

Technological Change in Agriculture and Poverty Reduction
Concept paper for the WDR on Poverty and Development 2000/01

by

Alain de Janvry, Gregory Graff, Elisabeth Sadoulet, and David Zilberman
University of California at Berkeley

I. The challenge for agricultural technology

The challenge for developing country agriculture in the next 25 years is enormous, particularly if it is not only to satisfy the growing effective demand for food, but also help reduce poverty and malnutrition, and do it in an environmentally sustainable fashion. Due to population growth and rising incomes, demand in the developing countries is predicted to increase by 59% for cereals, 60% for roots and tubers, and 120% for meat over this period (Pinstrup-Andersen, Pandya-Lorch, and Rosengrant, 1997). This increased supply cannot come from area expansion since that has already become a minimal source of output growth at a world scale, and a negative source in Asia and Latin America. Neither can it come from any significant expansion in irrigated area due to competition for water with urban demand and rising environmental problems associated with chemical run-offs. While it will thus need to come from growth in yields, the growth rate in cereal yields in developing countries has been declining from an annual rate of 2.9% in 1967-82 to 1.8% in 1982-94, which is the rate needed to satisfy the predicted 59% increase in cereals over the next 25 years. The growth in yields cannot consequently be let to fall below this rate in developing countries without increasing the share of food consumption that is imported. With 1.3 billion people in absolute poverty (earning less than \$1 per day) and 800 million underfed in the developing countries (World Bank, 1997), agriculture should also have a major role to play in poverty reduction, particularly since three quarters of these poor and underfed live in the rural areas where they derive part if not all of their livelihoods from agriculture as producers or as workers in agriculture and related industries. The real income of poor consumers also importantly depends on the price of food.

If poverty is to fall and the nutritional status of the poor is to improve at the current levels of food dependency, the decline in growth rate in yields will have to be stopped, and yield increases compared to current trends will have to occur in part in the fields of poor farmers and will have to generate employment opportunities for the rural poor. Since the growth rate in yields achieved with traditional plant breeding and agronomic practices has been declining, the next phase of yield increases in agriculture will have to rely on the scientific advances offered by biotechnology. Yet, while biotechnology has made impressive progress in the agriculture of some of the more developed countries, it has had little impact in most developing countries, and particularly in the farming systems of the rural poor. The objective of this paper, therefore, is to explore under what conditions could the current biotechnological revolution in agriculture be helpful for reducing poverty in developing countries. Failure to capture this potential would further increase the income gap between developed and developing nations and would be a serious setback in the struggle to reduce poverty.

II. The potential of agricultural technology for poverty reduction

2.1. Direct and indirect effects of technology on poverty

There are two channels through which technological change in agriculture can act on poverty. First, it can help reduce poverty directly by raising the welfare of poor farmers who adopt the technological innovation. Benefits for them derive from increased production for home consumption, more nutritious foods, higher gross revenues from sales deriving both from higher volumes of sales and higher unit value products, lower production costs, lower yield risks, lower exposure to unhealthy chemicals, and improved natural resource management.

Second, technological change can also help reduce poverty indirectly through the effects which adoption, by both poor and non-poor farmers, has on:

The price of food for net buyers.

Employment and wage effects in agriculture.

Employment and wage effects in other sectors of economic activity through production, consumption expenditures, and savings linkages with agriculture, lower costs of agricultural raw materials, lower nominal wages for employers (as a consequence of lower food prices), and foreign exchange contributions of agriculture to overall economic growth.

Through the price of food, indirect effects can benefit a broad spectrum of the national poor, including landless farm workers, net food buying small holders, non-agricultural rural poor, and the urban poor for whom food represents a large share of total expenditures. Indirect effects via employment creation are important for landless farm workers, net labor selling small holders, and the rural non-agricultural and urban poor. Hence, the indirect effects of technological change can be very important for poverty reduction not only among urban households, but also in the rural sector among the landless and many of the landed poor.

When are there trade-offs in technology between achieving direct and indirect effects? Within a given agro-ecological environment, if land is unequally distributed and if there are market failures, institutional gaps, and conditions of access to public goods that vary with farm size, then optimum farming systems will differ across farms. Small farmers will typically prefer new farming systems that are more capital-saving and less risky while large farmers would prefer new farming systems that are more labor saving and they can afford to assume risks. In this case, heterogeneity of farming systems prevails and there will exist trade-offs between achieving indirect and direct effects if budget constraints in research requires priority setting. The more unequally land is distributed and the more market, institutional, and government failures are farm size specific, the sharper the trade-off will be.

The relative magnitude of the direct and indirect effects of technological change in agriculture on poverty can be quantified through computable general equilibrium (CGE) models (Sadoulet and de Janvry, 1992). In these models, the direct effects include the change in agricultural profit, the changing opportunity cost of home consumption of own production, and the change in self-employment on own farm. The indirect income effect comes from changes in nominal income from all sources other than own agricultural production. The indirect price effect comes from the change in prices, excluding the effect through the opportunity cost of home consumption.

