7. Research and research policy for the poor

Agricultural biotechnology holds enormous promise for addressing a range of technical challenges facing poor farmers in poor countries (Chapter 2). We know from the Green Revolution that agricultural research can stimulate sustainable economic growth in developing countries, but the paradigm for research and technology delivery that made the Green Revolution possible has broken down (Chapter 3). That system was explicitly designed to promote the development and international transfer of productivity-enhancing technologies to farmers in poor countries as free public goods. Global agricultural biotechnology research, by contrast, is dominated by the private sector, which focuses on crops and traits of importance for commercial farmers in large profitable markets.

The private sector has proven that it can deliver transgenic crops to poor farmers in poor countries when farmers are able to capitalize on products developed for commercial purposes elsewhere, as in the case of Bt cotton in Argentina, Mexico and South Africa, or when the public sector plays a pivotal role, as in China (Chapter 4). Who will develop biotechnology innovations for the majority of developing countries that are too small in terms of market potential to attract large private-sector investments and too weak in scientific capacity to develop their own innovations? How can the barriers to international technology transfer be reduced so that more countries can take advantage of technological innovations developed elsewhere? At present, no institutional infrastructure exists that possesses both the resources and the incentives to focus on delivering a stream of biotechnology innovations to farmers in these countries.

This chapter explores some strategies for better focusing public- and private-sector research on the problems of the poor and for increasing the likelihood that farmers in developing countries can capture spillover benefits from technologies developed in other countries. Many of the same recommendations can both focus more research on the poor and help ensure they have access to the resulting technologies. In a world in which the science required to generate improved technologies is becoming increasingly complex and expensive, the level of collaboration among public institutions, and between public and private institutions, must increase (Pray and Naseem, 2003b).

Promoting access to biotechnology applications

How can more farmers in more countries gain access to the technologies that are emerging from the Gene Revolution? A number of factors inhibit the international transfer of new agricultural technologies and prevent farmers from taking advantage of the public and private agricultural research that is already taking place around the world. The following are among the most important steps that need to be taken by individual countries and the international community to facilitate the safe transfer of technologies. Many of these steps will also help attract public and private investment in research on the problems of the poor by reducing the costs of technology development and expanding the likely market for technological innovations. Countries and the international community need to:

- establish transparent, predictable science-based regulatory procedures and harmonize regulatory procedures, where appropriate, at regional or global levels;
- establish appropriate intellectual property rights (IPR) protections to ensure that developers can earn an adequate return on investment;
- strengthen national plant-breeding programmes and seed systems; and
- promote the development of efficient agricultural input and output markets and reduce trade barriers on agricultural technologies.

Regulatory requirements

Absent or poorly functioning biosafety regulatory systems constitute a major barrier to the development and diffusion of transgenic crops by private companies and the public sector. Private companies will neither invest in transgenic crop research tailored to the needs of a particular country nor attempt to commercialize an existing product there unless a transparent, science-based regulatory system is in place.

Regulatory requirements add substantial costs to the research and development process for transgenic crops. Biotechnology firms typically expect to spend about $10 million for each new transgenic product to develop the portfolio of health, environmental and agricultural biosafety information required by the regulatory authorities of a typical industrialized country. These costs are justified, of course, if the process results in scientifically sound decisions that command the confidence of the public and technology developers. However, if a technology company has to spend millions of dollars on biosafety research that unnecessarily duplicates research done elsewhere or in an effort to satisfy continuously changing requirements, it will be less interested in investing in the country.

An expensive, unpredictable and opaque biosafety regulatory regime is even more restrictive for public research than private research, because public institutes have considerably less money to finance the research trials required to meet regulatory requirements. If the regulatory process is very time-consuming and expensive, large transnational companies may be the only institutions that will be able to afford to commercialize a transgenic crop.

Governments must find ways to rationalize their regulatory requirements and fund the necessary environmental and human health safety trials if they want to attract privately developed technologies or to promote public biotechnology research to help the poor. Harmonizing biosafety regulatory measures, where appropriate, can reduce unnecessary duplication and lower barriers to the transfer of new conventional and transgenic plant varieties between developing countries. This would also allow private firms or public-sector institutions to reach a wider market for the products of their research. If biosafety standards were harmonized on a regional basis, countries with well-developed biotechnology research and development programmes could supply technology to neighbouring countries with similar agro-ecological conditions. The number of countries with functioning biosafety committees is increasing, but until there is some type of regional harmonization and sharing of biosafety information, the regulatory transaction costs present insurmountable entry barriers for a substantial number of countries.

Intellectual property rights

A second obstacle to the international transfer of agricultural biotechnology is the difficulty of protecting IPR. The experience to date with IPR protection for transgenic soybeans, maize and cotton worldwide is mixed: enforcement has been strong in some countries, weak in others and uncertain in most. Many people are concerned that IPR protections on biotechnology and plant varieties will limit farmers' access to seeds by granting private corporations monopoly control of vital genetic resources and research techniques. Although this has not been a widespread problem thus far (Chapter 4), governments have an ongoing responsibility to ensure that private companies cannot exploit their monopoly position by charging excessive prices for their products. At the same time, the essential role of IPR protection in stimulating research and technology development is clear. Firms must be able to appropriate enough of the economic returns from the technology to justify their investment (Chapter 3). Countries need to find the appropriate balance that provides enough IPR protection to encourage private-sector research and technology development while protecting farmers from monopoly exploitation.

The large transnational firms realize that resource-poor farmers growing subsistence crops in small countries are unlikely to become commercial buyers for their products, and IPR protection alone is unlikely to stimulate them to enter these markets. Enhanced IPR protection in some of the larger developing countries could provide a powerful incentive for private firms (transnational and local) to conduct more research on the problems of the poor and to adapt and commercialize products developed elsewhere. Large firms have worked with local companies to adapt patented products for smaller markets; for example, the Bt gene developed by Monsanto has been incorporated into cotton for small farmers in Africa and Asia and recently into white maize in South Africa. Private firms have been willing to donate and/or commercialize technology that can benefit the poor, and they would probably do so more widely if regulatory barriers could be overcome.

National plant-breeding programmes

The countries that will take the most advantage of transgenic crops developed elsewhere are those that have strong national plant-breeding programmes. National plant-breeding capacity, with or without the help of biotechnology, is necessary to incorporate imported transgenic innovations into cultivars that are appropriately adapted for local conditions. Breeding programmes manipulate genetic resources through combining genes from two or more parents. Selection and evaluation procedures are applied to help identify the best individuals for local agro-ecological conditions. Seed production follows to increase the availability of the best materials, allowing them to be released to farmers as commercial varieties. The International Treaty on Plant Genetic Resources for Food and Agriculture wisely stresses the role of plant-breeding programmes and seed production systems to deliver research results to poor farmers. Any investment in biotechnology, before ensuring these components are in place, has a high probability of failure.

