PATS STAFF PAPER SERIES

Program on Agricultural Technology Studies
College of Agricultural and Life Sciences
University of Wisconsin-Madison

Cooperative Extension
University of Wisconsin-Extension

Paper No. 9
September, 2003

The "Gene Revolution" in Global Perspective: A Reconsideration of the Global Adoption and Diffusion of GM Crop Varieties, 1996-2002

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Introduction

It is widely acknowledged that the introduction and commercialization of genetically modified (GM) crop varieties have comprised one of the most important chapters in the recent development of global agriculture. It is frequently noted that the diffusion curves for herbicide-resistant (HR) soybeans and for transgenic (insect-resistant [IR] and/or HR) cotton varieties have arguably been the steepest ones in U.S. history. IR cotton and HR soybeans have exhibited the most rapid percent increases in adoption of any agricultural technologies in the history of the world. The slopes of the adoption curves for insect-resistant (also know as "Bt") corn and HR corn in the U.S., and for HR canola in Canada, have been only slightly less steep than those for HR soybeans and Bt/HR cotton. No wonder so many people casually refer to GM or transgenic crop varieties as being the first step in an inevitable "gene" or biotechnology "revolution."[2]

It is clear that the GM variety adoption experiences within the U.S. have been significant by world and historical standards. And because of the rapid adoption of transgenic soybean, cotton, and corn varieties in the U.S. over the past seven or so years, there has been a tendency for many observers to presume that the rapid adoption of these GM crop varieties has occurred in relatively similar fashion elsewhere throughout the globe—or at least that there should be discernible tendencies in this direction across world nations. Indeed, there has been considerable discussion of the fact that world population growth and the persistence of widespread hunger make it obvious that the rapid adoption of GM crops in the U.S. is almost certainly heralding an incipient global-scale "gene revolution" (e.g., James, 1997:1). Even those, such as Pinstrup-Andersen and Sciøler (2000:Chapter 3), who recognize there is a "global controversy over GM crops," to quote the subtitle of their book, feel that persistent population pressures and hunger problems make it clear that there is no choice but to embrace a GM crop revolution across the globe. The purpose of this paper will be to examine the available evidence about the worldwide diffusion of GM crop varieties, and to place the U.S. experience in the context of global trends in the adoption and diffusion of genetically modified crop varieties.

This publication is an updated and expanded version of Buttel (2002). The present publication includes global data for the 2002 growing season. The data series for the five major GM crops in the U.S. (Bt corn, stacked corn, and HR corn HR soybeans, and GM upland cotton) have also been updated. A new section of the report concerns the growing controversy over GM crop adoption in the developing countries of the South. Detailed data on GM variety use in the five major developing countries where GM crops are grown (Argentina, China, South Africa, India, and Brazil) have been added.

ISAAA Data on Global Adoption and Diffusion of GM Crops

The data source that will be utilized in this paper is the series of annually issued reports from the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), located at Cornell University in Ithaca, New York. The ISAAA has been very actively involved in collecting data on the global diffusion of GM crop varieties as evidenced by the fact the bulk of their website (http://www.isaaa.org/) is devoted to reports of the adoption of GM varieties. Their data have become widely cited as the authoritative benchmark on the track record of GM crop varieties across the world. To my knowledge, there is no other data source that can match ISAAA's annual data compilations in terms of comprehensiveness and their availability over time from the beginning of the diffusion process in 1996 to the present.

In 1997 ISAAA initiated what has become an annual series of reports on the progress of the diffusion of GM crop varieties across the world; one of ISAAA's first publications (James, 1997) established a data series for the 1996 and 1997 calendar years, and with the publication of the latest report (James, 2002), there is now available a largely continuous series of data from 1996 to 2002. The data discussed in this report include only those that are available free of charge to the public from report summaries ("briefs") that are posted on the ISAAA website (e.g., James, 2001a and 2001b, 2002). In the tables that follow, there are some missing data and question marks. It is not clear whether these missing data are due to the fact that the data included in the ISAAA report summaries have not been entirely consistent over time or whether ISAAA has changed the nature of the data it collects. Question marks in the tables indicate areas in which one cannot be sure from the published briefs whether my recording of the data are accurate. Nonetheless, these missing data do not detract appreciably from the relatively obvious conclusions that we are able to draw from the ISAAA database.

