Global Review of Commercialized Transgenic Crops: 1998

by

Clive James
Chair, ISAAA Board of Directors

Global Area[*] of Transgenic Crops in 1996, 1997 and 1998
(millions of hectares/acres)

	Hectares (million)	**Acres** (million)
1996	1.7	4.3
1997	11.0	27.5
1998	**27.8**	**69.5**

*Excluding China

Increase in area from 1996 to 1997 is 9.3 million hectares (23.2 million acres)
Increase in area from 1997 to 1998 is 16.8 million hectares (42.0 million acres)

Source: Clive James, 1998.

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Executive Summary

This publication characterizes the adoption of commercialized transgenic crops globally in 1998, excluding China. A database was developed for transgenic crops globally. The data base is analyzed by country, crop and trait, and the economic benefits to growers was estimated for selected transgenic crops that were planted in 1996 and 1997 in the USA and Canada. Data on the current global status of commercialized transgenic crops is complemented with a discussion of several key issues, including global food security and the potential benefits for developing countries in a rapidly evolving global market.

Between 1996 and 1998, eight countries, 5 industrial and 3 developing, have contributed to more than a fifteen fold increase in the global area of transgenic crops. Adoption rates for transgenic crops are some of the highest for new technologies by agricultural industry standards. High adoption rates reflect grower satisfaction with the products that offer significant benefits ranging from more flexible crop management, higher productivity and a safer environment through decreased use of conventional pesticides, which collectively contribute to a more sustainable agriculture. In 1998, the global area of transgenic crops increased by 16.8 million hectares to 27.8 million hectares from 11.0 million hectares in 1997. Five principal transgenic crops were grown in eight countries in 1998, three of which, Spain, France and South Africa, grew transgenic crops for the first time in 1998. Data for China has not been included in the global database because only tentative estimates were available which suggest that <100,000 hectares of transgenic crops were grown in 1998, representing <1 % of global transgenic area, with *Bt* cotton being the principal crop.

The countries listed in descending order of transgenic crop area on a global basis in 1998 are: USA 20.5 million hectares representing 74 % of the global area, Argentina with 4.3 million hectares equivalent to 15 % of global area; Canada 2.8 million hectares representing 10 %; Australia with approximately 0.1 million hectares equivalent to 1 % and finally Mexico, Spain, France and South Africa each with <0.1 million hectares, equivalent to less than 1 % of the global area of transgenic crops in 1998. The proportion of transgenic crops grown in industrial countries was 84 %, about the same as 1997 (86 %) with 16 % grown in the developing countries, with most of that area in Argentina, and the balance in Mexico and South Africa. As in 1997, the largest increase in transgenic crops in 1998 occurred in the USA (12.4 million hectares) where there was a 2.5 fold increase, followed by Argentina (2.9 million hectares) with a 3.0 fold increase, and Canada (1.5 million hectares) with a 2.1 fold increase. USA continued to be the principal grower of transgenic crops in 1998 and its share of global area was the same (74 %) in 1997 and 1998. Argentina's transgenic crop area increase was the largest relative change, increasing 3.0 fold from 1.4 million hectares in 1997 to 4.3 million hectares in 1998; thus Argentina's global share of transgenic crop area increased from 13 % of global area in 1997 to 15 % in 1998. Canada's share of global transgenic crop area decreased marginally from 12 % in 1997 to 10 % of global area in 1998.

The five principal transgenic crops grown in 1998 were, in descending order of area, soybean, corn/maize, cotton, canola/rapeseed, and potato. Transgenic soybean and corn continued to be ranked first and second in 1998, accounting for 52 % and 30 % of global transgenic area, respectively. Cotton and canola shared third ranking position in 1998 each occupying 9 % of global area. The relative ranking of the principal transgenic traits were the same in 1997 and 1998, with herbicide tolerance being by far the highest, increasing from 63 % in 1997 to 71 % in 1998. Insect resistant crops decreased from 36 % in 1997 to 28 % in 1998. Stacked genes for insect resistance and herbicide tolerance increased from <0.1 % in 1997 (<0.1 million hectares) to 1 % or 0.3 million hectares in 1998 with quality traits occupying less than 1 % and <0.1 million hectares in both 1997 and 1998.

In reviewing the shift in global share of transgenic crops for the respective countries, crops and traits, the major changes between 1997 and 1998 were related to the following trends: growth in area of transgenic crops between 1997 and 1998 in the industrial countries continued to be significant and almost 5 times greater than in developing countries (13.9 million hectares versus 2.9 million hectares); in terms of crops, soybean contributed the most (56 %) to global growth of transgenic crops, equivalent to 9.4 million hectares between 1997 and 1998, followed by corn at 30 % (5.1 million hectares), canola at 7 % (1.2 million hectares) and cotton at 6 % (1.1 million hectares). There were three noteworthy developments in terms of traits, herbicide tolerance contributed the most (77 % or 12.9 million hectares) to global growth, and insect resistance contributed 22 %

equivalent to 3.7 million hectares; the multiple or stacked traits of insect resistance and herbicide tolerance increased by 0.2 million hectares in 1998 representing 1 % of global area with significant prospects for further growth in future. Of the 5 major transgenic crops grown in 8 countries in 1998, the two principal crops of soybean and corn, represented 82 % of the global transgenic area. In 1998 herbicide tolerant soybean was the most dominant transgenic crop (52 % of global transgenic area) followed by insect resistant corn (24 %), herbicide tolerant canola (9 %), and insect resistant/herbicide tolerant cotton at 9 % and herbicide tolerant corn at 6 %. The three major factors that influenced the change in absolute area of transgenic crops between 1997 and 1998 and the relative global share of different countries, crops and traits were: firstly, the enormous increase in herbicide tolerant soybean in the USA from 3.6 million hectares in 1997 to 10.2 million hectares in 1998 (equivalent to 36 % of the US national soybean area) coupled with a similar increase in herbicide tolerant soybean in Argentina from 1.4 million hectares in 1997 to 4.3 million hectares in 1998 and equivalent to >60 % of the Argentinean national soybean area; secondly, the significant increase of insect resistant corn in the USA from 2.8 million hectares in 1997 to 6.5 million hectares in 1998, equivalent to 22 % of the US national corn area in 1998; and thirdly, the large increase of herbicide tolerant canola in Canada from 1.2 million hectares in 1997 to 2.4 million hectares in 1998, equivalent to 50 % of the Canadian canola area. The combined effect of these three factors resulted in a global area in 1998 that was 16.8 million hectares higher and 2.5 fold greater than 1997. It is noteworthy that 1998 was the first year for a commercialized transgenic crop to be grown in the countries of the European Union. Estimates suggest that introductory quantities of insect resistant maize were grown primarily in Spain (20,000 hectares) and France (2,000 hectares); this is judged to be potentially a very significant development because it could have important implications for the further adoption of transgenics in countries of the European Union.

Estimated Benefits from Transgenic Crops

More information on the benefits associated with transgenic crops is becoming available following the substantial area of transgenic crops planted in the USA and Canada in 1997. Multiple benefits have been reported by growers for selected transgenic crops; these include more flexibility in terms of crop management (particularly important for herbicide tolerant crops), decreased dependency on conventional insecticides and herbicides, higher yields and cleaner and higher grade of grain/end product.

As expected, net economic returns to the grower vary by year, by crop product and by location, depending on factors such as level of infestation of the targeted pest, the epidemic level of a disease or the weed density. For the USA in 1996, economic benefits to growers from the following transgenic crops were estimated conservatively at $128 million for *Bt* cotton, $19 million for *Bt* corn, and $12 million for herbicide tolerant soybean for a collective national benefit of $159 million. Similarly, in 1997, economic benefits were estimated at $119 million for *Bt* corn, $109 million for herbicide tolerant soybean, $133 million for *Bt* cotton, and $5 million for herbicide tolerant cotton and <$1 million for *Bt* potato, for a collective national benefit in the USA of $366 million. In Canada, benefits at a national level, due to the use of herbicide tolerant canola, were estimated at $5 million in 1996, and $48 million in 1997, plus $5 million for *Bt* corn for a total of $53 million. Thus, in 1996 and 1997, selected transgenic crops in the USA and Canada resulted in economic benefits to growers, conservatively estimated at $583 million.

Future Global Markets and Global Food Security

Global sales of transgenic crop products have grown rapidly during the period 1995 to 1998. Global sales from transgenic crops were estimated at $75 million in 1995; sales tripled in 1996 and again in 1997 to reach $235 million and $670 million respectively, and doubled in 1998 to reach an estimated value of between $1.2 to $1.5 billion. Thus, revenues for transgenic crops have increased by approximately twenty fold in the four year period 1995 to 1998. The global market for transgenic crops is projected to increase to $3 billion or more in 2000, to $6 billion in 2005, and to $20 billion in 2010.

The number of countries growing transgenic crops has increased from 1 in 1992, to 6 in 1996, to 9 in 1998, and is expected to continue to grow to the year 2000 and beyond. In 1999, countries in North and Latin America already growing transgenic crops are expected to significantly expand the area of current products and also to introduce new single and multiple trait products and Brazil will probably grow transgenic crops for the first time in 1999. Similarly, China is expected to expand its transgenic crop area aggressively, with growth and diversification continuing in Australia and South Africa. Whereas public acceptance, including labeling of foods derived from genetically modified plants, will continue to be dominant issues that will impact on adoption of transgenic crops in countries of the European Union, the initial approval of several products in 1998 was encouraging. However, more recent developments have delayed plans for early expansion. India and several countries in Eastern Europe have transgenic crops that are ready for commercialization. As expansion of transgenic crops continues, a shift will occur from the current generation of "input" agronomic traits to the next generation of "output" quality traits, which will result in improved and specialized nutritional food and feed products that will satisfy a high-value-added market; this will significantly affect the value of the global transgenic crop market and also broaden the beneficiary profile from growers and consumers to food, feed and fiber processors.

Biotechnology-driven consolidations in the form of acquisitions, mergers and alliances continue to be a dominant feature of the biotechnology industry. In the last three years alone, corporations commercializing transgenic crops and involved with seeds, agricultural chemicals, and the life sciences have been engaged in more than 25 major acquisitions and alliances valued at >$15 billion. This consolidation is expected to continue. Genomics is pivotal to the growth of the industry and is catalyzing a new generation of alliances, acquisitions and mergers.

Transgenic crops are proprietary, developed almost exclusively by the private sector in the industrial countries, with the majority of the global transgenic crop area to-date grown in countries of the North. However, it is important to note that developing countries such as China played a pioneering role by being the first country to introduce a commercialized transgenic crop in the early 1990s. Argentina is a global leader in the accelerated adoption of transgenic crops with significant expansion imminent in Mexico and South Africa. Given that the food gap of many developing countries, including China, is expected to more than double in the next 25 years and that some developing countries like Argentina can meet some of those needs through exports, the long term potential and importance of transgenic crops for developing countries is evident. There are three considerations that underpin the strategic importance of transgenic crops for developing countries.

Firstly, developing countries have potentially more to gain from transgenic crops than industrial countries because the area of almost all crops is far greater in developing countries than in the USA and Canada where adoption has been highest to date. For example, there is 145 times more rice, five times more cotton, three times more maize and wheat and as much soybean grown in the developing countries compared with the USA and Canada. This excludes important staples such as cassava and sweet potato that are grown almost exclusively in the developing countries and have the potential to benefit significantly from biotechnology.

Secondly, yields of almost all crops are significantly lower in developing than industrial countries; for example, there is almost a threefold difference in maize yields between the USA and developing countries and almost a twofold difference in rice yields. Yields are low in developing countries for many reasons but one of the principal causes is that crops in developing countries suffer much more from biotic stresses, due to pests, weeds and diseases, for which current transgenic crops already offer improved protection. Thus, the potential gain for developing countries from improved control of biotic stresses is relatively greater than for industrial countries.

Thirdly, and most importantly, it is in the developing countries, not the industrial countries, where 800 million people suffer from malnutrition today and where transgenic crops could increase crop productivity and contribute to the alleviation of hunger and poverty which are inextricably linked. During the next decade an increase in productivity of 10 to 25 percent from transgenic crops is both feasible and realistic. This will be a critical and significant contribution to global food security, more nutritious food and feed, and to a safer environment. Transgenic crops have much to offer developing countries and should be an essential component of a global food security strategy that integrates conventional and biotechnology crop improvement applications to produce more food where the need is greatest, and where the welfare value of food is the highest. Denial of the new technologies to the poor is synonymous to condemning them to continued suffering from malnutrition which eventually may deny the poorest of the poor their right to survival.

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Introduction

This publication is the third by the author in an annual review series, published as *ISAAA Briefs*, to characterize and monitor the global status of commercialized transgenic crops. The first review was published in 1996 (James and Krattiger 1996), the second in 1997 (James1997a) and the current publication presents similar information for 1998. Introductions in previous reviews contained considerable information on global population growth rates and related statistics, so that the potential contribution of transgenic crops could be viewed within the context of global food security, particularly in relation to the developing countries which are the ones afflicted by poverty and hunger. Since the food security contextual framework was adequately covered in previous reviews, and given that the facts have not materially changed in the interim, the global food security information will not be repeated here. The reader is referred to the 1997 review (James 1997a) for the pertinent data.

China was the first country to commercialize transgenics in the early 1990s. The first approval for commercial sale of a genetically modified product for food use in an industrialized country was in the United States in 1994 when Calgene marketed its Flavr-SavrTM delayed ripening tomato. By year-end 1995, applications had been granted to commercially grow 9 transgenic crops, with most approvals in the United States and Canada. By 1996, approximately 2.8 million hectares of 7 principal transgenic crops were grown commercially globally with a significant area in the United States, China, Canada, Argentina, Australia and Mexico, with 57 percent grown in industrial countries and 43 percent in developing countries. Today, transgenic crops, and products derived from them, are generally accepted in the industrial countries of the United States, Canada and Australia and the developing countries of Argentina, China, Mexico and South Africa, whilst progress is evident but slower in Spain and France, as countries of the European Union continue to discuss the adoption of transgenic crops.

The principal aim of this publication is to:

- list the transgenic crops currently approved for growing and commercialization;
- briefly review the adoption of transgenic crops in the period 1995 to 1998;
- document detailed information on the global status and distribution of commercial transgenic crops in 1998 by region, country, crop and trait; note that information from China could not be included in the database because only *Bt* cotton information, which is presented separately in this text, was available;
- provide a preliminary assessment of the benefits resulting from the use of selected transgenic crops grown commercially in the USA and Canada in 1996 and 1997, and more generally in developing countries;
- estimate the value of the transgenic crop market from 1995 to 1998;
- assess the potential of transgenic crops to the developing countries compared with the USA and Canada;
- discuss current and future developments that will impact on the growth and commercialization of transgenic crops in the near-term and in the first decade of the 21st century, including the continuing consolidation in the private sector through acquisitions, alliances and mergers; the pivotal role of genomics, maintaining durable resistance to *Bt*, public acceptance, future prospects and global food security

Note that the words maize and corn, as well as rapeseed and canola, are used as synonyms throughout the text reflecting the usage of these words in different regions of the world. It is important to understand that when areas of transgenic crops are described for countries in the Southern hemisphere that plant in the last quarter of the year, the areas represented are planted (not harvested) in the year stated. Thus, the 1998 information for Argentina is hectares planted in the last quarter of 1998 and harvested in the first quarter of 1999. Finally note that an advance copy of the Executive Summary of this publication was distributed in September 1998; additional information has been received since September and the Executive Summary has been updated with the latest information, along with some editorial changes.

Review of Transgenic Crop Products Currently Approved for Commercialization

The data in Table 1A of the Appendix (p. 39) shows that, as of year-end 1998, 56 transgenic crop products, (as compared with 48 products at year-end 1997) have been approved for planting and commercialization in at least one country. It is noteworthy that of the 22 technology proprietors listed, 19, equivalent to 86 percent, are private corporations and that only 3, equivalent to 14 percent, are public sector organizations. It is also important to note that all 56 products listed are proprietary products and have been registered as proprietary technology by their respective developers for use in one or more countries. The 56 products involve 13 crops of which corn (28 percent), canola (13 percent), tomato (9 percent), cotton (9 percent) and squash (9 percent) represent the majority (68 percent) of the crops involved, with the balance made up of soybean, potato, tobacco, squash, beet, papaya, carnation, chicory and flax. In terms of traits, the list covers a total of six trait categories, 4 categories involving a single trait and two categories involving double traits. Herbicide tolerance (34 percent), virus resistance (14 percent), quality traits (12 percent), and insect resistance (12 percent) represent the majority (72 percent) of approved traits with the balance made up of multiple trait products, particularly insect resistance/herbicide tolerance (12 percent). The list of 56 approved transgenic crop products listed in Table 1A of the Appendix will change continuously as additional transgenic products are approved in countries already growing commercialized transgenics and as new countries will introduce approved transgenic crop products for the first time.

The Organization for Economic Cooperation and Development (OECD) provide details on their Bio Track Web site of transgenic crop applications approved by several national Regulatory Agencies. The most recent info (OECD, 1998) lists 82 approvals from 1992 to 1997 (see summary in Table 2A of the Appendix, p. 40). Of the 82 applications listed in Table 2A, 70 applications, equivalent to 72 percent have been approved for growing, 47 (57 percent) approved for food use and 31 (38 percent approved for feed use; note that the latter three percentages do not add up to 100 percent because some products have multiple approvals, for example, for growing and food.

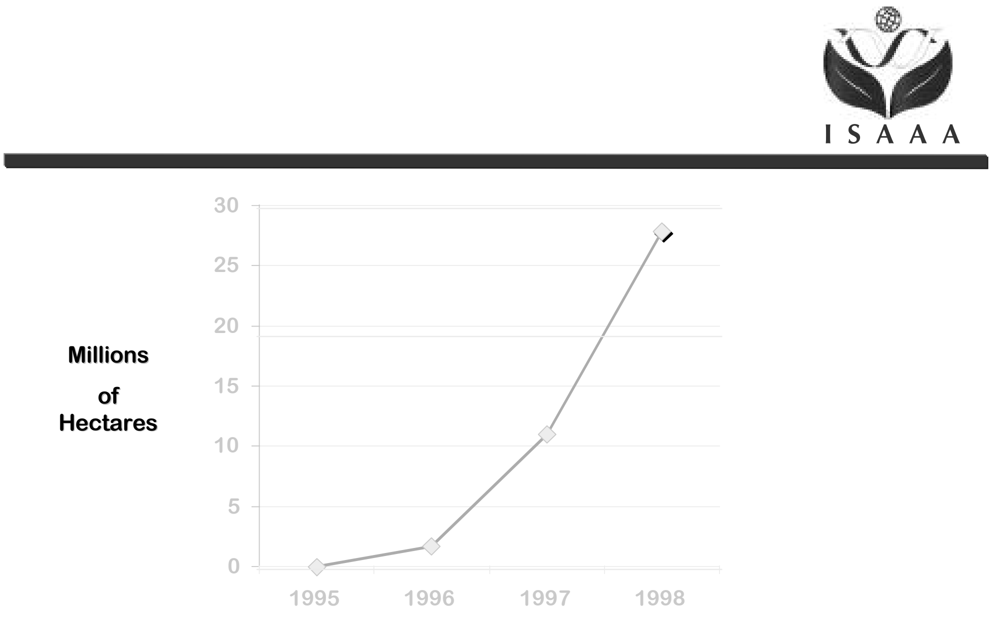
Global Status and Distribution of Commercial Transgenic Crops

Information on the adoption of commercial transgenic crops was provided by many independent sources from both the public and private sector. Multiple sources of data, as well as additional and independent commercial marketing information, allowed several cross checks to be conducted, which facilitated a rigorous verification of the estimates; Unfortunately, information from China could not be included in this publication because, only *Bt* cotton information, which is presented separately in the text, was available and verifiable.