Efficient markets for agricultural technologies

A fourth obstacle inhibiting the international transfer of transgenic crop innovations, and possibly the most difficult to remedy, is the absence of functioning seed markets in most countries for most crops. With the exception of maize, cotton and vegetables in a few countries, seed markets are very poorly developed, making it difficult to deliver modern varieties, including transgenic varieties, to farmers. Liberalizing input markets and eliminating government monopolies can increase the potential size of the market for biotechnology innovations. This was an important factor in increasing private agricultural research in Asia (Pray and Fuglie, 2000) and still may be important in the seed market in some countries because seed markets are often the last markets to be liberalized (Gisselquist, Nash and Pray, 2002). Many countries still need government intervention to create the necessary physical infrastructure, such as transportation and communication, and institutional infrastructure, such as law and order and enforceable contract law, that are required for markets to work.

Promoting public- and private-sector research for the poor

There is a strong consensus among economists regarding what type of research is needed for biotechnology to contribute to reducing poverty and which institutions should do it (Lipton, 2001; Byerlee and Fischer, 2002; Naylor *et al*., 2002; Pingali and Traxler, 2002). There is increasing debate about how to stimulate public biotechnology and conventional research on poor peoples' crops in developing countries, particularly in the current climate of scepticism about the benefits of biotechnology, declining donor interest in funding agricultural research and low agricultural prices. The tools for encouraging private biotechnology research are better known, albeit more controversial. Many of the steps described above to reduce barriers impeding the international transfer of biotechnology innovations will encourage more private-sector and public-sector research for the poor, but additional steps are also needed. The remainder of this chapter outlines a research agenda to address the problems of the poor and explores ways of stimulating public and private research in these areas, including public–private partnerships to ensure researchers in developing countries can gain access to research tools and genes that will assist the poor.

This section outlines a pro-poor research agenda and explores some strategies for focusing more research on the problems of the poor and ensuring that developing countries have access to emerging technologies.

Transgenic crop research priorities for the poor

The crops that should be the focus of a pro-poor research agenda are the basic staple foods of the poor: rice, wheat, white maize, cassava and millets (Naylor *et al*., 2002). The traits needed to improve the condition of the poor farmers include increasing yield potential, increasing stability of yields through resistance to biotic and abiotic stress, and enhancing the ability to grow more nutritious subsistence crops under difficult conditions, such as drought and salinity (Lipton, 2001). Insect resistance of crops can be a valuable trait for poor farmers, especially where other control methods are not available or where hazardous chemical controls can be reduced or replaced (Chapter 4). Herbicide tolerance, on the other hand, may not be so important in land-scarce, labour-abundant economies where hand-weeding is a source of employment. Finally, small farmers who have limited access to land, machinery and chemical inputs should be targeted.

One of the most efficient ways to reduce micronutrient malnutrition of the poor is through enhancing the micronutrient content of basic food grains (Graham, Welch and Bouis, 2001). In some cases this can be done through conventional breeding. In fact, the first new varieties for addressing micronutrient malnutrition are likely to be high-iron rice produced through conventional breeding. However, for some characteristics, such as enhancing rice with vitamin A and other micronutrients, transgenic crops can be an important part of the answer (Box 26).

In addition to the development of crops to meet the needs of the poor, consumers and governments in developing countries are starting to demand more research on the environmental and health impacts of transgenic crops. Many developing countries have little local scientific expertise to help policy-makers sort out the conflicting claims surrounding transgenic crops. Environmental concerns, in particular, should be evaluated under different agro-ecological conditions and thus require locally managed research (Chapter 5). Without such research, consumer and environmental opposition may prevent transgenic crops from being approved for commercial use in developing countries.

Priority activities can be established by preparing a detailed inventory of all prospective biotechnology products characterized by crop and by agro-ecological environment, followed by an *ex-ante* assessment of the potential impact of each of these technologies on the productivity and livelihoods of subsistence producers. Such an assessment would lead to the identification of a set of products already in the research pipeline with high pro-poor potential that public–private partnerships could be built around.

Stimulating public agricultural research for the poor

Stimulating public research to address the problems of the poor is constrained by the difficulty of obtaining reliable, long-term funding for agricultural research. Public agricultural research programmes in many developing countries and the International Agricultural Research Centres (IARCs) are facing declining financial support. Furthermore, in the competition for declining funds, the poor are often neglected. Almost by definition, the poor do not have well-

BOX 26
Can biotechnology address the needs of poor farmers? The role of participatory agricultural research

The potential of biotechnology, particularly genetic engineering, to meet the needs of resource-poor farmers is immense. The problem as articulated by Lipton (2001) is that the potential is "locked into a system where it is not used for such purposes, and where a few large firms are competitively bound to protect their investment by means that, at present, threaten public research". For the public and private sectors to work effectively together to address the problems of the poor, it is desirable that the needs of the farmers are properly accounted for through participatory research. In participatory agricultural research, farmers are considered to be active participants who may lead the research process and whose ideas and views influence its outcome, rather than passive bystanders or objects of research (Thro and Spillane, 2000). This is important because farmers' perceptions and preferences for particular technologies will influence ultimate adoption. Participatory agricultural research is considered as integral to the overall research strategy and priority setting rather than as a substitute.

Thro and Spillane (2000) suggest several reasons why participatory research related to transgenics is needed. First, collaborative and farmer-led decisions about whether to use genetic engineering require that farmers and researchers understand each other's vocabulary and typologies and have at least a rudimentary grasp of each other's expertise. Second, given the biosafety and environmental concerns surrounding transgenic products, it is important that farmers be aware of these issues. If farmers are not aware of these concerns, scientists may implicitly assume that they have no preference for one technological approach over another. Third, the ability of genetic engineering to allow the development of entirely new traits and plant types requires researchers to understand and identify new options, some of which may be identified only through participatory research with farmers.

To date, very few priority-setting exercises with resource-poor farmers have led to the implementation of biotechnology-assisted research. One area in which biotechnology tools could be particularly useful is in plant breeding. Tools such as marker-assisted selection, inducible promoters, controllable male sterility, inducible apomixis and visual markers provide greater flexibility in local breeding and increase the range of varietal options from which farmers can choose. Pingali, Rozelle and Gerpacio (2001) developed a methodology for eliciting farmers' preferences using an experimental voting method. The methodology allows for quantitative estimates of preferences and the socio-economic determinants of adoption. They find that farmers have strong preferences for certain technologies, in particular those that conserve scarce factors of production or maximize farm income, but are ambivalent about others.

For participatory biotechnology research to be successful, certain conditions need to be met. Perhaps the most important of these are that the information on proposed technologies is conveyed clearly and that there is sustained communication among biotechnologists, plant breeders and farmers. Although participatory research is focused on the improvement of local livelihoods, one must not lose sight of the fact that basic and applied research is still useful and needed. Even basic research must carefully address the issues raised by farmers, but it may call for greater collaboration between social scientists and biological scientists to translate the needs of farmers into priorities for basic research.

organized representatives who can lobby for their interests when government research resources are being allocated. Yet there are NGOs, charities, foundations and some donors that are specifically focused on the poor. These groups need to be mobilized to support agricultural research – conventional and biotechnology – on poor peoples' problems. Programmes such as participatory breeding (Box 26) that involve citizens in decision-making on the technology can help direct public research to the issues that are important for poor farmers.