While it is not apparent exactly how ISAAA collects data on GM adoption, it appears that the organization has good access to corporate data on GM variety sales as well as to governmental and other sources of data on GM adoption. ISAAA's access to corporate data on GM adoption is probably one of the reasons that their data are so comprehensive. It may or may not be coincidental that ISAAA's access to private data is related to the fact that from the outset, they have assumed a promotional posture toward transgenic technology and GM products. ISAAA has long been a strong voice of endorsement of the benefits of agricultural biotechnology across the world, in both developing countries and the developed-industrial world. More importantly, ISAAA has not only taken the lead in compiling a useful series of global GM adoption data, but also their interpretations of these data have been very influential in how scholars, policymakers, activists, and citizens interpret the data. For example, Michele C. Marra's (2001) article about the current and future impacts of agricultural biotechnologies (and several of the other contributions to the Pardey, 2001, anthology *The Future of Food*) relies heavily on the ISAAA data. Marra (2001) largely echoes the ISAAA's views about the profitability and the steep adoption curves exhibited by the current generation of GM crop varieties.

While a wide range of scholars, policymakers, and other persons have concurred with the notion that the biotechnology adoption experience has been precedent-setting in its scope and impacts, there is also a significant literature that adopts alternative views on this question. For example, in a series of papers and publications, Louise O. Fresco (2001a, 2001b), Assistant Director-General of the UN Food and Agriculture Organization Agriculture Department has stressed the very limited reach of GM crops; she writes that "the evidence suggests that the technology so far has addressed too few challenges, in few crops of relevance to production systems in the developing countries. Even in developed countries, lack of perceived benefits for consumers and uncertainty about their safety has limited their adoption."

Out argument in this report is that there is a need for a dispassionate look at the available data on the global adoption of GM crops. To anticipate the analysis that will be developed below, it seems apparent that the GM adoption story is one of relatively rapid adoption with respect to a very small handful of crops, traits, and countries, while the larger pattern of GM adoption is that it has been very slow and limited from a global perspective. We will now explore the main types of data series that the ISAAA has made available to interested parties across the world.

The ISAAA Data

Global Area and Sales Volume of GM Crops

Table 1 reports the ISAAA data series for GM crops in terms of total hectares (1 ha = 2.471 acres) of such crops by year. The table also reports data for 1996, 1997, 1998, 2001, and 2002 on the percent of these GM crop hectares that were accounted for by the industrial countries.

Table 1. Global Area of GM Crops, 1996-2002

Year	Total hectares (million)	% of Global GM Ha Accounted for by industrial countries
1996	2.8	57
1997	12.8	75
1998	27.8	84
1999	39.9	?
2000	44.2	?
2001	52.6	75
2002	58.7	73

1 hectare = 2.471 acres
SOURCE: International Service for the Acquisition of Agri-Biotech Applications, Cornell University

Several important conclusions are revealed in Table 1. First, there was very rapid growth of GM crop hectares globally during the late 1990s through 1999. Second, the *rate of growth* in GM crop hectares has declined since 1999, and especially from 2001-2002. Third, since 1997 the bulk—75 percent or more—of global hectares of GM crops has been planted in the developed-industrial countries (chiefly the U.S. and Canada).

The data in Table 2 on global GM seed sales volume show a very similar pattern of growth of GM crop adoption from 1995 to 2000. (To our knowledge James [2001b and 2002) does not report comparable seed sales data for 2001 and 2002.) The available seed sales volume data show a very vibrant pattern of growth through 1999, with some tapering off of the rate of increase after 1999.

Table 2. Value of the Global Transgenic Seed Market, By Year

Year	Value (millions of $ U.S.)
1995	1
1996	152
1997	851
1998	1,959
1999	2,947
2000	3,044

SOURCE: International Service for the Acquisition of Agri-Biotech Applications, Cornell University

The Role of the "Big Three" Countries in GM Crop Adoption

Table 3 reports data for 2001 and 2002 on the distribution of GM crop acres among the 16 countries within which these crops were grown in 2001 and/or 2002. These data show the enormously important role played by the U.S., Argentina, Canada, and China in GM crop adoption. Until 2001 or so, the U.S., Argentina, and Canada comprised a consistent "big three" in global GM crop adoption, as can be seen in Table 4 below. In recent years, however, China's widespread use of GM cotton has vaulted it into the upper echelon of GM crop-adopting countries, so that there has come to be a "big four." It should be noted, however, that the rates of GM adoption growth for the original "big three" have been modest in recent years (ranging from 9 percent in the U.S. and Canada to 14 percent for Argentina during 2001-2002). The most rapid rates of growth in GM crop acreage from 2001 to 2002 were in South Africa and China (50 and 40 percent, respectively).