Table 1 presents results from models representing archetypal poor economies in Africa, Asia, and Latin America. They show that the relative magnitude of these effects vary widely according the structure of the economy, the sectoral incidence of poverty, and the sources of income for the poor. In a typical African context where the agricultural sector is large and the bulk of the poor are smallholders, direct effects are very important: they account for 77% of the income gains for the rural poor and for 58% of the income accrued to all poor. Targeting technological change on poor farmers, with their particular crops, farming systems, market failures, institutional gaps, and public goods deficits is thus essential for aggregate poverty reduction. In Asia, by contrast, where most of the poor are rural landless, income gains for the rural poor derive mainly (64%) from indirect effects captured on the labor market. Of the total income gained by the poor, 74% is from indirect effects. Hence, targeting technological change toward employment creation is in this case fundamental for poverty reduction. Finally, in Latin America, where poverty is largely urban and a majority of the land is concentrated in the hands of large farmers, the rural poor derive 73% of their real income gains through indirect effects, mainly captured through falling food prices. The total real income gains captured by the poor derive mainly (86%) from indirect effects. In this case, the main role of technological change is consequently to lower the price of food, and this will have to occur principally in the fields of the large farmers. Clearly, at higher levels of geographical disaggregation, direct effects may also dominate in specific Asian and Latin American regions, requiring region-specific targeting of research budgets across innovations producing either direct or indirect effects.

If there are trade-offs between direct and indirect effects, care must be taken to allocate research budgets optimally between these effects to maximize poverty reduction. While little formal analysis has been made of these trade-offs, optimum allocation needs to be determined for each nation and agroecological region for which research programs are organized.

2.2. Technology and rural development

Technology offers a huge potential for poverty reduction in small holder agriculture. However, other potentially cheaper and faster sources of income gains have not been exhausted, particularly through institutional and policy changes, e.g., greater access to productive assets, improved property rights and contracts in accessing land, more effective agrarian institutions in support of productivity growth such as microfinance, infrastructure investment and service coops to reduce transactions costs in accessing markets, and policies that do not discriminate against agriculture and poor farmers. Hence, to be effectively used for poverty reduction, the technology instrument needs to be embedded within a comprehensive rural development and poverty reduction strategy that weights the effectiveness of this instrument against other substitute approaches.

III. Agricultural technology and poverty in a historical perspective

The history of technological change in developing country agriculture is one where farmers and farming communities have historically been the main innovators, followed by the public sector which released the technology of the Green Revolution as a public good, and subsequently the private sector when changes in intellectual property rights (IPR) legislation allowed to capture returns from research in biology, unleashing a new wave of biotechnological innovations as private goods.

3.1. Green Revolution

The Green revolution started with the release of hybrid maize in the United States in the 1950s. It was extended to the developing countries with the introduction of semi-dwarf varieties of rice and wheat in the mid-1960s. The Green Revolution in developing countries can be decomposed into two epochs:

Green Revolution I (1965-1975): The main purpose of research was to achieve rapid increases in yields through high yielding varieties (HYVs), and success was immense, creating large indirect effects for the poor via declining staple food prices and rising employment in agriculture and related activities. Direct poverty reduction effects were, however, small and often negative: HYVs were designed for the best areas (irrigation, high soil fertility) with chemical intensive technology (Byerlee, 1996). They consequently diffused first among commercial farmers, sometimes with backlash effects on non-adopting poor farmers through falling prices. GR I also often had negative environmental effects through genetic erosion and chemical run-offs.

Green Revolution II (1975-today): Research was aimed at the broadening of desirable traits to consolidate yield gains and to extend the benefits of the GR to other crops, areas, and types of farmers. This allowed the increase of pest and drought resistance. The benefits of the GR were thus extended toward rainfed areas (Beyerlee and Moya, 1993) and small farmers, enhancing direct effects on poverty. These technological innovations were, however, not able to prevent a steady decline in the growth of yields, reducing the pace of gains in poverty reduction through indirect effects compared to Green Revolution I.

3.2. Scientific revolution and intellectual property rights

There are three major scientific developments that are creating new openings for technological change in agriculture: the information technology revolution that opened the field of precision farming, the better understanding of ecological systems that underlies production ecology, and the gene revolution that launched biotechnology. While intellectually separate, these three technological advances should be seen as complementary in the domain of applications.

i) Precision farming is an application of the information revolution to agriculture (Wolf and Buttel, 1996). It is based on information derived from global positioning satellite systems and electronic monitoring, and processed through the geographical information system. This allows to take into account the heterogeneity of farmers' fields in space and time, and to adapt cultural practices to heterogeneity through variable rates in planting, chemical applications, and irrigation, and though just-in-time application of treatments. Increased precision is applied to the use of the traditional technologies of agriculture: chemical fertilizers, synthetic pesticides, tractor-based mechanization, and genetically uniform HYVs. Fine

tuning in the use of these technologies has allowed to postpone decreasing returns and to reduce pollution when there was overuse.

