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Global Diffusion of Plant Biotechnology

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Abstract: The paper is divided into four parts. Part I analyzes market adoption and commercial value in countries producing biotech crops in 2003/04. Part II summarizes the range of biotech activity during this technology's short life. It shows which field crops, fruits, and vegetables have been commercialized, approved for adoption, field tested, or simply researched in a laboratory or greenhouse in 63 countries around the world. Part III provides regional summaries. Part IV offers conclusions and a discussion of the prospects for further growth in plant biotech in the next decade and beyond.

Key words: plant, biotechnology, adoption, commercial value, commercialized, approved, field tested, researched, growth

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Introduction

For thousands of years, farmers carefully selected crops with higher yields and resistance to disease and pests. Through trial and error, plant varieties came down through the centuries with steadily altered genetic traits. At the turn of the 20th century, the experiments of an obscure Austrian monk, Gregor Mendel (1822-1884), who had researched the inherited characteristics of peas, were rediscovered and confirmed by German plant breeder and biologist Karl Erich Correns (1864-1933). Correns reintroduced the principles that led to modern genetics, allowing plants to be bred through a form of systematic experimentation based on the probability that certain traits would be passed from one generation to the next. These principles made plant breeding a form of calculated trial and error. Statisticians such as R. A. Fisher (1890-1962) developed general methods for the design and analysis of plant breeding experiments when it is not possible to control for every factor that can affect the outcome. These insights into the genetic patterns of life ushered in the modern era of plant breeding, and the capacity for tens of thousands of improvements and hybrid varieties, from fruits and vegetables to ornamental flowers and trees. This research and experimentation continues today, with new and improved plant varieties appearing each year due to new hybrids and genetic crosses.

Beginning in the 1950s and 1960s, insight into life forms at the subgenetic level resulted from the late Francis Crick and James Watsons' Nobel Prize-winning work on the molecular structure of DNA. Their insight eventually allowed genetic material to be identified in one organism and inserted into another, so that genetic traits could be transferred to other (even unrelated) species. The result was biotechnology, part of the broader field of genetic mapping, analysis and research called genomics. In contrast to earlier methods of plant breeding, the new techniques allowed a much wider set of traits to be introduced into plants, in a much shorter period of time. These included resistance to herbicides in soybeans, corn and canola, pest resistance in corn and cotton, cold and drought tolerance, tolerance to salt in soils, enhanced nutrition and vitamin content and many other traits. Beginning in 1996, the first biotech crops were marketed in the United States. Since then, biotech corn, soybeans, and cotton have grown to account in 2004 for 46, 86, and 76 percent of total U.S. crop acres respectively, up from the 2003-2004 planted area percentages of 40, 81, and 73 percent respectively.[1] The international adoption and diffusion of biotech crops, while less

[1] These value figures are based on end-of-season planting data for the U.S. in crop year 2003-2004. See Runge, C. Ford and Barry Ryan, 2003. "The Economic Status and Performance of Plant Biotechnology in 2003:

advanced than in the United States, has now gone global. While much international press attention has focused on opposition to biotechnology, especially in Europe, there is increasing adoption and diffusion of biotech crops and expanded research in many parts of the world.

This paper surveys the global diffusion of biotech crop varieties as of the end of 2004. It analyzes adoption, research and development by crop and by country, and aggregates these data by region. Four major biotech crops have come to market to date: maize, cotton, soybeans, and canola. In addition, other commodities like papaya, squash, and tobacco have reached commercial production in the U.S. Many more commodities have been approved for commercial use in one or more countries, but have not been adopted in the marketplace. Included are chicory, tomatoes, rice, potatoes, flax, sugar beets, melon, and green peppers. Beyond these crops, many more food and fiber plants have been the subjects of field or laboratory research.

The paper is divided into four parts. The countries and crops discussed are shown in Figures 1 and 2. Part I analyzes market adoption and commercial value in countries producing biotech crops in 2003/04. The focus is on the five countries and four crops that largely define today's agricultural biotech production. Part II summarizes the range of biotech activity during this technology's short life. It shows which field crops, fruits, and vegetables have been commercialized, approved for adoption, field tested, or simply researched in a laboratory or greenhouse in 63 countries around the world. Part III provides regional summaries. Part IV offers conclusions and a discussion of the prospects for further growth in plant biotech in the next decade and beyond. The overall picture is of a technology which, less than a decade after first commercialization, is poised to transform the nature of agricultural production and development in widely dispersed countries around the world.

Global Commercial Adoption and Market Value of Biotech Crops

Commercial production of biotech crop varieties in 2004 reached significant levels in four important commodities: corn, soybeans, cotton, and canola. As well, nearly all biotech production occurred in five countries: the United States, Argentina, Canada, Brazil, and China. There were other biotech countries and biotech crops, but these contributed only modestly to worldwide biotech production value. We estimate the 2003/04 global market value of biotech crop production at $44 billion.