For convenience and ease of interpretation the data for the global status and distribution of commercial transgenic crops are presented in two complementary formats. Figures are used to best illustrate the changes in global transgenic area between 1995 and 1998. Companion tables provide more detailed corresponding information for 1998 and to illustrate the changes that have occurred between 1997 and 1998. Thus, the data in Figure 1 graphically shows the very rapid increase in global area (excluding China) of transgenic crops from zero in 1995 to 27.8 million hectares in 1998. The adoption rates for transgenic crops in Figure 1 exhibit more than a fifteen fold increase between 1996 and 1998 and is amongst one of the highest adoption rates for new technologies by agricultural industry standards. The high adoption rates reflect grower satisfaction with the products that offer significant benefits ranging from more flexible crop management, higher productivity and a safer environment through decreased use of conventional pesticides, which collectively contribute to a more sustainable agriculture. The companion data to Figure 1, in Table 1, shows that the global area planted to commercial transgenic crops increased from 1.7 million hectares in 1996 to 11.0 million hectares in 1997 and to 27.8 million hectares in 1998. Thus, the global transgenic crop area increased by 9.3 million hectares between 1996 and 1997, equivalent to more than a 6 fold increase, and by 16.8 million hectares between 1997 and 1998. The 2.5 fold global increase in area of commercial transgenic crops between 1997 and 1998 represents a continuing high rate of adoption for this new technology and reconfirms the support of selected Governments and the motivation of farmers in those countries to invest rapidly in transgenic crops.

Figure 2 graphically illustrates that during the period 1996 to 1998, the substantial share of global transgenic crops were being grown in industrial countries with significantly less in the developing countries. The companion data to Figure 2, in Table 2, confirm that the proportion of transgenic crops grown in industrial countries in 1998 was 84 %, slightly less than 1997 (86 %),

Figure 1: Global Area of Transgenic Crops (excluding China): 1995 to 1998



Source: Clive James, 1998

Table 1: Global Area* of Transgenic Crops in 1996, 1997 and 1998

	Hectares (million)	**Acres** (million)
1996	1.7	4.3
1997	11.0	27.5
1998	27.8	69.5

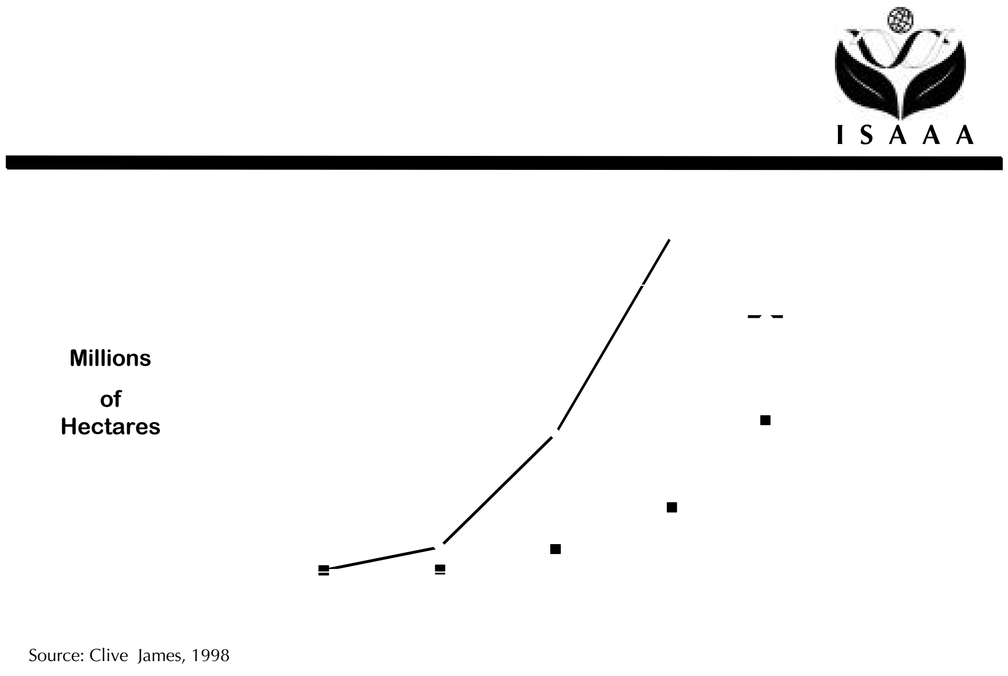
* Excluding China
Increase in area from 1996 to 1997 was 9.3million hectares (23.2 million acres)
Increase in area from 1997 to 1998 was 16.8 million hectares (42.0 million acres)
Source: Clive James, 1998.

with 16 % grown in the developing countries, with most of that area in Argentina, and the balance in Mexico and South Africa. However the relative increase in area between 1997 and 1998, expressed as a ratio, was higher for the developing countries at 2.9 compared with the corresponding ratio for industrial countries at 2.0 (Table 2); this mainly reflects the high rate of adoption of herbicide tolerant soybeans in Argentina in 1998. The actual increase in transgenic crop area between 1997 and 1998 was 13.9 million hectares, in industrial countries, and 2.9 million hectares in developing countries. In the industrial countries the major increase in area was due to soybeans, followed by corn, canola and cotton whereas the major increase in developing countries involved the same crops, excluding canola.

Distribution of Transgenic Crops, by Country

Excluding China, between 1996 and 1998, eight countries, five industrial and three developing, have contributed to more than a fifteen fold increase in the global area of transgenic crops. The number of countries growing commercialized transgenic crops increased from five in 1997 (USA, Argentina, Canada, Australia and Mexico) to eight in 1998 when South Africa, Spain and France grew transgenic crops for the first time. The countries listed in descending order of transgenic crop area on a global basis in 1998 are: USA 20.5 million hectares representing 74 % of the global area, Argentina with 4.3 million hectares equivalent to 15 % of global area; Canada 2.8 million hectares representing 10 %; Australia with approximately 0.1 million hectares

Figure 2: **Global Area of Transgenic Crops (excluding China): 1995 to 1998:** **By Region**



Source: Clive James, 1998

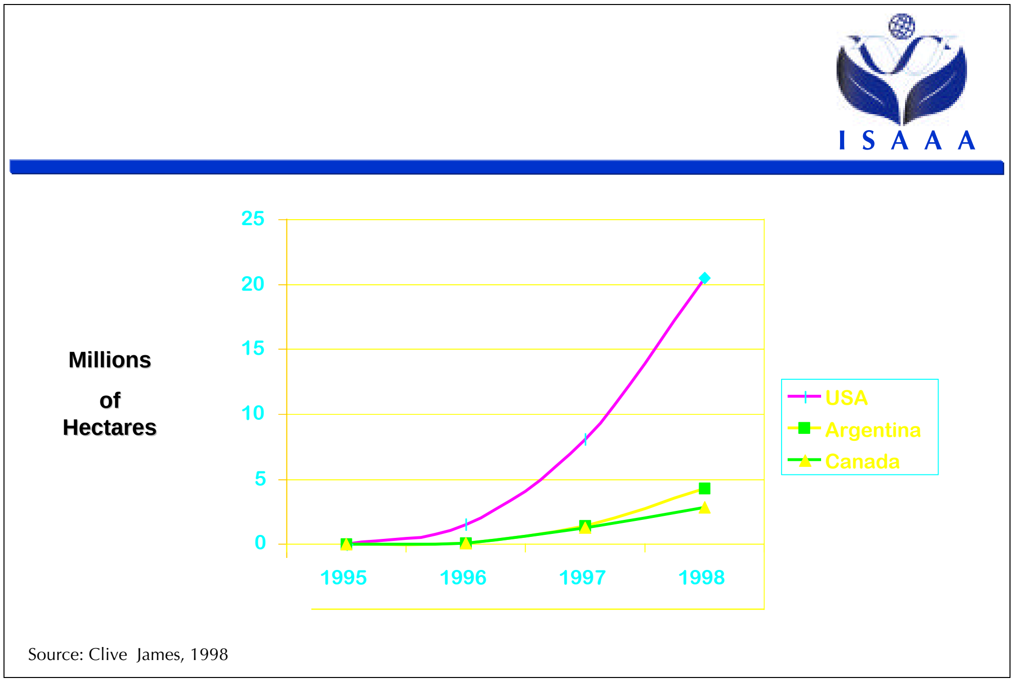
Table 2: **Global Area of Transgenic Crops in 1997 & 1998:** **Industrial & Developing Countries**
(millions of hectares)

	1997	**%**	**1998**	**%**	**Increase (Ratio)**
Industrial Countries	9.5	86	23.4	84	13.9 (2.5)
Developing Countries	1.5	14	4.4	16	2.9 (2.9)
Total	**11.0**	**100**	**27.8**	**100**	**16.8 (2.5)**

Source: Clive James, 1998.

equivalent to 1 % and finally Mexico, Spain, France and South Africa each with <0.1 million hectares, equivalent to less than 1 % of the global area of transgenic crops in 1998. Figure 3 and Table 3 clearly demonstrate that in 1998, the USA retained its first ranking as the country with the largest area of transgenics at 20.5 million hectares. Between 1997 and 1998 the USA increased its transgenic area by 12.4 million hectares but its global share remained constant at 74%, equivalent to 8.1 million hectares in 1997 and 20.5 million hectares in 1998. The USA grew almost five times more area of transgenic crops than Argentina, in both 1997 and 1998 which occupied second place in both years. The USA increased its transgenic crop area by a factor of 2.5 between 1997 and 1998 and benefited from a broader balance of 10 crop/trait combinations that included, for the first time, commercial crops of soybean and some canola with modified oil, and both cotton and corn with combined insect resistance and herbicide tolerance. In the USA in 1998 by far the biggest area increase in transgenic crop area was soybean which almost tripled in area from 3.6 million hectares in 1997 to over 10 million hectares, followed by corn which more than doubled in area to almost 8 million hectares. A 50 percent increase in area was realized in the USA for transgenic cotton of which the most significant element was herbicide tolerant cotton, followed by multiple trait corn with both insect resistance and herbicide tolerance.

Figure 3: Global Area of Transgenic Crops (excluding China): 1995 to 1998: By Country



Source: Clive James, 1998

Table 3: Global Area of Transgenic Crops in 1997 & 1998: By Country (millions of hectares)

Country	1997	%	1998	%	Increase 1997 to 1998	(Ratio)
USA	8.1	74	20.5	74	12.4	(2.5)
Argentina	1.4	13	4.3	15	2.9	(3.0)
Canada	1.3	12	2.8	10	1.5	(2.1)
Australia	0.1	1	0.1	1	<0.1	(1.0)
Mexico	<0.1	<1	<0.1	<1	<0.1	(- -)
Spain	0.0	0	<0.1	<1	<0.1	(- -)
France	0.0	0	<0.1	<1	<0.1	(- -)
South Africa	0.0	0	<0.1	<!	<0.1	(- -)
Total	**11.0**	**100**	**27.8**	**100**	**16.8**	**(2.3)**

Source: Clive James, 1998.

Argentina's area of transgenic crops increased threefold from 1.4 million hectares in 1997 to 4.3 million hectares in 1998 due to the threefold increase in herbicide tolerant soybean between 1997 and 1998. Argentina also increased the number of transgenic crops from one, herbicide tolerant soybean in 1997, to three in 1998, herbicide tolerant soybean, *Bt* cotton and *Bt* corn. Whereas Argentina's proportion of global acreage increased from 13 percent in 1997 to 15 percent in 1998, that of Canada decreased from 12 percent in 1997 to 10 percent in 1998. On a global ranking, Canada retained its third place in 1998 having doubled its area between 1997 and 1998 as a consequence of doubling its transgenic area of canola to 2.4 million hectares, mainly herbicide tolerant, doubling its area of *Bt* corn to approximately 0.3 million hectares and significantly increasing its herbicide tolerant soybean from less than 2 thousand hectares 1997 to almost 40,000 hectares in 1998. Australia is ranked fourth on a global basis and grows almost twice the transgenic crop area of Mexico which is ranked fifth. Australia planted about 80,000 hectares of *Bt* cotton in 1998 which is a 20 percent increase over 1997 as well as a very small area of transgenic carnation which was also planted in 1997. Australia has a policy in place to expand the *Bt* cotton area modestly with a priority assigned to achieving a broader distribution of its transgenic cotton within the country. Mexico is ranked fifth on a global basis in 1998, representing less than 1 percent of global acreage and growing approximately 40,000 hectares of *Bt* cotton, an almost three fold increase compared with 15 000 hectares of *Bt* cotton in 1997. Mexico is also growing about 1,000 hectares of the multiple trait *Bt*/herbicide tolerant cotton for the first time in 1998.

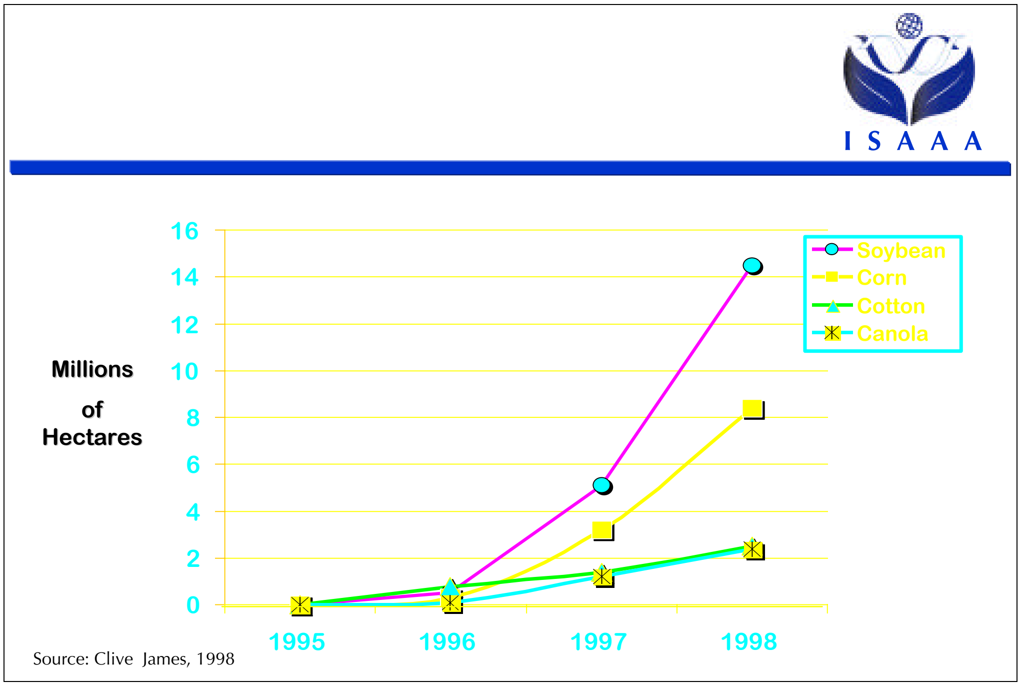
Three additional countries South Africa, Spain and France grew transgenic crops on a commercial scale for the first time in 1998, increasing the total number of countries in the world known to be growing transgenic crops from 6 in 1997 to 9 in 1998. It is noteworthy that 1998 was the first year for a commercialized transgenic crop to be grown in the countries of the European Union. Introductory quantities of approximately 22,000 hectares of *Bt* maize were planted in 1998 in the European Union, primarily in Spain (20,000 hectares) and France (2,000 hectares); this is judged to be a very significant development and has important implications for the further adoption of transgenics in countries of the European Union and elsewhere on the European continent. South Africa also grew approximately 12,000 hectares of insect resistant cotton for the first time in 1998. With the addition of two countries of the European Union and South Africa, 1998 will be the first year when transgenic crops have been grown commercially in all six continents of the world - North America, Latin America, Asia, Oceania, Europe and Africa.

Figure 4 clearly shows the increasing dominance, in area planted, of transgenic soybean followed by transgenic corn during the period 1996 to 1998. The companion data in Table 4 confirm that the top four transgenic crops on a global basis in 1998 were soybean (52 percent), corn (30 percent), with cotton and canola sharing third place at 9 percent each and collectively occupying more than 99 percent of the global transgenic crop area, with the balance of <1 percent occupied primarily by insect resistant transgenic potato. Soybean retained its first ranking in 1998 as the crop with the largest area 14.5 million hectares, equivalent to 52 percent of the global share of transgenic crops (Table 4), up from 46 % in 1997. The 2.9 fold increase in area planted with soybean between 1997 and 1998 was the highest for the top four transgenic crops and reflected almost a tripling of transgenic soybean area in 1998. This was due to two principal changes between 1997 and 1998. First, the biggest increase was in the USA where acreage of herbicide tolerant soybean increased by more than 6.5 million hectares from 3.6 million hectares in 1997 to more than 10 million hectares in 1998. Secondly, in Argentina soybean hectareage increased by almost 3 million hectares from 1.4 million hectares in 1997 to almost 4.3 million hectares in 1998. Additionally, the introductory 1,000 hectares of transgenic soybean in Canada in 1997 was increased substantially to 40,000 hectares in 1998. Thus, three countries grew transgenic soybean in 1998, USA, Argentina and Canada with a total area of 14.5 million hectares, equivalent to 52% of the transgenic crop area worldwide.

Corn retained its second ranking in 1998 with 8.3 million hectares equivalent to 30 percent of the total global transgenic area for all crops, and up from 3.2 million hectares in 1997. Thus, global transgenic corn acreage increased by more than 5.1 million hectares, a 2.6 fold increase, between 1997 and 1998, with more than 4.5 million hectares of this increase in the US and almost 300,000 hectares in Canada. In 1998, transgenic corn was introduced for the first time into Argentina; estimates suggest that an introductory area of 17,000 hectares of *Bt* maize was planted. For the first time, *Bt* maize was also planted in countries of the European Union with approximately 20,000 hectares in Spain and 2,000 hectares in France. Whereas over 90 percent of the corn acreage in 1997 was *Bt*, the percentage of transgenic crops with traits other than *Bt* increased to almost 20 percent in 1998. The additional traits included herbicide tolerant corn and a multiple trait corn. The total number of countries growing transgenic corn in 1998 was six, USA, Canada, Spain, France, Argentina and South Africa, up from two, USA and Canada, in 1997.

Although the area of transgenic cotton increased by a factor of 1.8 (Table 4), from 1.4 million hectares in 1997 to 2.5 million hectares in 1998, an increase of 1.1 million hectares, the global share occupied by transgenic cotton dropped from 13 percent in 1997 to 9 percent in 1998. This drop in global share for cotton is a reflection of the relatively higher increases in soybean and corn. The USA continues to grow most of the transgenic cotton in the world, but this is expected to change as the number of countries growing transgenic cotton increases. The cotton acreage in Australia in 1998 is

Figure 4: **Global Area of Transgenic Crops (excluding China): 1995 to 1998:** **By Crop**



Source: Clive James, 1998

Table 4: **Global Area of Transgenic Crops in 1997 & 1998:** **By Crops** (millions of hectares)

Crop	1997	%	1998	%	**Increase** (Ratio)	
Soybean	5.1	46	14.5	52	9.4	(2.9)
Corn	3.2	30	8.3	30	5.1	(2.6)
Cotton	1.4	13	2.5	9	1.1	(1.8)
Canola	1.2	11	2.4	9	1.2	(2.0)
Potato	<0.1	<1	<0.1	<1	<0.1	(-.-)
Total	**11.0**	**100**	**27.8**	**100**	**16.8**	**(2.5)**

Source: Clive James, 1998.

approximately 80,000 hectares, an increase of 20 percent over 1998. With 40,000 hectares of transgenic cotton in 1998, Mexico has less cotton than Australia but the almost three fold increase from 15,000 hectares in 1997 is much greater than Australia which is limiting expansion to achieve more uniform distribution of transgenic cotton within the country. Three countries, USA, Australia and Mexico, grew transgenic cotton in 1997 and by 1998 the number of countries had increased to six to include, China, Argentina and South Africa. China grew 63,000 hectares of *Bt* cotton in 1998. Whereas single trait insect resistance represented approximately 75 percent of the cotton transgenic corn in 1997, by 1998 there was significantly more diversity with single trait *Bt* cotton occupying less than 40 percent with the balance of 60 percent represented by other single traits, such as herbicide tolerance, and multiple trait which included *Bt* and herbicide tolerance. Considering that 1998 was the first year for China to grow transgenic cotton, it is noteworthy that the introductory area is substantial (63,000 hectares) and thus capable of very rapid expansion next year to meet market demands. Compared with China, the introductory area of *Bt* cotton in South Africa (12,000 hectares) and Argentina (8,000 hectares) are relatively small. However they are equally important elements in a global strategy that seeks to deploy, diversify and distribute transgenic crops to overcome significant biotic stresses that constrain crop productivity in the developing countries of the world.

