From the Green Revolution to the Gene Revolution: How will the Poor Fare?

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Abstract

The past four decades have seen two waves of agricultural technology development and diffusion to developing countries. The first wave was initiated by the Green Revolution in which an explicit strategy for technology development and diffusion targeting poor farmers in poor countries made improved germplasm freely available as a public good. The second wave was generated by the Gene Revolution in which a global and largely private agricultural research system is creating improved agricultural technologies that flow to developing countries primarily through market transactions. The Green Revolution strategy for food crop productivity growth was based on the premise that, given appropriate institutional mechanisms, technology spillovers across political and agro-climatic boundaries can be captured. A number of significant asymmetries exist between developed and developing, e.g.: agricultural systems, market institutions and research and regulatory capacity. These asymmetries raise doubts as to whether the Gene Revolution has the same capacity to generate spillover benefits for the poor. A strong public sector – working cooperatively with the private sector – is essential to ensure that the poor benefit from the Gene Revolution.

Key Words: Agricultural Biotechnology, Agricultural Research, Technological Change, Economic Development.

JEL: O13, Q12, Q16.

1 Introduction

The past four decades have seen two waves of agricultural technology development and diffusion to developing countries. The first wave was initiated by the Green Revolution in which improved germplasm was made available to developing countries as a public good through an explicit strategy for technology development and diffusion. The second wave was generated by the Gene Revolution in which a global and largely private agricultural research system is creating improved agricultural technologies that are flowing to developing countries primarily through market transactions. Asymmetries between developed and developing countries in research capacity, market institutions and the commercial viability of technologies raise doubts regarding the potential of the Gene Revolution to generate benefits for poor farmers in poor countries.

The Green Revolution was responsible for an extraordinary period of growth in food crop productivity in the developing world over the last forty years. Productivity growth has been significant for rice in Asia, wheat in irrigated and favorable production environments worldwide and maize in Mesoamerica and selected parts of Africa and Asia. A combination of high rates of investment in crop research, infrastructure and market development, and appropriate policy support fueled this land productivity. These elements of a Green Revolution strategy improved productivity growth despite increasing land scarcity and high land values (Pingali and Heisey, 2001).

The transformation of global food production systems defied conventional wisdom that agricultural technology does not travel well because it is either agro-climatically specific, as in the case of biological technology, or sensitive to relative factor prices, as with mechanical technology (Byerlee and Traxler, 2002). The Green Revolution strategy for food crop productivity growth was explicitly based on the premise that, given appropriate institutional mechanisms, technology spillovers across political and agro-climatic boundaries can be captured. Hence the Consultative Group on International Agricultural Research (CGIAR) was established specifically to generate spillovers particularly for nations that are unable to capture all the benefits of their research investments. What happens to the spillover benefits from agricultural research and development in an increasingly global integration of food supply systems?

Over the past decade the locus of agricultural research and development has shifted dramatically from the public to the private multinational sector. Three interrelated forces are transforming the system for supplying improved agricultural technologies to the world's farmers. The first is the strengthened and evolving environment for protecting intellectual property in plant innovations. The second is the rapid pace of discovery and growth in importance of molecular biology and genetic engineering. Finally, agricultural input and output trade is becoming more open in nearly all countries. These developments have created a powerful new set of incentives for private research investment, altering the structure of the public/private agricultural research endeavor, particularly with respect to crop improvement (Pingali and Traxler, 2002).

Developing countries are facing increasing transactions costs in access to and use of technologies generated by the multinational sector. Existing international networks for sharing technologies across countries and thereby maximizing spillover benefits are becoming increasingly threatened. The urgent need today is for a system of technology flows which preserves the incentives for private sector innovation while at the same time meeting the needs of poor farmers in the developing world.