Adoption, Research and Development in the United States." Washington, Center for Biotechnology

Four Major Crops and Five Leading Countries

Five countries had 67.5 million hectares planted to biotech varieties of maize, soybeans, cotton and canola in 2003/04 (Table 1) (James 2003). They were the United States (42.8 million hectares); Argentina (13.9 million hectares); Canada (4.4 million hectares); Brazil (3.0 hectares); and China (2.8 million hectares). According to James (2003) these five countries and four crops constituted 98 percent of the total biotech cropland worldwide. Among the five countries 63 percent were planted in the United States, 21 percent in Argentina, 6 percent in Canada, and 4 percent each in Brazil and China. The rest of the world accounted for only 2 percent of the total area planted to biotech crop varieties as of the end of 2004.

In the United States, adoption of biotech varieties was led in area by corn and soybeans, followed by cotton and canola. In Argentina, corn, soybeans and cotton led, while in Canada canola was first. Brazil's main biotech crop was soybeans (the area planted to biotech varieties in Brazil is widely believed to be underestimated). In China, the only reported acreage was in biotech cotton.

What was the value of this crop production? Using gross market values based on world prices we calculated in 2003-2004 that the total value of biotech crops for the five leading countries and four leading crops at $43.9 billion (Table 2).[2] The United States accounted for $27.5 billion of this total, Argentina for $8.9 billion, China for $3.9 billion, Canada for $2.0 billion and Brazil for $1.6 billion.

When broken out by crop, of the $43.9 billion total, biotech soybeans were valued at $23.5 billion, maize at $11.2 billion, cotton at $7.8 billion, and canola at $1.4 billion. Tables 3 through 6 detail these calculations by country for soybeans, maize, cotton and canola respectively.

Soybeans were planted to 88 million hectares worldwide in 2003/04, with global production estimated at 190 million metric tons, and the world price averaging $250 per

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Information. http://www.apec.umn.edu/faculty/frunge/plantbiotech.pdf

[2] Calculations are based on area planted by country; estimated adoption rate; and world crop prices in 2003. Area planted figures are based on U.S. Department of Agriculture Statistics, cross-checked against Food and Agriculture Organization estimates. Adoption rates are based on James (op. cit. note 2) and industry reports. World crop prices are based on data from the Food and Agricultural Policy Research Institute (FAPRI, 2004) and USDA. Note that the growing season starts in the northern hemisphere in spring, with harvest in fall. That same fall, southern hemisphere farmers plant crops to be harvested in spring. The result is that global production data is generated every six months, which is gathered and documented about six months later. For example, final 2003 U.S. crop production and price data were released by USDA in June, 2004. James (2003, op. cit. note 2) calculates the global value of transgenic crops somewhat differently, by taking the sales price of seeds and adding any associated technology fees. Using this method, he concludes that in 2003, the global

metric ton. The top five biotech countries represented 84% of land area planted to soybeans and 90% of production. More than half (54 percent) of soybean production in the top five biotech countries is from biotech varieties (Table 3).

Total biotech soybean market value in 2003/04 was $23.5 billion - the highest of any biotech crop. The United States had the largest area in soybeans and highest biotech crop value ($13.3 billion). Brazil had the next largest biotech soy area, but due to a low (official) adoption rate, generated only $1.6 billion in biotech market value. Some reports suggest that the real biotech adoption rate in Brazil is as high as 30%, which would more than double Brazil's biotech soybean production value. Argentina grew $8.3 billion in biotech soybeans in 2003/04. China grew 8.7 million hectares of conventional soybeans, but had no biotech production. The Canadian soybean area is just over a million hectares, and about half were biotech varieties.

Maize was grown on 140 million hectares worldwide in 2003-2004, producing 614 million metric tons, at an average world price of $100 per metric ton. The top five biotech countries represent 70 percent of worldwide maize production and 49 percent of the global maize land area. Biotech varieties are grown on 19 percent of maize production land in the top five biotech countries, which collectively produced $11.2 billion in biotech maize (Table 4).

The United States is the leading biotech maize producer, with $10.3 billion in production market value. China's maize production area is nearly as large as the United States, but China does not grow biotech varieties commercially. Brazil has no reported biotech maize production, but significant maize production land area. Argentina has a modest area of land planted to maize, and an estimated $500 million in biotech soybean market value. Canada grew $384 million in biotech maize, based on a 40 percent adoption rate.

Cotton was planted to 32.6 million hectares worldwide in 2003/04. Production (lint only) is estimated at 93.5 million bales of 480 pounds each. The adjusted world price averaged 59
cents per pound. Half of the world's cotton production takes place in the top five biotech countries, and 61 percent of that is from biotech varieties (Table 5).

The global value of the biotech cotton in 2003/04 was $7.8 billion. China has the most area in cotton, the highest production and yields, and generates the most biotech cotton market value. The United States has almost as much area as China, higher adoption, lower

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market value of biotech seeds and technology fees was $4.5 – 4.75 billion. This is equivalent to gross margins, yields, but essentially the same biotech production value. Argentina grew $75 million in biotech cotton on a relatively modest land area. This assumes a 60% adoption rate, although some reports suggest it may be as low as 20%. Brazil has more area in cotton production than Argentina, but no biotech adoption. No cotton is grown in Canada.