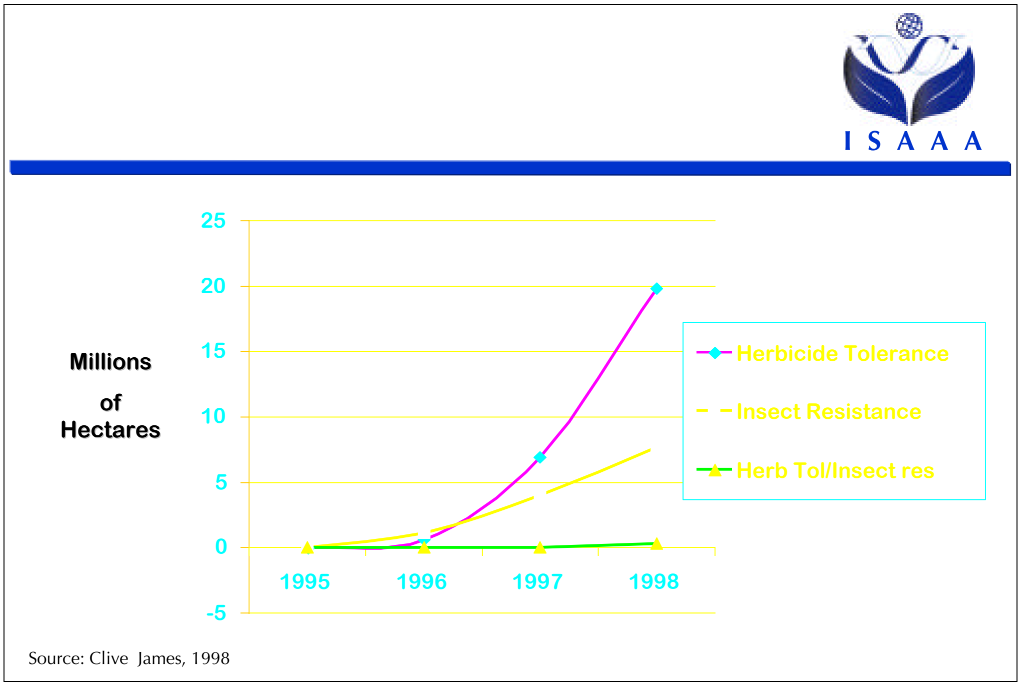
With the exception of a small acreage in the northern USA, the entire area of transgenic canola is grown in Canada where the acreage doubled between 1997 (1.2 million hectares) and 1998 (2.4 million hectares). Canola ranks third with cotton, after soybean and corn, in its global share of the transgenic global market, which was 11 percent in 1997 and 9 percent for 1998. In the last three years (1996-1998), the top four transgenic crops, soybean, corn, cotton and canola have shown consistently high adoption growth rates. Transgenic potato occupied less than 1 percent of the global transgenic crop market in 1998 with approximately 80 percent (20,000 hectares) of transgenic potatoes grown in the USA and the balance of 5,000 acres in Canada. Transgenic potato area is expected to grow significantly in the near term as the adoption rate increases in both USA and Canada, as multiple traits are introduced, and in the mid term as countries in Eastern Europe introduce transgenic potatoes for the first time. The number of transgenic crops remained constant at 7 during 1996 and 1997 but increased to 8 in 1998 with the addition of transgenic papaya, resistant to ringspot virus, approved in the USA with an introductory area of 200 hectares grown in Hawaii.

Distribution of Transgenic Crops, by Trait

Figure 5 demonstrates the marked increase in global share of herbicide tolerance during the period 1996 to 1998. Insect resistance has also exhibited a significant increase in area during the same period with the double trait of herbicide tolerance/insect resistance just starting to become evident in 1998. The data in Table 5 indicate that of the five trait categories marketed in transgenic crops on a global basis in 1998, the dominant trait was herbicide tolerance (71 percent), occupying almost three quarters of total transgenic area, followed in decreasing order of importance by insect resistance (28 percent), the combined traits of insect resistance and herbicide tolerance at 1 percent, and the balance of less than 1 percent in quality traits. Herbicide tolerance retained its first ranking in 1998 as the trait with the largest area (19.8 million hectares) equivalent to 71 percent of global share, which is up from 63 percent in 1997. The 2.9 fold increase in area planted between 1997 and 1998 was the highest for all single traits and reflected a tripling of the area occupied by herbicide tolerance crops in 1998. This was due to three principal changes between 1997 and 1998. First, the biggest increase was in the USA where area of herbicide tolerant crops increased by almost 9 million hectares from approximately 4 million hectares in 1997 to about 13 million hectares in 1998. Of the 9 million hectares increase in herbicide tolerant crops in the USA about 75 percent can be attributed to the increase in herbicide tolerant soybean, 15 percent to corn and 10 percent to cotton; in addition 400,000 hectares of cotton with both herbicide tolerance and insect resistance was planted in the USA in 1998, up from 20,000 hectares in 1997. Secondly, in Argentina, the herbicide tolerant area increased by almost 3 million hectares from 1.4 million hectares in 1997 to almost 4.3 million hectares in 1998. All of this increase was in herbicide tolerant soybean. Thirdly, Canada's herbicide tolerant area increased by 1.2 million hectares from 1.2 million hectares in 1997 to 2.4 million hectares in 1998. This increase was primarily in herbicide tolerant canola, with an additional 40,000 hectares of herbicide tolerant soybean. Thus, the three countries, USA, Argentina and Canada that grew herbicide tolerant crops in 1997 were also the same countries to grow a total of almost 20 million hectares of herbicide tolerant crops in 1998. These three countries account for 99 percent of the total transgenic crop area in the world. Analyzing the global herbicide tolerant area by crop, soybean represents approximately 72 percent of global area, canola 12 percent with cotton and corn at eight percent each. Similarly, a corresponding analysis by country indicates that of the global herbicide tolerant crop area 66 percent is grown in the USA, 22 percent in Argentina and 12 percent in Canada.

Insect resistance retained its 1997 ranking in 1998 as the trait with the second largest area (7.7 million hectares) equivalent to 28 percent of global share of transgenic crops (Table 4), down from 36 percent in 1997. The 1.9 fold increase in area planted between 1997 and 1998 was the second highest for all single traits and reflected almost a doubling of the area occupied by insect resistance crops in 1998. This was due to increases in transgenic insect resistant crops in the USA, Canada, Mexico, and Australia as well as new introductions of insect

Figure 5: Global Area of Transgenic Crops (excluding China): 1995 to 1998: By Trait



Source: Clive James, 1998

Table 5: Global Area of Transgenic Crops in 1997 & 1998: By Trait (millions of hectares)

Trait	**1997**	**%**	**1998**	**%**	**Increase** (Ratio)	
Herbicide tolerance	6.9	63	19.8	71	12.9	(2.9)
Insect resistance	4.0	36	7.7	28	3.7	(1.9)
Insect res. & Herbicide tolerance	<0.1	<1	0.3	1	0.2	(-.-)
Quality Traits	<0.1	<1	<0.1	<1	< 0.1	(-.-)
Global Totals	**11.0**	**100**	**27.8**	**100**	**16.8**	**(2.5)**

Source: Clive James, 1998.

resistant crops in China, Spain and France in the European Union, South Africa and Argentina. The biggest increase was in the USA where the area of insect resistant crops increased by 3.8 million hectares from approximately 3.5 million hectares in 1997 to approximately 7.3 million hectares in 1998. Of the 3.8 million hectares increase in insect resistant crops in the USA, with the exception of 20,000 hectares of *Bt* potato all of it was represented by an increase in *Bt* corn. The *Bt* cotton area in the USA in 1998 was approximately the same as 1997 at 1.0 million hectares but in 1998 the area was split into 0.6 million hectares with the single *Bt* trait and 0.4 million hectares of transgenic cotton with stacked genes for *Bt* and herbicide tolerance. In Canada, the area of transgenic insect resistance crops more than doubled from more than 0.1 million hectares in 1997 to almost 0.3 million hectares in 1998. This increase was in insect resistance corn with the exception of about 5,000 hectares of *Bt* potato. Australia's insect resistant hectareage in 1998 was exclusively cotton and increased approximately twenty percent to approximately 80,000 hectares. Similarly, Mexico's insect resistant hectareage in 1998 was exclusively *Bt* cotton and increased almost threefold from 15,000 hectares in 1997 to 40,000 hectares in 1998. Additionally, five countries, China, Spain, France, South Africa and Argentina introduced insect resistant transgenics for the first time. A large introductory area of 63,000 hectares of *Bt* cotton was planted in Hebei and other provinces in China for the first time in 1998. Introductory areas of *Bt* maize were also planted in 1998 for the first time in the European Union, primarily in Spain (20,000 hectares) and France (2,000 hectares). Finally, in 1998 South Africa and Argentina introduced 12,000 and 8,000 hectares, respectively of *Bt* cotton for the first time. Thus, the number of countries that grow transgenic resistant crops doubled from four in 1997 to nine in 1998. The four countries, USA, Canada, Australia and Mexico that grew insect resistant crops in 1997 were joined by China, Spain, France and South Africa in 1998, and collectively grew a total of 7.7 million hectares of insect resistant crops in 1998, equivalent to more than twenty five percent of the total transgenic crop area in the world. Analyzing the global insect resistance area by crop, corn represents approximately 84 percent of global area, cotton 13 percent and potato 3 percent. Similarly, a corresponding analysis by country indicates that of the global insect resistance crop area, 94 percent is grown in the USA, 4 percent in Canada and the balance of 2 percent in Spain, France, South Africa, Argentina and Mexico.

Herbicide tolerance and insect resistant transgenic crops represented 71 and 28 percent respectively, for a total of 99 percent of the global transgenic area. The multiple traits of insect resistance and herbicide tolerance represented the balance of approximately 1 percent, including cotton (400,000 hectares) and corn (10,000 hectares) in the USA and an introductory area of 1,000 hectares of herbicide tolerant/insect resistant cotton grown for the first time in Mexico in 1998. Crops with quality traits represented <0.1 percent of global transgenic area that include modified oil in soybean and canola. An introductory area of 200 hectares of transgenic papaya, resistant to ringspot virus, was planted in Hawaii, USA, for the first time in 1998.

Countries Growing New Transgenic Crops in 1998

Table 6 summarizes the seven countries that introduced eleven new transgenic crops in 1998. Three of the ten countries, Spain, South Africa and France grew transgenic crops for the first time, whilst the remaining four, China, Argentina, USA and Mexico grew transgenic crops before but added new products in 1998. The largest introductory area was the 63,000 hectares of *Bt* cotton in China, which comprised 53,000 of Monsanto/ Delta Pine product and 10,000 hectares of a product developed by the Chinese. Four countries, Spain, Argentina, South Africa and France, grew insect resistant corn for the first time. Similarly, three countries China, South Africa and Argentina grew insect resistant cotton for the first time. A soybean with modified oil, a papaya resistant to ringspot virus and a corn with multiple traits for herbicide tolerance and insect resistance were new products for the US in 1998, Finally, a multiple trait cotton with herbicide tolerance and insect resistance was a new product introduced to Mexico. Thus, in total approximately 150,000 hectares of eleven new products were grown by seven countries in 1998. It is noteworthy that five of the new products were grown in developing countries and five in industrial countries and that the distribution covered Asia, Latin America, Africa and North America and Europe.

Summary

In reviewing the shift in global share of transgenic crops for the respective countries, crops and traits, the major changes between 1997 and 1998 were related to the following trends: growth in area of transgenic crops between 1997 and 1998 in the industrial countries continued to be significant and almost 5 times greater than in developing countries (13.9 million hectares versus 2.9 million hectares); in terms of crops, soybean contributed the most (56 %) to global growth of transgenic crops, equivalent to 9.4 million hectares between 1997 and 1998, followed by corn at 30 % (5.1 million hectares), canola at 7 % (1.2 million hectares) and cotton at 6 % (1.1 million hectares). There were three noteworthy developments in terms of traits, herbicide tolerance contributed the most (77 % or 12.9 million hectares) to global growth, and insect resistance contributed 22 % equivalent to 3.7 million hectares; the multiple or stacked traits of insect resistance and herbicide tolerance increased by 0.2 million hectares in 1998 representing 1 % of global area with significant prospects for further growth in future. Of the 5 major transgenic crops grown in 8 countries in 1998, the two principal crops of soybean and corn, represented 82 % of the global transgenic area. Table 6 summarizes the five dominant transgenic crops in 1998 and their relative importance crop in terms of global share. Herbicide tolerant soybean was the most dominant transgenic crop (52 % of global transgenic area) followed by insect resistant corn (24 %), and insect resistant/herbicide tolerant cotton at 9 %, herbicide tolerant canola (9 %), and herbicide tolerant corn at 6 % (Table 7).

Table 6: Seven Countries Introduced Eleven New Transgenic Crops in 1998

Country	Crop	Trait	Hectares
China	Cotton	Insect Resistance	63,000
Spain	Corn	Insect Resistance	20,000
Argentina	Corn	Insect Resistance	17,000
South Africa	Cotton	Insect Resistance	12,000
USA	Corn	Herbicide Tolerance/Insect Res.	12,000
USA	Soybean	Oil Quality	10,000
Argentina	Cotton	Insect Resistance	8,000
South Africa	Corn	Insect Resistance	3,000
France	Corn	Insect Resistance	2,000
Mexico	Cotton	Herbicide Tolerance/Insect Res	1,000
USA	Papaya	Virus Resistance	200
Total			**151,200**

Source: Clive James, 1998.

Table 7: Dominant Transgenic Crops 1998

Crop	Million Hectares Areas	% Transgenic
Herbicide tolerant Soybean	14.5	52
Bt Corn	6.7	24
Insect resistant/herbicide tolerant Cotton	2.5	9
Herbicide tolerant Canola	2.4	9
Herbicide tolerant Corn	1.7	6
Total	**27.8**	**100**

Source: Clive James, 1998.

The three major factors that influenced the change in absolute area of transgenic crops between 1997 and 1998 and the relative global share of different countries, crops and traits were: firstly, the enormous increase in herbicide tolerant soybean in the USA from 3.6 million hectares in 1997 to 10.2 million hectares in 1998 (equivalent to 36 % of the US national soybean area) coupled with a similar increase in herbicide tolerant soybean in Argentina from 1.4 million hectares in 1997 to 4.3 million hectares in 1998 and equivalent to approximately >60 % of the Argentinean national soybean area; secondly, the significant increase of insect resistant corn in the USA from 2.8 million hectares in 1997 to 6.5 million hectares in 1998, equivalent to 22 % of the US national corn area in 1998; and thirdly, the large increase of herbicide tolerant canola in Canada from 1.2 million hectares in 1997 to 2.4 million hectares in 1998, equivalent to 50 % of the Canadian canola area. The combined effect of these three factors resulted in a global area in 1998 that was 16.8 million hectares more and 2.5 fold greater than 1997. It is noteworthy that 1998 was the first year for a commercialized transgenic crop to be grown in the countries of the European Union. Estimates suggest that introductory quantities of insect resistant maize were grown primarily in Spain (20,000 hectares) and France (2,000 hectares). This is judged to be potentially a very significant development because it could have important implications for the further adoption of transgenics in countries of the European Union.

It is important to note that the estimates of benefits in this publication are preliminary, and based on the limited information currently available. The estimates are indicative of the order of magnitude of benefits rather than precise estimates. Thus, estimates are being revised continuously as more precise information on the benefits associated with transgenic crops in North America and developing countries become available. It is hoped that more independent and industry studies will be initiated following the substantial area of 23.3 million hectares of transgenic crops planted in the USA and Canada in 1998. Multiple benefits have been reported by growers for selected transgenic crops; these include more flexibility in terms of crop management (particularly important for herbicide tolerant crops), decreased dependency on conventional insecticides and herbicides, higher yields and cleaner and higher grade of grain/end product.

As expected, net economic returns to the grower vary by year, by crop product and by location, depending on factors such as level of infestation of the targeted pest, the epidemic level of a disease or the weed density and more generally the influence of climate and growing conditions on crop performance. Table 8 summarizes the benefits for selected transgenic crops in the USA and Canada in 1996 and 1997 which overall are probably conservative estimates. It is noteworthy that the revised estimate for 1996 *Bt* cotton for the USA in Table 8 is based on a recent independent study ((Falck-Zepeda, Traxler and Nelson 1998) which provides the most comprehensive and precise information on benefits resulting from *Bt* cotton in the USA in 1996. The study of Falck-Zepeda et al estimates that the benefits to US farmers from *Bt* cotton in 1996 were $128 million as compared to an estimate of $60 million reported by Krattiger (1997) and James (1997a) which were based on industry estimates. The higher estimate is due to the use of a methodology that calculates benefits for each of the sub areas of the corn belt, rather than using one average return for the total corn belt, and takes into full account the *Bt* adoption rate in each of the sub areas, where returns were significantly higher in high infestation sub areas which coincidentally were sub areas where *Bt* adoption rates were also higher. Furthermore, the study (Falck-Zepeda et al, 1998) indicates that of the total economic surplus of $240 million generated through the use of *Bt* cotton in the USA in 1996 the relative returns to US farmers was 53% ($128 million), Monsanto and Delta & Pine Land 26 percent, US consumers 12 percent with the balance of 9 percent as economic surplus to the rest of the world. Thus, the relative returns for *Bt* cotton in the USA in 1996 are similar to those for conventional agricultural products (farmer/company benefit ratio of 2:1) and are not heavily in favor of the companies selling the products as some critics have suggested. More independent studies of this caliber should be encouraged to generate information to assess the benefits from transgenic crops.

Benefits from Selected Transgenic Crops in USA and Canada in 1996 and 1997

The estimated benefits to farmers are summarized below for each of the selected crops for which information is available at this time:

Herbicide Tolerant Soybean in US

- Provides more flexible crop management, assigned by far the highest priority by growers.
- Herbicide usage reduced 10 to 40 %; herbicides used with transgenic crops have favorable environmental characteristics re. soil, groundwater, and do not accumulate in the environment/food chain.
- No residual herbicide applied on 83 % of transgenic soybean area in 1997.
- Better weed control..
- Better soil and moisture conservation and erosion control; 56 % of farmers used conservation tillage in 1997.
- Average yield increase of 4.7 % in 1996 and 1997.
- Net return of $29.64 per hectares in 1996 and 1997; equivalent to US national benefit of $12 million in 1996 and $109 million in 1997.
- Above benefits have instilled confidence in the technology resulting in a high level of grower satisfaction and adoption rates:

400,000	hectares grown by 10,000 farmers in 1996 (1 % of US soybean area)
3,600,000	hectares grown in 1997 (13 % of US soybean area) - 9.0 fold increase
10,200,000	hectares grown in 1998 (36 % of US soybean area) - 2.8 fold increase

- All projections call for another significant increase in area in 1999.

Table 8: Estimated Benefits for Selected Transgenic Crops in USA and Canada 1996 and 1997

Crop	1996			1997		
	Transgenic Hectares (millions)	National Transgenic Crop Area (%)	Benefits ($millions)	Transgenic Hectares (millions)	National Transgenic Crop Area (%)	Benefits ($millions)
USA						
Herb.tol. soybean	0.4	1.4	12[1]	3.6	12.6	109[1]
Bt Corn	0.3	0.8	19[2]	2.8	8.8	119[3]
Bt Cotton	0.7	12.8	128[4]	1.0	17.1	133[5]
Herb tol. Cotton	--	--	--	0.3	5.7	5[6]
Bt Potato	<0.1	0.9	<1	<0.1	2.4	<1[7]
Total USA	**1.4**		**159**	**7.7**		**366**
Canada						
Herb, Tol. Canola	0.1	3.0	5[8]	1.2	30.0	48[8]
Bt Corn	<0.1	0.1	<1	0.1	26.0	5[3]
Bt Potato	<0.1	<0.1	<1	<0.1	3.0	<1
Total Canada	>0.1		**5**	**1.3**		**53**
Grand Total	**3.8**		**164**	**21.7**		**419**

Based on a net return per hectare of:

[1] $29.64 for Herb. Tol. Soybean
[2] $67.30 for *Bt* Corn in 1996,
[3] $42.00 for *Bt* Corn in 1997
[4] $175 for *Bt* Cotton in 1996 (Falck -Zepeda et al, 1998)
[5] $133 for *Bt* Cotton in 1997
[6] $19.76 for Herb. Tol. Cotton in 1997
[7] $47.00 for *Bt* Potatoes in 1996/97
[8] $39.19 for Herb. Tol. Canola in 1996/97.