2 Green Revolution R&D: access and impact

The major breakthroughs in yield potential that kick started the Green Revolution in the late 1960s came from conventional plant breeding approaches. Crossing plants with different genetic backgrounds and selecting from among the progeny individual plants with desirable characteristics, repeated over several cycles/generations, led to plants/varieties with improved characteristics such as higher yields, improved disease resistance, improved nutritional quality, etc. The yield potential for the major cereals has continued to rise at a steady rate after the initial dramatic shifts in the 1960s for rice and wheat. For example, yield potential in irrigated wheat has been rising at the rate of 1 percent per year over the past three decades, an increase of around 100 kilograms per hectare per year (Pingali and Rajaram, 1999).

Prior to 1960, there was no formal system in place that provided plant breeders access to germplasm available beyond their borders. Since then, the international public sector (the CGIAR) has been the pre-dominant source of supply of improved germplasm developed from conventional breeding approaches, especially for self-pollinating crops such as rice and wheat and for open pollinated maize. CGIAR managed networks of international nurseries for sharing crop improvement results evolved in the 1970s and 1980s, when financial resources were expanding and plant IPR laws were weak or nonexistent.

The international flow of germplasm has had a large impact on the speed and the cost of NARSs crop development programs, thereby generating enormous efficiency gains (See Evenson and Gollin, 2003, for a global assessment of gains from the international exchange of major food crop varieties and breeding lines). Traxler and Pingali (1999) have argued that the existence of a free and uninhibited system of germplasm exchange that attracts the best of international materials allows countries to make strategic decisions on the extent to which they need to invest in plant breeding capacity. Small countries behaving rationally choose to free ride on the international system rather than invest in large crop breeding infrastructure of their own (Maredia, Byerlee and Eicher, 1994).

Evenson and Gollin (2003) report that even in the 1990s, the CGIAR content of modern varieties was high for most food crops; 36% of all varietal releases were based on CGIAR crosses. In addition, 26% of all modern varieties had a CGIAR-crossed parent or other ancestor. Evenson and Gollin (2003) suggest that germplasm contributions from international centers helped national programs to stave off the 'diminishing returns' to breeding that might have been expected to set in had the national programs been forced to work only with the pool of genetic resources that they had available at the beginning of the period.

Impacts of food crop improvement technology

Substantial empirical evidence exists on the production, productivity, income, and human welfare impacts of modern agricultural science and the international flow of modern varieties of food crops. Evenson and Gollin (2003) provided detailed information for all the major food crops on the extent of adoption and impact of modern variety use, they also show the crucial role played by the international germplasm networks in enabling developing countries to capture the spillover benefits of investments in crop improvement made outside their borders. The adoption of modern varieties during the first 20 years of the green revolution-aggregated across all crops-reached 9% in 1970 and rose to 29% in 1980. By the 1990, adoption of MVs had reached 46%, and by 1998 63%. Moreover, in many areas and in many crops, first generation modern varieties have been replaced by second and third generation modern varieties Evenson and Gollin (2003).

Much of the increase in agricultural output, over the past 40 years, has come from an increase in yields per hectare rather than an expansion of area under cultivation. For instance, FAO data indicate that for all developing countries, wheat yields rose by 208% from 1960 to 2000; rice yields rose 109%; maize yields rose 157%; potato yields rose 78%; and cassava yields rose 36% (FAOSTAT). Trends in total factor productivity (TFP) are consistent with partial productivity measures, such as rate of yield growth Pingali and Heisey (2001) provide a comprehensive compilation of TFP evidence for several countries and crops.

The returns to investments in high-yielding modern germplasm have been measured in great detail by several economists over the last few decades. These studies found high returns to the Green Revolution strategy of germplasm improvement. The very first studies that calculated the returns to research investment were conducted at IRRI for rice research investments in the Philippines (Flores-Moya et al. 1978) and at CIAT in Colombia (Scobie and Posada 1978). More detailed evidence on the high rates of return to public-sector investments in agricultural research was provided by the International Service for National Agricultural Research (ISNAR) (Echeverría 1990) and the International Food Policy Research Institute (IFPRI) (Pardey et al. 1992). For detailed synthesis of the numerous studies conducted across crops and countries, see Evenson (2001) and Alston et al. (2000). Alston et al. concluded from a review of 289 studies that there was no evidence that the rate of return to agricultural research and development has declined over time.