Canola (or rapeseed) was planted to 26 million hectares worldwide in 2003/04, with total production estimated at 39 million metric tons, and an average world price of $285 per metric ton. The top five biotech countries account for half the worldwide land area devoted to canola, and half the global production (Table 6).

Among these top five countries, 28 percent of canola was a biotech variety. In 2003/04 the worldwide market value of the biotech canola crop was $1.4 billion. China grows the most canola among the five countries, but none in biotech varieties. Canada has the next largest land area planted to canola worldwide, but the majority of this crop is biotech, generating nearly $1.3 billion in biotech market value. The United States, by contrast, has modest canola production, but still produces $138 million in biotech canola value. Argentina and Brazil have no meaningful canola production and no biotech varieties in use.

Other Commercial Biotech Countries and Crops

Other countries grow biotech varieties of soybeans, cotton, and maize, apart from the five leading nations, and James identifies 13 countries with biotech crop production, with 8 of these at meaningful levels (James 2003a). Combined, these countries grew more than 600,000 hectares of biotech crops commercially in 2003/04, producing an additional $160 million in global biotech crop value. South Africa planted 400,000 hectares to a combination of maize, soybeans, and cotton, is the only country in Africa to produce a biotech crop, and could arguably be included as a top biotech country with its estimated $147 million in biotech crop value. In Latin America, Colombia grew 5,000 hectares of Bt cotton. Honduras planted less than 1,000 hectares of Bt maize, while Mexico also planted small areas of commercial biotech soybeans and Bt cotton. Uruguay grew 60,000 hectares of biotech soy, and produced its first crop of Bt maize. In the Asia-Pacific region, Australia planted 100,000 hectares or 59 percent of its cotton area in biotech varieties in 2003/04. The Philippines planted Bt corn for the first time on 20,000 hectares. India grew Bt cotton on 100,000 hectares, and Indonesia had unconfirmed reports of Bt cotton production. Several European countries grew biotech corn or soybeans in 2003/04. Romania grew 70,000 hectares of biotech soybeans. Spain put

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whereas our estimate captures the market value of gross sales.

32,000 hectares or 6 percent of its maize area in Bt varieties. Bulgaria had a few thousand acres of herbicide tolerant maize production, and Germany also had a small area of Bt maize.

Finally, there are other biotech food and fiber plants in commercial production around the globe. They have a relatively minor economic impact, compared with the four major crops, but are important to the areas and farmers that grow them. More details on these crops can be found in the country profiles in the Appendix and in Part III below. For example, biotech papaya varieties are grown in the United States that account for about half of the average $20 million papaya crop. Biotech tobacco is also grown in the United States, but the market penetration is too small to measure. Reports from other countries indicate market availability of biotech tomatoes and sweet peppers in China. Again, compared to soybeans, maize, or cotton the market impacts are relatively minor. As we will show in Part II, there are many more crops approved for use that could have significant market value potential.

Biotech Crop Adoption, Research and Development in 2004

Commercial biotech crop production is the final stage in a four step process. The first step begins in government and private sector laboratories or greenhouses, where scientists investigate potential biotech traits and genetic strategies. If these lab results are successful, the plant may advance to the second step, open air field trials, where breeding and testing continue in a real life environment. The third step to commercialization is securing regulatory approval in each country where the plant will be grown, and/or consumed by humans or animals. The fourth and final step is market acceptance and widespread production, like the four major crops described earlier. Part II summarizes the wide array of food and fiber plants that have undergone biotech research over the last two decades. Fifty-seven plants were identified and divided into four groups: field crops, vegetables, fruits, and other plants. The timeframe of this assessment is as far back as the biotech research records of each country allow, although not every research effort, in every county, is documented in the same detail. The country-by-country profiles in Part III provide data for each biotech trait and plant under investigation, as well as other facts about research in the area.

The matrices of Tables 7-10 note by country and crop the highest level of biotech research a plant has reached over time. For some commodities or countries interest never progressed past the laboratory, in other cases the process matured to commercial production. The labels for each country and crop (P,A,F,L) indicate the most advanced stage of biotech development that the country and crop has achieved: commercial production (P), regulatory approval (A), field trial (F), or laboratory/greenhouse study (L). Note, however, that even where the matrices show a plant in commercial production (P) or with regulatory approval

(A), the same crop may also be in another stage of research for some other biotech trait. Indeed, all four major commercial biotech crops have lab, field, and regulatory investigations ongoing somewhere in the world today. Most regulatory approvals are for the environmental release and human or animal consumption of a biotech variety. In some cases -- indicated in the matrices by an (a) -- the approval is for consumption from imports only, and can apply to the entire crop or individual lines. One opposite exception is the export-only approval (p) for Chilean corn and soybean seed production.

Sixty-three countries were identified as having participated in biotech plant research activity at some point in the technology's development. This participation can range from a single greenhouse experiment to the widespread adoption of biotech crop varieties. Most countries are identified separately in the tables, but European countries are treated collectively in two groups, West and East. The reader can find more details in the county profiles of the Appendix. Generally speaking, Western Europe is the "original" 15 members of the EU, while the 13 Eastern European countries include many parts of the former Soviet Union.