Table 4 provides some data on the geographical spread of global GM crop acres in the "big three" countries in transgenic crop adoption from 1996 to the present. The data in Table 4 are quite striking in two related respects. First, since 1997, the U.S. has accounted for two-thirds or more of global GM crop acres *alone*, though the U.S. share of the global total has declined from 74 percent in 1998 to 66 percent in 2002. Second, the big three's share of global GM crop adoption reached 99 percent in 1998, and has remained at 95 percent or more from 1999 to the present. It can be seen from Table 3 that China has now joined the ranks of major GM-adopting countries. In 2002 the "big four"—the U.S., Argentina, Canada, and China—accounted for 99 percent-plus of GM crop area. (Note that the ISAAA briefs do not contain a continuous data series from 1996 to the present for the big four countries). In other words, while the rate of diffusion of GM crops has been quite impressive in the U.S., Canada, China, and Argentina, it remains—in relative terms—trivial essentially everywhere else across the globe.

Distribution of GM Crop Acres by Crop

Information on the percent distribution of the principal GM crops over time is provided in Table 5. These data show that from the beginning of the global diffusion of GM crop varieties in the mid-1990s, this diffusion pattern has been confined to a small—and actually a *decreasing*—handful of crops: soybeans, corn, cotton, and canola. GM tomato and GM potato varieties, which were once thought to be major commodities with regard to transgenic innovation, have largely disappeared from the radar screen from the perspective of global GM adoption.[3]

Soybeans alone accounted for nearly two-thirds (62 percent) of global GM acres in 2002. The percent of GM acres accounted for by GM soybeans increased each year from 1996 to 2001. Due mainly to expanded cultivation of GM corn—most likely, due to the introduction of HR and stacked corn—since 2001, the percent of global GM area accounted for by soybeans has decreased very slightly. Corn and cotton were the second and third most important GM crops, accounting for 21 and 12 percent, respectively, of global GM acreage in 2002. While corn and canola remain major GM crops on a global scale, their shares of total global GM acres have stagnated (in the case of cotton) or slipped (in the case of canola) each year since 1998.

Distribution of Global GM Area by Trait

Table 6 reports the ISAAA data series on the distribution of GM crop area from 1996 to 2002 according to five major traits: herbicide resistance, insect resistance (essentially "Bt crops"), virus resistance, "stacked" (both herbicide and insect resistant), and "quality" (so-called quality traits such as high oleic acid canola varieties).[4] These global data show a dramatic trend: GM varieties at a global scale are increasingly being accounted for by just one trait—that of herbicide resistance. While herbicide-resistant crop varieties accounted for 23 percent of global GM acres in 1996, herbicide resistance's share skyrocketed to 77 percent by 2001, though it decreased slightly to 75 percent in 2002. Insect resistance and virus resistance, which as late as 1997 accounted for 45 percent of global GM acres, had decreased to a total of 17 percent of GM crop area by 2002; virus resistance has virtually disappeared as a significant transgenic trait by global standards as of 2002. The global

Table 3. Global Area of Transgenic Crops, By Country, by Year, 2001 and 2002 (millions of hectares)

Country	2001	%	2002	%	Change in number of hectares, 2001-2002	Percent Change in number of hectares, 2001-2002
USA	35.7	68	39.0	66	+3.3	+9
Argentina	11.8	22	13.5	23	+1.7	+14
Canada	3.2	6	3.5	6	+0.3	+9
China	1.5	3	2.1	4	+0.6	+40
South Africa	0.2	<1	0.3	1	+0.1	+50
Australia	0.2	<1	0.1	<1	-0.1	—
India	—	—	<0.1	<1	<0.1	—
Romania	<0.1	<1	<0.1	<1	<0.1	—
Spain	<0.1	<1	<0.1	<1	<0.1	—
Uruguay	<0.1	<1	<0.1	<1	<0.1	—
Mexico	<0.1	<1	<0.1	<1	<0.1	—
Bulgaria	<0.1	<1	<0.1	<1	<0.1	—
Indonesia	<0.1	<1	<0.1	<1	<0.1	—
Colombia	—	—	<0.1	<1	<0.1	—
Honduras	—	—	<0.1	<1	—	—
Germany	<0.1	<1	<0.1	<1	<0.1	—
Totals	**52.6**	**100**	**58.7**	**100**	**+6.1**	**+12%**