Widespread adoption of modern seed-fertilizer technology led to a significant shift in the food supply function, contributing to a fall in real food prices. The primary effect of agricultural research on the non-farm poor, as well as on the rural poor who are net purchasers of food, is through lower food prices.

Early efforts to document the impact of technological change and the consequent increase in food supplies on food prices and income distribution were made by Hayami and Herdt (1977), Pinstrup-Andersen (1976), Scobie and Posada (1978), and Binswanger (1980). Pinstrup-Andersen argued strongly that the primary nutritional impact for the poor came through the increased food supplies generated through technological change.

Several studies have provided empirical support to the proposition that growth in the agricultural sector has economy-wide effects. One of the earliest studies showing the linkages between the agricultural and non-agricultural sectors was done at the village level by Hayami et al. (1978). Hayami provided an excellent micro-level illustration of the impacts of rapid growth in rice production on land and labor markets and the non-agricultural sector. Pinstrup-Andersen and Hazell (1985) argued that the landless labor did not adequately share in the benefits of the Green Revolution because of depressed wage rates attributable to migrants from other regions. David and Otsuka (1994), on the other hand, found that migrants shared in the benefits of the Green Revolution through increased employment opportunities and wage income. The latter study also documented that rising productivity caused land prices to rise in the high-potential environments. For sector level validation of the proposition that agriculture does indeed act as an engine of overall economic growth see Hazell and Haggblade (1993); Delgado et al. (1998); and Fan et al. (1998).

Although the favorable, high-potential environments gained the most in terms of productivity growth, the less favorable environments benefited as well through technology spillovers and through labor migration to more productive environments. According to David and Otsuka, wage equalization across favorable and unfavorable environments was one of the primary means of redistributing the gains of technological change. Renkow (1993) found similar results for wheat grown in high- and low-potential environments in Pakistan. Byerlee and Moya (1993), in their global assessment of the adoption of wheat MVs, found that over time the adoption of MVs in unfavorable environments caught up to levels of adoption in more favorable environments, particularly when germplasm developed for high-potential environments was further adapted to the more marginal environments. In the case of wheat, the rate of growth in yield potential in drought-prone environments was around 2.5 percent per year during the 1980s and 1990s (Lantican and Pingali, 2003). Initially the growth in yield potential for the marginal environments came from technological spillovers as varieties bred for the high-potential environments were adapted to the marginal environments. During the 1990s, however, further gains in yield potential came from breeding efforts targeted specifically at the marginal environments.

3 The changing locus of agricultural R&D: from national public to international private sector

In the decades of the 1960s through the 1980s, private sector investment in plant improvement research was limited, particularly in the developing world, due to the lack of effective mechanisms for proprietary protection on the improved products. This situation changed in the 1990s with the emergence of hybrids for cross-pollinated crops such as maize, etc. The economic viability of hybrids led to a budding seed industry in the developing world, but the coverage of seed industry activity has been limited to date, leaving many markets under served. The seed industry in the developing world was started by multi-national companies based in the developed world, and then led to the development of national companies (Morris, 1998). Despite its rapid growth, the private seed industry continued to rely, through the 1990s, on the public sector gene banks and pre-breeding materials for the development of its hybrids (Morris and Ekasingh, 2001; Pray and Echeverría, 1991). The break between public and private sector plant improvement efforts came with the advent of biotechnology, especially genetic engineering. The proprietary protection provided for artificially constructed genes and for genetically modified plants provided the incentives for private sector entry.