Field crops

Sixteen field crops have been the subject of biotech research or development in 55 countries (Table 7). Soybeans, cotton, maize, and canola have widespread commercial application, as well as regulatory approval in many countries. Sugar beets, flax, and rice also have the necessary approvals in the United States and Canada. Australia grows biotech cotton, and has given import approval to biotech maize, soybean, canola, and sugar beets.

Biotech rice has been studied in as many countries, particularly in the developing world, as have soybeans or cotton. Wheat is another important global field crop that has biotech field studies in more than 10 countries. Sugar cane, barley, alfalfa, cassava, sunflowers, palm oil, clover and safflower have all been field trial subjects. Sorghum is the only crop with just a laboratory experiment, and that was in China.

Countries are listed somewhat arbitrarily in the matrices, but the objective is to help identify countries with interest in biotech crop science. Canada has studied or approved a larger number of field crops than any other country. In the United States regulatory approval of biotech varieties has been granted for soybeans, cotton, maize, canola, sugar beets, flax and rice, while field study has occurred for sugar cane, barley, wheat, alfalfa and safflowers. Among other developed countries, Japan, Australia and Western Europe have one or more biotech field crops with production or import approval. In the developing countries, South Africa and Argentina lead the list of regulatory approvals for soybeans, cotton and maize.

Brazil, Egypt, Mexico, Uruguay, China, the Philippines, Indonesia, India, South Korea and Russia also have approvals.

Vegetables

Fourteen vegetables have drawn biotech research interest in 50 countries, including 13 Western Europe and 10 Eastern European countries. Potatoes and tomatoes are most researched and have the most regulatory approvals (Table 8). But squash in the United States and Canada and sweet peppers and tomatoes in China also have approval for commercial production. Peas and beans are combined into one category for this analysis, despite the numerous varieties that have been field tested, from lentils to long beans. More specific details on particular varieties are found in the country profiles. The widest biotech vegetable research interest is in Western European countries, reaching beyond the noted crops, to lettuce, cabbage, carrots, eggplant, onions and cucumbers. The leading countries for regulatory approvals are Canada and the United States (potatoes, tomatoes, squash); Australia (potatoes); Japan (potatoes, tomatoes); China (tomatoes, green peppers); and Mexico (tomatoes).

Fruits

Sixteen fruits have seen biotech research interest in 29 countries. In 11 countries the investigation reached field testing (Table 9). By country, the Western Europe group of 15 countries had the most research activity. The United States and Canada, however, have regulatory approval for papaya, which is commercially produced in Hawaii. Papaya is the most researched fruit, with at least 15 countries in some stage of investigation. Melon also has U.S. market approval for environmental release and human consumption. Banana (and the kindred plantain) has been the subject of biotech research in nine countries, including the United States. Apples, pineapple and grapes have multiple field study countries, whereas, plums, strawberries, watermelon, citrus, cherries, cantaloupe, kiwi and raspberry may only have one country and trial. Two fruits, mango and coconut, have only reached the laboratory stage.

Papaya is the only commercially available biotech fruit product, and grown only in the United States Hawaiian Islands. Field studies have also been conducted in numerous other countries, such as South Africa (strawberries); Mexico (papaya, banana, pineapple, melon); Australia (papaya, pineapple, apples, grapes); and China (papaya, melon). Laboratory and/or greenhouse experiments have occurred in Chile (melon, apples, grapes, and stone fruit) plus numerous other countries.

Other crops

Eleven crops not discussed thus far have been researched, tested, or approved in 29 countries (Table 10). Except for tobacco, this group of crops has not been as widely researched for biotech potential. Another exception is chicory, which has regulatory approval in both the United States and Western Europe. Biotech tobacco is produced commercially in the U.S., and has regulatory import approval in Western Europe. Tobacco has attracted field study and/or laboratory experiments in numerous other countries, including Argentina, Brazil, Mexico, Chile, Venezuela, the Philippines, Indonesia, India, Bangladesh, South Korea and Malaysia. Other biotech crops with field study or lab work are groundnuts (China); coffee (Indonesia, Venezuela); peanuts (Indonesia, Bangladesh); Indian mustard (Australia); brown mustard (Canada); cocoa (Argentina); lupins (Australia) and oilseed poppy (Australia).

In summary, around the world, many biotech plant varieties already have regulatory approval, and could be taken from field studies to commercial production quite rapidly, allowing substantial adoption within a few growing seasons. Two obvious examples are soybeans and maize in China. China had total soybean and maize production in 2003-2004 of 16.2 and 114 million metric tons, respectively. If half of this production was biotech, it would add about $2.5 billion to the total value of biotech crop production at 2003-2004 prices. When the deeper levels of activity preceding commercialization are explored at an international level, it is clear that a wide array of biotech plants is of potential interest (and value) in both developed and developing countries. We turn now to a geographic assessment of this activity by region of the world.