Source: James (2002)

Table 4. Percent of Global GM Crop Acres Accounted for by the U.S., and by the U.S., Canada and Argentina, by Year

Year	Percent accounted for By U.S.	Percent accounted for by U.S., Canada, and Argentina
1996	51	59
1997	64	85
1998	74	99
1999	72	99
2000	68	98
2001	68	96
2002	66	95

SOURCE: International Service for the Acquisition of Agri-Biotech Applications, Cornell University

Table 5. Percent Distribution of Global GM Acres by Crop, by Year

Year	Soybean	Corn	Tobacco	Cotton	Canola	Tomato	Potato	Totals
1996	18	10	35	27	5	4	<0.1	100
1997	46	30	--	13	10	<0.1	<1.0	100
1998	52	30	--	9	9	<0.1	<1.0	100
1999	54	28	--	9	9	<0.1	<0.1	100
2000	59	23	--	12	6	<0.1	<0.1	100
2001	63	19	--	13	5	<.01	<0.1	100
2002	62	21	--	12	5	<.01	<.01	100

SOURCE: International Service for the Acquisition of Agri-Biotech Applications, Cornell University role of "stacked" GM varieties increased sharply until 1999, but the ISAAA data suggest that stacked varieties have stagnated or even lost ground since that time. Transgenic "quality" traits have never played a major role. Despite the tremendous amount of speculation about quality traits being the next major generation of GM crops, Table 6 suggests no evidence that this is becoming the case in the early part of the twenty-first century.

Table 6. Distribution of Global Area of Transgenic Crops by Trait, by Year

Year	Herbicide Resistance	Insect Resistance	Virus Resistance	Stacked (HR+IR)	Quality Traits	Totals
1996	23	37	40	--	<0.1	100
1997	54	31	14	<1.0	<1.0	100
1998	71	28	<0.1	1.0	<1.0	100
1999	69	10	<0.1	21	<0.1	100
2001	77	15	<0.1	8	<0.1	100
2002	75	17	<.01	8	<0.1	100

SOURCE: International Service for the Acquisition of Agri-Biotech Applications, Cornell University

Global GM Area by Crop

The ISAAA data reported in Table 7 show the distribution of transgenic varieties accounted for by the "big two" GM crop types: herbicide resistant soybeans and Bt corn. The results in Table 7 are consistent with those reported earlier on how transgenic crops are distributed by crop and trait. By 2001, fully 63 percent of all global GM crop area was accounted for by essentially only one technology: herbicide resistant soybeans. The percent of global GM area accounted for by HR soybeans declined only slightly from 2001 to 2002 (to 62 percent). The data show that since 1998, HR soybeans and Bt corn have accounted at least 73 percent of the global area of GM crops.

Global Adoption Rates for the Major GM Crops

The final set of ISAAA data to be examined in this article concerns global adoption rates of the four major GM crops—soybeans, cotton, canola, and corn—from 2000 to 2002 (Table 8). Table 8 shows that for one of these crops—soybeans—there has been a quite remarkable pattern of diffusion since the turn of the twenty-first century. The James (2001b, 2002) reports indicate that the global diffusion rate for HR soybeans has increased from 36 percent in 2000 to 51 percent in 2002; that is, in 2002, 51 percent of world soybean acres were planted to transgenic varieties. The data in Table 7 for transgenic cotton and canola varieties show intermediate, but still impressive, global adoption rates (20 and 12 percent, respectively, in 2002). And while we noted in Table 5 above that GM corn is second only to GM soybeans in *global acreage*, Table 8 shows that GM corn trails soybeans, cotton, and canola in its *global adoption rate* by a substantial margin (9 percent in 2002). Table 8 also indicates that the global adoption rates for transgenic canola and corn have stayed virtually constant from 2000 to 2002.