The large multi-national agro-chemical companies were the early investors in the development of transgenic crops. One of the reasons that agro-chemical companies moved into crop improvement was that they foresaw a declining market for pesticides (Conway, 2000). The chemical companies got a quick start in the plant improvement business by purchasing existing seed companies, first in industrialized countries and then in the developing world.

The amalgamation of the national private companies with the multi-national corporations makes economic sense (Pingali and Traxler, 2002). The process of variety development and delivery is a continuum that starts at the upstream end of generating knowledge on useful genes (genomics) and engineering transgenic plants to the more adaptive end of backcrossing the transgenes into commercial lines and delivering the seed to farmers. The products from upstream activities have worldwide applicability, across several crops and agro-ecological environments. On the other hand, genetically modified crops and varieties are applicable to very specific agro-ecological and socioeconomic niches. In other words, spillover benefits and scale economies decline in the move to the more adaptive end of the continuum. Similarly, research costs and research sophistication decline in the progression towards downstream activities. Thus, a clear division of responsibilities in the development and delivery of biotechnology products has emerged, with the multinational providing the upstream biotechnology research and the local firm providing crop varieties with commercially desirable agronomic backgrounds (see Pingali and Traxler, 2002 for a more detailed discussion on this point).

The options available for public research systems to capture the spillovers from global corporations are less clear. Public sector research programs are generally established to conform to state or national political boundaries, and direct country-to-country transfer of technologies has been limited (Traxler and Pingali, 2002). Strict adherence to political domains severely curtails spillover benefits of technological innovations across similar agroclimatic zones. The operation of the CGIAR germplasm exchange system has mitigated the problem for several important crops, but it is not clear whether the system will work for biotechnology products and transgenic crops, given the proprietary nature of the technology.

Moreover, in the case of biotechnology innovations, the national and international public sector, do not have the resources to effectively create an alternative source of knowledge and technology supply. To understand the magnitude of private sector investment in agricultural research today, one need only look at its annual research budget relative to public research targeted to the developing country agriculture. The World's top ten multinational bioscience corporations' collective annual expenditure on agricultural research and development is nearly three billion U.S. dollars. In comparison the CGIAR, which is the largest international public sector supplier of agricultural technologies, spends less than 300 million U.S. Dollars annually on plant improvement research and development. The largest public sector agricultural research programs in the developing world, those of Brazil, China, and India, have annual budgets of less than half a billion dollars each (Byerlee and Fischer, 2001).

If we look at public expenditures for biotechnology alone, the figure comes out to be substantially smaller for the developing world as a whole. Public research expenditures on agricultural biotechnology (Table 1) reveal a sharp dichotomy between developed and developing countries. Byerlee and Fischer (2001) show that developed countries spend four times as much on public sector biotech research than developing countries, even when all sources of public funds – national, donor and CGIAR centers – are counted for developing countries. Developed countries also spend a higher proportion of their public sector agricultural research expenditures on biotech than developing countries or the CGIAR centers (Byerlee and Fischer, 2001).

The rapid growth of private sector investment in biotech research in developed countries means that private research expenditures now exceed public sector expenditures, both in absolute terms and as a share of total agricultural R&D expenditures. Comprehensive data on private sector biotech research in developing countries are not available, although partial evidence suggests that the private sector is less developed than in industrialized countries. Data for seven Asian countries show that private agricultural research is equivalent to about 10 percent of total public sector agricultural research (Pray and Fuglie, 2000). If this ratio is applied to all developing countries (probably an upper bound), we can estimate private sector research expenditures at about $1 150 million per year. If we assume that the share of biotech in total private R&D is the same as in developed countries (40 percent, also an upper bound), this gives us an estimate of $458 million in annual private sector biotech research in developing countries. A lower-bound estimate could build on the fact that the share of total public sector research devoted to biotech in the developing countries is about 8 percent. If we apply that ratio to the private sector expenditures, we get a lower-bound estimate of $92 million for private biotech in developing countries. Although it is likely that private sector investment is somewhere between these estimates, even the upper bound estimate is only about one-third the level of private sector investment in developed countries.