In the industrialized countries, precision farming allows to deal with heterogeneity in spite of scale, recuperating the informational advantages of small scale farming at a larger scale. Hence, information technology has been used to disaggregate heterogeneous large scale farms into locationally differentiated management practices. In the developing countries, information technology has been used to aggregate heterogeneous small scale plots into homogenous (spatially disconnected) mega-environments to which common technological practices can be applied. While monitoring in the industrialized countries is done at the farm level, it is done through centralized services in developing countries such as weather stations, satellite monitoring of biomass, and regional intelligence on insect infestations.

ii) Production ecology uses the concept of agroecosystem as the unit of analysis (Harwood, 1998). Such systems are characterized by complex biological processes and relationships through which a multitude of species interact. Production ecology starts from the analysis of these processes, and defines a set of interventions to modify them to achieve desirable outcomes. Interventions thus include the management of carbon flows and biota, increased nutrient cycling from soil to crops, integrated pest management and ecologically-based pest management, diversified farming with crop rotations and multiple cropping, the provision of ecosystem services (hydrological cycling, wildlife habitat, preservation of animal and plant diversity, and landscape management), and use of carbon sinks to improve atmospheric chemical balance. The approach has been successfully pursued in agroforestry systems (e.g., by ICRAF, the International Center for Research on Agro-Forestry) and agroecology for smallholders (e.g., by CLADES). Except in the organic agriculture movement, it has not yet gained mainstream recognition but offers considerable promise.

iii) Biotechnology is based on the understanding of how biological organisms function at the molecular level, and manipulation of the DNA molecules from which genes are made to achieve desirable outcomes (Kendall et al., 1997). It includes genomics (the identification of genes), functional genomics (the characterization of how genes work), bioinformatics (data banks on genomics), marker-assisted selection to speed traditional breeding, plant and tissue culture, the transfer of genes across species to confer useful traits to the genetically modified organisms (GMOs), diagnostic kits for identification of plant and animal pathogens, and vaccine technology. Biotechnology started 25 years ago with the discovery of scientific procedures to alter DNA sequences. With introduction of intellectual property rights in biology, it has become a booming field of research with already extensive applications to agriculture.

IV. Main features of agbiotechnology for the poor

4.1. Traits: potentials and risks

The advent of biotechnology offers the possibility of amplifying the achievements of traditional breeding in Green Revolution II for three reasons:

- (1) Broadening of the spectrum of potential new products and traits through genetic engineering (recombinant DNA techniques, insertion of genetic materials) of plants and animals: wide crossings (genes transfers from wild relatives of the crop) and transfers of foreign genes (gene transfers across species).
- (2) Acceleration of the pace of plant breeding through use of selectable gene markers, promoters, and new scanning devices.
- (3) Cheapening of research due to productivity gains in research.

For smallholders, the GMO technology offers the possibility of using gene transfers to insert into the best plant varieties they use a number of desirable traits which these varieties do not have. For the poor, GMO technology offers both potential benefits and risks. Some of the most important are the following:

Potential benefits of agbiotechnology for poverty reduction

- Yield increases in staple food crops produced in tropical and semi-tropical environments, and in peasant farming systems.

- Area expansion toward less favored lands: tolerance to acid soils, saline soils, aluminum soils; tolerance to droughts.
- Multiple cropping: shorter maturation period.
- Cost reduction via resource-saving effects: nitrogen fixation, low nitrogen tolerance, chemical-saving. Possibility of exact reproduction of seeds by farmers (apomixis).
- Risk reduction: lower susceptibility to biotic stress (insect resistance (e.g., Bt crops) and virus resistance) and to abiotic stress (droughts, frosts). Diagnostics to detect and identify diseases, for instance on seeds purchased.
- Improved storability: insect resistance, delayed maturation (reduces marketing costs).
- Nutritional improvements as food and feed: high lysine, improved micronutrient content.
- Health benefits for humans and animals: reduced exposure to chemicals, new vaccines.
- Environmental benefits: reduce application of chemical pesticides, preservation of biodiversity through gene insertion in a wide range of varieties.

Potential risks of agbiotechnology for the poor

- Staple food crops produced in tropical and semi-tropical environments and by smallholders are by-passed by research.
- Labor-displacement by diffusion of herbicide tolerant plant varieties.
- Production in MDCs of substitutes for crops previously produced in LDCs, particularly labor intensive and/or by small holders (trade substitution effect).
- Traits pursued in private sector research are for non-poor consumers: improved industrial processing, delayed ripening.
- Consumer risks: allergies.
- Environmental risks: insect and virus resistance, gene flows in centers of biodiversity (superweeds), weediness, destruction of useful insects and species.
- Terminator gene to enforce IPR raises costs by preventing reproduction of seeds.

4.2. Current achievements of agbiotechnology

By contrast to the Green Revolution research that was conducted in the public sector, delivered international public goods, and occurred purposefully in the developing countries (CGIAR research), most research in biotechnology has been done in the developed countries, using patents mainly owned by a few large multinational corporations, on commodities that are principally for animal feed and fiber, and with traits favorable to large capital-intensive commercial farms and to high income consumers. The data in Table 3 indicate the global status of this technological revolution as of 1998.

The data show that 75% of the area planted in transgenics is located in the developed countries, with the USA accounting for 64% of the world total. Herbicide tolerant soybeans and Bt corn (feed) are the dominant crop/trait combinations, followed by insect resistant and herbicide tolerant cotton. In Argentina, by far the developing country (besides China) most advanced in agbiotechnology, the main transgenics are herbicide tolerant soybeans, Bt corn, and Bt cotton. Hence, the global status of transgenic crops clearly shows developing countries lagging far behind and the purpose of transgenics directed at non-food crops and principally labor-saving technological change. Observation of the frequency distribution of GMO field trials across countries indicates that several developing countries have advanced research capacity in DNA techniques, notably China, Argentina, India, Brazil, Mexico, and Egypt, followed by countries with modest capacity such as Indonesia, the Philippines, and Kenya (Pray, Courtmanche, and Brennan, 1999).