More studies are needed on the economic, environmental and health impacts of biotechnology and alternative technologies, particularly for the poor. Such research can help answer some of the remaining scientific questions about the safety and efficiency of transgenic crops and can help people compare them with existing alternative production systems. Programmes that educate farmers and consumers about the potential benefits and risks of biotechnology can empower people to make informed choices. In addition, transparent biosafety regulations can help ensure that appropriate regulatory decisions are made and can reassure people that they are protected from unacceptable risks.

Although there is a need for countries to develop their national agricultural research capacity in order to evaluate and adapt biotechnology innovations, it is neither necessary nor economically rational for every developing country to establish capacity in the more advanced biotechnology research approaches. The capacity needed to use technology is different from the capacity needed to generate technology. Countries should strategically evaluate their research capacity and focus their efforts on ensuring at least a minimum capacity to evaluate biotechnologies and adapt imported technologies. Certainly, there are numerous small countries that lack the capacity for even this type of research.

There may be some potential for the larger developing countries – Brazil, China, India and South Africa – to become regional suppliers of biotechnology research for smaller countries. The advantages of clustering research efforts for countries with similar agroclimatic conditions are obvious, and each of these countries has significant research capacity in both basic and agricultural science. Of these countries, however, only China has experience with public-sector delivery of a transgenic product; in fact, Brazil and India have only recently approved GMOs for commercial use. There is no indication that the public sector in any other country will soon become a major player, and no other country has yet benefited from biotechnology discoveries made in China.

The lack of institutional arrangements for sharing intellectual property is a large hurdle to be overcome in the transfer of technologies from one national public-sector institution to another. Contrary to the pace at which private-sector companies now share intellectual property, there is scant experience anywhere in the world where public-sector institutions have the flexibility or the motivation to achieve such exchanges. This implies that a radically new mindset and new institutional arrangements would need to emerge before the sharing of intellectual property could become sufficiently routine to allow smaller countries to depend on their large public-sector neighbours to supply useful research outputs. At present, except for germplasm being shared within the CGIAR networks, there is very little cross-border sharing of technology between public-sector institutions, probably because of a lack of incentives for public officials to negotiate such arrangements, but also because of the implicit competition among countries in international commodity markets.

Stimulating private research to focus on the poor

Despite the evidence from the field trial data that first-generation research of private firms did not concentrate on the crops, traits and countries needed to make a difference for the poor, there is a considerable amount of biotechnology research in the private sector that is producing knowledge, research tools, genes and GM varieties that can be useful to the poor in developing countries. Such research includes the rice genome research financed by Monsanto and Syngenta and the functional genomics research on rice that will identify what genes and groups of genes do in rice and other grains. Research of this type will probably require public-sector plant breeding to produce actual varieties for the poor, but with some changes in appropriability the private sector could play a role. This section explores some options that could increase the incentives for private-sector biotechnology and plant breeding firms to pursue research and product development more specifically targeted to the poor.

One scenario under which the private sector could become a more reliable source of biotechnology innovations for developing countries is that in which the large-market developing countries, i.e. Brazil, China, India and South Africa, became more "GMO friendly". If these countries were to achieve stable regulatory and IPR regimes and GMO products were accepted by consumers in these large markets, the private sector would very likely make substantial research and development (R&D) investments in developing GMO products for their significant agricultural problems. These four countries have a combined seed market of about $5 billion. Products developed for these markets would then become available for neighbouring countries that have mounted the necessary biosafety regulatory and IPR enforcement capacity. Once the private sector had developed useful products for farmers in the tropical and semi-tropical regions of these countries, they could begin marketing them in other countries with similar agro-ecological conditions.

In addition to the measures needed to promote access to the technological innovations discussed above, governments can take other steps to encourage private-sector investment in agricultural research for the poor. These steps would reduce the costs of research and technology development, increase the potential market size for biotechnological innovations and provide direct incentives to address the problems of the poor.

Governments can reduce the cost of research by using public-sector research universities that produce highly skilled scientists. Cooperative research programmes with universities in the developed world could enable universities in developing countries to gain access to knowledge, research tools and germplasm for research on problems of the poor.

Easing restrictions on foreign direct investment can attract more resources for research and technology transfer, and easing restrictions on trade in inputs required for research, such as chemicals, can reduce research costs. Small local firms may also need government assistance in gaining access to proprietary technology.

In addition to providing commercial incentives for private research to assist the poor, governments can show goodwill by providing positive publicity, perhaps in the form of prizes to firms that develop and spread technology to the poor. The introduction of tax incentives or better investment opportunities for private firms that invest in the needs of the poor are also possibilities. In the United States and elsewhere, private foundations and charitable organizations such as the Rockefeller Foundation have been established and have grown in part because of tax incentives.

Another possibility for providing incentives to the private sector to conduct more research is a major prize programme for agricultural technology that reduces poverty or food insecurity (Lipton, 2001). Such a competition would focus on crops of major importance to the poor; both public and private institutes could compete and the monetary prizes would be large enough to make it worthwhile for firms to compete. The prize money could come from a combination of government and private foundations. The $200 million programme funded by the Bill and Melinda Gates Foundation for research on diseases that cause millions of deaths in developing countries that was recently announced offers a possible model for funding such a programme.[10]

Public–private partnerships

In many cases, public- and private-sector entities could work together more effectively so that each focuses on its area of expertise and capitalizes on the contributions of the other. The question that needs to be asked is whether incentives exist, or can be created, for public/private-sector partnerships that allow the public sector to use and adapt

[10] See their Web site at http://www.gatesfoundation.org.

technologies developed by the private sector for the problems faced by the poor. Can licensing agreements be designed that will allow private-sector technologies to be licensed to the public sector for use in relating to problems of the poor? Pingali and Traxler (2002) suggest that the public sector may have to purchase the right to use private-sector technology on behalf of the poor.

A recent review of the options for accessing biotechnology highlighted the possibilities for partnerships between public NARS, local seed companies, global companies and the CGIAR (Byerlee and Fischer, 2002). This section summarizes some of the key points of the review and then focuses specifically on the few successful cases of transferring biotechnology to farmers and developing new technologies.

Public-sector access to patented biotechnology genes and tools

There are at least five ways in which public research institutes or local firms can obtain patented biotechnology genes and tools. First, they can simply use the technology without seeking permission from the owner. For technologies that are easily copied or fully revealed in patent disclosures, it may be efficient and legal for scientists to do this if no patent on the invention has been filed in the country or if the technologies are excluded from patent coverage. Many important biotechnology tools are widely patented, however, especially in countries with well-developed NARS, and products made using proprietary tools would not be exportable to markets where they are patented. Nevertheless, where patents are not in force and for goods that are not traded, this could be an option.