Regional Summary and Country Profiles

- Some phase of biotech plant R&D is occurring in Africa, Latin America, Asia and the Pacific, Western and Eastern Europe and North America.
- In Africa, the leading country is South Africa, with a total commercial market value for its biotech maize, soybeans and cotton of $146.9 million. There also are important developments in Kenya and Egypt, and some activity in Morocco and Tunisia. Work in Zimbabwe has been disrupted by political instability.
- Latin American and the Caribbean nations are home to some of the most aggressive adopters of plant biotech and appear poised to move to adopt more varieties in the near future. In Latin America and the Caribbean, the adoption process is led by Argentina, with Brazil likely to emerge rapidly as a leader as well. Chile is an

important potential base of plant biotech activity, and Colombia has begun to plant biotech cotton. Cuba has no market approvals, but is active in field trials and experimental studies, and Mexico has an active commercial and scientific plant biotech sector.

- Twelve countries in the Asia-Pacific region are involved in some aspect of plant biotech. Australia has the most active sector, planting biotech cotton and approving for import six other biotech crops. Perhaps the most significant single potential actor in Asia is China, which is aggressively engaged in biotech adoption and research. India has at least 20 academic and research institutions engaged in biotech research covering 16 crops, and Indonesia also has commercial approvals, field studies and experiments. The Philippines has approved a biotech maize variety. South Korea has approved three lines of maize and soybeans, and has launched a 20-year plant biotech research program. Japan had granted import approval to six biotech crops in 2003, and has studied in the lab various biotech fruits, vegetables and grains. Malaysia launched its Biotechnology Agenda in 2004. Finally, Thailand has conducted field studies on cotton, rice and several vegetables, and experiments on biotech cassava, papaya and long beans.
- In Western Europe (EU member states Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Ireland, Netherlands, Portugal, Spain, Sweden and the United Kingdom, as well as non-EU-member Switzerland) regulatory import, as well as environmental release, approvals have been granted for a limited group of biotech crops. In the EU, these include biotech canola, chicory, maize, soybeans and tobacco. In all, 1,849 field trials were conducted from 1991 to August 2004.
- All 14 EU members in Western Europe have reported field trials to the Joint Research Center of the European Commission in Brussels. In descending order the largest number of biotech field trials in Western Europe's EU countries has been France (520), Italy (270), Spain (263), the United Kingdom (199), Germany (138), Belgium (129), Sweden (68), Denmark (38), Greece (19), Finland (16), Portugal (11), Ireland (50) and Austria (3).
- In Eastern Europe (including Armenia, Boznia-Herzogovina, Bulgaria, Croatia, The Czech Republic, Georgia, Hungary, Poland, Romania, Serbia-Montenegro, Slovenia, the Ukraine and Russia) there has been some biotech commercial approval, field trials

or lab/greenhouse activity but at a much lower rate than in Western Europe. The Balkans, in particular, has suffered from war and economic disruption.

- North America remains the epicenter of R&D on plant biotech, with the United States and Canada in the top five producing nations in terms of 2003-2004 commercial biotech crop value: $2.0 billion in Canada and $27.5 billion in the United States. Thousands of field trials have been conducted in the two countries. Canada has produced, approved, or field tested more field crops than any other country. In the United States, approvals have been granted for canola, chicory, cotton, flax and linseed, maize, melon, papaya, potatoes, rice, soybeans, squash, sugar beets, tobacco, and tomato.

Conclusions and Future Directions

This study has evaluated the global diffusion of plant biotechnology as of 2004. It estimated the total value of the leading five countries producing biotech crops in 2003-2004 at $43.9 billion, resulting from production on 67.5 million hectares. The preponderance of the land in biotech crops is in the United States, which accounts for 63 percent of the area planted to them. Argentina accounts for 21 percent, Canada for 6 percent and Brazil and China for 4 percent each. These plantings of maize, soybeans, cotton and canola in the leading countries are already impressive, but there is still a huge land area potentially available for such plantings, especially in Argentina, Brazil and China, and also in Canada.

When one moves beyond these major crops, the proliferation of commercial and R&D activity represented by field trials and laboratory/greenhouse experiments extends well beyond the five leading countries. In the most comprehensive assessment of the ultimate consequences of widespread global adoption of biotech crops, the Australian Bureau of Agricultural Resource Economics in 2003 estimated an additional $210 billion in income by 2015 (ABARE 2003). The greatest gains would be in the developing countries, where Gross Domestic Product (GDP) could be expected to rise by as much as two percent. This estimate assumes that regulatory regimes will emerge allowing this adoption. In particular, if the European Union remains closed to further adoption of plant biotech, the global cost by 2015 would be $43 billion.

A reexamination of Tables 7-10 suggests two types of insights into the pattern of R&D diffusion: *tiers* of plant biotech activity by country, showing a group of leading nations, a group of emerging nations, and a group of countries to watch; (2) *spheres* of activity by region of the world. In conclusion, we will evaluate both of these aspects of the pattern of diffusion.