Table 7. Percent of Global GM Crop Acres Accounted for by HR Soybeans and Bt Corn, by Year

Year	HR Soybean	Bt Corn	Total
1996	18	10	28
1997	40	23	63
1998	52	24	76
1999	54	19	73
2000	59	15	74
2001	63	11	74
2002	62	13	75

SOURCE: International Service for the Acquisition of Agri-Biotech Applications, Cornell University

Table 8. Gobal Adoption Rates (Percent of Acres) of GM Crops, 2000-2002

	2000	2001	2002
Crop	**(Percent Devoted to GM Varieties)**		
Soybeans	36	46	51
Cotton	16	20	20
Canola	11	11	12
Corn	7	7	9

SOURCE: International Service for the Acqusition of Agri-Biotech Applications, Cornell University

GM Crop Adoption in the Developing Countries of the South

It is becoming increasingly apparent that the GM crop/food debate is shifting to the developing countries of the South, in several respects (International Center for Technology and Sustainable Development, 2003). First, many GM crop proponents take this position because of a conviction that GM-type crops will be necessary to increase food output and/or reduce poverty in the developing countries. By contrast, GM crop opponents tend to suggest that GM-type technology is poorly suited to sustainable poverty alleviation in the South because it is capital-intensive, promotes monoculture, and increases dependence on purchased inputs. Second, both the U.S. and the European Union—respectively, the major proponent and opponent countries/blocs with respect to GM crop products and technologies—are placing pressure on developing countries to structure their new crop variety regulatory systems to be consistent with their own systems; the U.S. prefers that the developing countries adopt the U.S.' "substantial equivalence" system, while the European Union is pushing for the developing countries of the South to adopt a "precautionary principle" system that is consistent with the Cartagena Protocol of the

Convention on Biological Diversity (see Schurman and Kelso, 2003). Third, and most germane to the present paper, there are divergent claims about the course of adoption and success of adoption of GM crop varieties in the developing countries of the South. Proponents of GM crops usually point to the rapid diffusion of GM crops in the South as validation of their point of view (though see Paarlberg, 2002, a GM proponent who has, in fact, used ISAAA data to document what he sees as the unfortunate slow pace of GM adoption in the South). Conversely, GM opponents tend to see that the slow diffusion of GM crops in the developing countries reflects the inappropriateness of these innovations for agricultural development in the Third World (because of their being most well suited for only a small set of large farmers who employ substantial levels of purchased inputs).

Table 9 provides a capsule view of GM crop adoption in five "significant" developing countries: Argentina, China, South Africa, India, and Brazil. Note that these countries are significant in quite varied ways. Recall the data in Table 2 to the effect that Argentina, China, South Africa, and India are the four leading developing countries in area of GM crops. In addition, while Brazil has nominally been a "GM-free" country and has become a major export supplier to the European Union because of its GM-free status, it is widely recognized that tens of thousands of Brazilian soybean producers plant smuggled HR soybeans. Estimates of clandestine HR soybean area in Brazil range from 10 to 30 percent of soybean area in the country, with the most likely figure being closer to 30 than to 10 percent (in 2002). The five countries represented in Table 9 arguably account for 99 percent or so of GM crop area in the South.

Of these five developing countries, Argentina and China already have significant amounts of (legal) GM crop area. Argentina, as noted earlier, has been part of the "big three" (along with the U.S. and Canada) since 1997. It should be noted in this regard that Argentina is a temperate country, has a small population relative to its land surface, and is a major exporter of the basic food and feed grains and oilseeds. Thus, while Argentina is normally considered to be part of the South, there is no other developing country that has its agro-economic characteristics. In very short order (since roughly 2000), China has become a major player in GM crop adoption. China, along with Argentina, the U.S., and Canada, is now among the world's now "big four" in GM adoption that collectively accounted for over 99 percent of global GM area in 2002. South Africa currently has very little GM crop acreage relative to the "big four," but GM crop production is legal and strongly encouraged through national public policy and foreign aid, and there has been a sizable rate of growth of GM cotton acreage (due, in part, to the small base).