A second option is to purchase the technology. The public sector may have the most success in purchasing these technologies from universities or small private companies. For example, a consortium of public research institutes in Asia, led by IRRI, purchased the rights to a Bt gene from a small Japanese biotechnology company (Byerlee and Fischer, 2002). However, few key technologies will be available for purchase.

Material transfer and licensing agreements are a third possibility. Material transfer agreements (MTAs) define the conditions for research use and leave the conditions for commercialization to a future date. Initially this method is cheaper, but there is the risk that the company that undertakes the research will not be allowed to commercialize the technology developed later. Licensing agreements, on the other hand, specify the conditions for commercialization of a technology, the payments and the sharing of benefits. They are probably the most common mechanism for technology and knowledge transfer (although in some countries the first option, used without permission, is more frequent).

Alliances and joint ventures are the fourth possibility. In joint ventures both parties agree to provide specific assets and to share the benefits; joint venture contracts typically include MTAs and licensing agreements on technology. There is a growing consensus that partnerships between the public and private sectors will be needed to use biotechnology effectively for the poor in developing countries (Byerlee and Fischer, 2002; Pingali and Traxler, 2002).

A fifth possibility is that certain technologies could be donated for humanitarian use. Many technologies could be used to meet the needs of the poor, but the markets are too small to be profitable for large private firms. Firms might be willing to donate their technologies, but they would want to retain their patent rights for use in places where they can be profitable. If markets can be segmented such that the public sector has the rights to use any technology that is provided by the firm or is jointly developed to serve the resource-poor farmers, and the private sector is given the rights to sell the technology to commercial farmers, then the two groups can have the basis for a partnership. A number of agreements of this type (which segment the world by crop, by region, by country income level and by trade status) have been negotiated, notably for Golden Rice, but none has yet been tested to see how they work. The experience with Bt cotton and HT soybeans suggests that it will be very difficult to segment markets by certain traits effectively.

Elements of successful partnerships

To negotiate successful partnerships, partners have to identify their goals, value their assets,

TABLE 11
Values and assets of public and private sectors in agri-biotechnology research

	Public sector	Private sector
Performance measure	Social benefits including share to poor producers and consumers	Profits
National-level organizations	Public NARS	Local seed companies
Key assets	Local diverse germplasm	Local knowledge
	Local knowledge	Breeding programmes and infrastructure
	Breeding and evaluation programmes and associated infrastructure	Seed delivery system
	Access to delivery system including extension	Marketing network
	Upstream capacity in Type I NARS	
	Positive public image	
Regional and global-level organizations	CGIAR International Centres	Global life science companies
Key assets	Diverse germplasm	Biotechnology tools, genes, knowledge
	Breeding programmes and associated infrastructure	Access to capital markets
	Global germplasm exchange and evaluation networks	Economies of market size
	Economies of market size	Skills in dealing with regulatory agencies
	Upstream capacity in a few centres	Possible negative public image
	Generally positive public image	

Source: Byerlee and Fischer, 2002.

identify complementarities and identify the potential to segment markets for the different partners (Byerlee and Fischer, 2002). Partners must also recognize their different cultures and values – public research attempts to maximize social benefits whereas private firms maximize profits. To reach a partnership agreement requires negotiations.

Table 11 identifies the research assets of the different groups that might be partners in a public–private joint venture. The strongest assets of public research institutions tend to be their germplasm, variety assessment infrastructure and (in the stronger NARS) the capacity to conduct upstream research. They generally also have a positive public image, which can be an important asset. Private local firms have local knowledge, breeding programmes, and seed marketing and delivery systems. Transnational companies have the biotechnology, access to capital markets, economies of market size and skills in dealing with regulatory agencies. The CGIAR institutes have germplasm, breeding programmes, global germplasm exchange, etc. Assets such as germplasm and genes are clearly complementary assets. For example, Embrapa (Brazilian Agricultural Research Corporation) has used its soybean germplasm assets to development a partnership with Monsanto to obtain Roundup Ready® genes and plant transformation technology. Together they have produced a series of Roundup Ready® soybean varieties tailored for the Brazilian market.

Examples of public–private partnerships

Public- and private-sector institutions are experimenting with many different types of research partnerships and technology transfer arrangements. Only a few have been successful in developing useful technologies and these have been less successful in passing the technology on to the poor – primarily because of regulatory or other legal challenges that have delayed the commercial release of the products. Some of the more successful joint ventures are summarized below, together with some of the characteristics that they have in common.

The most successful examples of a joint venture that has been able to spread biotechnology to poor farmers are the Ji Dai and An Dai seed companies in China. Ji Dai is a joint venture between two companies based in the United States (Monsanto and D&PL) and the Hebei Provincial Seed Company in China. An Dai is a joint venture between the same United States companies and the Anhui Provincial Seed Company in China. These joint venture contracts provide that Monsanto supplies the Bt gene and D&PL provides the cotton varieties while Ji Dai and An Dai provide the variety testing, seed multiplication, and seed distribution networks in their respective provinces and beyond. Ji Dai and An Dai sales of Bt cotton seed now total about 2 000 tonnes and the total area planted with their Bt varieties – including farmer-saved seeds and unauthorized sales by other seed companies – is over 1 million ha. All of their seed sales go to small farmers (under 2 ha), although not always to poor farmers. Approximately two-thirds of the households that adopted Bt cotton had per capita annual incomes of less than $360, converted at official exchange rates (see Chapter 4 for an analysis of the economic impacts of Bt cotton in China).

The incentives for participating in these joint ventures were money and perhaps some publicity. The United States companies hoped that the provincial government-owned seed companies would provide them with the political weight they needed to ensure that their GM cotton varieties were approved by the Biosafety Committee and put into commercial production. They also hoped that the provincial seed companies would provide them with some market power so that they could charge high enough prices to make a profit. Their first hope seems to have been fulfilled as they were able to obtain approval for their varieties in some (but not all) provinces. However, their second hope of gaining market power appears to have been more difficult to fulfil. The provincial seed companies were also looking for new money-making opportunities. Previously, cotton seed had not been a commercially interesting enterprise, but introducing the Bt gene greatly increased the value of the cotton seed that contained it. They could now make money from the seed. In addition, the provincial authorities were able to revive an important cash crop that had been declining as a result of severe pest attacks.

Another project that successfully targets poor farmers is Bt cotton adoption by small farmers in Makhathini Flats in South Africa. This land is located in an area that forms part of a government irrigation project where all of the growers are small African farmers and many do not have access to irrigation. Monsanto, D&PL and Clark[11] (the major cotton purchasing and ginning company in South Africa) made special investments in technical personnel and other resources to teach small farmers how to use Bt cotton profitably. They also worked with the local government research station and government extension service, and provided credit for inputs and labour costs of cotton production. The money for this credit in the early years came from the government Land Bank and the interest rate was fixed by the government. Virtually all cotton farmers in Makhathini Flats have adopted Bt cotton and most appear to have made substantial gains in income as a result of it (see Chapter 4 for an analysis of the economic impacts of Bt cotton in South Africa).