4.3. Main differences between agbiotechnology and GR II for poverty reduction

If the potential offered by agbiotechnology for poverty reduction is to be seized and the risks contained in the approach are to be avoided, the specificity of the technology and how it is made available need to be understood in contraposition to the technology of the Green Revolution II, the last important technological epoch for developing country agriculture. The main differentiating features of agbiotechnology are the following:

1. Technological features of agbiotechnology

i) Research on traits separated from research on varieties. Compared to traditional breeding (GR I and II) where research on trait identification was confounded with variety development, biotechnology dissociates research on traits (functional genomics) from product development (insertion of genes corresponding to traits into selected varieties). Agbiotech research results on traits may be usable over a wide range of local conditions. Hence, if information on relevant functional genomics exists and can be accessed through markets, contracts, or as public goods, and if technology to insert these traits into local varieties is widely available, developing countries can produce improved varieties without the need to engage in fundamental research. This has powerful implications for the division of labor in research between developed and developing countries and the type of capacity building needed in the latter, in this case principally to screen and adapt these technologies to their own needs.

ii) Potential environmental externalities and consumer risks. New varieties under GR research were achieved by natural crossings. With GMOs, new species and varieties are created by artificial gene transfers, with yet poorly known risks for the environment and consumers. As a result, the experimentation on and the diffusion of agbiotechnology innovations need to be accompanied by specific regulatory procedures to safeguard environmental and consumer safety, and weight risks against the benefits of the innovations.

iii) Biodiversity as the source of research materials. New genes to be inserted in cultivated varieties are found in the stock of biodiversity. The option value of preserving biodiversity in-situ and ex-situ is thus enhanced. Incentives to establish property rights over biodiversity and to invest in biodiversity conservation are thus important side effects of progress in agbiotechnology.

2. Role of intellectual property rights

i) IPR and access to biotechnology materials for the LDC. The current patenting system on life forms allows private appropriation of knowledge on genomics, the basic raw materials of biotech research (Wright, 1998). There is serious concern that such appropriation will create hurdles for access to the relevant materials for research in developing countries, public sector institutions, and the CGIAR and for downstream product development. Some of the patents that have been granted are very broad and they can be used to block access to discoveries to others. Evolution of patent law is, however, in full progress as it is still drawn by case law without having been submitted to open national debates. Pressed by public concerns with biosafety, by governments' interest in preserving the competitiveness of the industry, and by the need for World Trade Organization (WTO) members to introduce IPR legislation on life forms, such debates are likely to occur in the near future, potentially leading to changes in the current IPR system.

ii) Market failures for IPR and industry concentration. A large number of technological innovations are involved in the development of a final product, and ownership of these innovations is often scattered over many institutions. Rapid concentration of patent ownership in the corporate sector through acquisitions and mergers evidences these technological complementarities in product development and existence of serious market failures in the acquisition of patented materials needed for product development (Graff, Rausser, and Small, 1999). As the Bt example shows (Figure 2), university and public institutions held 50% of the stock of patents in 1987, independent biotech companies and individuals held 77% of the stock in 1994, and the "big 6" held 67% of the stock of patents in 1999. As can be seen from Figure 3, 75% of the patents controlled by the "big 6" in the industry in 1999 (AstraZeneca, Aventis, Dow, DuPont, Monsanto, and Novartis) were obtained via acquisitions of subsidiary biotech and seed companies. Concentration fueled by market failures for IPR shows that LDCs and the CGIAR will have considerable difficulties engaging in biotech R&D until an effective clearinghouse for the rights to utilize biotech knowledge is available.

iii) Intellectual property rights and access to GMO seeds. Property rights over seeds can be established by (1) concentrating on hybrid seeds, (2) introducing terminator genes in open pollinated varieties, and (3) legal enforcement of prohibition to reproduce seeds of open pollinated varieties. Failure to achieve property rights over seeds via legal enforcement will (1) limit research on biotechnology to hybrids and terminator-charged varieties, (2) limit insertion of new traits into a broad range of local varieties, implying

sub-optimal seeds for the poor and loss of biodiversity through simplified farming systems, (3) increase reliance on contract farming by seed producers, with increased concentration of control over the industry, and (4) raise the price of seeds as producers attempt to recoup the cost of research and development in one single sale, increasing liquidity constraints for smallholders exposed to credit market failures. However, IPR raise the cost of seeds for traditional farmers who have historically reproduced their own seeds.

iv) Role of barter in accessing biotechnology. Since biodiversity is the raw material for agbiotech research, and much of the relevant biodiversity is located in developing countries and peasant farming communities, granting access to biodiversity to MDC interests can potentially be used as a source of leverage for bartering access to agbiotech innovations held by these interests. Such barterers can apply to both scientists in developing countries, including the CGIAR, who need access to patented research materials for their own research, and to farming communities who need access to seeds improved by biotech research.