4 Emerging trends in biotechnology research, development and commercialization in the developing world

Only a few developing countries have highly sophisticated biotech research programs, but growing numbers have the capacity to adopt and adapt innovations developed elsewhere. Only three countries – China, India and Brazil – have extensive research programs in all areas of biotechnology, including advanced genomics and gene manipulation techniques (FAO BioDeC). According to IFPRI (2004) 15 developing countries have significant and growing capacity for biotechnology research, but these are typically more advanced countries such as Brazil, Argentina, and Egypt. Most of the least developed countries, however, have no documented research experience with genetically modified organisms and many have limited capacity for agricultural research of any kind (FAO BioDeC).

Many developing countries, including some higher-income countries, also lack regulatory capacity in the areas of intellectual property rights protection and biosafety procedures (food safety and environmental protection. Subsistence agriculture remains the dominant agricultural system in much of the developing world. The agricultural sectors of several more advanced developing countries exhibit a dualistic agricultural structure in which a few large very modern commercial farms coexist with many small subsistence farms. As a result, commercial markets for agricultural inputs and outputs remain weak, especially in the least developed countries, suggesting that the potential for commercial joint ventures between multinational biotech companies and local seed companies is limited to the more advanced developing countries.

Commercial cultivation of GM crops in the developing world

James (2004) reports that transgenic crops were commercially planted on 81 million hectares in 2004, in 17 countries, 12 of them developing. Developing countries accounted for 37 percent of the total global transgenic crop area in 2004, having increased consistently from 14 percent of 12.8 million hectares in 1997. Argentina, Brazil, and China are the largest developing country producers (Figure 2).

Herbicide tolerance and pest resistance remain the main GM traits that are currently under commercial cultivation and the main crops are soybean, maize, canola and cotton (Figure 3). In addition to these major crops, China also produces small quantities of virus resistant tomatoes and peppers, delayed ripening tomatoes and flower-color altered petunias.

Comprehensive data are not available on the origin of the GM varieties being planted in developing countries; however, the available evidence suggests that most of the GM varieties grown in developing countries in 2004 were developed by multinational companies for the developed country markets of North America or were adapted locally from imported varieties. China is the exception. China is the only developing country to have developed transgenic varieties in the public sector from a locally developed genetic transformation construct. (Pray and Naseem, 2003). In other countries, commercial GM crops are imported or locally adapted from imported varieties.

This evidence suggests that globalization and the international transfer of technology have been essential factors in promoting the commercial spread of GM crops in developing countries. It also suggests that developing countries that lack strong public sector research systems and/or strong commercial seed sectors will be handicapped in the adoption of transgenic varieties.

5 Accessing biotechnology knowledge and products for the poor

Unlike the green revolution technologies, transgenic technologies are transferred internationally primarily through market mechanisms, often through commercial relationships between the multinational bio-science firms and national seed companies. This system of technology transfer works well for commercially viable innovations in well-developed markets, but perhaps not for the types of innovations needed in developing countries: crops and traits aimed at poor farmers in marginal production environments. These “orphan” technologies have traditionally been the province of public sector research. Given the dominance of private sector research in transgenic crop research and meagre resources being devoted to public sector research in most developing countries, it is unlikely that public sector research can play this role for transgenic crops.

The options available for public research systems in developing countries to capture the spillovers from global corporations are limited. Public sector research programmes are generally established to conform to state or national political boundaries, and direct country-to-country transfer of technologies has been rare (Pingali and Traxler, 2002). Strict adherence to political domains severely curtails spillover benefits of technological innovations across similar agroclimatic zones. The operation of the CGIAR germplasm exchange system has mitigated the problem for several important crops, but it is not clear whether the system will work for biotechnology products and transgenic crops, given the proprietary nature of the technology.

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 for a very small number of crops. A large part of the private sector investment is concentrated on just four crops: cotton, corn, canola, and soybeans. Private sector investment on 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 meager 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.