The incentive for private South African firms to participate in this programme seems to derive from a combination of political and social goals. The South African Government is putting pressure on all private firms to undertake more social welfare projects. The success of Bt cotton in Makhathini Flats has provided excellent publicity for the companies involved. It is highly unlikely that the increased income that the project makes from the sales of Bt seed would cover all the research and extension resources that the firms have invested. However, what they are getting is valuable experience in developing strategies to work with poor small farmers in Africa.

[11] Clark is owned by the farmer cooperative OTK. Clark, in turn, owns Vunisa, which deals directly with the farmers in Makhathini Flats.

Examples of successful technology development

Brazil provides a number of examples of collaboration in research and technology development that may be replicable in other countries with large public and private research capacity. The joint venture between Embrapa and Monsanto on transgenic soybeans, mentioned above, is an example of collaborative applied research. Embrapa provides the varieties and some plant transformation technology and Monsanto provides the genes and most of the transformation technology. Monsanto plans to sell the GM soybeans through its dealer system and Embrapa will receive royalties from the sales. A portion of the sales will go back to a research fund for sustainable soybean production.

A second type of collaborative research occurs when private firms or cooperatives in developing countries hire individual scientists or rent laboratories at universities or government institutions in a collaborative effort. For example, the Cooperative of Cane, Sugar and Ethanol Producers of the State of São Paolo (COPERSUCAR) developed transgenic, virus-resistant sugar-cane varieties by hiring researchers at the University of São Paolo at Campinas, the University of Minnesota and Texas A&M University to perform specific parts of the research that they could not do in-house. As a result of this collaboration, COPERSUCAR has developed virus-resistant sugar cane that has been tested by its biosafety regulators and is ready for production when officially approved (Pray, 2001).

Several of the smaller but more advanced NARS have had successful partnerships with large firms to develop new technology. Egypt provides one useful example of a public–private joint venture in research (Byerlee and Fischer, 2002). In this case the Agricultural Genetic Engineering Research Institute (AGERI), an Egyptian public research institute, and Pioneer Hi-Bred jointly developed a new Bt gene. In the collaboration, the Egyptian public system gains access to expertise to develop the local strain of Bt (the innovation) and to educate its staff. The private sector partner pays the legal costs of patenting the invention and has access to the new Bt strain for use in markets outside Egypt.

Another example is the Monsanto and the Kenya Agricultural Research Institute collaboration on virus-resistant sweet potatoes, which began more than a decade ago. Monsanto provided the gene and trained a Kenyan scientist in biotechnology. Virus-resistant varieties are now in field trials and the commercial release of this technology is possible in the next few years.

Promising examples of collaboration

For smaller countries with less well-established NARS, the international research centres of the CGIAR system or regional intellectual property holding companies may be the only source of transgenic technology. The international centres have entered into a limited number of joint ventures to secure access to specific technologies for the poor. Examples include: the Kenya, CIMMYT and Syngenta project to develop Bt maize for eastern Africa; IRRI's collaboration with European government laboratories and Syngenta to develop Golden Rice; and the international collaboration on rice genomics led by IRRI (Byerlee and Fischer, 2002).

Recently, several new multicountry programmes to obtain access to technology for the poor have been initiated. The African Agricultural Technology Foundation (AATF) is a non-profit corporation funded initially by the Rockefeller Foundation. It will license and hold technology from the major biotechnology firms with a humanitarian use licence and subsequently provide the technology free to scientists in poor African countries.[12] In addition, the Australian-based institute, CAMBIA (Center for the Application of Molecular Biology to International Agriculture), is making information about patented technology more readily available and developing non-proprietary technologies for biotechnology researchers in poor countries.[13] Another recent initiative is the proposed IP Clearing-House programme in the United States, which has the goal of making intellectual property from universities and government research institutes more readily available. This programme seeks to design a toolbox of

[12] See their Web site at http://www2.merid.org/AATF.
[13] See their Web site at http://www.cambia.org.

biotechnologies for public-sector researchers in industrialized and developing countries at an affordable rate (Graff and Zilberman, 2001).

Elements of successful collaboration

The joint ventures that have actually transferred technology or produced new technology have had several characteristics. First, both parties had something substantial to gain from the collaboration. The gains do not have to be financial, although financial gains may provide the strongest incentives for long-term collaboration. Second, governments had the political will and ability to negotiate with private firms; in many countries this can be very difficult because of mistrust of the private sector and inexperience. Third, both parties had to make long-term, sustained investments of time and money; research and the development of new products always takes longer than expected. Fourth, joint ventures required a budgetary commitment from the public-sector partners, which in the cases in Egypt and Kenya were financed by foreign donors. Fifth, for weaker national systems some type of broker such as the International Service for the Acquisition of Agri-biotech Applications (ISAAA) or a CGIAR institute may be important in matching the technology with the needs of the country. The number and variety of joint ventures is growing rapidly. A systematic study into what makes successful joint ventures work could be extremely useful at this time.

Conclusions

The dominance of the private sector in agricultural biotechnology research and commercialization has raised a number of concerns about who will benefit from biotechnology. The available empirical evidence on the impact of transgenic crop research in developing countries shows that resource-poor farmers can benefit from GM crops if the crops address their needs and if they have access. This chapter suggests three groups of policies that would provide more technology to the poor.

First, policies are needed to encourage private investment in research and marketing biotechnology applications that meet the needs of the poor. These include commercial incentives such as more efficient biosafety regulations and stronger IPRs, government incentives for research for the poor, and financial prizes for research and technology for the poor.

Second, more public research is needed on the problems of the poor. Sustainable public biotechnology research for the poor requires the development of groups that will lobby for the poor. With leadership from local antipoverty groups and donors who are committed to reducing poverty, effective local support for public research to reduce poverty might be built. International support for the IARC biotechnology research programmes is also essential and we hope can be strengthened when the IARC biotechnology programmes start to prove their usefulness through the development of new technology for farmers.

Third, public–private joint ventures are needed to make efficient use of the propriety technology developed by the private and public sectors in industrialized countries. Governments can take a number of actions to facilitate such joint ventures.

Fourth, investments have to be stimulated first in strengthening national capacity to develop varieties (plant breeding) and seed systems; only then will investments in biotechnologies produce the expected results for poor farmers.

These steps could be helpful, but they are no guarantee that the resulting technologies would ever reach the poor. Given that conventional technologies available today have not yet reached the poorest farmers' fields, the new biotechnologies may not fare any better. Are there any policy interventions that will improve the situation? Identifying factors that impede small farmers' access to and use of technology continues to be an issue that the development community must deal with. Investments in biotechnology research capacity for the public sector will only be worthwhile if the current difficulties in delivering conventional technologies to subsistence farmers can be reversed.