3. Research and development on GMO technology in LDCs

i) Current research gaps for the poor. Because agbiotech innovations are generated principally in the industrialized countries for major crops produced in these countries by a clientele of large farmers with few market failures and for relatively high income consumers, there are important gaps that need to be filled to make biotech innovations relevant for poverty reduction in developing countries (Nuffield Foundation, 1999). They include research on staple foods for tropical and semi-tropical environments, labor intensive technologies, and traits desirable for peasant farming systems that operate under extensive market failures, institutional gaps, and government biases. Institutional mechanisms need to be devised to fill these research gaps, including defining the new role of the public sector research institutes and the CGIAR.

ii) Structure of research costs and access by LDCs. Biotech changes the structure of research costs: it increases the costs of fundamental research, but lowers the costs of product development. If fundamental research relevant for LDCs and smallholders is done in the MDCs, development of agbiotechnology products for poverty reduction is made cheaper. If such research is not available, the cost of generating agbiotechnology products for poverty reduction may be significantly higher than under traditional breeding.

iii) Complementarity between agbiotechnology and traditional breeding. Biotechnological research is complementary to traditional breeding since the new traits need to be inserted into the best possible local varieties in order to deliver to farmers the myriad of traits that cannot be controlled by gene transfer. An effective traditional breeding program thus creates scale effects for biotech research by enabling transfers of traits to a wide range of improved local varieties.

iv) Complementary roles of public and private research. Many agbiotech innovations have originated in public sector research and been refined by start-up biotechnology companies. These companies have generally spun-off from universities, were financed by venture capitalists, and their products were commercialized by large multinational corporations. Analysis of the granting of patents in agbiotechnology shows the sequential roles of the universities and public sector, the biotechnology firms, and the corporate sector in research and development. Using Bt technology as a case study (Figure 1) shows that university and public institutions generated 60% of the patented research in 1976-86, small biotech firms and individuals 77% in 1987-95, and large corporate firms 55% in 1999. Continued support to public sector research is thus essential for the flow of innovations to be replenished. For this sequential division of labor to be effective, linkages between these institutions is important for research to yield useful products, particularly through offices of technology transfer in universities and public institutions, venture capital for biotech firms, and efficient trading of property rights across all these institutions.

v) Public-private research partnerships. With some 75% of world investment in agbiotech research coming from the private sector, the public sector and the CGIAR are increasingly seeking to develop research partnerships with the private sector (Herdt, 1998). Design of these partnerships is complex since the objectives of partners are at odds: the private sector pursues profits, while the public sector and the CGIAR are in principle pursuing the delivery of public goods.

vi) *Participation of smallholders to research priority setting on traits.* Genetic engineering increases widely the range of potential new traits for resistance to pests, tolerance to stress, improved food quality, and environmental sustainability. Some of these traits are favorable to the poor while others offer risks. As the range of trade-offs rises, who sets priorities for research on traits will be key in determining the impact of biotechnological innovations on poverty. Failures for the poor to participate to priority setting increases the risk that they will be bypassed by technological progress.

4. *Institutional context for diffusion*

i) *Trait insertion into local varieties and biodiversity.* Biotech allows an increase in the range of varieties of a crop to which new traits can be applied. Hence, the benefits of research on trait improvement that were confined to major varieties under GR II have greater potential to be extended to varieties used in peasant farming systems and in niche farming. If incentives and means can be given for broad insertion into local varieties, this offers the potential of better serving small holders and preserving biodiversity.

ii) *Biosafety regulation with weak institutions.* Biotechnology takes breeding science into uncharted territories. Hence, the need for regulation of environmental and food safety effects is enhanced, increasing the role of the public sector in defining rules and of local communities in monitoring and enforcing them. Regulation poses a set of specific problems for implementation in developing countries and among large numbers of poor smallholders. It is also a double edged sword since costly regulatory procedures operate against smaller biotech firms and against smaller farmers, inducing concentration in industry and farming. Releasing genetically-engineered crops in developing countries that are centers of origin and diversity of these crops (such as maize in Mexico, wheat in the Middle East, and potatoes in Peru) creates higher risks of gene flows in nature and weediness. The need for strict biosafety regulations is consequently greater precisely where they are more difficult to implement, calling for innovative approaches in institutional design.

iii) *Gene stacking and new farm management.* The current state of knowledge in biotech processes only allows the stacking (pyramiding) of a few traits by gene transfer. Hence, the question of which functions are to be achieved by gene transfers and which by traditional means (chemical pest management, integrated pest management, precision farming, production ecology, etc.) needs to be assessed for each particular set of circumstances. Use of biotechnology in heterogeneous farming conditions requires the ability to assemble these technological packages for each particular agroecological and socio-institutional environment, opening the need for a new approach to the science and practice of farm management which relies importantly on precision farming techniques.

iv) *Preventative vs. remedial technologies.* Biotechnological control of pests and weeds is preventative (ex-ante relative to infestations) as opposed to chemical pesticides and herbicides which are remedial (ex-post). Hence, optimum use of biotechnology instruments should be planned as part of the total crop production system, calling upon engaging in integrated crop management (ICM). ICM aims at the joint management of soil organic matter and structure, pest and disease resistance, and conservation of the beneficial insect and micro-organism population. Instruments for ICM include use of crop rotations, pest and disease resistant cultivars, weed and disease free seeds, and complementary pesticides and chemicals. ICM thus effectively combines agbiotechnology with precision farming and production ecology.