The data in Table 9 summarize what is currently known about GM crop adoption from various sources. Some observations from the data in the table are: Argentina not only has a large amount of GM soybean area, but it is now on the threshold of becoming a major player in GM maize, and shortly in GM cotton as well. Argentina is on its way to joining the U.S. and Canada as the world's third "full-service" GM crop producer, wherein there is significant acreage of several crops of considerable world importance. About half of China's cotton acreage in 2002 was devoted to GM cotton. China has many other GM crops in the pipeline—including, most importantly, GM rice. China is taking a very strategic position in biotechnology—for example, in permitting access by multinationals when they need their expertise (but with the considerable likelihood these multinationals will be dispatched when their expertise is no longer needed). At the same time, China is being quite restrictive in terms of imports of GM foods.

South Africa is something of a glamour country in terms of GM crop adoption because of its important geopolitical position and its economic role in sub-Saharan Africa. South Africa is somewhat distinctive in Africa in its pro-GM stance, and in the attention that has been directed to South Africa by corporations and governments that wish to support its pro-GM posture (International Center for Technology and Sustainable Development, 2003). GM cotton is the most important GM crop in South Africa, and because of South Africa's geopolitical and symbolic importance much of the pro- vs. anti-GM debate regarding the developing countries has turned to the issue of whether the performance of GM cotton in South Africa (as well as India) has been favorable. There is considerable conflicting literature and intense debate on the performance and appropriateness of GM cotton in South Africa (compare Ismail et al., 2002, and Kuyek, 2002). There is now a substantial amount of GM soybeans and maize in South Africa as well.

Table 9. Summary of GM Crop Adoption in Five Developing Countries

	Total GM Crop Area 2002					
Country	Millions of hectares	Note on calculation	Cotton	Soybean	Corn	Others
Argentina	13.5	James 2002	May 2001, Argentina approved herbicide tolerant cotton, ending a three-year moratorium on new approvals that was triggered in part by concerns about antibiotech sentiment in Europe.(http://www.whybiotech.com/index.asp?id=1809) Cotton area planted with transgenic seeds will probably hold steady at 40,000 hectares.(http://www.planetark.org/dailynewsstory.cfm/newsid/13760/newsDate/19-Dec-2001/story.htm).	11.3 million hectares forecast to be planted with soy this year, nearly all will be sown with genetically modified seeds, according to ISAAA data (http://www.planetark.org/dailynewsstory.cfm/newsid/13760/newsDate/19-Dec-2001/story.htm)	Genetically modified corn plantings look set to grow to 800,000 hectares out of a total of 3.34 million hectares, about 14 percent more than a year ago. (http://www.planetark.org/dailynewsstory.cfm/newsid/13760/newsDate/19-Dec-2001/story.htm)	
China	2.1	James 2002	More than half of the national cotton area of 4.1 million hectares were planted with Bt cotton (ISAAA Pres Release Jan 16, 2003)			China has released rice varieties resistant to three major pests and done field trials on GM wheat. Other GM crops on sale include pest and disease-resistant cotton, tomatoes and sweet peppers. In the pipeline are GM potatoes, rape, peanuts, cabbage, melons, maize, chillies, papaya and tobacco. (New Scientist Feb 2, 2002). But ISAAA brief in 2003 "GM Rice: Will This Lead the Way for Global Acceptance of GM Crop " seems to indicate that rice is still not yet commercially grown. (http://www.isaaa.org/Publications/briefs/isaaa_briefs.htm)

	Total GM Crop Area 2002					
Country	Millions of hectares	Note on calculation	Cotton	Soybean	Corn	Others
South Africa	0.3	James 2002	In 1999/2000 a total area of 100,000 ha of Bt cotton was grown in South Africa by 1530 commercial farmers and 3,000 small scale farmers. (Ismael et al, Outlook on Agriculture Vol 31. No.2 2002)	Last year SA officials approved the commercial use of Rounup ready soybean allowing the domestic production of the country's first commercial biotech food crop, which were planted on nearly 17,500 acres (7000 ha) in 2001. Imports had been improved previously. (BioExchange.com, Feb 11, 2002)	58,000 has of Bt white maize is grown (ISAAA Press Release Jan 16, 2003)	
India	Less 0.1	James 2002	In 2002, government approved commercial release of Mahyco Monsanto Biotech's GM cotton in Southern and Central states for three years. "Farmers in five Indian states are cultivating Monsanto's Bt cotton on over 100,000 acres" (Naturebiotechnology Nov 2002, Vol 20, P. 1069). However, the result of the harvest has been much contested and parliamentary report has found some doubts about the efficacy of Bt cotton in the country. The permission for commercial release of Bt cotton in northern India was rejected in April 2003.			According to Department of Biotechnology report published in April 2003, there are 48 trangenic projects involving 15 crops in the public sector and 20 projects involving 9 crops in the private sector are in various stages of development in India. DBT also earmarked 15.9 million dolllars for crop biotechnology for the period of 2002-07. However, there are some negative development, such as recent rejection of approval of Bt cotton release in northern states and also ProAgro's field trials for GM mustards. (Nature Biotechnology Vol 21. No. 6 2003)
Brazil	unknown					30% of soyseeds is ilegal transgenic according to Association of Brazilian Seed Producers (CropChoice News April 7, 2003). Officials say that 12% of soycrop for the year's harvest is illegal transgenic (CropChoice News, March 10, 2003, Financial Times March 7,