Tiers of Biotech Activity

The main field crops shown in Tables 7-10 illustrate the division of nations into leaders, emerging countries and those to watch for commercial adoption, field trials and laboratory/greenhouse experiments. The leading five countries in terms of commercial adoption – the United States, Argentina, Canada, Brazil and China – all fall in the first tier. In terms of overall activity, including field trials and laboratory/greenhouse experiments, Australia, Western Europe, Mexico and South Africa also belong in this group, although the particular role and future of the EU remains unclear.

At this point, activity falls off, showing a second tier of countries where activity is emerging, but where limited resources, inadequate regulation or restricted technical capacity constrain the adoption and R&D process. These countries include Indonesia, Egypt, and India. The remaining countries (as well as those not listed due to the absence of reported activity) constitute the third tier.

Within Europe, where we have chosen to aggregate countries into Western and Eastern European countries (including several parts of the former Soviet Union), there is substantial variation in the level of activity, with some countries such as France and Italy leading in the number of field trials while others such as Ireland and Austria show relatively little R&D activity. In the European Union, the 1999 moratorium on plant biotech approvals has slowed the entire R&D process. How the EU ultimately regulates plant biotech will also be important to developing countries seeking European markets, and new entrants to the EU, who will position themselves in the R&D process by reference to EU policies and markets.

Spheres of Biotech Investment and Research

A slightly different perspective on global plant biotech activity results from a geographical examination of spheres investment and research by location. As noted above, North America is the largest of these spheres. As such, it exercises a gravitational pull on global investment and human capital, drawing to it the best companies and researchers. The sphere of North American influence in plant biotech has grown at the expense of the European Union, from which investment capital and talent have fled. For example, Syngenta, a Swiss-based multinational, has chosen to locate its global plant biotech research at the Research Triangle in North Carolina.

The principal spheres of plant biotech influence outside of North America and Europe are in China, Argentina and Brazil, South Africa, Australia and India. Although none of these areas can match North America in overall investment and R&D, there is reason to expect China to emerge as an influential force in plant biotech in the years to come. In Latin America, Argentina and Brazil will in our estimate also emerge as leaders in the southern part of the Western Hemisphere. In Africa, South Africa has the scientific capability, political stability and investment resources to lead the continent in plant biotech. In Asia and the Pacific apart from China, Australia appears poised to move quickly to establish itself as a sphere of influence, as does India. In both Australia and India, investment and human capital resources make this growing influence possible.

A recent assessment of the constraints to diffusion of plant biotech in developing countries cited both the dominance of North America and Europe in research and development, and a simple lack of financial resources. These are remediable through technology-transfer partnerships and a recommitment to technical assistance funding, both bilateral and multilateral, especially aimed at improving regulatory capacity (Lawrence 2004).

Our final assessment of the diffusion of plant biotech is that important gains have been made in adoption in the less than 10 years since commercialization began in 1996, but that major expansions in biotech crop hectares are still to come, especially in Asia, Latin America and parts of Africa. Apart from this expansion, we expect the range of biotech crops approved commercially to continue to grow, resulting in new markets and opportunities, especially in developing countries. If the European Union continues to restrict activity in the sector, it will slow down this global diffusion, but it cannot stop it. As it becomes increasingly isolated, it will discourage its young scientists and technicians from pursuing European careers. If, on the other hand, the EU engages biotech in an orderly regulatory framework harmonized with the rest of the world, it will encourage a more rapid international diffusion of the technology. More nations will join the top tiers of commercial production, and emerging nations will continue to expand the sector. It is unlikely that Europe will catch up with North America as a sphere of plant biotech influence, but its scientific and technical capabilities will allow it to recover relatively quickly. We see continuing expansion of commercial and scientific possibilities for plant biotech in the next decade and beyond.

Figure 1: Sixty-three Countries with Biotech Production or Research Activity.

AFRICA/MIDEAST	ASIA/PACIFIC	LATIN AMERICA	WESTERN EUROPE	EASTERN EUROPE
Egypt	Australia	Argentina	Austria	Armenia
Kenya	Bangladesh	Belize	Belgium	Bosnia Herzegovina
Morocco	China	Bolivia	Denmark	Bulgaria
South Africa	India	Brazil	Finland	Croatia
Tunisia	Indonesia	Chile	France	Czech Republic
Zimbabwe	Japan	Colombia	Germany	Georgia
(6)	Malaysia	Costa Rica	Greece	Hungary
	New Zealand	Cuba	Ireland	Moldova
	Pakistan	Guatemala	Italy	Romania
	Philippines	Honduras	Netherlands	Russia
	South Korea	Mexico	Portugal	Serbia/Montenegro
	Thailand	Paraguay	Spain	Slovenia
NORTH AMERICA	(12)	Peru	Sweden	Ukraine
Canada		Uruguay	Switzerland	(13)
United States		Venezuela	United Kingdom	
(2)		(15)	(15)	

Figure 2: Fifty-seven Crops of Biotech Research Interest.