Source: Compiled by Clive James, 1998, from industry and independent estimates.

***Bt* Corn in US and Canada**

- Very effective targeted control of European Corn Borer (ECB), which is a very important insect pest of maize in USA and Canada. ECB does not lend itself for effective control with insecticides.
- Compatible with Integrated Pest Management and promotion of beneficial insects.
- Average yield increase of approximately 9 % in 1996 and 7 % in 1997.
- Net return per hectare of $67.30 in 1996 and $42.00 in 1997, equivalent to estimated US national benefits of $19 million in 1996 and $119 million in 1997.
- Approximately 15 million hectares (50 %) of the 30 million hectares of corn in USA estimated to be infected with ECB, with annual national losses estimated at up to $1 billion per annum; losses can be as high as 30 % when infestation is severe.
- Above benefits have resulted in high grower satisfaction and adoption rates in USA:

300,000	hectares in 1996 (1 % of US corn area)
2,800,000	hectares in 1997 (9 % of US corn area) - 9.0 fold increase
6,500,000	hectares in 19998 (22 % of US corn area) - 2.3 fold increase

- A significant increase in area is projected for 1999.

***Bt* Cotton in US**

- Control of cotton bollworm, pink bollworm and tobacco budworm.
- Compatible with Integrated Pest Management, and protection of beneficial insects.
- More effective control of targeted pests.
- Insecticide usage reduced. In 1996, 70 % of *Bt* cotton in US did not require insecticide for targeted pests.
- Total economic return to farmers adopting *Bt* cotton in 1996 - $128 million.
- Average yield increase of 14 % in 1997, equivalent to 114 kg. per hectare.
- Average net economic benefits to farmers in 1997 of $133 per hectare, equivalent to a US national gain of $133 million.
- High grower satisfaction:

700,000	hectares grown by 5,600 farmers in 1996 (13 % of US cotton area)
<1,000,000	hectares grown by 8,000 farmers in 1997 (17 % of US cotton area)
>1,000,000	hectares grown in 1998 (20 % of US cotton area)

Note that total transgenic cotton area in the USA increased more than two fold from <1,000 million hectares in 1997 to more than 2 million hectares in 1998, which included single trait *Bt* cotton, double trait *Bt*/herbicide tolerant cotton as well as single trait herbicide tolerant cotton.

***Bt* Potato in US and Canada**

- Targeted and very effective control of Colorado Potato Beetle, the most devastating insect pest on potatoes in North America and important on a global basis.
- Use of *Bt* gene is an integral element of an Integrated Pest Management strategy.
- A partial substitute for insecticides; in 1997 *Bt* potatoes required up to 40 % less insecticides than non-*Bt* potatoes. Insecticide costs for potatoes range from $75 to $300 per hectare.
- In 1996 yield increases plus better quality and size of potatoes resulted on average in increased revenue of $35 per hectare.
- On average *Bt* potatoes required 1.2 fewer insecticide applications than non-*Bt* potatoes.
- Net economic return per hectare was $47.00 in 1996/1997.
- Above benefits have led to grower satisfaction in reflected in higher adoption rates in the USA:

4,000	hectares planted in 1996 (1.0 percent of US potato area)
10,000	hectares planted in 1997 (2.5 percent of US potato area) - 2.5 fold increase
20,000	hectares planted in 1998 (5.0 of US potato area) - 2.0 fold increase

- In 1999, transgenic potatoes with the multiple traits of *Bt*/virus resistance will be available that will allow integrated control of Colorado Potato Beetle and the important potato leaf roll virus (PLRV) - the most important pest and virus disease of potatoes in North America.

Herbicide Tolerant Canola in Canada

- Greatly facilitates flexible crop management assigned the highest high priority by growers.
- Herbicide usage reduced: 70 percent of growers in 1996 and 1997 used only one application of herbicide.
- Better weed control.
- Allows conservation tillage including direct seeding with reduced tillage which in turn allows better soil and moisture conservation and erosion control.
- Average yield increase of 7.5 % in 1996 and 1997.
- Cleaner grain and higher proportion (85 % versus 63 %) of No.1 Grade of canola.
- Net return of $39.19 per hectare in 1996 and 1997; equivalent to national benefit of $12 million in 1996 and $109 million in 1997.
- High level of grower satisfaction and adoption rates:

100,000	hectares grown in 1996 (3 % of Canadian canola area)
1,200,000	hectares grown in 1997 (30 % of Canadian canola area)
2,400,000	hectares grown in 1998 (60 % of Canadian canola area)

The estimated economic benefits for each of the selected crops for the US and Canada, detailed above, have been consolidated for 1996 and 1997 in Table 8. For the USA in 1996, economic benefits to growers were estimated conservatively at $128 million for *Bt* cotton, $19 million for *Bt* corn, and $12 million for herbicide tolerant soybean for a collective US national benefit of $159 million in 1996. Similarly, in 1997, economic benefits were estimated at $119 million for *Bt* corn, $109 million for herbicide tolerant soybean, $133 million for *Bt* cotton, $5 million for herbicide tolerant cotton and <$1 million for *Bt* potato, for a collective national benefit in the USA of $419 million. In Canada, benefits at a national level, due to the use of herbicide tolerant canola, were estimated at $5 million in 1996. In 1997 benefits associated with the use of transgenic canola in Canada were estimated at $48 million plus $5 million for *Bt* corn for a total of $53 million. It is noteworthy that these benefits for canola are only direct economic benefits associated with decreased herbicide usage and increased yield and exclude the significant crop management benefits which growers judge to have much higher value than the direct economic benefits.

Thus, in 1996 and 1997 selected transgenic crops in the USA and Canada resulted in economic benefits to growers of $164 million and $419 million respectively for a total, conservatively estimated at $583 million for North America in 1996 and 1997. Acknowledging that any estimated benefits for selected crops in 1998 without supporting field data, are speculative, the 2.5 fold increase in transgenic crop area in the US and Canada between 1997 and 1998, would be expected to result in commensurate benefits that would be of the order of $1 billion for the USA and Canada, if 1998 crop conditions, pest and weed levels were comparable to 1996/1997. It is important to note that all the above benefits are due to improved control of biotic stresses (weeds, insects and diseases) on only a modest portion of the area occupied by the selected major crops in the US and Canada and that major crops such as wheat have not yet benefited from the potential advantages that transgenic crops offer. Given that diseases alone are estimated to result in losses of $9.1 billion annually in the US (IWG 1998), the potential for improved control of biotic stresses caused by pests weeds and diseases through the further deployment of transgenic crops in the USA and Canada is enormous. Transgenic crops provide a unique opportunity for North America to contribute to global food security through increasing crop productivity economically and generating affordable exports of grain, oil seeds and other food /feed crops on which developing countries will become increasingly dependant in the future.

Benefits from Transgenic Crops in Developing Countries

As would be expected, at this early stage of deployment, there is much less data available on the benefits of transgenic crops in the developing countries compared with industrial countries. However, the information that is available confirms that the developing countries enjoy similar benefits to industrial countries. The first reported benefits were for virus resistant tobacco in China, (James 1997a). Additional information is now available for *Bt* cotton in China. Although there is no direct information on benefits in Argentina the very high rates of adoption of herbicide tolerant soybeans in Argentina reflect grower satisfaction with the products that offer significant multiple benefits.

Virus Resistant Tobacco in China

In 1992, transgenic tobacco, resistant to Cucumber Mosaic Virus (CMV) incorporating a single coat protein construct, was sown on approximately 100 acres for commercial seed increase. In 1994/1995 a double construct (CMV and TMV [tobacco mosaic virus]) was developed and introduced into commercial production. The virus resistant transgenic tobacco in China is reported to result in significant benefits which include a yield increase averaging 5 to 7 percent more leaves for processing, with savings of 2 to 3 insecticide applications from the normal program of approximately 7 applications. Insecticides are used to control the aphids that transmit the CMV and TMV viruses, that infect tobacco, and the significant saving on insecticides has both environmental and economic implications.

Bt Cotton in China

Cotton is the most important cash crop in China and in 1996, grown on 4.72 million hectares with an output of 4.2 million metric tons. Historically the area planted has been as high as 6.7 million hectares but severe damage due to cotton bollworm (*Helicoverpa armigera*) was a major factor responsible for a 30 percent reduction in area from 6.7 to 4.7 million hectares. An important implication is that China is now an importer of cotton whereas formerly it was an exporter. In 1992 the loss due to cotton bollworm (Jia 1998) was estimated at 10 billion RMB (equivalent to $1.2 billion at 1998 exchange rates of 8.27 RMB = US$1.00).

In 1998, *Bt* cotton was deployed commercially for the first time in China. The total area was 63,000 hectares, of which 53,000 was planted in Hebei Province with a *Bt* cotton variety developed by Monsanto/Delta & Pine Land in Hebei Province. The balance of 10,000 hectares was planted in four provinces (Anhui, Shangdong, Shanxi, and Hubei) using a *Bt* cotton developed by Chinese scientists. The following information provides background information on the *Bt* cotton developed by the Chinese and deployed on 10,000 hectares in 1998. Work on the *Bt* gene was undertaken at the Biotechnology Centre of the Chinese Academy of Agricultural Sciences. A total of 10 transgenic *Bt* cotton varieties have been developed and by 1996 a total of 17 field trials were conducted occupying 650 hectares In 1997, the

Biosafety Committee of the Ministry of Agriculture approved commercialization and the area planted was extended to 10,000 hectares in 1998.

Initial results indicate that the benefits of *Bt* cotton are significant, resulting in a dramatic decrease in labor requirements for insecticide applications which were reduced from approximately 15 to 20, to 1 to 2. This reduction resulted in savings of 1,200 to 1,500 RMB per hectare equivalent to $145 to $182 per hectare (Jia 1998). The *Bt* cotton is being carefully monitored to develop the most effective means for achieving durable resistance within the context of a *Bt* management strategy. Results to-date demonstrate that field performances of the *Bt* cotton are excellent with no indication that resistance is developing. It is judged that the multiple cropping system employed in China is important as a natural "refuge", and it is projected that the current *Bt* cotton may provide adequate levels of resistance for up to 8 or 9 years during which alternative strategies of control will be developed and implemented. One of the current alternative strategies that is being employed by the Chinese, is to utilize the *Bt* gene in conjunction with the CPTI gene which encodes for an insecticidal protein with an independent mode of action from *Bt*. This strategy is being employed to provide better control and delay the development of resistance.

Transgenic Crops in Argentina

In 1998, Argentina grew almost 4.3 million hectares of three transgenic crops, of which transgenic herbicide tolerant soybeans occupied more than 99 percent of the area along with 17,000 hectares is *Bt* corn, and 8,000 hectares of *Bt* cotton. Although data on benefits are not available to-date for herbicide tolerant soybeans, it is evident that when they occupy almost two-thirds of the national area of soybeans that farmers are very satisfied with the benefits the technology provides. This satisfaction is reflected in the exceptionally high adoption rates.

A progressive agriculture provides the stimulus in Argentina for a high rate of adoption of improved technologies including transgenic crops and the rich pampas of the country is undergoing an agricultural revolution. It is noteworthy that in 1998, with the exception of the US, Argentina grew more hectareage of transgenic crops than any other country in the world. Furthermore its adoption rates for herbicide tolerant soybean, the highest in the world, even higher than the USA, (13.0 fold increase in 1997, followed by a three fold increase in 1998) has resulted in over 4 million hectares accounting for over 60 percent of the national area of soybean. In addition to soybean, Argentina planted about 17,000 hectares of *Bt* corn in 1998 as well as 8,000 hectares of *Bt* cotton. This rapid adoption of transgenic crops is occurring at a time when agriculture in Argentina is enjoying a boom. Since 1990, harvests of grains and oilseeds have jumped by 50 percent with record crops of wheat, corn, sunflower, soybean, cotton and rice. The 1997/1998 crop was a bumper crop of 65 million tons - a 13 percent increase over the previous year.

Several factors underpin Argentina's boom in agriculture. Economic stability, following the pegging of Argentina's peso to the US dollar, has controlled inflation and increased availability of credit. Elimination by the current administration of export taxes on agricultural products, which were as high as 45 percent. This was a major stimulus, as well as more efficiency resulting from privatization of grain elevators, railroads and ports. It is estimated that US$ 10 billion has been invested in agriculture in Argentina since 1996 to access improved crop varieties including transgenics, increased supply of fertilizers and pesticides, enhanced irrigation systems and modern agricultural machinery. Foreign investors have also invested significantly in Argentina. For example, Agrium Fertilizer Company of Canada has a joint venture with Perez Company, a local agricultural company and YPF, a local oil company, to build a US$ 600 million urea fertilizer plant which will be the largest in the world. The high commodity prices of recent years coupled with the relatively low price of land and the freedom from subsidies places Argentina in a privileged position at a time when the World Trade Organization is negotiating lower global agricultural subsidies for initiation in the year 2000. The world's leading grain traders and oil seed manufacturers such as Andre, Bunge & Borne, Cargill and Dreyfus are investing heavily in, silo storage, oil seed crushing mills, processing plants and waterways for transportation to lower freight costs for agricultural products. Oil seed sales are expected to be over $ 3.5 billion in 1998, up from $ 700,000 in 1980. Continued weakness in 1998 in grain markets will moderate some of the expected continued growth. In October 1998 the price for corn was $1.75 per bushel, which was 30 percent below the average price in March 1998 and 65 percent below the highest price reached in 1996.

Argentina is not highly exposed to the Asian markets, exporting more than half of its grain to Brazil, with stability provided through diversification and expansion of its traditional market of 12 countries to the current 40 countries. 1997 was a watershed for Argentinean agriculture, with the opening of the export beef market to

USA, following a 60 year period when foot and mouth disease precluded beef exports. Argentina is the fifth largest beef producer in the world and the eighth largest exporter. Following the declaration of freedom from foot and mouth disease in 1997, unprecedented opportunities have opened up for Argentina to increase its beef production, with implications for domestic demand for feed grains. Increasing global demand for more food, feed, and fiber crops favors Argentina. Transgenic crops are seen as playing an increasingly important role in a world agriculture in which the ability to trade competitively will be critical. The growth in the agricultural sector in Argentina has catalyzed the establishment of private and bank sponsored "seeding pools" which shares the costs of seeding and crop production amongst a larger group of investors. Private seeding pools are estimated to manage 1 million hectares whilst private pools manage an additional 250,000 hectares. In 1998, agricultural exports, equivalent to 60 percent of all exports, are estimated to have reached $ 14.5 billion, of which crops represented $ 8 billion. Agricultural analysts predict that the country's crop harvest will increase from 61 million tons in 1998 to 75 million tons in the year 2000, provided that grain prices remain attractive. This progressive agriculture in Argentina should stimulate increased adoption rates of herbicide tolerant soybean, which is already >60 percent of the national average, accelerate the adoption of transgenic corn and cotton being commercialized for the first time in 1998, and open up new opportunities for transgenic wheat, sunflower and rice when these products become available.

Value of Global Transgenic Crop Market, 1995 to 1998

Global sales of transgenic crop products have grown rapidly during the period 1995 to 1998. Global sales were estimated at $75 million in 1995; sales tripled in 1996 and again in 1997 to reach $235 million and $670 million respectively, and doubled in 1998 to reach an estimated value of between $1.2 to $1.5 billion (Table 9). Thus, revenues for transgenic crops have increased by approximately twenty fold in the four year period 1995 to 1998. The global market for transgenic crops is projected to increase to $3 billion or more in 2000, to $6 billion in 2005, and to $20 billion in 2010 (James 1997a).

Table 9: Estimated Value of Global Transgenic Crop Market, 1995 to 1998
(US $ millions)

Year	Market value $	Increase $	Increase %
1995	75[1]		
1996	235[1]	160	+ 213
1997	670[1]	435	+ 185
1998	1,200 to 1,500[2]	530 - 830	+ 79 to 124

Source: Compiled by Clive James, 1998.

Global Potential for the Principal Transgenic Crops

The five principal crops, in descending order of area, which have benefited from transgenic technology to-date are soybeans, maize, canola, cotton and potato. In 1998 about half of the global transgenic crop area was planted to herbicide tolerant soybean, one-quarter to *Bt* corn, 10 percent each to herbicide tolerant canola and *Bt*/herbicide tolerant cotton and the remaining 5 percent to herbicide tolerant maize. 84 percent of the global area of transgenic crops in 1998, equivalent to 23.3 million hectares, were grown in the USA and Canada. In 1998, at the national level, the highest proportion of principal crops planted with transgenics were reported by Argentina (>60 percent of its soybean), Canada (50 percent of its canola and 25 percent of its maize), US (40 percent of its cotton, 35 percent of its soybean and 25 percent of its corn). Whereas these proportions of national crop areas occupied with transgenics are impressive, particularly when it has been achieved within a short three year period, they are relatively modest when viewed within the context of the global potential for these transgenic crops.

Table 10 compiles global information on five principal crops (soybean, maize, cotton, canola and potato) and lists five corresponding sets of data. The information can be used to assess the transgenic status of these crops globally, and to estimate the potential for further transgenic growth on a global basis. For example, the data indicate that there are 67 million hectares of soybean globally, of which it is judged that 30 million hectares can benefit from transgenic herbicide technology. The data further shows that of the 30 million hectares global potential that 15 million have already been planted to herbicide tolerant transgenic soybeans, leaving 15 million hectares, equivalent to 50 percent of the global potential area, as an unrealized opportunity for using transgenic herbicide tolerance to increase the productivity of soybeans. Table 10 has corresponding data that allows a similar assessment to be made for each of the transgenic crop/trait combinations that already occupy a significant area on a global basis today viz. *Bt* maize, *Bt* cotton, herbicide tolerant canola, herbicide tolerant maize, and finally *Bt* potato. Note that careful consideration is required when assessing the potential area when considering more than one trait for a single crop, for example, *Bt* maize and herbicide tolerant maize in Table 10. The assessment can be made for each of the two traits separately in the knowledge that in practice they will be often combined in one crop.

The information in Table 10 can be used to assess the global potential for growth of the specific crop trait combinations listed. Given the current availability of crop transgenic technology already approved for growing in one or more countries, maize offers more opportunities than the other four crops. The data in Table 10 indicate that whereas only 9 million hectares of transgenic maize is grown today, there is a potential for 100 million hectares equivalent to 10 times the current transgenic crop area planted. Of this 100 million hectares 58 percent is judged to be appropriate for herbicide tolerance and 42 percent would benefit from insect resistant transgenic technology. To put it in a different context, the growth potential for transgenic maize alone is equivalent to 4 times the total area planted to all transgenic crops in North America today.

Canola offers the second largest opportunity for growth. Of the 25 million hectares of canola that are judged to have potential for herbicide tolerant varieties, only 2 million (< 10 percent) have been planted with transgenics leaving 23 million hectares (>90 percent) as unrealized potential. Whereas soybean herbicide tolerance is the trait that has been most widely adopted to-date, there still remains an estimated 15 million hectares that can probably benefit from transgenic herbicide tolerance. Of the 11 million hectares that are judged to lend themselves to insect resistant cotton technology, only 1 million hectares (<10 percent) have been planted, with 10 million hectares (>90 percent) currently unexploited. Finally, of the 18 million hectares of potatoes grown

Table 10: Global Potential for Selected Transgenic Crops (millions of hectares)

Transgenic Crop	Global Crop Area[1]	Potential Transgenic Area[2]	1998 Transgenic Area	Potential Minus 1998	1998 Transgenic Area expressed as % of Potential
Herb. Tolerant Soybean	67	30	15	15	50
Bt Maize	140	49	7	42	14
Bt Cotton	34	11	1	10	9
Herbicide Tolerant Canola	25	25	2	23	7
Herbicide Tolerant Maize	140	60	2	58	3
Bt Potato	18	2	<0.1	2	1
Total	**424**	**177**	**27**	**150**	**--**

Source: Clive James, 1998.
[1] 1997 FAO Crop Data used for global areas.
[2] Anonymous, 1997.

globally, only 2 million hectares are judged to be areas that could potentially benefit from *Bt.* Only 1 percent of the 2 million hectares is currently planted with *Bt* potatoes to control Colorado Potato Beetle.