India, despite its poverty, has an impressively skilled cadre of agricultural science and biotechnology researchers, and Indian public researchers have undertaken a considerable amount of research on transgenic crop varieties. India, however, has veered from anti- to pro-GM positions over the past eight or so years, for several reasons. Among these are the fact that there a numerous movement groups in India that are fiercely anti-GM. Also, some ministries and state governments are quite anti-GM while are parts of the government are pro-GM. While there is a great deal of GM research in the pipeline in India, the major story in Indian agricultural biotechnology is GM cotton. As with South Africa, there has been an enormous amount of debate as to the performance of GM cotton (again, compare Qaim and Zilberman, 2003, and Sahai and Rahman, 2003).

In sum, there are very contradictory tendencies with regard to GM crop adoption and promotion in the South. The vast bulk of (legal) GM crop adoption in the South is in Argentina and China. If Brazil's clandestine HR soybean acreage is included, it would be part of the world's "big five." But for the vast majority of developing countries, there is essentially no GM crop adoption at all.

Summary

The data discussed in this paper suggest that four general kinds of conclusions about the global adoption and diffusion pattern for GM or transgenic crops are warranted.

1. There has been an *unprecedented expansion of the adoption of HR soybeans*—and, to a lesser extent, of GM cotton, corn, and canola varieties—in the U.S., Canada, and Argentina (and in Brazil, if clandestine production of HR soybeans is considered).

2. Outside the "big three" plus China and Brazil, there is *essentially no transgenic crop acreage in the world today***.** Global GM crop area outside of these five countries is approximately a half million hectares or so (see Table 3 above).

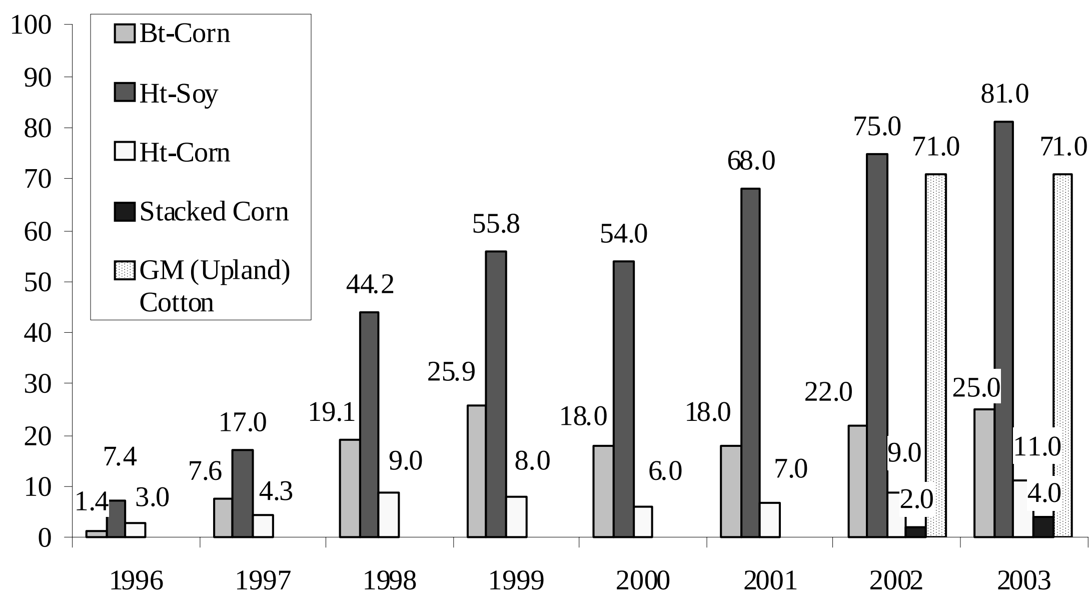
3. If anything, the *global GM adoption pattern is becoming deeper but narrower***.** There has been a remarkable global adoption of transgenic soybean varieties, but even for cotton, canola, and corn the global penetration of GM crop varieties has been fairly limited. The global diffusion of transgenic varieties is accounted for by one crop—soybeans—in one country—the U.S.—and by the use of one technology—herbicide resistance. The trend toward global GM crop adoption becoming more narrowly focused on soybeans will necessarily end shortly, because over 80 percent of U.S. soybean area is already transgenic, and the global adoption rate of HR soybeans is already 51 percent.