Field Crops	Vegetables	Fruits	Miscellaneous
Alfalfa	Broccoli	Apple	Chicory
Barley	Cabbage	Banana	Cocoa
Canola	Carrot	Cantaloupe	Coffee
Cassava	Cauliflower	Cherry	Garlic
Clover	Cucumber	Citrus	Lupins
Cotton	Eggplant	Coconut	Mustard
Flax	Lettuce	Grape	Oil palm
Maize	Onion	Kiwi	Oilseed poppy
Rice	Pea/Bean	Mango	Olive
Safflower	Pepper	Melon	Peanut
Sorghum	Potato	Papaya	Tobacco
Soybean	Spinach	Pineapple	(11)
Sugar beet	Squash	Plum	
Sugar cane	Tomato	Raspberry	
Sunflower	(14)	Strawberry	
Wheat		Watermelon	
(16)		(16)	

Table 1: Global Biotech Crop Area: Leading Countries

Five leading counties	Area in biotech crop production	Share of world biotech area	biotech crop varieties:
	67.5 million hectares	**98%**	
United States	42.8 million hectares	63%	maize, cotton, soy, canola
Argentina	13.9 million hectares	21%	soy, maize, cotton
Canada	4.4 million hectares	6%	canola, maize, soy
Brazil	3.0 million hectares	4%	soy
China	2.8 million hectares	4%	cotton

Source: James, 2003.

Table 2: Global Biotech Crop Value: Leading Countries

2003/04	Biotech-related crop value*		2003/04	Biotech-related crop value*
Five countries:	**$43.9 billion**		**Four crops:**	**$43.9 billion**
United States	$27.5 billion		Soybean	$23.5 billion
Argentina	$8.9 billion		Maize	$11.2 billion
China	$3.9 billion		Cotton	$7.8 billion
Canada	$2.0 billion		Canola	$1.4 billion
Brazil	$1.6 billion			

* Market value of crop production associated with biotech plant varieties
Source: USDA (2004a,b); FAO (2004); FAPRI (2004); James (2003).

Table 3: Global Biotech Soybean Value: Leading Countries

Soybean 2003/04 *price = $250/MT*	Crop area (1) M Ha	Production (2) MMT	Biotech adoption rate	Biotech-related crop value (3)
Five countries:	**74.2**	**171.8**	**54%**	**$23.5 billion**
United States	29.2	65.8	81%	$13.3 billion
Brazil	21.3	53.5	12%	$1.6 billion
Argentina	14.0	34.0	98%	$8.3 billion
China	8.7	16.2	-	-
Canada	1.1	2.3	50%	$284 million
Rest of the world	*13.8*	*18.3*	-	-

(1) area in million hectare; (2) production in million metric tons; (3) assumes world price $250/metric ton
Source: USDA (2004a,b); FAO (2004); FAPRI (2004); James (2003).

Table 4: Global Biotech Maize Value: Leading Countries

Maize 2003/04 *price = $100/MT*	Crop area * M Ha	Production ** MMT	Biotech adoption rate	Biotech-related crop value***
Five countries:	**68.5**	**434.5**	**19%**	**$11.2 billion**
United States	28.8	256.9	40%	$10.3 billion
China	23.5	114.0	-	-
Brazil	12.6	41.5	-	-
Argentina	2.1	12.5	40%	$500 million
Canada	1.2	9.6	40%	$384 million
Rest of the world	*71.9*	*179.5*	-	-

* area in million hectares; ** million metric tons; *** average world price of $100/metric ton
Source: USDA (2004a,b); FAO (2004); FAPRI (2004); James (2003).

Table 5: Global Biotech Cotton Value: Leading Countries

Cotton 2003/04 *price = $0.59/lb.*	Crop area * M Ha	Production ** M Bales	Biotech adoption rate	Biotech-related crop value***
Five countries:	**11.2**	**46.7**	**61%**	**$7.8 billion**
China	5.1	22.4	62%	$3.9 billion
United States	4.9	18.3	73%	$3.8 billion
Brazil	1.0	5.7	-	-
Argentina	0.3	0.4	60%	$75 million
Canada	-	-	-	-
Rest of the world	*21.4*	*46.8*	-	-

(1) area in million hectare; (2) million metric tons; (3) assumes world price 59-cents per pound
Source: USDA (2004a,b); FAO (2004); FAPRI (2004); James (2003).

Table 6: Global Biotech Canola Value: Leading Countries

Canola 2003/04 *price = $285/MT*	Crop area * M Ha	Production ** MMT	Biotech adoption rate	Biotech-related crop value***
Five countries:	**12.6**	**18.8**	**28%**	**$1.43 billion**
China	7.5	11.4	-	-
Canada	4.7	6.7	68%	$1.29 billion
United States	.4	.7	73%	$138 million
Argentina	-	-	-	-
Brazil	-	-	-	-
Rest of the world	*13.4*	*20.2*	-	-

(1) area in million hectare; (2) million metric tons; (3) assumes world price $285 per metric ton
Source: USDA (2004a,b); FAO (2004); FAPRI (2004); James (2003).