In summary, the data in Table 10 suggest that for the six crop/trait combinations listed, which currently occupy 27.8 million hectares, there is approximately 6 times this area, equivalent to an additional 150 million hectares globally, that could potentially benefit from these technologies. Comparison of the total global crop area of 424 million hectares in Table 10 and the corresponding potential area for transgenic crops (177 million hectares) indicates that approximately 40 percent of the global area planted to soybean, maize, cotton, canola and potatoes, may lend themselves to specific transgenic technologies that have already been approved and deployed today; of the 177 million hectares that is a potential area for transgenic crops only 27 million hectares, equivalent to 15 percent, have already been planted. As new applications are developed to overcome additional production constraints, the global potential area of 177 million hectares for transgenic crops will increase. It is important to note that the principal crops listed in Table 10 does not include two of the three principal staples, rice and wheat, which together occupy 400 million hectares globally, and for which specific biotechnology applications are being currently field tested today. For example, insect resistant rice is being tested in China and insect resistant and herbicide tolerant wheat are being field-tested in Australia.

Potential Benefits for Developing Countries

The compelling case for growing transgenic crops in developing countries is supported by the fact that the greatest need for food is in the countries of the South, where 800 million suffer from malnutrition today and where food imports are expected to double in the next 25 years. Transgenic crops offer developing countries a unique opportunity to increase domestic/local food, feed and fiber production by 10 to 25 percent in the next decade (Kendall et al, 1997) and decrease their dependency on imported foods which many of the poor cannot afford to purchase. Table 11 lists the areas of eight principal crops for all developing countries, and the corresponding areas for the same crops in the USA and Canada. The data show that developing countries have about four times more crop area than the USA and Canada. The yield gap data in Table 11 is the ratio of US yields and the yields of developing countries for the same crops. The data indicate that US yields are up to three times (2.9) higher than developing country yields for the respective crops. The data in Table 11 support three strategic reasons as to why developing countries have potentially much more to gain from transgenic crops than industrial countries.

Table 11: Comparison of Areas and Yield of Selected Principal Crops: North America (USA & Canada) versus Developing Countries (Africa, Asia & Latin America)

Crop	Millions of Hectares: Developing Countries (DC)	Millions of Hectares: North America (NA)	Ratio DC/NA	Yield Gap[1]
Rice	145	1	145	1.8
Wheat	104	37	3	1.0
Maize/Corn	91	31	3	2.9
Soybean	37	29	1	1.4
Cotton	25	5	5	1.3
Potato	8	0.6	13	2.8
Rapeseed/Canola	15	5	3	1.2
Tomato	2	0.2	10	2.6
Total	**427**	**109**		

[1] Ratio of USA crop yield to developing countries yield.

Source: Compiled by Clive James, 1998, from 1997 FAO Crop Statistics.

Firstly, developing countries have potentially more to gain from transgenic crops than industrial countries because the area of almost all the crops listed in Table 11 is far greater in developing countries than in the USA and Canada where adoption of transgenic crops has been highest to date. For example, there is 145 times more rice, five times more cotton, three times more maize and wheat, and as much soybean grown in the developing countries compared with the USA and Canada. For the principal crops listed in Table 11, developing countries have four times the crop area (427 million hectares) compared with the USA and Canada combined (109 million hectares). Furthermore, Table 11 excludes important staples such as cassava and sweet potato that are grown almost exclusively in the developing countries and have the potential to benefit significantly from biotechnology.

Secondly, yields of almost all the crops listed in Table 11 are significantly lower in developing than industrial countries. For example, there is almost a three fold (2.9) difference in maize yields between the USA and developing countries, almost a two fold (1.8) difference in rice yields and almost a three fold (2.8) difference in potato yields. Yields are low in developing countries due to many reasons. One of the principal causes is that crops in developing countries suffer much more from biotic stresses, due to pests, weeds and diseases, for which current transgenic crops already offer improved protection. Thus, the potential gain for developing countries from improved control of biotic stresses through the use of transgenic crops is relatively greater than for industrial countries.

Thirdly, and most importantly, it is in the developing countries, not the industrial countries, where 800 million people suffer from malnutrition today and where transgenic crops could increase crop productivity and contribute to the alleviation of hunger and poverty which are inextricably linked. During the next decade an increase in productivity of 10 to 25 percent from transgenic crops is both feasible and realistic. This will be a critical and significant contribution to global food security, more nutritious food and feed, and to a safer environment. Transgenic crops have much to offer developing countries and should be an essential component of a global food security strategy that integrates conventional and biotechnology crop improvement applications to produce more food where the need is greatest, and where the welfare value of food is the highest. Denial of the new technologies to the poor is synonymous to condemning them to continued suffering from malnutrition which eventually may deny the poorest of the poor their right to survival.

Current and Future Developments that Impact on Transgenic Crops

This final section is devoted to a discussion of current and future developments that impact on the growth and commercialization of transgenic crops in the near-term and in the first decade of the 21st century. Topics include: the continuing consolidation in the private sector through acquisitions, alliances and mergers; the very rapid scientific developments and investments in genomics; the management of *Bt* in North America; public acceptance of transgenic crops and the products that derive from them; and finally future prospects for transgenic crops and their contribution to global food security

Acquisitions, Alliances, and Mergers in the Agribiotechnology Industry

One of the most significant features to impact on agribiotechnology in the last three years is the number, magnitude and extent of biotechnology-driven acquisitions, alliances and mergers that has resulted in an unprecedented consolidation of the industry. The three year period, fall of 1995 through 1998, witnessed a very large number of acquisitions, alliances and mergers that have changed the face of the private sector involved with biotechnology, seeds, and agricultural chemicals. Table 12 lists approximately 50 acquisitions, alliances and mergers mainly involving companies from the private sector but also institutions from the public sector. The transactions listed in Table 12 have ranged from an annual commitment of up to $100 million for an R&D joint venture to a proposed mega-merger that involved $35 billion in a stock swap, that eventually did not materialize. Whereas the stimulus for these acquisitions, alliances and mergers is often, but not always, driven by pharmaceutical /biotechnology considerations of companies that also have investments in agriculture, the transactions have an enormous effect on the future deployment of transgenic crops and have far reaching policy and technology implications for both industrial and developing countries. In order to illustrate the magnitude and value of the acquisitions, alliances and mergers listed in Table 12, a subset of 25 of the major acquisitions and alliances are valued in Table 13; the value of these 25 transactions alone is $17 billion. Similarly, Table 13 lists the three major mergers that were consummated during the last three years; the 1998 agricultural sales value alone for the three newly formed mergers totals $13.0 billion. These investments are setting stellar new records for the agricultural industry in terms of R&D and sales. Biotechnology considerations are effectively coupling the private sector investments in pharmaceuticals and agriculture, with transgenic crops currently being the principal agricultural product, to be augmented overtime with animal health and productivity products. The high values of recent biotechnology-driven transactions have resulted from competitors being prepared to bid very high prices, up to a hundred times current earnings, in order to gain early market share of the fast emerging market for transgenic crops in both industrial and developing countries, currently valued at up to $1.5 billion annually.

A discussion of some of the major acquisitions and alliances listed in Table 12 is instructive in that it provides an insight into the commercial issues involved and illustrates the scale and scope of the initiatives. There were eight major acquisitions, alliances and mergers completed within the space of two months in May/June 1998 and one major corporation announced plans for significant increased investments in life sciences, including agri-biotechnology. In May 1998 Monsanto completed its acquisition of DeKalb Genetics Corporation, a seed company in Illinois, USA, with 1997 sales of $451.4 million, income of $28.8 million and business activities in corn, soybeans, sorghum, alfalfa and sunflowers. Earlier in 1996, Monsanto had invested $170 million in DeKalb and later acquired 40 % of its stock for a total of $1.4 billion. Monsanto completed the acquisition of the 60 % remaining stock in May 1998 for a cash deal of $2.3 billion, bringing the total acquisition price for DeKalb to $3.7 billion. DeKalb has 11 % of the USA corn market and holds strategic patents in crop biotechnology. DeKalb will continue to trade under its original name but its activities will be integrated with those of Monsanto. DeKalb was the last big seed company in the USA that was available for acquisition and which controlled more than 10 % of the seed market for corn. Other companies that displayed interest in DeKalb included Dow Chemical which formed Dow AgroSciences in January 1998 to consolidate its biotechnology activities and later in 1998 completed its acquisition of Mycogen which controls 4 % of the US seed corn market. In May 1998, Monsanto also completed its acquisition of Delta & Pine Land, the largest cotton seed company in the USA with 1997 sales of $183.2 million and income of $6.8 million. Monsanto had earlier acquired 4.7 % of Delta & Pine Land and in May 1998 completed its acquisition of the company for a total of $ 1.9 billion. Delta & Pine Land will continue to trade under its original name in the USA and in other countries, including China, where it first commercialized *Bt* cotton in 1998 on approximately 53,000 hectares, all of which is planted in Hebei Province. Adding DeKalb Genetics and Delta & Pine Land to its prior acquisitions of Holdens and Asgrow Agronomics provided Monsanto with access to a significant market share of the seed business in North America.

On 1 June 1998, competitive pressures in the biotechnology industry catalyzed the proposed mega-merger between Monsanto Corporation and American Home Products (AHP) with a $35 billion stock swap. Although the merger between Monsanto and AHP did not eventually materialize it serves as a useful example to capture the major issues that drive mergers in the agri-biotechnology industry. The two companies have growing and significant interests in the life sciences, more specifically pharmaceuticals and agricultural products (including chemicals and transgenic products) where biotechnology is playing an increasingly important role. AHP had earlier been involved in unsuccessful merger discussions with SmithKline, a large pharmaceutical company that does not have an agricultural business. The proposed new company was to be 35 % owned by Monsanto and 65 % by AHP with a market capitalization of $96 billion, estimated sales of $23 billion in 1998 of which $12 to $13 billion would have been pharmaceuticals and $6 billion in agricultural sales. This would have made the new company the world's fourth largest pharmaceutical company and one of the top agricultural companies. The new company was expected to be the world's largest investor in biotechnology (pharmaceutical and agricultural) investing more than $ 1 billion annually out of a total R&D budget of $3 billion of which $2 billion would have been devoted to pharmaceuticals and up to $1 billion on agriculture.

In any merger, synergies and complementarities are important from financial, R&D, product development and global marketing viewpoints and are considered the critical dealmakers or breakers. Thus, cost reductions as a result of reducing administrative overheads, balancing of credit, debt and cash flow, streamlining of research functions, combining of market forces to optimize

Table 12: Listing of approximately 50 selected Biotechnology-driven Acquisitions, Alliances and Mergers (fall of 1995 through 1998) of Corporations involved in Seeds, Crop Protection and Life Sciences

Month	**Year**	**Corporations Involved**
October	**1995**	**ELM (Seminis)** acquired **Petoseed** (ELM acquired Asgrow from UpJohn, Dec, 1994)
September	**1996**	**ELM (Seminis**) acquired **DNAP**
January	1996	**Dow Elanco** acquired 46% interest in **Mycogen**, increased to 69% by January 1998.
February	1996	**Zeneca** (formerly ICI, United Kingdom) and **Suiker Unie**, which owns **Van der Have Group** merged to form a new company, **ADVANTA**
March	1996	**Sandoz** and **Ciba** agreed to merge to form **NOVARTIS**
March	1996	**Monsanto** acquired significant equity position in **Calgene**
March	1996	**Monsanto** acquired significant equity position in **DeKalb**
May	1996	**Monsanto** acquired plant biotechnology assets of **Agrocetus** for $ 150 million
August	1996	**AgrEvo** acquired **PGS**, Belgium
November	1996	**Monsanto** acquired a controlling interest in **Calgene**
February	**1997**	**Monsanto** acquired the **Asgrow Agronomics** Seeds Business
May	1997	**Monsanto** completed its acquisition of the remaining shares of **Calgene** that it did not already own
August	1997	**Du Pont** and **Pioneer** announced a joint venture named **Optima Quality Products**
August	1997	**Du Pont** acquired **Protein Technologies International** from **Ralston Purina**
September	1997	**Monsanto** completed the acquisition of **Holden's Foundation Seeds Inc. and Corn States Hybrid Service Inc**.
September	1997	**AgrEvo** acquired **Sun Seeds**
November	1997	**Zeneca** acquired **Mogen** to form **Zeneca Mogen**
December	1997	**Monsanto** acquired controlling interest in **Sementes Agroceres** SA, a Brazilian seed company
January	**1998**	**Dow** acquired **Eli Lilly** and renamed **Dow Elanco, Dow AgroSciemecs**
April	1998	**Rhone Poulenc Agro and Biogemma** agreed to form **Rhobio,** a joint venture in plant biotechnology
April	1998	**Mycogen** acquired two corn companies in **Brazil, Dinamilho** and **Carol Products Agricolas**
May	1998	**Monsanto** completed the acquisition of **DeKalb Genetics Corp.**
May	1998	**Monsanto** completed the acquisition of **Delta & Pine Land Co**.
May	1998	**Du Pont** announced intention to divest assets in its petroleum company, **Conoco**, that could generate up to $ 25 billion for investment in Life Sciences/Biotechnology
May	1998	**Cargill** and **Monsanto** announced an R&D joint venture, with each company investing $ 100 million per year
June	1998	**American Home Products** and **Monsanto** announced a proposed merger, involving a $ 35 billion stock swap, which was later cancelled
June	1998	**Monsanto** acquired **International Seeds Operations of Cargill** (excluding USA, Canada and UK) for $1.4 billion
June	1998	**Seminis** acquired **Hungong Seed** and **ChoongAng Seed** companies in Korea specializing in vegetable seeds, for $117 million
June	1998	**Seminis** increased equity to 90% for $1.5 million in **Nath Sluis**, a biotechnology company in India specializing in research on vegetable seeds, particularly diseases
June	1998	**Seminis** formed alliance with **LSL Technologies**, USA, investing $27 million on global research on improved fruit and vegetables including the RIN gene for shelf life in tomatoes that will include collaboration with labs in Israel.
July	1998	**Monsanto** acquired **Plant Breeding International Cambridge (PBIC**) from **Unilever** for $ 525 million. PBIC breeds several of the principal crops for the European market, including winter wheat, barley, oil seed rape, and potatoes.
July	1998	**Mycogen and Rhone Poulenc** formed an alliance for plant biotechnology
July	1998	**AgrEvo** agreed to a 3 year alliance in genomics with **Gene Logic**

continued…

Table 12 continued:

August	1998	**Novartis** acquires an Italian corn company**, Agritrading**
August	1998	**Du Pont** formed alliance with **Curagen** for identifying crop protection products
August	1998	**Novartis** formed alliance with **Acacia Biosciences** for selection of crop protection products
August	1998	**BASF** formed two joint ventures**; Metanomics** with a **Max Plank Institute,** and **SuGene** with another **public Institute of Genetics in Germany.**
August	1998	**Dow** completed acquisition of **Mycogen**
September	1998	**Dow AgroSciences** formed biotech alliance with **Performance Plants, Canada**
September	1998	**Mycogen** acquired two corn/sorghum companies in **Brazil-Hibrido Colorado** and **Biogenetica de Milho**
September	1998	**Dow AgroSciences** invested in functional genomics research **with Biosource Technologies of California**
September	1998	**Du Pont** formed alliance with **John Innes Research Centre in the UK** to develop improved wheats and to share genomic tools
September	1998	**Zeneca** formed alliance with **John Innes Centre** to develop tolerance to herbicides and diseases in wheat and to explore changing starch content
September	1998	**Rhone Poulenc Agro** formed **Genoplante,** a genomic initiative involving several French seed companies and public institutions in France
September	1998	**AgrEvo** acquired the US and Canadian operations of **Cargill** for $605 million
September	1998	**Dow AgroSciences** formed a new biotech company**, Advanced Agritraits** as a clearing house for facilitating strategic biotechnology alliances
December	1998	**Zeneca and Incyte** announced a strategic partnership in agrogenomics
December	1998	**Hoechst** and **Rhone Poulenc** merged to create **AVENTIS,** a new global leader in Life Sciences with **annual agricultural sales** of **AgrEvo and R P Agro exceeding $4.5 billion annually**

Source: Compiled by Clive James, 1998**.**

Table 13: Value of a sample of Biotechnology-driven Acquisitions and Alliances, fall of 1995 through 1998, of Corporations in Seeds, Crop Protection and Life Sciences

Company/ Partners	**Corporations Involved/Activity**	**Estimated Value** ($ billion)
Acquisitions and Alliances		
Monsanto	Agracetus, Asgrow, Calgene, DeKalb, Delta & Pine Land, Holdens, Sementes Agroceres, selected International Seeds Operations of Cargill, Plant Breeding International Cambridge (PBIC) (acquisitions)	8.6
Pioneer/Dupont	Joint venture to form “Optimum Quality Products”	1.7
DuPont	Protein Technologies Inc.- soybean miller and processor (acquisition)	1.5
AgrEvo	PGS, Sun Seeds . Cargill North America (acquisition)	1.5
Seminis (ELM/Pulsar)	Asgrow, Petoseed, Royal Sluis, DNAP, Hungong and ChoonAng, Nath Sluis (acquisitions) LSL Biotechnologies (alliance)	1.2
Dow AgroSciences	Mycogen, Performance Plants, Brazil Hibrido &others	0.8
Cargill/Monsanto	R& D joint venture; $100 million per year from each	0.2
Others	Includes Crop Genomics Acquisitions and Alliances	1.5
	Total	**17.0**

Source: Compiled by Clive James, 1998.

Table 14: Value of Three Biotechnology-driven Mergers, 1996 to 1998, of Corporations in Seeds, Crop Protection and Life Sciences

Company/ Partners	Corporations Involved/Activity	Estimated Value ($ billion)
Mergers		
Ciba/Sandoz	Novartis created, with seed/pesticide sales of approximately $5billion	5.0
Hoechst/Rhone Poulenc	Aventis created, with agricultural sales of AgrEvo and Rhone Poluenc Agro exceeding $ 4.5 billion annually	4.5
Zeneca and Van der Have	ADVANTA with annual sales of seed plus pesticides from Zeneca of approximately $3.5 billion	3.5
	Total	**13.0**

Source: Compiled by Clive James, 1998

coverage and efficiency of implementing a global market strategy, and finally lowering legal and regulatory costs associated with proprietary products that are becoming extremely expensive, are all critically important considerations. Management estimated that on completion of the Monsanto/AHP merger, savings from complementarity would have been $1.25 to $1.50 billion annually which, along with product and global markets complementarity were the major driving forces underpinning the merger. Market analysts predicted that the merger between Monsanto and AHP would trigger further consolidation in the pharmaceutical, agricultural and food industry in the near-term. Antitrust considerations are becoming increasingly important as consolidation occurs in the biotechnology industry. Market analysts opined that the merger between Monsanto and AHP would probably not have been precluded by antitrust issues because their combined market share in the major business area of pharmaceuticals would have been small compared with the market share of market leaders such as Merck, Pfizer and Glaxo; in agriculture, AHP's annual sales of $2 billion is in conventional pesticides with very little investment in biotechnology, whereas Monsanto's sales of $3 billion per year are also derived from pesticides, particularly herbicides, but increasingly will be from biotechnology related products, particularly transgenic crops. To put the $35 billion Monsanto-AHP merger into a global financial perspective, had it materialized, it would have been the third largest merger on record for industrial companies, only exceeded by the BP/Amoco merger at $48 billion and the Daimler Benz /Chrysler merger at $40 billion.

In May 1998, DuPont reported its intent to divest its estimated $25 billion petroleum investment in Conoco and invest the proceeds in its growing life sciences businesses. DuPont had considerably strengthened its investment in crop biotechnology/life sciences in August 1997 when it formed a $1.7 billion joint venture, Optima Quality Products, with Pioneer Hi-Bred International (See ISAAA Brief No. 5, 1997). DuPont sales in 1997 were $45.1 billion, of which $2.5 billion, equivalent to 5 %, was generated from life sciences. In March 1998, DuPont was reorganized into 3 main business areas, cyclical chemicals, speciality products, and life sciences which includes pharmaceuticals and agricultural biotech products. DuPont's investments in agbiotech in 1997 included the $1.7 billion joint venture with Pioneer and the purchase of Protein Technologies International for $1.5 billion from Ralston Purina for a total of $3.2 billion. DuPont's stated future strategy is that biotechnology will become a major thrust in the company's business contributing more than a third of the company's earnings in five years time, compared with the current 18 percent. In September 1998, DuPont announced a collaborative agreement with the John Innes Center in the UK to develop improved wheats and to share genomic tools.