5. *Use of GMOs by smallholders*

i) *Biotechnology, human capital, and effort requirement.* By offering “smart seeds” (e.g., plants that self-protect with biopesticides or can adapt to stress), agbiotechnology demands less human capital, effort, and specialized equipment from users than chemicals or integrated pest management. Its relative simplicity may be a major cause for the very fast rate of adoption in developed countries within the three years since available. It is a feature clearly favorable to diffusion among developing country smallholders with low human, physical, and institutional capital endowments.

ii) *Structure of production costs and adoption by smallholders.* By embodying traits in the seed, biotechnology changes the structure of costs for farmers from variable costs (e.g., chemical insecticides) to

fixed costs (e.g., seeds with biopesticides). With IPR and greater value added in seeds, these fixed costs can be sharply increased. While the new technologies can be beneficial in expected value, the changing cost structure has several implications for adoption by poor farmers: partial and sequential adoption of pest control is prevented, fixed costs are increased, beginning-of-season liquidity requirements are raised, and risks are enhanced as seed expenditures are committed irrespective of subsequent stochastic events.

iii) Changing exposure to market failures and institutional gaps at the farm level. Because biotech is resource saving by contrast to the Green Revolution that was resource deepening, use of GMOs may reduce exposure to market failures and institutional gaps. The same is true for the risk reducing effects of biotech that mitigates the cost on smallholders of insurance and credit market failures. However, biotechnology creates other sources of exposure to market failures by displacing the structure of production costs and requiring imposition of biosafety regulations.

V. What can be done to use biotechnology for poverty reduction

1. Overall conclusion: the role of institutional innovations

Agricultural biotechnology has great promise for poverty reduction, both through direct and indirect effects, with considerable flexibility in striking differential balances between these two sets of effects to reduce aggregate poverty according to country and regional characteristics. Failing to capture this potential would be both a serious missed opportunity in the struggle against poverty and a risk that the competitiveness of smallholders in developing countries be further weakened relative to that of other producers and other countries. As the large gaps in the use of agbiotechnology across countries and the biases in crop and trait innovations indicate, the current situation is one of massive market and government failures for potential developing country and smallholder users. However, meeting the institutional requirements to overcome these failures is highly demanding. The effort to use biotechnology for poverty reduction will consequently fail or succeed not so much depending on ability to progress in biological sciences as on the ability to put in place the necessary public and private institutions for the generation, transfer, delivery, and adoption of biotechnological innovations favorable to poverty reduction. Since weak institutional development is an integral feature of under-development, and a pro-poor bias in developing country institutions has been notably lacking, this poses particular difficulties in achieving success that need to be pro-actively addressed. In what follows, we identify the institutional innovations that are needed for this purpose.

2. Generation of biotechnological innovations

Institutional requirements to secure the generation of biotechnologically modified crops and animals with traits favorable to poverty reduction include the following:

i) An IPR regime that does not hamper further research and downstream product development, particularly for public institutions, international organizations such as the CGIAR, and NGOs that are concerned with the poor. Questioning the features of current patent systems and guiding their future evolution should thus be an integral part of efforts to maximize the role of biotechnology for poverty reduction.

ii) IPR regimes that recognize the legitimate ownership rights of traditional farming communities over biological resources and give them leverage in gaining access to the private products of biotechnology. Experimentation with innovative contracts to reconcile farmers ownership rights over biodiversity with efficient bio-prospecting is needed (e.g., Shaman pharmaceuticals and INBio in Costa Rica).

iii) Development of markets for the trading of patented materials. An efficient clearinghouse, based on publicly available information, for the rights to utilize patented biotechnology materials and products is thus essential to protect developing country and smallholder interests.

iv) Use of defensive patents on CGIAR and public sector research innovations that have high potential for poverty reduction with the purpose of keeping them expressedly in the public domain for selected clientele. Due to costs and legal complexities, patents will likely be taken in joint ventures with the private sector. Identification of best practices for the delivery of IPG under defensive patents is urgently needed.

v) Development of the capacity of the national academic and public sectors to engage in fundamental research complementary to that of the private sector, to test alternative technological options, to adapt technology to their own needs, and to engage in product development. The type of national capacity to be developed thus depends on the particular optimum balance between these functions that varies by country. This should be pursued on a regional basis for the smaller and poorer countries.

vi) Participation of poor producers in the setting of priorities for applied research and product development, particularly regarding choice of crops, traits, and farming systems. Effective participation requires pro-active information campaigns to empower the poor.

vii) Promotion of collaborative arrangements (partnerships, consortia, contract research, gifts) bringing together corporate, non-profit, public, and international institutions for the development of biotech products favorable to poverty reduction. Experimentation to identify best practice for these arrangements is needed (e.g., role of ISAAA, the International Service for the Acquisition of Agri-biotech Applications).

viii) Identify opportunities for technological spillovers from industrialized countries that do not threaten commercial markets for private sector innovations. Under these conditions, technology transfers can be handled as gifts (e.g., Monsanto's virus resistant subsistence potatoes in Mexico).

ix) Enhanced public sector and CGIAR research budgets to work on (1) crops and traits not addressed by private sector research that are important for the urban and rural poor and (2) a more complete understanding of developing countries' ecosystems. Declining real budgets for the CGIAR and NARI should thus be an issue of concern if the potential of biotechnology for the poor is to be captured.

x) Institutions to link public and CGIAR research to private sector product development through offices of technology transfer attached to universities and public research institutes, venture capital for the financing of agbiotech companies, and mechanisms for the fair and effective enforcement of property rights.

xi) Traditional breeding efforts should continue. An increased number of good varieties will improve the value of traits introduced by biotechnology. Biotech both alters the practice of breeding through the use of markers and tissue culture and increases the pay-off of breeding by providing better local varieties for gene insertion.