Table 7 - Global Biotech Activity: Field Crops - highest level of biotech development

FIELD CROPS by COUNTRY	Soybean	Cotton	Maize	Canola	Sugar beet	Rice	Flax	Wheat	Sugar cane	Barley	Alfalfa	Cassava	Sunflower	Clover	Safflower	Sorghum
Canada	P	A	P	P	A	A	A	F		F	F		F	F	F	
United States	P	P	P	P	A	A	A	F	F	F	F				F	
Australia	a	P	a	a	a			F	F	F				F		
West Europe (15/15)	a	F	P	a	F	F		F		F	F		F			
Argentina	P	P	P		F			F	L	L	F		F			
Mexico	A	P	F	F		F	F	F								
China	F	P	F	L	L	F		L		L						L
Japan	a	a	a	a	a	F		L								
South Africa	P	P	P	F					F							
Brazil	P	F	F			F			F	L						
East Europe (8/13)	P		A	F	L		L	F		L	F		F			
Indonesia	F	a	F			L			L			L				
Uruguay	P		P													
Egypt		A	F	A				F	F	L						
India		P		F		L										
Colombia		P										L				
Philippines			P			L										
Paraguay	P															
Chile	p		p													
South Korea	a		a													
Honduras			A													
Belize	F	F	F													
Cuba			L			L			F							
Thailand		F				F						L				
Venezuela						L			L			F				
Zimbabwe		F										F				
Bolivia	F	F														
Costa Rica			L			F										
New Zealand				F												
Malaysia						L										
Pakistan		L				L										
Morocco								L								
Bangladesh						L										
Kenya			L													

Legend	
commercial Production	P
regulatory Approval	A
Field study	F
Lab / greenhouse	L

Source: AGBIOS (2004); FAO (2004); ISB (2002); WISARD (2004); BINAS (2003).

Table 8 - Global Biotech Activity: Vegetables - highest level of biotech development

VEGETABLES by COUNTRY	Potato	Tomato	Squash	Pepper	Pea/Bean	Lettuce	Cucumber	Cabbage	Carrot	Eggplant	Onion	Cauliflower	Broccoli	Spinach
West Europe (13/15)	F	F	F		F	F		F	F	F		F	F	F
United States	A	A	P		F	F	F				F			
Canada	A	A	A											
Australia	a	F			F	F								
Japan	a	a			F	L	F					F	F	
China	F	P		P				F	L					
Mexico	F	A	F	F										
Brazil	F	F			F	L			F					
Egypt	F	F	F		L		F							
Thailand		F		F	L									
Argentina	F	F												
East Europe (10/13)	F	L			F									
Cuba	F	L												
Zimbabwe	F													
Bolivia	F													
Peru	F													
South Africa	F													
Kenya	F													
Guatemala		F												
New Zealand											F			
South Korea				F										
Indonesia	L	L		L										
Malaysia				L	L					L				
India	L	L						L		F				
Chile	L	L												
Colombia	L	L												
Bangladesh					L									
Philippines		L												
Tunisia	L													

Legend	
commercial Production	P
regulatory Approval	A
Field study	F
Lab / greenhouse	L

Source: AGBIOS (2004), FAO (2004), ISB (2002), WISARD (2004), BINAS (2003).

Table 9 - Global Biotech Activity: Fruits - highest level of biotech development

FRUITS by COUNTRY	Papaya	Melon	Banana	Pineapple	Apple	Grape	Plum	Strawberry	Watermelon	Citrus	Cherry	Cantaloupe	Kiwi	Raspberry	Mango	Coconut
United States	P	A	F		F		F		F							
West Europe (8/15)		F			F	F	F	F	F	F	F	F	F	F		
Australia	F			F	F	F										
Canada	A					F										
Mexico	F	F	F	F												
Cuba	F		L	L						L						
Philippines	L		F												L	L
China	F	F														
Egypt		F	L									F				
Japan	L	F						L								
East Europe (3/13)						L	F									
South Africa								F								
Brazil	F															
Malaysia	L	L	L	L												
Chile		L			L	L	L									
Venezuela	L		L												L	
Colombia			L													
Costa Rica			L													
Bangladesh	L															
Thailand	L															

commercial Production	P
regulatory Approval	A
Field study	F
Lab / greenhouse	L

Source: AGBIOS (2004); FAO (2004); ISB (2002); WISARD (2004); BINAS (2003).

Table 10 - Global Biotech Activity: Other Crops - highest level of biotech development

OTHER CROPS by COUNTRY	Tobacco	Chicory	Mustard	Peanut	Coffee	Lupins	Oilseed poppy	Olive	Oil palm	Cocoa	Garlic
United States	P	A		F	F						
West Europe (9/15)	a	A	F					F			
Australia			F			F	F				
China	F			F							
Brazil	F									L	
Canada			F								
East Europe (3/13)	F										
South Korea	F										
India	F										
Mexico	F										
Indonesia	L			L	L				L	L	
Chile	L										L
Bangladesh	L			L							
Malaysia	L								L		
Venezuela					L						
Philippines	L										
Argentina	L										
Cuba					L						
Japan	L										

commercial Production	P
regulatory Approval	A
Field study	F
Lab / greenhouse	L

Source: AGBIOS (2004); FAO (2004); ISB (2002); WISARD (2004); BINAS (2003).

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