8. Capacity building for biotechnology in food and agriculture

The case studies examined in Chapter 4 revealed that small farmers in developing countries can benefit from transgenic crops, as they have done in the past from other productivity-enhancing technological innovations. However, these gains are not automatic. Nations need adequate policy and institutional/technical capacity to deliver them and farmers need access to suitable innovations on affordable terms. Unlike the Green Revolution, which was based on an explicit strategy of the international transfer of improved technology as a free public good, almost all transgenic crop varieties and most other agricultural biotechnology innovations are being created and disseminated by the private sector. Chapter 7 addressed some strategies to increase public and private research and partnerships that focus on developing technologies to address the problems of the poor.

However, several barriers stand in the way of biotechnology reaching resource-poor farmers and especially the poor countries that could benefit substantially from these innovations. Safe and informed use of biotechnology requires adequate capacity for policy formulation, agricultural research, financial resources and marketing channels, as well as a framework for intellectual property rights and the capacity to handle the regulatory matters regarding food safety, human and livestock health, and environmental safety. Although biotechnology is evolving rapidly and is poised to play a fundamental role in further agricultural and economic development, there remains a large gap in most developing countries and especially among the least developed in their ability to assess their specific circumstances, meet their commitments and benefit from the opportunities that may arise from biotechnology. There is often a policy vacuum and inadequate capability to comply with the international instruments relating to biotechnology.

The most frequent problems encountered by developing countries and countries in transition are:

- insufficient capacity within ministries and their institutions to analyse options, set priorities for investment and formulate policies for national deployment of biotechnology in food and agriculture that support national development goals;
- limited technical, legal and administrative capability to establish and implement regulatory procedures, including biosafety, risk assessment and intellectual property rights, protection of indigenous knowledge and local resources, and communication to raise public acceptance of new technologies; and
- limited resources and capabilities to design, establish and operate infrastructures needed to generate, adapt, transfer and regulate biotechnology applications in food and agriculture, including enabling environments for furthering collaboration between the public and the private sectors.

National capacities in agricultural biotechnology

Strong and dynamic capacity at the technical, institutional and management levels is the most important requisite for successful and sustainable application of biotechnology in food and agriculture. However, developing countries and countries with economies in transition vary widely in their capacity to manage agricultural biotechnology effectively. In particular, they span a wide spectrum in their capacities for agricultural biotechnology research and regulatory management, including intellectual property rights.

In recent years, there has been a steady development of agricultural biotechnology capacity in several of the larger countries, notably in Brazil, China and India, where human and financial resources allocated to biotechnology R&D are relatively high and experience in the commercialization of biotechnology products is growing. Where governments have made substantial investments in public-sector agricultural biotechnology research in the developing world, several common themes emerge. First, they have gradually built a strong scientific base in agricultural research and biotechnology. Their national research institutes are encouraged to be actively involved in bilateral and international collaborative research programmes in diverse fields of agricultural biotechnology. Second, in their national policies they have specifically identified science and technology, and biotechnology in particular, as an important engine of economic growth both for agriculture and for the health sector. Third, their public agricultural research programmes have had substantial success in promoting rapid agricultural growth. These countries have seen the explosive growth of information technology and its contributions to their economies and hope for similar growth through medical and agricultural biotechnology.

Towards the middle of the spectrum are those developing countries that are now beginning to incorporate biotechnology increasingly in their agricultural research programmes, for instance Egypt and Indonesia. These countries generally have moderately strong conventional agricultural research capacity and are developing strong biotechnology capacity in several areas.

Further towards the other end of the spectrum are those countries that have not advanced far in direct application of the tools and techniques, except for applications of simpler techniques such as micropropagation and tissue culture. Again, these countries have several things in common. Research efforts are less advanced and often several related programmes are scattered over a wide range of products and institutes. The programmes are often heavily dependent on donor funding and run the risk of drying up as soon as the funds are exhausted. Furthermore, the marketing and management of biotechnology products are virtually absent, as is the critical mass required to raise public awareness. In many instances, governments do not accord sufficient priority to agricultural research, and policies to support agricultural research in general and agricultural biotechnology in particular are either lacking or not implemented. Because advancements in agricultural biotechnology are severely constrained in these countries, potential payoffs from biotechnology research and development programmes remain low.

The recently launched FAO-BioDeC[14] is a database providing updated baseline information on the state-of-the-art biotechnology products and techniques that are in use or in the pipeline in developing countries and those with economies in transition. Currently, the database includes about 2 000 entries from 70 countries and focuses on research, testing and commercialization of specific crop technologies and products in developing countries. Although the data are limited, they do give an overview of the different stages of adoption and development of these technologies in different countries and regions and offer the possibility of identifying gaps, as well as potential partners for joint programmes in areas of common interest.

In addition to research capacity, countries also vary widely in their capacity to regulate biotechnology. The spectrum ranges from those that have well-developed IPR regimes and food safety and environmental safety regulatory procedures to those that have little or no capacity to manage these issues.

International capacity-building activities in agricultural biotechnology

A number of private, governmental, non-governmental and intergovernmental

[14] Available at http://www.fao.org/biotech/inventory_admin/dep/default.asp.

organizations are involved in one or more ways in capacity-building programmes in biotechnology. The focus areas include policy development assistance, research, technology transfer, biosafety measures and related regulatory oversight, development of associated legislation and creating public awareness. A wide range of activities are carried out for strengthening the policy, institutional and technical level of competence. Agencies involved in such initiatives are the International Service for National Agricultural Research (ISNAR) Biotechnology Service (IBS), the International Centre for Genetic Engineering and Biotechnology (ICGEB), the ISAAA, the Global Environment Facility (GEF), the United Nations Industrial Development Organization (UNIDO), USAID and many more. Although there is some overlap between the services offered by these organizations, each fulfils a certain function different to the others or places more emphasis on certain areas. There is no global information on the entire range of activities being carried out in agricultural biotechnology; however, the Biosafety Capacity Building database of the Biosafety Clearing-House[15] provides a good overview of the various project activities being carried out in this area around the world.

FAO role and assistance to member countries

FAO provides global fora to facilitate dialogue, and is a repository of statistical information. FAO can play a pivotal role in assisting Member Governments with science-based guidance on this subject as well as in standard-setting. Some of the key activities focused on biotechnology are as follows.

- Promoting international standard-setting bodies. FAO supports several agreements that have an important bearing on agricultural applications of biotechnology, particularly in relation to the WTO SPS and Technical Barriers to Trade (TBT) Agreements. These include the IPPC and the Codex Alimentarius Commission, and the International Treaty on Plant Genetic Resources for Food and Agriculture, which covers conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of benefits derived from their use.
- Capacity building through technical assistance and training. FAO is assisting member countries in building their legal and regulatory frameworks in harmony with international obligations; training and strengthening facilities and institutions for the appropriate and safe utilization of biotechnology for food and agriculture; developing their national legislations in this area; and building the capacity for participating in international negotiations on biotechnology to optimize national benefits. See Box 27 with regard to Bangladesh.
- Information dissemination. FAO provides objective, science-based information on agricultural biotechnology, collecting, analysing and disseminating information in five languages, including through the corporate Web site[16] and publications. This activity covers all aspects of biotechnology in food and agriculture, taking into consideration that member countries and their citizens need balanced and unbiased information on the potential benefits and risks of biotechnology.