3. Transfer of technologies and the delivery of products

Institutions to link the results of research to the delivery of products adoptable by developing country farmers and particularly smallholders include the following:

i) Public and non-profit sector roles in (1) the insertion of new traits in poor farmer crops and varieties with insufficient market size to provide private sector incentives, (2) the assembly of idiosyncratic technological packages for smallholder farming that combine traits controlled by gene insertion with functions delivered by other approaches such as chemical pest management, IPM, and production ecology.

ii) Coordination of private sector initiatives toward market expansion among smallholders, allowing them to overcome the commons problem typical of such investments.

iii) IPR incentives and availability of low cost technology to insert new traits into a wide range of alternative varieties, allowing better adaptation to local conditions, preservation of biodiversity, and competitive farming (as opposed to generalized contracting).

iv) Development of a regulatory framework for biosafety and consumer protection that corresponds to each country's preferences for risk and expected income gains, which change with stages of development. Attempts to equalize regulations affecting agbiotech in the name of harmonization, for instance to satisfy WTO requirements, should be scrutinized for their impact on the poor.

v) Decentralization of the monitoring and enforcement of biosafety regulations to the community level, based on community-level cooperation and verification by central agencies.

vi) Focus first on simple technologies with low biosafety risks (e.g., Rhizobium inoculation in Kenya) for as long as enforcement of regulatory frameworks remain weak.

vii) Discriminatory pricing of genetically modified seeds if market segmentation between poor and non-poor is possible.

viii) Subsidies to private marketing strategies that promote adoption of new technologies favorable to poverty reduction.

ix) Promotion of the private sector to deliver integrated services to smallholders combining GMOs and other technological approaches.

4. Adoption by small holders

Institutions to reduce poverty among smallholders by supporting adoption of favorable technologies include:

- i) Organization of credit schemes to face higher and earlier liquidity requirements in the purchase of seeds with improved trait content that are protected by IPRs, and potentially subject to non-competitive pricing.
- ii) Insurance and risk sharing mechanisms to absorb higher risks associated with committed seed expenses and higher cash outlays.
- iii) Development of institutional mechanisms (such as labeling) and production contracts for identity-preservation of improved small-farmer products.
- iv) Promotion of grassroots organizations such as service cooperatives in support of contract farming with smallholders for the acquisition of information on GMOs, access to modern inputs, and production of improved small-farmer products.
- v) Negotiated exemptions for poor smallholders to the prohibition of reproducing for home use seeds covered by IPR.

Table 1. Direct and indirect effects of technological change by region

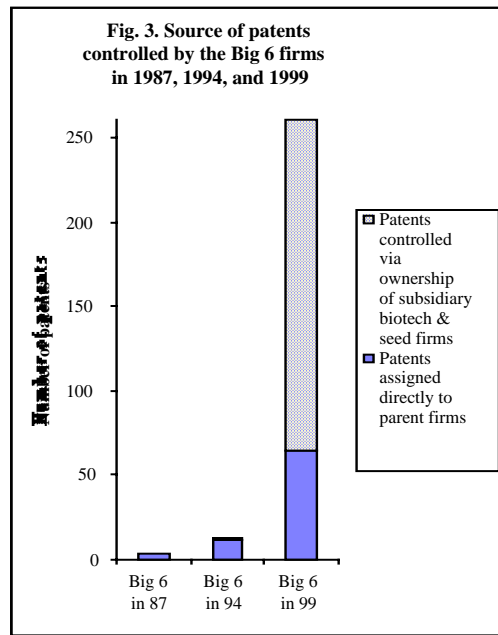
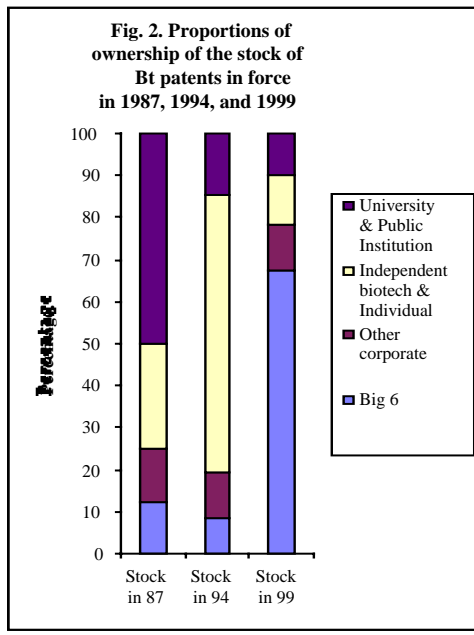
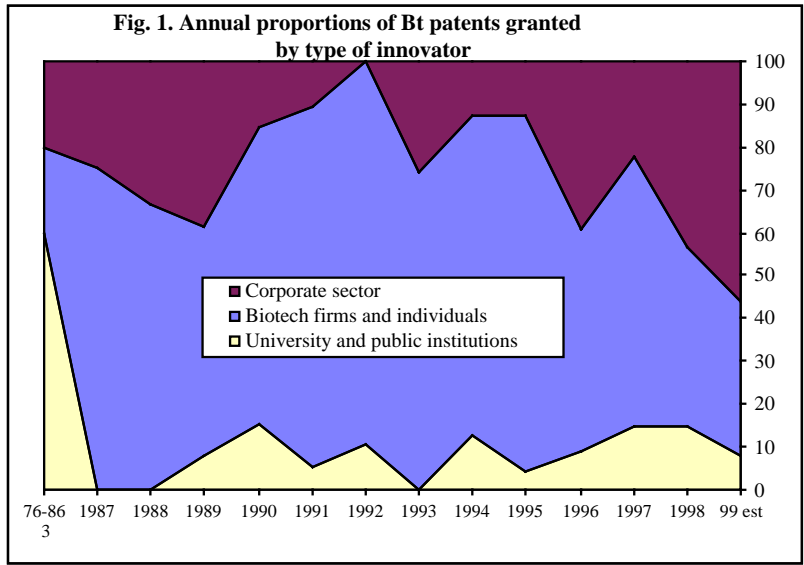
Impact of a 10% increase in TFP in agriculture	Africa	Asia	Latin America
Sources of income gains for the rural poor			
From direct effects (%)	77	37	27
From indirect effects (%)	23	64	73
Sources of income gains for all poor			
From direct effects (%)	58	26	14
From indirect effects (%)	42	74	86

