in the public sector, including increasing support for genebanks. The second is support for the creation of market conditions favorable to private sector investment. This could include initiatives to streamline variety registration, the regionalization of variety approval, support for national and regional seed associations, strengthening of IP legislation/enforcement, streamlining legislation controlling seed importation, genebank support.

Support for Studies Supporting Regulation. Even though a lot of information regarding ecological and food safety issues is becoming available, it is clear that there is still a very wide range of areas to be covered, especially taking into consideration the fact that Latin America is the center of origin of a relatively large number of species. Studies regarding gene flows and how they would potentially affect populations, insect resistance, allergenicity, toxicity and nutrition issues are needed to continue to develop effective risk evaluation protocols. At the same time as commercial approvals evolve and cover a wider range of species, there is also the need to establish long-term monitoring systems to strengthen scientific databases for risk assessments, as well as serve as early warming mechanisms for the eventual development of unwanted or unexpected effects.

Scientific Research Capacity Development. The Bank has always supported capacity building in science and technology programs, including human resources as well as infrastructure and direct support for projects to develop technologies of a public goods nature. Biotechnology development will continue to demand this type of support. Greater attention should be given to a system-wide perspective and where these capacities are located, attending to the need to create critical mass in the handling of given techniques. It is also important to promote networking approaches in their utilization, instead of the traditional institutional support aimed at strengthening NARS that has prevailed until now. This broader approach to capacity development should also include increased use of strategic alliances with centers of excellence in other countries and with the private sector as a more rapid and effective way to gain access to critical technologies, of speeding product development and obtaining cutting edge training for scientists.

Regulatory System Support. Two key aspects that should be considered are the high costs of setting up the institutional circuits for risk evaluation and biosafety assessments and the fact that these are extremely complex processes requiring substantial analytical capacities in disciplines such as biology, ecology and the social sciences. Even though regulatory institutions are often extensions of already existing capacities in the agricultural and food health areas, there is a rapidly evolving international legal framework that countries need to take into consideration. Because of eventual conflicts of interest, the new institutions cannot rely on the specialized human resources of research institutions. At a minimum, the in-depth review of existing regulatory frameworks and judging their adequacy for handling biosafety issues should be an integral part of program and project preparation, not only for agricultural research projects but also for more broadly targeted agricultural and natural resources operations. Substantial resources will be required to bring countries into compliance with requirements of the Cartagena protocol and CODEX.

Technology Systems Management.

Biotechnology implies a new organizational paradigm for technology systems with very clear and distinct management requirements than those of the conventional agricultural technologies. Scientific knowledge coming from different types of institutions, different levels and types of investment requirements, and new types of public/private interactions, all demand management skills that are quite different than those currently available in most R&D institutions. Support in this area should include the development of organizational capabilities to work in a proprietary knowledge environment (IP management, including technology negotiation skills) and handle public/private partnerships.

Support for Regional Initiatives

Public Awareness Issues. Directly related to all the above is the need to provide support for the proper handling of public awareness issues. Public debate and education at both the producer and the consumer level are critical aspects for the successful use of biotechnological approaches. Most national institutions are ill equipped to generate the information and the kind of dialogue mechanisms needed to set up a transparent and constructive interaction among all the parties interested in biotechnology issues.

However important support at the national level may be, it is in the regional and subregional approaches where international financial assistance could be more innovative and of high impact. For a large number of the countries in the region affordable access to the new technologies will necessarily require a more aggregate market perspective. Support at this level should focus on (i) strengthening international/regional capacities for implementing R&D related to the production of international public goods and/or in areas with high spillover potential, (ii) facilitating access to proprietary technologies of common interest to groups of countries, and (iii) reducing the cost of implementing regulatory frameworks and processes.

In the first area, strengthening regional R&D capacities, support should focus on (i) promoting a more active role of the CGIAR centers in the development of biotechnology events relevant to regional conditions, including their participation in the acquisition of genes or technologies of strategic value for the region or for groups of countries, (ii) strengthening the role of the PROCIs and other existing networking mechanisms such as CABBIO, as facilitators for the development of multicountry initiatives in R&D, and (iii) strengthening regional competitive funds, such as FONTAGRO, to allow them to play a more active role in promoting joint efforts between the region's NARS themselves and CGIAR and other centers of excellence from the region and other parts of the world.

In addition to regional projects individual countries can take advantage of research capacity in the region to either contract research or do collaborative research. For example, the USDA and the state of California are providing financing to ONSA, the public sector virtual genomics institute in São Paolo, to sequence the *Xylella* bacteria, which causes Pierce's disease in the United States (Fulmer 2000).

In the area of access to proprietary technologies, solving IPR issues and developing viable freedom to operate (WTO) strategies is going to be, at least for the medium term, a critical hurdle for exploiting the potential benefits offered by the new technologies. Countries are facing both the processes of developing national IP legislation and the need to comply with the intricacies of international treaties (OMC, TRIPs, CDB). Yet, in many cases, they lack the capacities to do so. Support for regional mechanisms to generate the information needed to develop FTO in different fields and assist specific countries and research institutions in the actual negotiation of technology transfer agreements could be a cost effective way to lower the high transaction costs involved in this type of activities.

Opportunities for IDB support in the area of biosafety regulation are in efforts to harmonize regulatory frameworks and establish appropriate information mechanisms to facilitate the transfer of technology and provide a more solid and transparent base for continued growth trade in biotechnology products. The Bank should formally consider supporting the harmonization efforts already started by other international entities (UNIDO, FAO, OECD and the WTO) to ensure that countries approach regulatory requirements from the same perspective. IDB involvement in this area is also important to promote the cross acceptance of biosafety assessments among countries. In addition, smaller countries would benefit from the creation of regional or subregional scientific panels that could assist individual countries with the risk assessment process.

Finally, it is also important to highlight the relationship of agricultural biotechnology development to the broader process of regional economic integration and the development of a free trade area for the Americas. These three areas are critical for strengthening national agricultural sectors and broadening the scope of intraregional trade.

Without a more active technology transfer process it is very unlikely that the agricultural potential of the region's natural resources can be fully realized and become the basis of a more equal negotiation process among the different regions of the hemisphere.

Efforts to bridge the mounting knowledge gap and promote the transboundary movement of the products that may result from new technologies are strategic investments that will increase market potential and trade opportunities, providing additional incentives to the implementation of the free trade zone. Given this potential, it appear that the traditional grant and soft money approach to the financing of regional cooperation mechanisms needs to be revised, and more realistic multicountry loan program alternative should be given more serious consideration.

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