Will the poor benefit from any of the technological advances that are taking place today in the private sector? Private sector investments in genomics and genetic engineering could be potentially very useful for addressing the problems faced by poor farmers, particularly those in the marginal environments. Knowledge generated through genomics, for example, could have enormous potential in advancing the quest 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. 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? 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.

Pingali and Traxler (2002) suggest three possible avenues for public sector institutions in developing countries to gain access to transgenic technologies: (i) directly import private- or public-sector transgenic varieties developed elsewhere, (ii) develop an independent capacity to develop and/or adapt transgenic varieties, and (iii) collaborate on a regional basis to develop and/or adapt transgenic varieties. The second option is the most costly and requires the highest degree of national research capacity, while the first option depends on the availability of suitable varieties developed elsewhere. The third option would require a higher degree of cooperation across national boundaries than has typically characterized public sector research. Pingali and Traxler (2002) ask whether incentives exist or can be created for public/private partnerships that allow the public sector to use and adapt technologies developed by the private sector.

Before considering the prospects for partnerships for accessing technologies in the pipeline it is important to conduct a detailed inventory of all prospective biotechnology products characterized by crop and by agro-ecological environments. Followed by an ex ante assessment of the impact each of these technologies could have on the productivity and livelihoods of the subsistence producers. The above assessment would lead to the identification of a set of products with high pro-poor potential that public/private partnerships could be built around.

Even if public-private partnerships could be developed, will the resulting technologies ever get to the poor? Given that technologies that are on the shelf today (generated by conventional research methods) have not yet reached farmers' fields, there is no guarantee that the new biotechnologies will fare any better. Are there any policy interventions that will make the situation any better? Identifying small farmer constraints to technology access and use continues to be an issue that the development community ought to deal with. This suggests a need for a third wave of globalization to ensure that international spillovers from the Gene Revolution make their way to the poor. 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.

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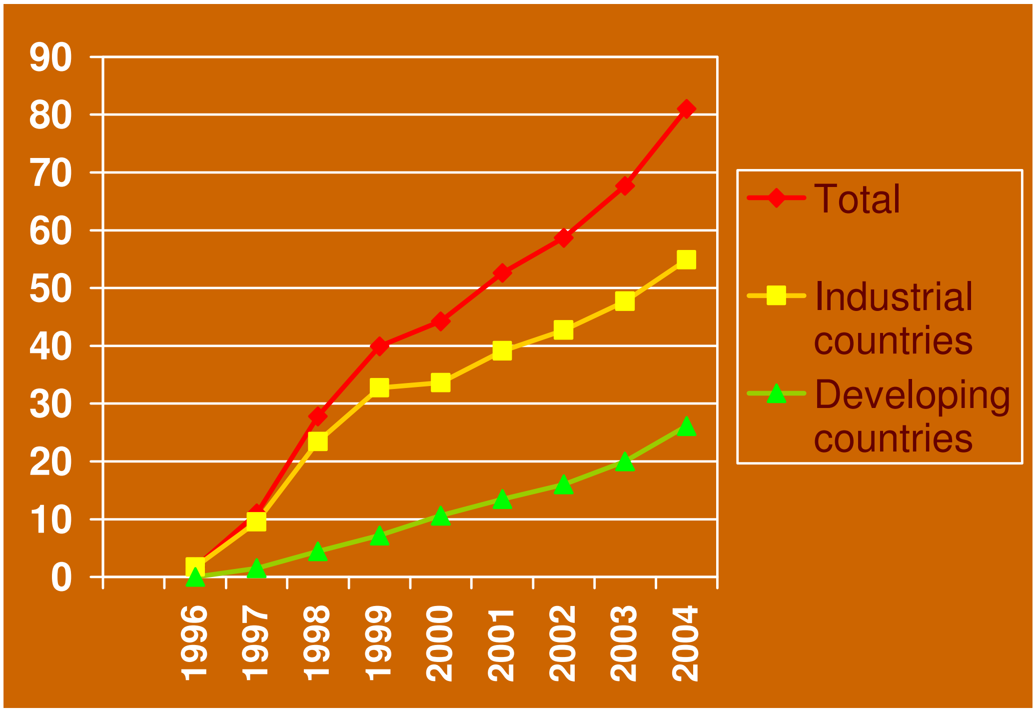
7 Tables and figures