Source: own calculations.

Table 2. Global Status of Transgenic Crops, 1996-98

	1996	1997	1997 % of total	1998
Area in transgenics crops by country (10⁶ ha)				
USA	1.5	8.1	64	20.5
Canada	0.1	1.3	10	2.8
Australia	<0.1	0.1	<1.0	0.1
Total industrialized countries	1.6	9.5	75	23.4
China	1.1	1.8	14	?
Argentina	0.1	1.4	11	4.3
Mexico	<0.1	<0.1	<1.0	<0.1
Total developing countries including China	1.2	3.3	25	
Total developing countries excluding China		1.5		4.4
World total including China	2.8	12.8	100	30.4
World total excluding China	1.7	11.0		27.8
Area in transgenics crops by commodity (10⁶ ha)				
Soybean	0.5	5.1	40	14.5
Corn	0.3	3.2	25	8.3
Tobacco	1.0	1.6	13	?
Cotton	0.8	1.4	11	2.5
Canola	0.1	1.2	10	2.4
Tomato	0.1	0.1	1	?
Potato	<0.1	<0.1	<1.0	<0.1
Total	2.8	12.8	100	
Area in transgenics crops by trait (10⁶ ha)				
Herbicide tolerance	0.6	6.9	54	19.8
Insect resistance	1.1	4.0	31	7.7
Virus resistance	1.1	1.8	14	?
Insect resistance and herbicide tolerance		<0.1	<1.0	0.3
Quality traits	<0.1	<0.1	<1.0	<0.1
Total	2.8	12.8	100	
Area in crops by trait (10⁶ ha)				
Herbicide tolerant soybean				19.8
Bt corn				7.7
Insect resistant/herbicide tolerant cotton				?
Herbicide tolerant canola				0.3
Herbicide tolerant cotton				<0.1

Source: ISAAA (1997 and 1998)



References

Byerlee, Derek. 1996. "Modern Varieties, Productivity, and Sustainability", *World Development* 24(4): 697-718.

Byerlee, Derek, and Piedad Moya. 1993. *Impact of International Wheat Breeding Research in the Developing World, 1966-90*. Mexico City: CIMMYT.

Graff, Gregory, Gordon Rausser, and Art Small. 1999. "Agricultural Biotechnology's Complementary Intellectual Assets", Department of Agricultural and Resource Economics, University of California at Berkeley

Harwood, Richard. 1998. "Sustainability in Agricultural Systems in Transition: At What Cost". Department of Crop and Soil Sciences, Michigan State University.

Herd, Robert. 1998. "Enclosing the Global Plant Genetic Commons", New York: The Rockefeller Foundation.

Kendall, Henry, et al. 1997. *Bioengineering of Crops: Report of the World Bank Panel on Transgenic Crops*. Washington D.C.: The World Bank.

Nuffield Foundation (The). 1999. "Genetically Modified Crops: The Ethical and Social Issues", <http://www.nuffield.org/bioethics/publication/modifiedcrops>.

Pray, Carl, Ann Courtmanche, and Margaret Brennan. 1999. "The Importance of Policies and Regulations in the International Spread of Plant Biotechnology Research", Department of Agricultural Economics and Marketing, Rutgers University.

Sadoulet, Elisabeth, and Alain de Janvry. 1992. "Agricultural Trade Liberalization and Low Income Countries: A General Equilibrium-Multimarket Approach", *American Journal of Agricultural Economics* 74(2): 268-80.

Series No. 12. Washington D.C.: The World Bank.

Wolf, Steven, and Frederick Buttel. 1996. "The Political Economy of Precision Farming", *American Journal of Agricultural Economics*, 78(5): 1269-74.

World Bank. 1997. *Rural Development: From Vision to Action*. ESSD Studies and Monographs Series No. 12. Washington D.C.: The World Bank.

Wright, Brian. 1998. "Public Germplasm Development at a Crossroads: Biotechnology and Intellectual Property", *California Agriculture* 52(6): 8-13.