In June 1998, Monsanto acquired the international seed operations of Cargill in Europe, Asia, Latin and Central America, and Africa for $1.4 billion. Cargill retained its seed operations in the USA, Canada and the UK. Cargill's international seed operations specialize in corn, sunflower, rapeseed, soybean, alfalfa, sorghum, wheat and hybrid rice. The acquisition includes operations in seed research, production and testing in 24 countries and seed sales and distribution operations in 51 countries.

In a further consolidation of the seed/biotechnology industry, Monsanto announced on 15 July 1998 the acquisition of Plant Breeding International Cambridge Ltd. (PBIC), a principal plant breeding organization in Europe owned by Unilever, for $ 525 million. Unilever had acquired the Plant Breeding Institute in Cambridge in the 1980s when the British Government elected to privatize many organizations during the Thatcher Government. PBIC produces improved varieties of several of the principal European crops including winter wheat, barley, oil seed rape and potatoes. PBIC's principal operations are in the United Kingdom, where Cambridge is the hub of a European network with a potato facility in Perth, Scotland, and nodes in Chartres, France, and Silstedt in Germany. The acquisition will allow PBIC's operations in Europe to be complemented by Monsanto's significant biotechnology expertise in the production of biotechnology-derived cereal varieties which are expected to be marketed by 2003 and beyond. A focus is expected on the production of hybrid wheat through conventional procedures in the near-term as well as biotechnology-derived oil seed rape and potatoes, whilst wheat and barley varieties derived from advanced technologies will probably be commercialized by 2005, or earlier if technological developments and the regulatory framework will facilitate early adoption.

The current consolidation underway involving corporations that are investing in pharmaceuticals and crop biotechnology directly, is expected to develop a close interface with corporations involved in the production, processing and transportation of food. In May 1998 Cargill and Monsanto agreed to establish a joint venture that would be funded annually at $ 200 million with equal contributions from the two partners. The joint venture is designed to build complimentarity between the comparative advantages of Cargill, with sales of $65 billion in 1997, operating a global program involved in the production, processing and transportation of grain with Monsanto's comparative advantage in the production of improved transgenic crops. As consolidation continues the global seamless web of biotechnology that is being woven around transgenic crops will probably extend to involve all the major global, and eventually national, corporations involved with food. These will probably include companies such as Archer-Daniels Midland, a US grain processor with interest in biotechnology, ConAgra and General Foods - two large US food companies, European based transnationals such as Unilever, an international food/trading company, and Nestle, a Swiss based international food company and the CP conglomerate from Thailand with extensive seed and food processing operations in China and South East Asia.

In June 1998, Empresa La Moderna (ELM) from Mexico, through its Seminis and DNAP holdings acquired three companies and agreed to an alliance with another. The four transactions totaling approximately $ 145 million, are designed to strengthen Seminis' global program to utilize biotechnology to improve fruits and vegetables in terms of increased productivity, better shelf life and nutrition, therapeutic and medicinal purposes, particularly in Asian markets. The acquisition of Hungnong Seed and ChoongAng Seed in South Korea for $ 117 million specializing in vegetable seeds will increase Seminis' global market share of the vegetable seed industry to 22-26 percent. Both Korean companies have biotech applications that offer significant advantages; for example traits in hot pepper (chilies) and peppers that can be transferred to fruits, such as melon, on a global basis. Seminis' 90 percent equity investment of in Nath Sluis, the third largest biotechnology vegetables/fruit research company in India, will focus on disease resistance in vegetables and fruits. Finally, Seminis' $ 27 million strategic alliance with ILS Technologies in the USA will strengthen the company's program in biotechnology traits for tomato, including the RIN gene for shelf life. With these acquisitions and alliances, Seminis will have an estimated 30 percent global share of the world fresh tomato seed market which is currently valued at $ 150 million. Seminis is the largest producer of vegetable and fruit seeds in the world, producing 20 species and over 3,000 varieties with production facilities in 28 countries and product sales in approximately 125 countries. Since 1995 Seminis has strengthened its biotechnology capacity through acquisition of Asgrow, Petoseed and DNAP, fortified recently with the four acquisitions and alliances in June 1998.

In October 1998 Zeneca formed a $ 80 million, 10-year alliance with the John Innes Centre and Sainsbury Laboratory in conjunction with Plant Bioscience Limited in the UK. The alliance will explore advanced genomic techniques for the development of improved wheat varieties. More specifically the aim will be to improve the quality, yield and disease resistance of wheat for world-wide markets and to strengthen existing collaboration between John Innes ands Zeneca in starch biochemistry.

This initiative by Zeneca builds upon its acquisition of Mogen which has genetic modification technology for fungal and nematode resistance. The alliance also complements Zeneca's links with Advanta which has substantial wheat and barley breeding programs in Europe.

AgrEvo, whose parent company is Hoechst from Germany, initiated its acquisitions three years ago. In August 1996 it acquired the Belgium-based PGS and one year later in September 1997 acquired Sun Seeds. In September 1998 AgrEvo acquired the US and Canadian operations of Cargill for $605 million which provided it with a strong presence in North America. Finally, in December 1998, AgrEvo's parent company Hoechst, announced a merger with Rhone Poulenc to form new company called Aventis,. in order to create a platform for sustainable growth for powerful emerging technologies and enhanced global marketing. Aventis is now one of the world leaders in pharmaceuticals and agricultural businesses with combined annual sales of US$ 20 billion. The combined R&D annual budget of the two companies will be almost $ 3 billion annually. The merger was designed to create a new company, Aventis, with European roots and global reach. Combining the assets of both companies will result in higher operational efficiencies and synergies worth $ 1.2 billion over the next years, with 40 % of the savings in agriculture. Approximately 25 % of annual sales, equivalent to $ 4.5 billion, are expected to be in crop science with 42 % of global share in Europe, 25 % in USA, 14 % in Asia, and the rest of the world 19 %. Aventis will evolve its business from the current emphasis on crop protection to crop production, combining the technologies of biotechnology, chemistry and plant breeding. The USA will be the top priority for Aventis whose goal is to achieve a 10 % share of the crop science market in the US Mid West in the next few years.

There are several implications arising from the consolidation of biotechnology interests in the private sector including the following:

- There are now fewer corporations who have a larger market share of the transgenic crop business than 3 years ago.
- The scale of R&D investment in biotechnology by an individual corporation has increased substantially to $1 billion or more per annum and this is substantial considering that R&D investments will have to be sustained over a 10 year period, or more, to complete product development and registration.
- With the globalization of agriculture the strategy for deploying transgenic crops has become international in scope and scale and coincides with the implementation of the world trade protocol.
- The onus for the effective and equitable deployment of transgenic crops, that is judged to be an essential contribution to global food security, now rests by and large with government and the private sector. On the one hand the private sector must continue to exercise its comparative advantage in product development and distribution at equitable prices. On the other hand, governments must ensure that responsible regulation is based on objective assessments, completed within reasonable time frames to meet national needs and priorities, optimized to the maximum extent possible through international harmonization, with products marketed equitably and competitively.

Genomics

The study of genomes is known as genomics and involves the mapping, sequencing and analysis of genomes to determine the structure and function of every gene in an organism. For convenience, genomics research and studies may be categorized into three separate but complementary components:

Structural genomics - the structure and organization of genomes
Functional genomics - relating genome structure and organization to plant function
Application genomics - application of genomic knowledge for the development of improved plants.

Genomic information can be used to improve useful plant traits through genetic engineering to increase food and fiber production, provide a safer and healthier environment and a sustainable source of renewable energy and chemicals.

The first investors in genomics were private sector corporations in the pharmaceutical industry who have employed genomics in conjunction with bioinformatics and related tools to accelerate drug discovery. Companies have either invested in-house or more typically, through alliances with small specialized companies involved in human drug development. During the last two years as the global market for transgenic crops has exceeded $ 1 billion annually and consolidation continues in the ag-biotech industry, all of the leading companies have made significant investments in plant genomics. In 1998, the USA also launched a publicly funded National Plant Genome Initiative with international links to other programs such as the Japanese Rice Genome Program. This section comprises a review of recent major investments in plant genomics, and related technologies in the private and public sectors.

Private Sector Investments in Plant Genomics and related areas

Table 15 (Erickson, 1998) lists a sample of recent agreements between large agricultural companies involved in transgenic crops and/or crop chemicals and companies specializing in human drug discovery and involved in genomics, combinatorial chemistry and bioinformatics. The increased level of investments during the period 1996 to 1998 is reflected in the table which lists one agreement in 1996, 5 in 1997, and 4 in only the first four months of 1998. Table 15 lists a sample of four agreements involving Pioneer, four involving Monsanto, and one each involving Rhone-Poulenc Agro and the Burrill & Co.'s Ag Biotech Venture Capital fund in which a group of companies have invested. The agreements are either exclusive or non-exclusive; they have been brokered to achieve a range of objectives including the use of genomic tools for sequencing and gaining a better understanding of the functioning of corn genes, modifying gene-expression, providing access to bioinformatics systems; and delivering sets of combinatorially created chemicals as novel crop protection agents. The largest of the agreements listed in Table 15, valued at $ 218 million over a five year period, was signed at the end of October 1997 between Monsanto Company and Millenium Pharmaceuticals Inc. Under the agreement, Millenium will provide its genomics platform technologies to Monsanto to create new products including novel seeds, pesticides and nutraceuticals. The transfer will be facilitated through Cereon Genomics UC, which is a new Monsanto subsidiary located near to Millenium Inc.

Table 15: A Sample of Recent Agreements involving Plant Genomics and Related Technologies

Date	**Value of Agreement** ($ millions)	**Companies**	**Subject of Agreement**
1/96	$16	Pioneer Hi-Bred/Human Genome Sciences	HGS agrees to sequence corn genes, determine their function, exclusively for Pioneer.
1/97	$12 plus milestones, royalties	Monsanto/Arqule	Arqule to deliver sets of combinatorially-created chemicals Monsanto will screen for novel crop-protection agents. Non-exclusive, 5-year collaboration.
3/97	Undisclosed	Pioneer/Kimeragen	Biotech grants non-exclusive license to a technology for altering genes to enhance their expression.
5/97	Undisclosed	Pioneer/Affymetrix	Affymetrix agrees to array corn genes (found by HGS) on chips for screening.
6/97	$7.5 in equity, $12.5 for research support over 5 years	Pioneer/Curagen	Curagen agrees to share its gene-expression technology, and bioinformatics systems. Pioneer doubles research commitment as of 4/98, to minimum of $25mm.
10/97	$218	Monsanto/Millenium = Cereon	Millenium agrees to help Monsanto build new subsidiary, and transfer its genomics technologies into it, for exclusive use in plant agriculture.
3/98	Undisclosed	Monsanto/Incyte (Synteni)	Monsanto tells academic researchers it will pay for Synteni to run experiments on microarrays of plant genes - if the ag firm gets first refusal on resulting intellectual property.
4/98	$17.2	Monsanto/Gene Trace (GT)	Monsanto buys options to exclusively license all aspects of GT's genomics technologies for plant, animal ag.
4/98	$100+	Burrill & Co./Bayer, AgrEvo, Transamerica, others	Corporations contribute to Burrill's ag biotech venture capital fund, anticipating strategic return from start-up companies.
4/98	Undisclosed	Rhone-Poulenc Agro/Biogemma	Firms create Rhobio, a plant biotechnology joint venture.

Source: After Erickson, Windhover Information Inc. (1998).

Table 15 is only a sample of agreements in the plant genomics area (more are listed in Table 12) and is by no means a comprehensive listing of genomic investments by agricultural companies involved with crop biotechnology. On the contrary, several of the large agricultural companies such as Novartis and Du Pont have considerable in-house capacity in genomics. In July 1998 Novartis confirmed a 10 year $600 million (in house) investment which will involve the establishment of the Novartis Agricultural Discovery Unit in San Diego, California, to be located at the same site as the Novartis Pharmaceutical Genomics Unit. The Novartis Agricultural Discovery Unit will focus on the application of genomic technologies for the development of new crop traits, novel crop protection technologies and animal health applications. Du Pont also has significant in-house capacity in plant genomics. In a 1998 research alliance between Du Pont and the John Innes Centre/Sainsbury Laboratory/Plant Bioscience Ltd., access to genomics tools developed by Du Pont will be provided. Similarly, AgrEvo, Dow AgroSciences, Zeneca and Rhone Poulenc have significant investments in the area of genomics, bioinformatics and combinatorial chemistry. In the latter part of 1998, Rhone Poulenc brokered a private-public sector agreement called Genoplante, with several French seed companies and national institutions on plant genomics. Taking into account the in-house investments in genomics as well as agreements between large agricultural companies and companies specializing in genomics, the overall investment by the private sector in plant genomics is significant and growing.

Public Sector Investments in Plant Genomics - The U.S. National Plant Genome Initiative (NPGI)

This important initiative was developed by the Interagency Working Group on Plant Genomes under the aegis of the US National Science and Technology Council (NSTC) Committee on Science; for more details the reader is referred to the reference listed under (Interagency Working Group, 1998), in this publication. In 1998, the NSTC endorsed a "National Plant Genome Initiative" (NPGI) with proposed funding of $ 320 million over the first five years to achieve the following objectives:

- Complete the sequencing of the model plant species, Arabidopsis, by the year 2000;
- Participate with Japan and other nations in an international effort to sequence rice by the year 2004;
- Develop the biological tools (e.g. physical maps, expressed sequence tags - ESTs, mutants) to study complex plant genomes (e.g. corn, wheat, soybean cotton);
- Increase knowledge of gene structure and function of important plant processes, such as stress resistance, grain quality characteristics and function of genes that control other genes, including signaling factors;
- Develop the appropriate data handling and analysis capabilities; and
- Ensure that this new information will be accessible to the broader community of plant biologists (e.g. growers, breeders, physiologists, biotechnologists) and maximizing the training opportunities that will arise from the initiative including under-represented groups

The NPGI will focus on structural and functional genomics in the first five years, but is viewed as a long term project with all research grants made on a competitive basis, all information and materials openly accessible, and partnerships with the private sector and other nations viewed as essential and vital for the success of the initiative. The proposal recognizes that despite the fact that 27.8 million hectares of transgenic plants were grown globally in 1998, that the total number of genetically engineered plant traits is still few. This reflects the limitations in the current genomic knowledge base for plants. Given that the genes that code for plant traits are nearly identical for a wide range of plant species, and acknowledging the rapid development of genomic technology, it is foreseen that this will result in the expeditious development of practical applications; comparative genomic analysis offers an additional avenue for significantly enhancing the value of genomic information generated for a specific plant when that same information is applied to other plants. The ultimate success of NPGI will be determined by its impact on the development of improved plants that result in increased productivity of food that is more nutritious for the growing global population.

The National Plant Genome Initiative developed by the United States is laudable. The NPGI has also been instrumental in focussing attention on several key issues in relation to plant genomics. These include:

International collaboration

There are more than 40 economically important plant species in the USA alone and it is evident that the USA does not have the resources to support a major genome project for each crop. NPGI takes the position that international coordination and cooperation is essential and can be best facilitated through the free exchange of information and experimental materials.

Public-Private Sector Interactions in Genomics

Private sector investments in genomics are significant and it is highly likely that extensive sequence data for the most important crops are already available to major corporations, which begs the question of duplication of investments. Following consultation with Government, private sector, and commodity and user groups the NPGI advocates Government responsibility for providing public funding to generate a publicly-accessible data base on genomics, whilst continuing to dialogue with the private sector to minimize duplication and impediments to future research and collaboration.

Intellectual Property Rights

The patenting of products from NPGI is an issue that will continue to be open for discussion as more experience is gained. One of the important tools that the NPGI will generate are ESTs for gene discovery which private sector companies are also actively sequencing. It appears that ESTs are patentable if the patent application contains at least some evidence of known gene product function. This provides the incentive for the private sector to patent ESTs. The NPGI has adopted the principle that all data and material, including ESTs, should be openly accessible. This decision was based on experience with the Human Genome Project that "open access to a common set of research tools will advance the whole field of plant genomics and is a sound investment of public funds" (Interagency Working Group, 1998).

Overview

The initial concept of a gene as the unit of inheritance was proposed by Mendel more than a century ago, following his conclusive research on peas. Timberlake (1998) noted that Mendel switched from bees to peas because the latter permitted rapid and accurate experimentation and was a more appropriate model for studying inheritance. Furthermore, he contends that much of the basic understanding of genetics has evolved from plant genetics and crop breeding and that the discovery that dominance and recessivity also applied to humans. This has had a major impact on disease control/therapeutics which in many ways paved the way for the current revolution in genomics.

Several reasons have been offered as to why agriculture, through plant genomics, may be better positioned than medicine to benefit from the current significant investments in genomics. These reasons include the fact that plant genetic engineering is well established with 27.8 million hectares of transgenic crops already commercialized in 1998, with the highest priority on genomics accorded to economically important crops but not to the exclusion of model systems such as *Arabidopsis* whose 100 mb genome will yield volumes of important genomic information that will have a significant impact on crop improvement. On the other hand, the application of genomics in plant science has been constrained by lack of critical mass in material and human resources, the absence, until recently, of large plant genomic projects, and exacerbated by the fact that most of the important crops have complex and large genomes. Collectively these factors resulted in a genomic information and application gap between plant scientists and their counterparts in other sectors, particularly medicine/pharmaceuticals. However, Timberlake concludes that there has been a major change recently in opinion vis-à-vis the role of genomics in crop production. He cites four changes that will facilitate a significant impact of genomics on global crop productivity:

- significant investments by the private and public sectors in large plant genome projects;
- the information from the above plant genome projects to be readily accessible for bio-information analysis;
- information from the rich legacy of plant science in physiology and other specializations, including the knowledge gained in traditional crop improvement, to be integrated with the new genomic information;
- increased investments in functional genomics to identify the genes that can contribute to increased crop production and quality.

With the implementation of these four changes it is judged that agriculture will be well-positioned to benefit from crop genomics during the next few years when the primary sequences of most plant genes will be determined. Timberlake foresees that the increased power and reduced costs of crop improvement due to genomics will dramatically decrease product development time frames and coincidentally increase the number of products that can be developed simultaneously.

It is evident from the information presented in this section on recent private and public investments in plant genomics and related areas, that the changes advocated by Timberlake have already been initiated. It is vital that private and public sector investments in plant genomics continue to accelerate so that global food security can fully benefit from the rapid advances in genomics. Scientists from the developing countries, where the need for food is greatest, need to be exposed to the new advances through collaborative projects so that awareness of genomics is increased and capacity in the science achieved in the countries of the South.

The rapid scientific and collaborative institutional developments that are propelling genomics is illustrated by a recent initiative in relation to the human genome project. In May 1998, Dr. Craig Venter, Head of the Institute for Genomic Research (TIGR), a private not-for-profit US organization and Michael Hunkapiller, President of the Research Department of Elmer Perkins, the major US producer of DNA sequencing equipment, unveiled an ambitious joint venture that could further revolutionize the science of genomics (Anonymous, 1998a). The three year project was unveiled in the presence of the US National Institute of Health (NIH) and the Department of Energy (DOE) which are jointly funding the human genome project, initiated in 1990 and planned for completion in 2005, after a 15 year investment at a projected cost of $3.8 billion in US public funds. The bold aim of the new project is to initiate a parallel human genomic program to be completed in 3 years, as opposed to 15 years, with completion in the year 2000 at a cost of $ 150 - 200 million equivalent to only 10 % of the $ 2 billion cost for finishing the NIH/DOE project between 1998 and the year 2005. The new joint venture partners claim that this quantum leap in productivity is possible because of two breakthroughs. First, access to a new high-throughout DNA sequencing machine developed by Elmer Perkins that is highly automated and can run for 24 hours following a minimal 15 minute loading. Second, a new protocol that utilizes ultrasound to break-up DNA into fragments which when processed in the new machine increases sequencing capacity to 100 million bases per day. At this capacity even the human genome of 3 billion bases can be sequenced in less than 3 years compared with 15 years using current technology.