4. Given that the world's three major food crops are rice, wheat, and maize, and given the limited adoption of transgenic maize and the negligible presence of GM varieties in rice and wheat, there is *scarcely any real beginning of a "gene revolution" in the world's staple crop sectors***.** The GM revolution is largely limited to a revolution in the production of animal feed, industrial raw materials, and textile fibers.

In summary, with a very few crops in a very few places, there have been some remarkable changes, but for most of world agriculture transgenic crop technology still has virtually no presence. This conclusion describes the global data on GM adoption, but it is worth noting that it has some relevance as well to the GM adoption process in the U.S. and Wisconsin. Figure 1 shows GM variety adoption rates over time, expressed as percent of total acres, for the four major GM variety products grown in Wisconsin and elsewhere in the Corn Belt—Bt corn, HR corn, "stacked corn," and HR soybeans (as reported by the U.S.D.A. Economic Research Service at http://www.ers.usda.gov/Briefing/biotechnology/chapter1.htm). In addition, U.S. data on GM cotton adoption are included for 2002 and 2003.

Figure 1 also shows that there have been persistent increases in the market penetration of HR soybeans and GM (upland) cotton from 1996 through 2002 (with the exception of the slight decline of HR soybean adoption from 1999 to 2000 during the initial flare-up of the U.S. and European Union disagreement over U.S. GM crop exports to Europe). The use of HR soybean and GM cotton varieties is now virtually at saturation (81 and 71 percent, respectively, in 2003). Major increases in GM area in the U.S. if they are to occur will need to come in other crops. Adoption of both HR and Bt corn in the U.S. has leveled off since 1999, and use of "stacked" corn varieties remains limited (about 4 percent of national corn acreage). Relatively similar trends for these four corn and soybean technologies have occurred in Wisconsin (Chen et al. 2001; a comprehensive picture of GM adoption in the United States can be found at http://pewagbiotech.org/resources/factsheets/display.php3?FactsheetID=2).

Figure 1. The Adoption of GMO Crop Varieties in the US (% acres)



In Wisconsin, the U.S., and the world as a whole, the overall pattern of GM adoption is deep in a handful of places and crop sectors (in the sense of there being widespread adoption of certain GM crops such as HR soybeans in the American Midwest and transgenic cotton in the U.S. South and Southwest). However, GM adoption is also narrow, in that it has bypassed most of agriculture and is becoming increasingly limited to a handful of commodities in a handful of countries. Both proponents and opponents of GM technology will need to recognize this contradictory nature of GM adoption in order to understand the significance of biotechnology research and development in global as well as national terms.

Endnotes

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[2] It is, of course, the case that a wide range of authors spoke of the nascent emergence of a "biotechnology revolution" well prior to the actual commercialization of major GM products such as recombinant BST and transgenic crop varieties. A representative example of this is the publication in 1988 of Molnar and Kinnucan's anthology, *Biotechnology and the New Agricultural Revolution*.

[3] One interesting anomaly in Table 5 concerns GM tobacco, which accounted for 35 percent of global GM crop acres in 1996. Virus-resistant tobacco varieties were grown on a widespread basis in the People's Republic of China in 1996 but were largely discontinued after that time.

[4] Note that, to the best of our knowledge, the James (2001a) report did not include such data for 2000.

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