Challenges in capacity building for agricultural biotechnology

Despite the range of capacity-building activities being carried out, much more needs to be done. The challenges faced are on a scale unlike those of other technological revolutions, including the Green Revolution in the 1960s and 1970s. For instance, any application of biotechnology requires a framework for safety including that of the environment and of human and animal health. There is a demand for equitable distribution of the benefits

[15] Available at http://bch.biodiv.org/Pilot/CapacityBuilding/SearchOpportunities.aspx.

[16] Available at http://www.fao.org/biotech/index.asp?lang=en.

BOX 27
FAO and capacity building in agricultural biotechnology in Bangladesh

In 2002, FAO and the United Nations Development Programme (UNDP) conducted an assessment of the status of biotechnology application in Bangladesh. Based on this assessment, the Government of Bangladesh formulated a National Programme for Biotechnology (NPB), which aims to utilize biotechnology as an important complementary route to fight food insecurity and poverty, two pressing problems of the nation. The NPB will promote awareness at all levels; establish and implement appropriate policies, strategies and partnerships; strengthen investment, institutional and market support; and undertake focused and integrated biotechnological research and development. The key components of the NPB are:

- **National Policy for Biotechnology, its implementation and governance**. Address the technological and enabling aspects of biotechnology application. A National Taskforce for Sustainable Biotechnological Development (NTSBD), under the chairmanship of the Principal Secretary of the Office of the Prime Minister, will ensure that the policy is being effectively implemented. The NTSBD will provide transparent and efficient governance and build the required confidence in all stakeholders.
- **Enabling regulatory measures.** Legislative and regulatory frameworks for IPR, TRIPS, biosafety, and access to and negotiations on new technologies and products, consistent with the national needs and farmers' aspirations and rights, will be established and strengthened. Effective containment facilities, risk analysis, other biosafety-related capacities and human resources to manage regulatory aspects have high priority. The introduction, evaluation and commercialization of "Golden BR 29" (an elite Bangladeshi rice variety transformed at IRRI for high beta-carotene content) will be showcased to strengthen the national capacity in instituting and handling regulatory measures.
- **Institutional strengthening.** Biotechnological R&D institutions in the country will be strengthened by equipping them with state-of-the-art infrastructure, centralized facilities, suitably trained human resources, information and communication facilities and by fostering public–private partnerships. The capacity of NTSBD will be augmented for priority-setting, system-based decision-making, handling of issues in a disaggregated manner, cementing research–extension–farmer–market links and for generating and allocating resources.
- **Biotechnology programmes.** The NPB, following effective monitoring and evaluation, will focus on ecotechnologies towards an evergreen revolution, especially addressing the problems of small farmers. The following areas have been prioritized: production and distribution of *in-vitro*-cultured propagules, molecular characterization of genetic resources, diagnostics and recombinant vaccine production, biocontrol of pests and diseases, production and commercialization of quality (fish) fingerlings, development of transgenics for resistance to biotic and abiotic stresses, nutritional and other quality attributes, and molecular marker-assisted selection.
- **Three developments to help Bangladesh realize its goal.** (a) For the first time, Bangladesh has created a budget line for biotechnology in its national budget; (b) in order to ensure high efficiency and interdepartmental cooperation and to avoid wasteful duplication of effort, the NTSBD is being chaired by the Principal Secretary of the Office of the Prime Minister; and (c) UNDP and other donors and international organizations have shown considerable interest in funding the new initiative.

from the genetic resources utilized for biotechnology. In addition, it is important to develop consensus within society on the use of biotechnology-based products through full and transparent participation of all stakeholders in decision-making. Some of the major challenges in adoption of biotechnology include:

- ensuring resources to cover the high costs of inputs and development;
- building an enabling environment for the promotion of biotechnology;
- integrating biotechnology with conventional research programmes;
- addressing corporate control, market power and distributional implications;
- ensuring consumer protection and acceptance; and
- enhancing the sustainability of biotechnology programmes.

These factors, either directly or indirectly, affect capacity building, retention of personnel, and the balance between public- and private-sector capabilities. Although not exclusive to biotechnology, the initial costs of developing these technologies may increase the difficulties. Developing countries need to avoid the trap of dependence and unsustainability in their biotechnology programmes. Government policies should establish mechanisms to encourage both public- and private-sector investment and participation in agricultural biotechnology. Public- and private-sector research should be consciously complementary and not competitive. The policy framework should not only promote the safe use of biotechnology but also ensure that policies are not a deterrent to investment by the private sector and to collaboration with external partners. In many developing countries such progressive institutional and organizational reforms are hampered by the absence of appropriate policies or their appropriate implementation.

Next steps

Recognizing the constraints, there is a conscious need to take a sustained, holistic, multistakeholder, participatory approach to realize the potential benefits of agricultural biotechnology. In developing countries, there is a greater need to ensure not just capacity creation but also its retention and enhancement. Capacity-building activities have to be carried out at all levels: to raise the awareness of policy- and decision-makers, to initiate necessary legal and regulatory frameworks, to enhance technical and regulatory capacity, and to revamp institutions if necessary. More importantly, there is a need for continuous assessment and deployment of competent human resources and institutional capacity so that, as biotechnology advances, the tools for its safe use are constantly evaluated, upgraded and applied. It appears to be a daunting task, but through a firm commitment and partnerships it can be achieved.

9. Conclusions: meeting the needs of the poor

One of the main messages emerging from this year's *State of Food and Agriculture* report is that biotechnology is capable of benefiting small, resource-poor farmers. The key question is how this scientific potential can be brought to bear on agricultural problems of developing-country producers. Biotechnology holds great promise as a new tool in the scientific toolkit for generating applied agricultural technologies, but it is not a panacea.

Although the evidence suggests that biotechnology is relevant to all areas of agriculture, the research and farm-level applications – with some exceptions primarily in the plant sector – are taking place primarily in developed countries. The challenge at present is to design an innovation system that focuses this potential on the problems of developing countries.

Agricultural production systems in developing countries are complex and diverse. Many producers are small-scale and resource-poor, and for such producers some biotechnology innovations may be inappropriate. For example, animal reproductive technologies such as artificial insemination or embryo transfer that are quite common in North America and Europe require capital infrastructure beyond the reach of the scale and scope of their farms. Transgenic crops, by contrast, may be relatively easy for farmers to adopt because the technology is embodied in the seed – rendering it the most scale-neutral and easily transferable form of agricultural technology. Modern biotechnology must be incorporated into agricultural research and development programmes that begin with breeding and improved management, not as stand-alone technologies.

A second important message of this issue of *The State of Food and Agriculture* is that some transgenic crops, especially insect-resistant cotton, are yielding significant economic gains to small farmers as well as important social and environmental benefits through the changing use of agricultural chemicals. The evidence to date suggests that small farmers as well as large farmers can benefit from the adoption of transgenic crops targeted towards insect resistance.