The joint venture plans to make available the "raw" sequence data free of charge which is welcomed by institutes in the public domain and by academia. Income generation is planned through sequencing different human genomes with a view to identifying polymorphisms that can be used in disease diagnosis and drug development, and selling the products of the gene discovery program. The latter objective has been welcomed with some skepticism from established genomic companies who claim that they have already identified 80 to 90 percent of the key genes and have already gained several years of experience in gene discovery and polymorphism projects. Assuming that the new joint venture is successful, it begs the important question of what are the options for eliminating duplication by building a partnership between the TIGR/E. Perkins initiative and NIH/DOE project to achieve mutual objectives, so that the gains from pooled resources invested in genomics are optimized for the benefit of global society.

The situation has many parallels with agricultural biotechnology, where the private sector has comparative advantage in product development and distribution and where public-private partnerships have been advocated (James 1997b, 1996) to achieve mutual objectives and to optimize the benefits that will contribute to food security for the global community. The issues that are central to both debates are similar, i.e. management of intellectual property rights, equity, ethics which are beyond the scope of this publication. However, it is noteworthy that biotechnology is the common denominator and that the applications, food and health, are the two most important elements essential for the survival of mankind.

Maintaining Durable Resistance to *Bt*

Status in the USA

The concept of a refuge crop in conjunction with a high dose of *Bt* to kill almost all target pests has been an integral component of the *Bt* transgenic cotton strategy for durable resistance from the outset in the USA. The strategy has been incorporated as a contractual agreement between the vendors of *Bt* cotton seed and farmers who are required to plant a refuge "non-*Bt* cotton area" alongside the *Bt* cotton. The rationale underpinning the strategy is that the target insect cotton pests are exposed to high doses of *Bt* that are sufficient to kill almost all the target pests; the rare insect survivors mate with the pests from the refuge area resulting in hybrid offspring that are susceptible to *Bt* toxins, thereby precluding the selection for resistance to *Bt* in the target insect population.

In 1997 the US environmental Agency (EPA) required a refuge only for *Bt* cotton and asked seed producers to submit proposals for *Bt* corn in 1998. In 1998 one group called on EPA, to expand the size of the existing refuge for cotton and corn, ensure that the refuge is close enough to the *Bt* corn to be effective and to make the refuge mandatory. Several considerations prompted the group to recommend to EPA a more stringent strategy for ensuring durable resistance in *Bt* transgenic crops; an outbreak of cotton bollworms in the Southern USA in 1996 where not all the target pests were killed by *Bt* cotton; lab experiments that demonstrate that some pests can evolve resistance to multiple *Bt* toxins that target different receptors and that resistance can evolve as a dominant trait; evidence that insect pests can develop new mechanisms of resistance - resistance to *Bt* can develop in the Indian meal moth if it lacks a protinease enzyme essential to activate *Bt* toxins.

Proprietors of *Bt* transgenic cotton in the US are confident that the existing strategy for *Bt* cotton is operating effectively. Their assessment is based on the premise that, to-date no resistance to transgenic *Bt* crops has been demonstrated in the field, and that this is unlikely to happen in the next five years when different and multiple enhanced sources of *Bt* and other toxins are planned for introduction that will further reduce the likelihood that insect pests will overcome the source of resistance being deployed. Work is underway at several public and private sector laboratories to develop biopesticides as alternatives to *Bt*. For example, researchers at the University of Wisconsin, Madison, have recently reported the cloning of a gene from the bacterium *Photorhabdus luminescens,* which inhabits the gut of nematodes, that code for a toxin that can kill some insect pests; the enzyme triggers a reaction that results in the dying insect becoming a fluorescent blue color. Dow AgroSciences, which collaborate with the Wisconsin group is now attempting to incorporate the cloned genes into various crops to determine whether resistance can be conferred to targeted insect pests.

Continuing discussions between industry representatives in the US are reported to have recently resulted in an agreement to use a 20 percent refuge for *Bt* corn as an industry standard in the US in the year 2000. The agreement to use 20 percent refuge for *Bt* corn follows a similar recent ruling by Canada for *Bt* corn in 1999, which is described in more detail below.

Insect Resistance Management of **Bt** *Corn in Canada*

The Plant Biotechnology Office (PBO) of the Canadian Food Inspection Agency (CFIA), is responsible for the regulation of plants with novel traits in Canada. Given that the companies which market *Bt* corn in Canada were using different resistance management plans, an effort was made by PBO to adopt a single plan to be used as an industry and national standard.

In October, 1998, the PBO endorsed recommendations that are consistent with those of the United States Department of Agriculture North Central Regional Research Committee on *Bt* corn management (USDA, 1998). In particular, the mandatory implementation of a minimum 20% unsprayed refuge of non-*Bt* corn on each farm planted with *Bt* corn was considered a critical component for the responsible management of this technology. As of 3 December, 1998, the authorizations of *Bt* corn in Canada are conditional on the implementation of the new Resistance Management Plan (CFIA,1998). The following is a brief summary of Canada's new policy on insect resistant management of *Bt* corn.

The new policy recognizes that all individuals and institutions in Canada involved in *Bt* technology are responsible for its proper use and stewardship. The seed industry accepts responsibility for maintaining and marketing *Bt* corn hybrids that deliver a high dose of *Bt* toxin throughout the season, and for continuing to produce high quality non-*Bt* corn hybrids that can serve as refuge areas for *Bt*-susceptible European corn borers. Corn producers accept responsibility to apply appropriate measures for management of resistance by corn borer populations to *Bt* toxins to ensure extended use of this technology. The research and extension community accept responsibility to provide scientifically based information pertinent to the use of this technology and to transmit this information in a timely and clear manner to the seed industry and to corn producers.

The recommendations for implementing the new resistance management strategy include the following:

- All growers should plant a minimum of 20% non-*Bt* corn not sprayed with insecticides on their planted acreage each year.
- Non-*Bt* corn should be planted within 1/4 mile of the farthest *Bt* corn in a field to provide a refuge where *Bt*-susceptible moths may exist.
- Non-*Bt* corn hybrids for use as refuges in a field should be selected for growth, maturity and yield traits similar to the *Bt* hybrid used in the remainder of the field.
- Refuge areas may be planted in blocks on the edges or headlands of fields or in strips across the entire field. When refuge corn is planted in strips across a field a minimum of 6 rows should be planted with non-*Bt* corn alternating with *Bt* hybrid across the entire field. Refuge created by mixing seed in the hopper is ineffective.
- Individual corn producers using *Bt* technology are responsible to ensure that the minimum 20% refuge occurs on their farm.

The Canadian *Bt* Corn management strategy recognizes that a single, clear and concise message concerning stewardship of *Bt* technology is essential for all groups and individuals concerned and for public awareness and acceptance.

Public Acceptance

Whereas transgenic crops are well accepted in North and South America, China, Australia and South Africa, some European consumers continue to show reluctance. European politicians and the European Union (EU) are reflecting this view and have introduced bureaucratic procedures that make registration of transgenic crops both unnecessarily complex and confusing. In the EU, a public institute or private sector corporation that seeks to introduce a transgenic crop has to approach a member state to act as *rapporteur*. Provided that the *rapporteur* is satisfied that the application meets health and safety requirements, the application is submitted for consideration to the European Commission and the other 14 member states. Following judgment by all 15 national committees, a vote is taken and if it is approved by a qualified majority, the product is accepted by the EU. However, before the product can actually be marketed in a specific EU country, that member state has to legislate regulations and/or promulgate laws that allow the product to be sold in that member state. In 1998, France was the *rapporteur* for a maize *Bt* product that was approved by the EU, after which France introduced an additional step in the approval process by organizing a “consensus” conference in June 1998 to review the status and approval of genetically modified organisms (Anonymous 1998b). Acknowledging that public acceptance debates related to choice and labeling must continue to address consumer concerns, the approval process for transgenic crops is unnecessarily cumbersome and bureaucratic and in practice continues to deny European farmers and consumers the choice between conventional and transgenic crops. European public organizations and private sector corporations seeking to register products also suffer because they are unable to benefit from significant R&D investments in biotechnology by offering their products for sale to farmers in the countries of the European Union, and are disadvantaged in offering their products in global markets.

Much of the concern expressed about biotechnology by special interest groups is because of lack of understanding or a reluctance to understand and accept the technology The number of “what if” questions that can be posed about any area of science are without limit but the history of science indicates that the agricultural scientific community has been responsible in its conduct of science and has taken reasonable precaution to ensure that products are safe before being approved for commercialization. The need to transfer and fully disclose and inform the public about all aspects of biotechnology and respond in a transparent mode to questions and concerns must continue to be a central thrust in the quest to ensure safety and to gain public trust and confidence in biotechnology. Unfortunately transgenic crops are being introduced at a time when the perception of the public has been heightened because of government action and political considerations about food safety issues related to other products, for example, poisoning from *E. coli*. However the results of the June 1998 Referendum in Switzerland confirm that public opinion can be influenced by frank and open discussion of the facts. A few months before the June 1998 referendum opinion polls indicated that the public was almost equally divided on the pros and cons of biotechnology. Following a vigorous campaign in which scientists communicated frankly and openly with the public and drew the clear distinction between perceptions and facts, and pros and cons, two-thirds voted against a ban on genetic modification of plants and animals and their release into the environment (Anonymous 1998c). Thus, the generation and continued sharing of information with the public on all aspects of biotechnology is vital. Hence, it is distressing to witness environmental groups in Europe continuing to destroy transgenic crop field experiments. It is ironic that some of the same interest groups that insist on choice re. labeling and full disclosures of information about biotechnology products are the same groups that deny the public the choice and the right to have access to information about the products by destroying field experiments with transgenic crops, which are specifically designed to generate information for regulatory agencies, the public and the proprietors of the technology.

The following is a brief summary of the status in Europe of transgenic crops, as of year end 1998. In the last quarter of 1998, France, the United Kingdom and Denmark instituted a partial moratorium on approvals for transgenic crops. Austria, Luxembourg and Greece placed bans on specific transgenic crops/products in 1998. Austria and Luxembourg have banned *Bt* maize and Greece banned a genetically modified rapeseed. In February 1998, France approved 3 varieties of *Bt* maize and approximately 2,000 hectares of the *Bt* maize were planted in 1998. In August 1998 France also approved another variety of *Bt* maize and a herbicide tolerant maize for import and planting. However, in September 1998, France's highest Administrative Court (Conseil d'Etat) suspended sales of the 3 varieties of *Bt* maize approved in February 1998. The decision to suspend has now been referred to the European Court of Justice to seek opinion on whether a member state retains discretionary authority after the European Commission had approved the use of the three specific maize varieties in countries of the EU in January 1997. The Commission, in turn, is threatening France, Austria and Luxembourg with legal action for imposing bans on the *Bt* maize which the EU had approved in January 1998. Pending the opinion of the European Parliament, the Council of Ministers will seek to revise Directive 90/220 to ensure that the scope of the directive and of the environmental risk are well defined and broad enough to cover indirect and direct effects of transgenic crops, as requested by some member governments. As a result of all these unnecessarily complex and bureaucratic legal actions, it is unclear whether any variety of *Bt* maize or herbicide tolerant maize will be planted in France in 1999. The above decisions do not affect the consumption of imported *Bt* maize or the marketing of *Bt* maize seeds in other EU countries.

In October 1998, the UK announced a program of "managed development" of transgenic crops which would limit the area of the first commercial plantings of herbicide tolerant transgenic crops which will be strictly monitored. In addition, Government and Industry has agreed not to market any transgenic insect resistant crops for three years. The UK amendments also call for a reassessment of herbicides to be used on transgenic herbicide tolerant crops and a revision of the 90/220 Directive of the EU. In December 1998, Denmark announced a one year moratorium on the commercial cultivation of genetically modified crops and the marketing of transgenic seeds. After the moratorium has been lifted, the transgenic crop that is likely to be the first commercialized in Denmark is a herbicide tolerant sugar beet for animal fodder.

One of the potential crop biotechnology applications that has stimulated much discussion in 1998 is the recent issue of a patent to Delta & Pine Land Company for "control of Plant Gene Expression" - more commonly referred to as the "gene protector" by its developers and as the "terminator gene" by its critics (Anonymous, 1998d). In principle, the gene has the potential to prevent the germination of seeds. Critics have been concerned about the gene's impact on farmers' rights to save seeds for replanting from season to season, more limited choice of varieties, and protection of biodiversity in crop germplasm. Developers of the technology have countered by emphasizing the potential advantages, which include provision of quality controlled improved varieties, minimization of outcrossing and thus protection of the integrity of related plant species and biodiversity, and as a tool for facilitating the implementation of resistant management programs. Several key points need to be understood prior to making judgements on the application of this technology.

Firstly, whereas the technology has been patented, it is premature to draw major conclusions about its potential use, because the technology is in its infancy and it will probably be at least five years before it is ready for deployment consideration. Secondly, to-date the only crops that have undergone preliminary testing with the new technology are tobacco and cotton; the effectiveness of the technology on other crops are unknown at this time. Thirdly, like any other technology, before it is granted approval for deployment, it will undergo a rigorous assessment by evaluators who will consider both the disadvantages and advantages of the technology; this will include an assessment of its effectiveness as a method for minimizing outcrossing of transgenic plants with non-transgenics or native species which has been a major concern of critics of transgenic crops generally, and more particularly for developing countries with centers of crop genetic diversity. Premature assessment and extrapolation of the pros and cons of any technology is inappropriate and can lead to misleading conclusions. This new gene technology should be assessed only when there is sufficient information available about its potential pros and cons, which are best evaluated by independent assessors.

Future Prospects and Global Food Security

The number of countries growing transgenic crops has increased from 1 in 1992, to 6 in 1996, to 9 in 1998, and this number is expected to continue to grow to the year 2000 and beyond. It is probable that Brazil, a major market in Latin America, will commercialize a transgenic crop for the first time in 1999, with India and some countries from Eastern Europe considering commercialization in the near-term. However, in the next two years the significant increase in the global area of transgenic crops will occur due to expansion of the area and number of transgenic crops deployed in the USA, Argentina, Canada, Australia, China, Mexico, Spain and South Africa.

The largest increase is expected to be in the USA where 74 percent of the global transgenic crop area was grown in 1998. In 1999, herbicide tolerant soybeans and *Bt* corn in particular are expected to continue to show high growth rates. Herbicide tolerant corn and cotton are likely to increase significantly as well as corn and cotton with the multiple traits of *Bt* and herbicide tolerance. Whereas potatoes occupy a very small area in the USA compared to corn, soybean and cotton, seed stocks of *Bt* potatoes should allow a significant increase in area in 1999 and a multiple trait potato with Bt and resistance to the economically important Potato Leaf Roll Virus (PLRV) will be available.

In Argentina, which occupied 15 percent of the global transgenic crop area in 1998, the growth in area of herbicide tolerant soybean in 1999 will likely continue to be the dominant feature although growth will be modulated compared with 1998 because of the high proportion (>60 percent) of Argentinean soybean area already occupied by herbicide tolerant soybeans. It is expected that the 17,000 hectares of *Bt* corn in 1998 will increase significantly in 1999 with a more modest increase for *Bt* cotton which occupied 8,000 hectares in 1999. There is a good probability that Argentina will again exhibit one of the highest relative growth rates between 1998 and 1999, albeit lower than the threefold difference between 1997 and 1998.

Canada grew 10 percent of global transgenic crop area in 1998 and prospects are excellent for continued growth in 1999. A more detailed comparison of the 1998 status in Canada versus expectations in 1999 and beyond serves to provide a more comprehensive overview of the potential for future growth. Canada's largest area of transgenic crop is herbicide tolerant canola. In 1998, 50 percent of the 5 million hectares of canola were planted to herbicide tolerant transgenics. Out of a total of 130 *B. napus* varieties on the market in 1998, 22 of the varieties were transgenic,and of 31 varieties of *B. rapa* offered for sale, 2 were transgenic (Watson 1998). The number of transgenic B. *napus* and *rapa* varieties are expected to increase significantly in 1999 and it is projected that the area of transgenic canola in Canada may occupy up to 3.5 million hectares in 1999 and ultimately cover 4.0 million hectares, equivalent to 80 percent of the national area. Corn is the second most important transgenic crop in Canada. Approximately 1.2 million hectares of corn are grown in Canada, 70 percent of which is grown in Ontario. Of the 248 corn varieties recommended for growing in Ontario in 1998, 20 *Bt*. transgenic varieties were offered plus 8 herbicide tolerant varieties. In 1998 up to 0.3 million hectares (up to 25 percent) of the corn was planted to *Bt*. Corn and this is expected to grow to at least 0.4 million hectares in 1999 plus 0.1 million hectares, or more, of herbicide tolerant maize. The smaller areas of the other two transgenic crops currently grown in Canada, herbicide tolerant soybean and *Bt*. potatoes are also expected to grow in 1999. In 1998, of the 0.8 million hectares of soybean in Ontario, 60,000 hectares were herbicide tolerant and this is expected to increase about threefold to between 150,000 and 200,000 hectares in 1999. Of the 180 varieties of soybean offered in 1998, 14 were herbicide tolerant and again this number is expected to increase significantly in 1999. Finally, 3 out of 145 varieties of potatoes offered for sale in 1998 were *Bt*. potatoes in Canada. The area planted to *Bt.* Potatoes in 1998 was 5,000 hectares and this is expected to increase at least 2 or 3 fold in 1999. In summary, the total area of transgenic crops in Canada could be expected to grow by a factor of approximately 1.5 between 1998 and 1999 to reach a total area of about 4.25 million hectares in 1999.

Thus, in summary the major countries growing transgenics crops in North America, (USA and Canada) and Latin America (Argentina) are again expected to be the major contributors to global growth in transgenic crop area in 1999. China is expected to expand its transgenic crop area aggressively in 1999 with growth and diversification continuing in Australia, Mexico, South Africa and Spain. Brazil will probably grow commercial crops of transgenics for the first time and India and several countries in Eastern Europe are near-term possibilities. In 1999, on a global basis, the area of transgenic crops could increase to between 40 and 50 million hectares. Public acceptance, including labeling of foods derived from genetically modified plants, will continue to be dominant issues that will impact on adoption of transgenic crops in countries of the European Union. Several countries in Eastern Europe have transgenic crops that are ready for commercialization. "Output traits" to modify oil quality have already been incorporated in commercial varieties of transgenic soybean and canola already being grown in North America. As expansion of transgenic crops continues, a shift will occur from the current generation of "input" agronomic traits to the next generation of "output" quality traits, which will result in improved and specialized nutritional food and feed products that will satisfy a high-value-added market; this will significantly affect the value of the global transgenic crop market and also broaden the beneficiary profile from growers and consumers to food, feed and fiber processors.

Transgenic crops are proprietary, developed almost exclusively by the private sector in the industrial countries, with the majority of the global transgenic crop area to-date grown in countries of the North. However, it is important to note that developing countries such as China played a pioneering role by being the first country to introduce a commercialized transgenic crop in the early 1990s. Argentina is a global leader in the accelerated adoption of transgenic crops with significant expansion imminent in Mexico and South Africa. Given that the food gap of many developing countries, including China, is expected to more than double in the next 25 years and that some developing countries like Argentina can meet some of those needs through exports, the long term potential and importance of transgenic crops for developing countries is evident.

The world's population is currently almost six billion people and despite the encouraging decrease in projected population growth rates it is still expected to reach around 7 billion by 2010 and 8 billion around the year 2020. About 96 % of new-borns will begin life in the developing countries of Asia, Africa and Latin America where there are 800 million poor people suffering from malnutrition today. As the burgeoning population of the South will seek to improve its inadequate living standards this will require a significant increase in per capita production of food and feed crops, as they consume more food crop products and eat more animal protein in their daily diets. World food demand was 4.9 billion tons in 1994 and is expected to be 7 billion tons by 2020 with cereals continuing to account for about two-thirds of total world food supply. Most of this 50 % increase in demand in the next 25 years will have to be supplied from land already in production with the possible exception of areas in South America and Sub-Sahara Africa. The net cereal imports of the developing countries in 1995 were 95 million tons that are projected to grow almost two-and-a-half fold to 228 million tons in the 25 year period culminating in the year 2020. It is therefore crucially important that developing countries be given the choice and opportunity to have full access to transgenic crops that have the potential to make a significant and sustainable contribution to food security in the near and long term. This access can be threatened by anti-biotechnology groups in industrial countries whose actions can result in either a delay or a halting of development of biotechnology products in industrial countries or negatively influence donor policy on the transfer and sharing of biotechnology products with developing countries.