Table 1: Estimated crop biotechnology research expenditures (million US dollars)

	Biotech R&D (million $/year)	Biotech as share of sector R&D
Industrialized countries	**1900-2500**	
Private sector*	1000-1500	40
Public sector	900-1000	16
Developing countries	**165-250**	
Public (own resources)	100-150	5-10
Public (foreign aid)	40-50	n.a.
CGIAR centres	25-50	8
Private sector	n.a.	n.a.
World total	**2065-2730**	

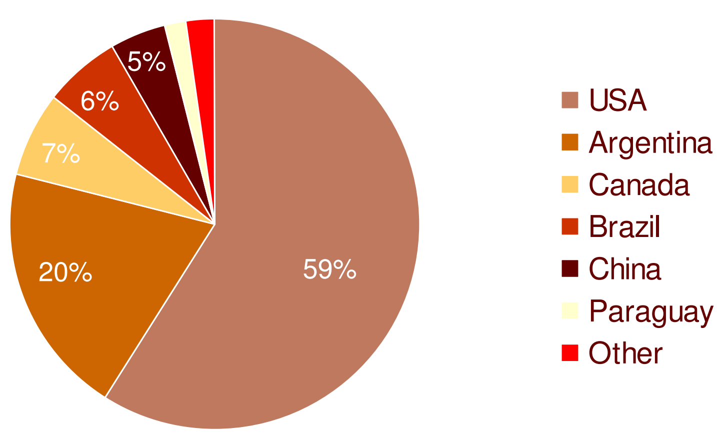
* Includes an unknown amount of R&D for developing countries
Source: Byerlee and Fischer (2001)

Figure 1: Global area of GM crops in 2004 (81.1 million ha)



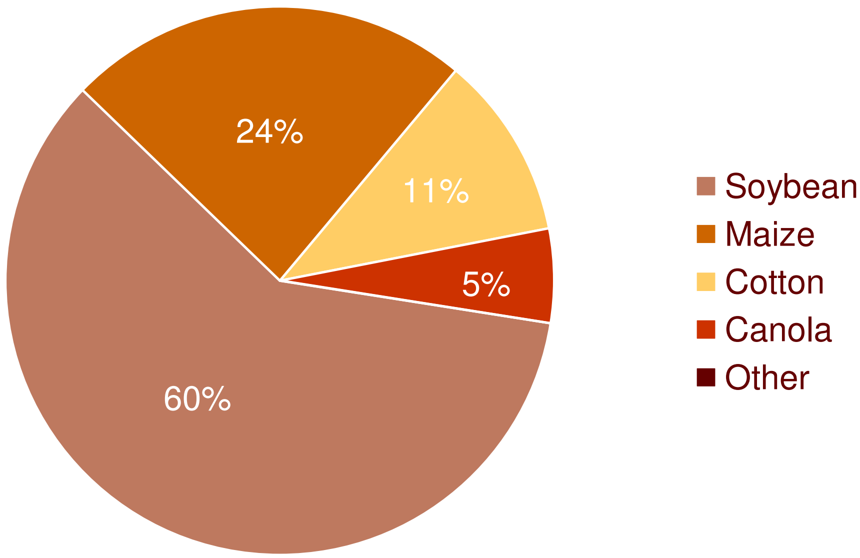
Source: James 2004.

Figure 2: GM crops by country (2004)



Source: James 2004.

Figure 3: Transgenic crops, by crop, 2004



Source: James 2004.

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