Even though transgenic crops have been delivered through the private sector in most cases, the benefits have been widely distributed among industry, farmers and consumers. This suggests that the monopoly position engendered by intellectual property protection does not automatically lead to excessive industry profits. The Bt cotton results in Argentina demonstrate that the balance between the intellectual property rights of technology suppliers and the financial means of farmers has a crucial impact on adoption of the products and hence on the level and distribution of benefits. The case of China clearly illustrates that public-sector involvement in research and development and in the delivery of transgenic cotton can help ensure that poor farmers have access to the new technologies and that their share of the economic benefits is adequate.

Overall, it is the producers and consumers who are reaping the largest share of the economic benefits of transgenic crops, not the companies that develop and market them. Research evidence from Argentina, China, Mexico and South Africa suggests that small farmers have had no more difficulty than larger farmers in adopting the new technologies. In some cases, transgenic crops seem to simplify the management process in ways that favour smaller farmers. Further research needs to focus on policies and incentive structures that ensure that these gains are sustained as larger numbers of farmers adopt the technologies. Time and more carefully designed studies are required to determine what the level and distribution of benefits from transgenic crops will be.

A third message is that the changing locus of agricultural research from the public sector to the private transnational sector has important implications for the kinds of products that are being developed, how those products are commercialized and who receives the benefits. Private-sector research naturally focuses on the crops and traits of commercial interest to farmers in higher-income countries where markets for agricultural inputs are robust and profitable.

Although private-sector agricultural research expenditures seem overwhelmingly large, the reality is that they are focused very narrowly on the development of biotechnology-related plant varieties, and even that only for a very small number of crops. A large part of the private-sector investment is concentrated on just four crops: cotton, maize, canola and soybean. Private-sector investment in the world's two most important food crops, rice and wheat, is insignificant in comparison.

Moreover, all of the private-sector investment is targeted towards the commercial production sector in the developed world, with some spillover benefits flowing to the commercial sector in the developing world. The public sector, with its increasingly meagre budget, is left to take care of the research and technology needs of the subsistence farming sector, as well as being the only source of supply for conventionally bred seed as well as crop and resource management technologies.

Agricultural public goods, such as crops and traits of importance to subsistence farmers in marginal production environments, are of little interest to large transnational companies. The data on transgenic crop research show that the needs of resource-poor smallholders are being neglected, and the data on commercialization are even more dramatic. One of the lessons of the Green Revolution is that agricultural technology can be transferred internationally, especially to countries that have sufficient national agricultural research capacity to adapt the high-yielding cultivars developed by the international public sector for local production environments.

So how will farmers in developing countries be able to capture economic spillover benefits from the transgenic crops developed and commercialized by the private sector? Private-sector investments in genomics and genetic engineering could be potentially useful in addressing the problems faced by poor farmers, particularly those in marginal environments. Knowledge generated through genomics, for example, could have enormous potential in advancing the search for drought-tolerant crops in the tropics.

The question that needs to be asked is whether incentives exist, or can be created, for public–private sector partnerships that allow the public sector to use and adapt technologies developed by the private sector for the problems faced by the poor. How can licensing agreements be designed that will allow private-sector technologies to be licensed to the public sector for use on problems of the poor? Research presented in this report suggests that the public sector may have to purchase the right to use private-sector technology on behalf of the poor.

A fourth message from this report is that biotechnology is not a panacea, but a resource that can be useful when combined with adaptive research capacity. Regulatory regimes matter. Biosafety processes need to be in place. Countries that lack biosafety protocols or the capacity to implement them in a transparent, predictable and trusted way may not have access to the new technologies. Where crops have not been cleared through biosafety risk assessments that take into consideration local agro-ecological conditions, a greater risk of harmful environmental consequences exists. Additionally, unauthorized varieties may not provide farmers with the expected level of pest control, leading to continued need for chemical pesticides and a greater risk of the development of pest resistance.

A final message is that the environmental effects in terms of pesticide reduction can be positive. In the case of Bt cotton, the environmental outcomes have been strongly positive. In virtually all instances, insecticide use on Bt cotton is significantly lower than on conventional varieties. Furthermore, for herbicide-tolerant soybeans, glyphosate has been substituted for more toxic and persistent herbicides, and reduced tillage has accompanied herbicide-tolerant soybeans and cotton in many cases. Negative environmental consequences, although meriting continued monitoring, have not been documented in any setting where transgenic crops have been deployed to date.

So how can the Gene Revolution reach those left behind? First, by overcoming production constraints that are intractable with conventional breeding, biotechnology can speed up conventional breeding programmes and provide farmers with disease-free planting materials. Second, biotechnology can develop crops that resist pests and diseases, replacing toxic chemicals that harm the environment and human health. Third, biotechnology can develop diagnostic tools and vaccines that help control devastating animal diseases. Finally, biotechnology can improve the nutritional quality of staple foods such as rice and cassava and create new products for health and industrial uses.

The problem is that biotechnology cannot overcome the gaps in infrastructure, regulation, markets, seed systems and extension services that hinder the delivery of agricultural technologies to poor farmers in remote areas. Neither can it overcome the institutional failures, market failures and policy failures that hinder all efforts to promote agricultural and rural development in many countries. A great deal needs to be done so that developing-country producers are empowered to make their own decisions regarding these technologies for their own benefit.

Given that technologies that are on the shelf today (generated by conventional research methods) have not yet reached the poorest farmers' fields, there is no guarantee that the new biotechnologies will fare any better. Identifying small farmers' constraints to technology access and use continues to be an issue that the development community must address. Investments in biotechnology research capacity for the public sector will only be worthwhile if the current difficulties in delivering conventional technologies to subsistence farmers can be reversed.

The six main lessons for ensuring that the potential benefits of agricultural biotechnology reach the poor areas are as follows:

- Biotechnology – including genetic engineering – can benefit the poor when appropriate innovations are developed and when poor farmers in poor countries have access to them on profitable terms. So far these conditions are only being met in a handful of developing countries.
- Biotechnology should be part of an integrated and comprehensive agricultural research and development programme that gives priority to the problems of the poor. Biotechnology is not a substitute for research in other areas such as plant breeding, integrated pest and nutrient management and livestock breeding, feeding and management systems.
- The public sector in developing and developed countries, donors and the international research centres should direct more resources to agricultural research, including biotechnology. Public-sector research is necessary to address the public goods that the private sector would naturally overlook.
- Governments should provide incentives and an enabling environment for private-sector agricultural biotechnology research, development and deployment. Public–private partnerships and other innovative strategies to mobilize research efforts for the poor should be encouraged.
- Regulatory procedures should be strengthened and rationalized to ensure that the environment and public health are protected and that the process is transparent, predictable and science-based. Appropriate regulation is essential to command the trust of both consumers and producers, but duplicative or obstructionist regulation is costly and should be avoided.
- Capacity building for agricultural research and regulatory issues related to biotechnology should be a priority for the international community. FAO has proposed a major new programme to ensure that developing countries have the knowledge and skills necessary to make their own decisions regarding the use of biotechnology.