At the 1992 Summit in Rio de Janeiro a Biodiversity Treaty was signed which was eventually ratified by 168 countries. One of the elements in the Treaty addresses issues related to genetically modified organisms (GMOs) and biodiversity. As a follow-up, in 1996, the signatory nations to the Treaty appointed an ad hoc team to determine whether GMOs could threaten biodiversity. The team comprises mainly representatives of environmental agencies from signatory nations, including both industrial and developing countries. In a recent article (Carter, 1998), former US President Jimmy Carter expressed concern about the thrust and potential impact of the international protocol that the team may recommend for adoption by the signatory nations early in 1999. President Carter concluded that the team decided, without supporting evidence, that any GMO could potentially threaten biodiversity, and then proceeded to exceed its original mandate of studying GMOs that could threaten biodiversity, by proposing broad regulation to control the shipment and import of all GMOs and derived products. President Carter and Nobel Laureate Norman Borlaug (Borlaug, 1998) both recognize the important contribution that transgenic crops can make to food security in developing countries. The US National Academy of Science and the World Bank (Kendall et al 1997) have also carefully studied potential risks involved and have determined that with appropriate management, transgenic crops can increase the production of rice by 10 to 25 percent in the next decade - a crucial technology for developing countries, particularly Asia.

President Carter is concerned that the zealousness of the ant-biotechnology groups and the information that they disseminate could result in a binding and restrictive protocol that would deny developing countries timely access to transgenic crops that offer a unique opportunity for increasing food, feed and fiber production in the near and long term. He notes that the proposed protocol not only includes regulation of transgenic seed but important agribiotech research tools that are essential for sustainable agriculture in developing countries. It is evident that a restrictive and binding international protocol could paralyze the international exchange of genetically modified germplasm, and international trade in grains and oil seeds. The developing countries would be the biggest losers because they have the greatest need for increased food in the next 25 years. A restrictive protocol would also constrain developing countries form using transgenic crops domestically to increase productivity and from importing GMO grain and oil seeds, and products derived from them. In his plea for a more rational and pragmatic protocol, President Carter calls on countries negotiating the protocol to" reject the propaganda of extremists groups" (Carter, 1998) so that developing countries will not be disadvantaged and condemned to the use of outdated and inadequate agricultural technology in their quest for food security.

From a global perspective, the major impact of transgenic crops to-date has been in North America (USA and Canada), followed by Latin America (Argentina and Mexico), Asia/Oceania (Australia and China) with the first introduction in the EU (Spain and France) and Africa (South Africa) in 1998. Whereas Asia gained an early lead when China commercialized its first transgenic crops in the early 1990s, until recently, progress in the interim period in the developing countries of the region has been relatively slow with transgenic crop field trials. However a review of current developments in Asia/Oceania may provide the basis for cautious optimism. Australia and China are both growing commercialized transgenic crops and have an impressive portfolio of products being field tested (see ISAAA Brief 5, 1997). India has field tested transgenic crops, and it is possible that India could approve its first commercial release of *Bt* cotton on limited introductory areas in the near-term. Japan which has yet to plant a commercial transgenic crop has completed field tests on 16 crop/trait combinations (Tabei,1998, Table 3A of the Appendix, p. 43). The trials feature 10 crops (Tomato, Petunia, Rice, Tobacco, Soybean, Canola, Carnation, Corn, Cotton and Melon). A total of six traits have been tested in Japan including three input traits, virus resistance, insect resistance, and herbicide tolerance, plus three quality traits, delayed ripening in tomato, shelf life in carnations and low allergen rice. Equally important, Japan has approved 20 products derived from transgenics for food use, and 15 products for feed use. (Table 4A of the Appendix, p. 43).

Of the ASEAN countries, Thailand was the first to initiate field testing with a delayed ripening tomato in 1995, and *Bt* cotton in 1996 and 1997. Malaysia followed in 1997 with a field test using the GUS gene in rubber. In 1998 Indonesia initiated transgenic field tests with *Bt* cotton, herbicide tolerant cotton, herbicide tolerant maize, *Bt* maize and herbicide tolerant soybean. In the Philippines, two applications for *Bt* maize are currently under consideration, and if approved, would represent the first transgenic crops to be tested in the country. Thus, of the five developing countries of ASEAN, almost all are now conducting, or in the process of approving, field trials of transgenic crops.

Of all the regions of the developing world, Asia has the greatest need for food and it is the continent where 50 percent of the world's poor resides. With leadership from China and Australia in commercializing transgenic crops, encouragement from Japan in approving many food and feed products derived from GMOs, the specter of India commercializing transgenic crops in the near term, plus most ASEAN countries conducting field tests, collectively, this may provide the momentum for transgenic crops that has been missing in Asia to-date. National programs in Asia have infrastructures that can accelerate the adoption of technology, and transgenic crops could be adopted rapidly following successful field trials to openly demonstrate the benefits and the safety of the products to regulators and the public. The current economic situation in South East Asia could hinder or facilitate the adoption of transgenic crops. On the one hand the economic crisis has graphically highlighted the importance of food security and could provide the incentive for national programs to accelerate the introduction of transgenic crops. On the other hand there are significantly less resources in South East Asia today as a result of the financial crisis and this may preclude national programs from adequately funding transgenic crop initiatives even though they have been assigned high priority. For all these reasons South East Asia should be given all the assistance possible by institutions with capability in transgenic crops. These include aid agencies such as the World Bank, the International Centers of the Consultative Group on International Agricultural Research, (CGIAR, 1998), particularly the International Rice Research Institute (IRRI), and technology transfer organizations such as ISAAA all of whom are active in the region.

Asia is unique in that it is the region where one crop, rice, plays such a dominant role. Of the three major staples (wheat, rice and maize) the greatest concentration of a single staple is rice in Asia. Over 90 percent of the world's 150 million hectares of rice is grown in Asia. Biotechnology offers unique opportunities for improving rice productivity ranging from the use of molecular markers to facilitate more effective conventional breeding programs, to incorporation of genes for overcoming biotic and abiotic stress, quality and improved hybridization technology. The panel of international experts commissioned by the World Bank concluded that biotechnology can increase rice productivity by 10 to 15 percent in the next decade (Kendall et al, 1997) and advocated the appropriate use of biotechnology. National Programs such as China, public sector research organizations such as IRRI, the transnational private sector and industrial countries such as USA and Japan, have, collectively, an impressive portfolio of biotechnology applications that could contribute to improved rice production and nutrition in Asia. Given rice's unique role in Asian diets, tradition and culture, the introduction of transgenic rice could make a critical contribution to food security in the region during the next decade.

Transgenic crops have much to offer developing countries and should be an essential component of a global food security strategy that integrates conventional and biotechnology crop improvement applications to produce more food where the need is greatest, and where the welfare value of food is the highest. Denial of the new technologies to the poor is synonymous to condemning them to continued suffering from malnutrition which eventually may deny the poorest of the poor their right to survival.

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Table 1A: STATUS OF APPROVED TRANSGENIC CROPS IN 1998 LISTED BY TECHNOLOGY PROPRIETOR AND TRANSGENIC CROP: 56 PRODUCTS APPROVED IN AT LEAST ONE COUNTRY

COMPANY	TRANSGENIC CROP
AgrEvo	Glufosinate Herbicide Tolerant Corn
	Glufosinate Herbicide Tolerant Canola
	Glufosinate Herbicide Tolerant Soybean
	Glufosinate Herbicide Tolerant Beet[1]
	Glufosinate Herbicide Tolerant/Insect Resistant Corn
Agritope, Inc.	Modified Fruit Ripening Tomato
Asgrow Seed Co.	Virus Resistant (WMVZ) Squash `
	Virus Resistant (ZYMV) Squash
	Virus resistant (CMV) Squash
BASF	Sethoxydim Herbicide Tolerant Corn
Bejo-Baden	Male Sterility Chicory
Calgene Inc.	Flavr Savr™ Tomato
	Bromoxynil Herbicide Tolerant Cotton
	Laurate Canola
	Insect Protected and Bromoxynil Herb. Tolerant Cotton
China	Virus Resistant Tomato
	Virus Resistant Tobacco
	Bt Cotton
Cornell U./U. of Hawaii	Virus Resistant Papaya (Ring Spot Virus)
DeKalb Genetics Corp.	Glufosinate Herbicide Tolerant Corn
	Insect Protected Corn
	Insect Protected and Glufosinate Herb.Tolerant Corn
DNA Plant Technology	Improved Ripening Tomato
Du Pont	Sulfonylurea Herbicide Tolerant Cotton
	High Oleic Acid Soybean
Florigene	Carnations with Increased Vase Life
	Carnations with Modified Flower Color
Monsanto Co.	Glyphosate Herbicide Tolerant Soybean
	Improved Ripening Tomato
	Insect-Protected Potato
	Insect-Protected Cotton
	Glyphosate Herbicide Tolerant Cotton
	Insect Protected and Glyphosate Herb. Tolerant Cotton
	Glyphosate Herbicide Tolerant Canola
	Insect-Protected Corn
	Glyphosate Herbicide Tolerant Corn
	Insect Protected and Glyphosate Herb.Tolerant Corn
	Insect Protected and PLRV Resistant Potato
	Glyphosate Tolerant Beet[1]
Mycogen	Insect-Protected Corn
Novartis Seeds	Insect-Protected Corn
	Insect-Protected/Glufosinate Tolerant Corn
	Insect-Protected/Glufosinate Tolerant Sweet Corn
Pioneer Hi-Bred International	Male Sterile Corn

continued…

Table 1A continued:

Plant Genetic Systems	Hybrid Glufosinate Tolerant Oilseed Rape Male Sterility /Glufosinate Tolerant Oil Seed Rape Fertility Restorer /Glufosinate Tolerant Oil Seed Rape Hybrid Glufosinate Tolerant Corn Male Sterility/Glufosinate Tolerant Corn Fertility Restorer/Glufosinate Tolerant Corn
Rhone-Poulenc	Bromoxynil Tolerant Canola
Seita	Bromoxynil Tolerant Tobacco
Seminis Vegetable Seeds	Virus resistant (ZW20) Squash Virus resistant (CZW3) Squash
University of Saskatchewan	Sulfonylurea Tolerant Flax
Zeneca/Petoseed	Improved Ripening Tomato

[1] Regulatory Approval of Herbicide is pending
Source: Compiled and updated by Clive James, 1998.

Table 2A: OECD Listing of transgenic crops approved for planting, food & feed, 1992-1997

			Approval for			
Company	**Crop/Gene**	**Country**	**Planting**	**Food**	**Feed**	**Year**
Calgene	Tomato/Fruit ripening	USA	x	x		1992
Zeneca	Tomato/Fruit ripening	USA	x			1994
Calgene	Tomato/Fruit ripening	USA	x	x		1994
Upjohn	Squash/Viral resistance	USA	x			1994
Monsanto	Soybean/Glyphosate Herbicide tolerance	USA	x	x		1994
Calgene	Tomato/Fruit ripening	USA	x	x		1994
DNA Plant Tech. Corporation	Tomato/Fruit ripening	USA	x	x		1994
Calgene	Oilseed Rape/Modified fatty acid	USA	x	x		1994
Monsanto	Potato/Insect resistance	USA	x	x		1994
Calgene	Cotton/Herbicide tolerance	USA	x			1994
Monsanto	Soybean/Glyphosate Herbicide tolerance	USA	x	x	x	1994
SEITA	Tobacco/Herbicide tolerance	France/EU				1994
Calgene	Tomato/Fruit ripening altered	USA	x	x		1995
De Kalb/De Kalb Genetics	Corn/Herbicide tolerance	USA	x	x		1995
AgrEvo Canada Inc.	Oilseed rape/herbicide tolerance	Canada	x	x	x	1995
Monsanto	Cotton/Herbicide tolerance	USA	x	x		1995
CIBA-Geigy	Corn/Insect resistance	EU	x	x		1995
Monsanto Canada Inc.	Oilseed rape/herbicide tolerance	Canada	x	x	x	1995
Zeneca & Petoseed	Tomato/Fruit ripening	USA	x	x		1995
Monsanto	Tomato/Fruit ripening	USA	x	x		1995
Florigene Pty. Ltd.	Carnation/Modified flower Colour	Australia	x			1995
Monsanto	Cotton/Insect resistance	USA	x			1995
Florigene Pty. Ltd.	Carnation/Increased vase life	Australia	x			1995

continued…

Table 2A continued:

AgrEvo	Corn/Herbicide tolerance	USA	x	x		1995
Monsanto	Corn/insect resistance	USA	x	x		1995
Calgene	Tomato/Fruit ripening altered	USA	x	x		1995
Plant Genetic Systems	Oilseed rape/male sterility & Fertility + Herbicide tolerance	Canada	x	x	x	1995
Monsanto Canada Inc.	Soybean/Herbicide tolerance	Canada	x		x	1995
Calgene	Tomato/Fruit ripening	USA	x			1995
Pioneer Hi-Bred International Inc.	Oilseed rape/herbicide tolerance	Canada	x			1995
Monsanto Australia Ltd.	Cotton/Insect resistance	Australia	x			1996
Plant Genetic Systems	Oilseed rape/male sterility & Fertility restorer + herbicide tol.	EU	x			1996
Monsanto Canada Inc.	Potato/Insect resistance	Canada	x	x	x	1996
Mycogen Corp. & Ciba Seeds	Corn/Insect resistance	Canada	x	x	x	1996
Pioneer Hi-Bred	Corn/Herbicide tolerance	Canada	x	x	x	1996
Calgene	Oilseed rape/Modified fatty acid	Canada	x		x	1996
Monsanto Canada Inc.	Oilseed rape/Herbicide tolerance	Canada	x			1996
AgrEvo Canada Inc.	Oilseed rape/Herbicide tolerance	Canada	x	x	x	1996
Northrup King Seeds Ltd.	Corn/Herbicide tolerance + Insect resistance	Canada	x	x	x	1996
BASF Canada Inc.	Corn/Herbicide tolerance	Canada	x		x	1996
Plant Genetic Systems	Corn/Male sterility + Herbicide Tolerance	Canada	x			1996
University of Saskatchewan	Flax/Herbicide tolerance + Kanamycin resistance	Canada				1996
Zeneca Seeds	Corn/Herbicide tolerance	Canada				1996
AgrEvo Canada Inc.	Corn/Herbicide tolerance	Canada				1996
Plant Genetic Systems	Oilseed rape/Male sterility & Fertility restorer + Herbicide Tolerance	Canada	x			1996
Pioneer Hi-Bred	Corn/Herbicide tolerance + Kanamycin resistance + insect resistance	?	x	x	x	1996
Monsanto	Corn/Herbicide tolerance	USA				1996
Monsanto	Corn/Herbicide tolerance + Insect resistance	USA	x			1996
DeKalb	Corn/Insect resistance	USA	x	x	x	1996
Calgene	Tomato/Fruit ripening altered	USA				1996
AgrEvo	Soybean/Herbicide toelerance	USA	x			1996
Cornell University	Papaya/Virus resistance	USA	x			1996
Asgrow	Squash/Virus resistance	USA	x			1996
Monsanto	Potato/Insect resistance	USA	x			1996
Agritope	Tomato/Fruit ripening	USA	x			1996
DuPont	Cotton/Herbicide tolerance	USA	x			1996
Plant Genetic Systems	Corn/Male sterility + Herbicide tolerance	USA	x			1996

continued…

Table 2A continued:

Northrup King	Corn/Insect resistance	USA	x			1996
Florigene Europe B.V.	Carnation/Modified flower colour	Netherlands				1996
Monsanto	Soybean/Herbicide tolerance	Japan	x	x	x	1996
AgrEvo	Oilseed rape/ Herbicide tolerance	Japan	x	x	x	1996
Plant Genetic Systems	Oilseed rape/Male sterility & Fertility restorer + herbicide tol.	Japan	x	x	x	1996
Monsanto	Oilseed rape/Herbicide tolerance	Japan	x	x		1996
CIBA-Geigy	Corn/Insect resistance	Japan	x	x	x	1996
Northrup King	Corn/Insect resistance	Japan	x	x	x	1996
Monsanto	Corn/Insect resistance	Japan	x	x	x	1996
Calgene	Tomato/Fruit ripening altered	Japan	x	x		1996
Monsanto Europe	Soybean/Herbicide tolerance	EU				1996
Bejo Zaden BV	Chicory/Herbicide tolerance, male sterility & Kan. resistance	Netherlands				1996
Monsanto	Potato/Oinsect resistance	Japan		x		1996
Monsanto	Cotton/Insect resistance	Japan	x	x	x	1997
AgrEvo	Corn/Herbicide tolerance	Japan	x	x	x	1997
Plant Genetic Systems	Oilseed rape/Herbicide tolerance	Japan	x	x	x	1997
CIBA-Geigy, CIBA Semences	Corn/Insect resistance	EU				1997
Monsanto	Potato/Insect resistance	Japan		x		1997
Plant Genetic Systems	Oilseed rape/Herbicide tolerance	Japan	x	x	x	1997
Plant Genetic Systems	Oilseed rape/Herbicide tolerance	Japan	x	x	x	1997
AgrEvo	Oilseed rape/Herbicide tolerance	Japan	x	x	x	1997
AgrEvo	Oilseed rape/Herbicide tolerance	Japan	x	x	x	1997
Plant Genetic Systems	Oilseed rape/Herbicide tolerance	Japan		x	x	1997
Monsanto	Cotton/Herbicide tolerance	Japan	x	x	x	1997
Calgene	Cotton/Herbicide tolerance	Japan	x	x	x	1997

Source: OECD, 1998.

Table 3A: Field Tested Transgenic Crops in Japan

Crop		Trait
1.	Tomato	Virus Resistance (TMV)
2.	Tomato	Quality
3. .	Tomato	Virus Resistance (CMV)
4.	Petunia	Virus Resistance (CMV)
5.	Rice	Virus Resistance (RSV)
6.	Rice	Quality, Low Allergen
7.	Tobacco	Virus Resistance (CMV)
8.	Soybean	Herbicide Tolerance
9.	Canola	Herbicide Tolerance
10.	Canola	Herbicide Tolerance/ Male Sterility
11.	Carnation	Quality, Shelf Life
12.	Corn	Insect Resistance
13.	Corn	Herbicide Tolerance
14.	Cotton	Insect Resistance
15.	Cotton	Herbicide Tolerance
16.	Melon	Virus Resistance

Source:Tabei, 1998 (Personal Communication).

Table 4A: 1998 Status of Food/Feed Products from Transgenic Crops, approved in Japan

Organism/Phenotype	Company	Purpose
1. Herbicide Tolerant Soybean (40-3-2)	Monsanto	Food, Feed
2. Herbicide Tolerant Canola (HCN92)	AgrEvo	Food, Feed
3. Herbicide Tolerant Canola (PGS1)	Plant Genetic Systems	Food, Feed
4. Herbicide Tolerant Canola (GT73)	Monsanto	Food, Feed
5. Lepidopteran Resistant Corn (Event176)	Ciba-Geigy	Food, Feed
6. Lepidopteran Resistant Corn (*Bt*11)	Northrup King	Food, Feed
7. Coleopteran Resistant Potato (New Leaf Potato)	Monsanto	Food
8. Lepidopteran Resistant Corn (Yield Guard Corn:MON810)	Monsanto	Food, Feed
9. Coleopteran Resistant Potato (New Leaf Potato)	Monsanto	Food
10. Lepidopteran Resistant Cotton (Ingard Cotton)	Monsanto	Food, Feed
11. Herbicide Tolerant Corn (T14, T25)	AgrEvo	Food, Feed
12. Herbicide Tolerant Hybrid Canola (PHY14, PHY35)	Plant Genetic Systems	Food, Feed
13. Herbicide Tolerant Canola (PGS2)	Plant Genetic Systems	Food, Feed
14. Herbicide Tolerant Hybrid Canola (PHY36)	Plant Genetic Systems	Food, Feed
15. Herbicide Tolerant Canola (T45)	AgrEvo	Food, Feed
16. Herbicide Tolerant Cotton (Roundup Ready Cotton)	Monsanto	Food
17. Herbicide Tolerant Cotton (BXN Cotton)	Calgene	Food
18. Herbicide Tolerant Canola (MS8RF3)	Plant Genetic Systems	Food, Feed
19. Herbicide Tolerant Canola (HCN 10)	AgrEvo	Food, Feed
20. Ripening Delayed Tomato	Calgene	Food

Source: Tabei, 1998 (Personal Communication).

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